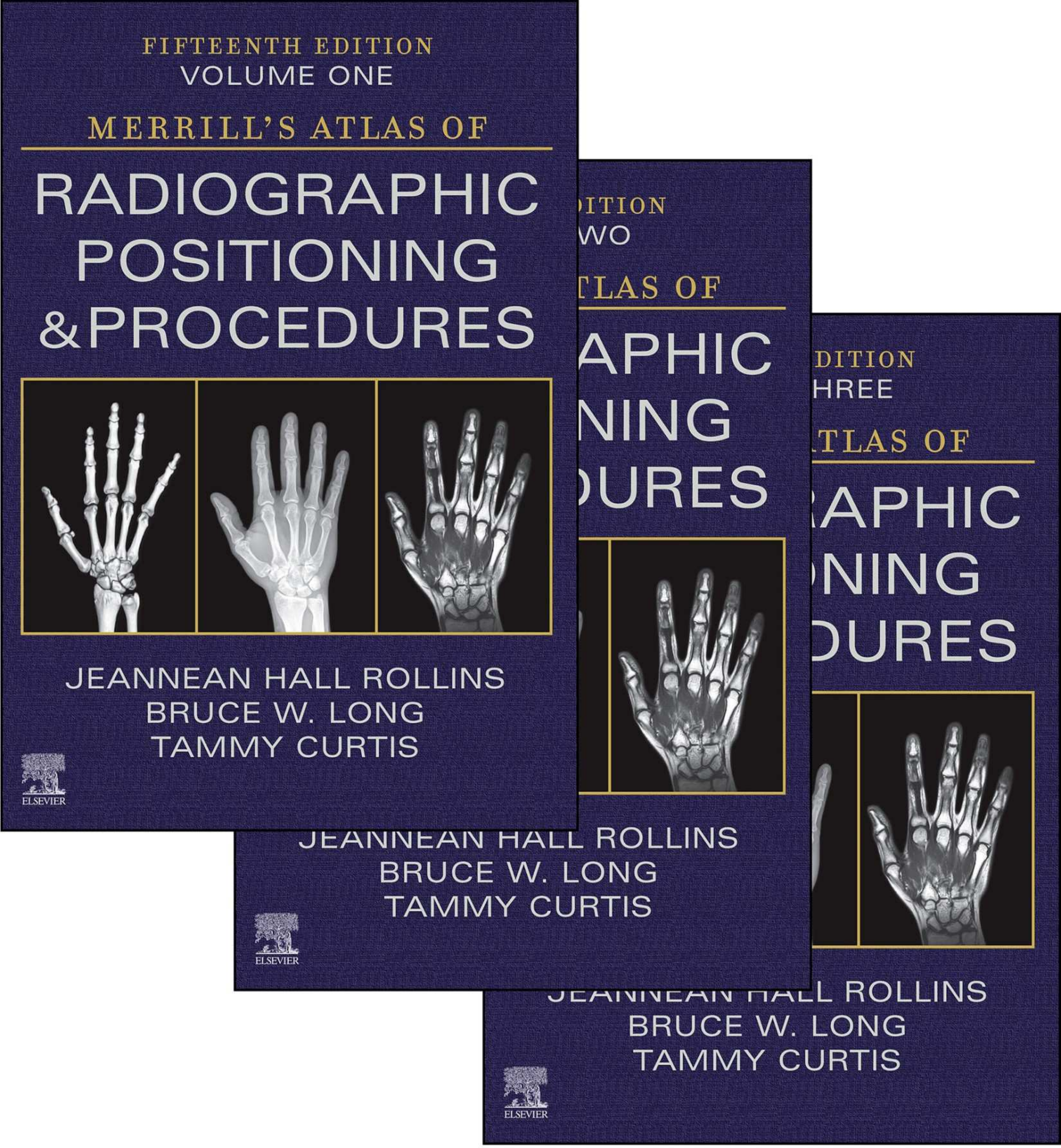
FIFTEENTH EDITION
VOLUME ONE
MERRILL'S ATLAS OF
RADIOGRAPHIC POSITIONING & PROCEDURES
JEANNEAN HALL ROLLINS
BRUCE W. LONG
TAMMY CURTIS
ELSEVIER

3-Volume Set

Merrill's Atlas of Radiographic Positioning & Procedures

FIFTEENTH EDITION

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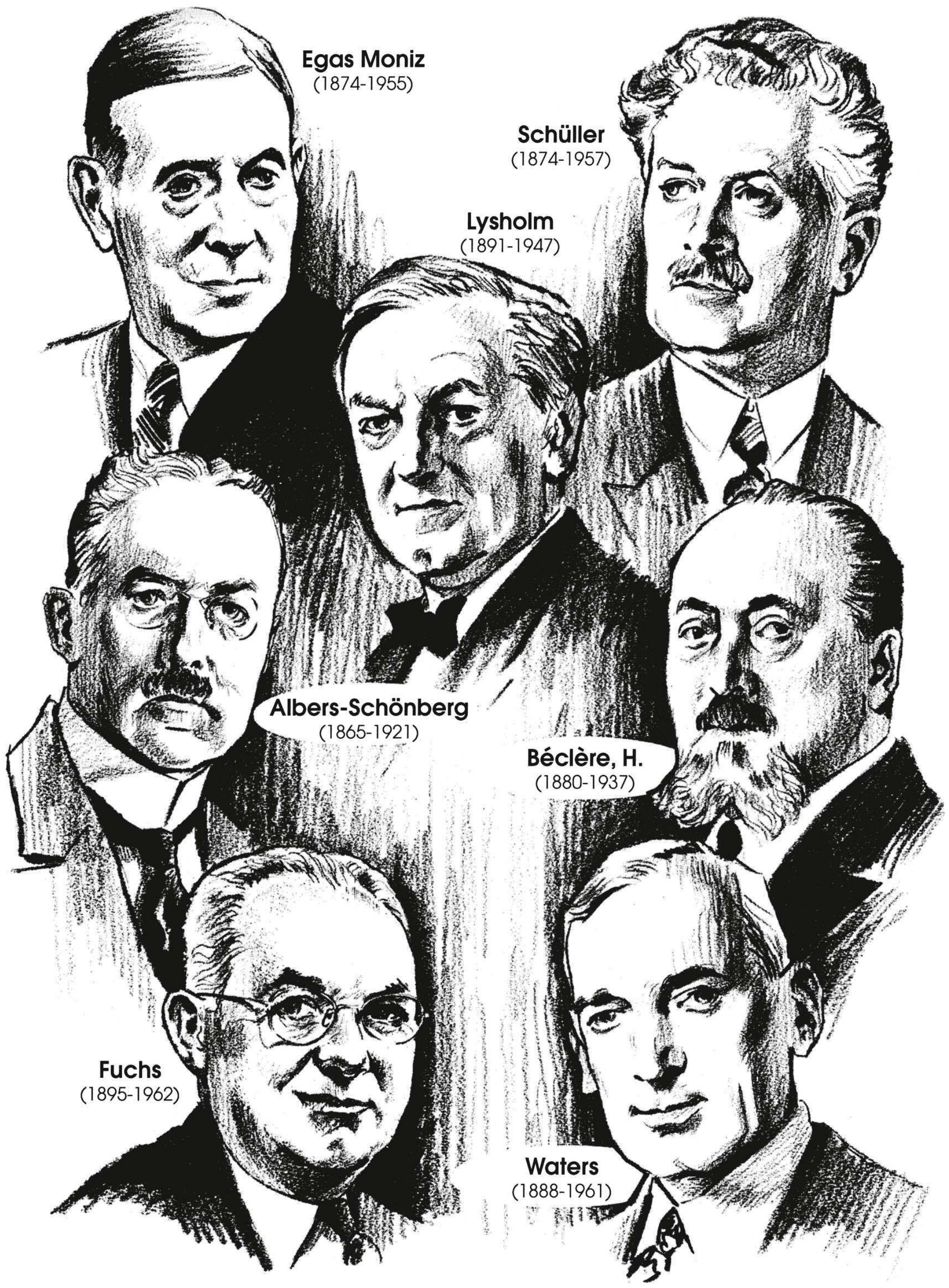
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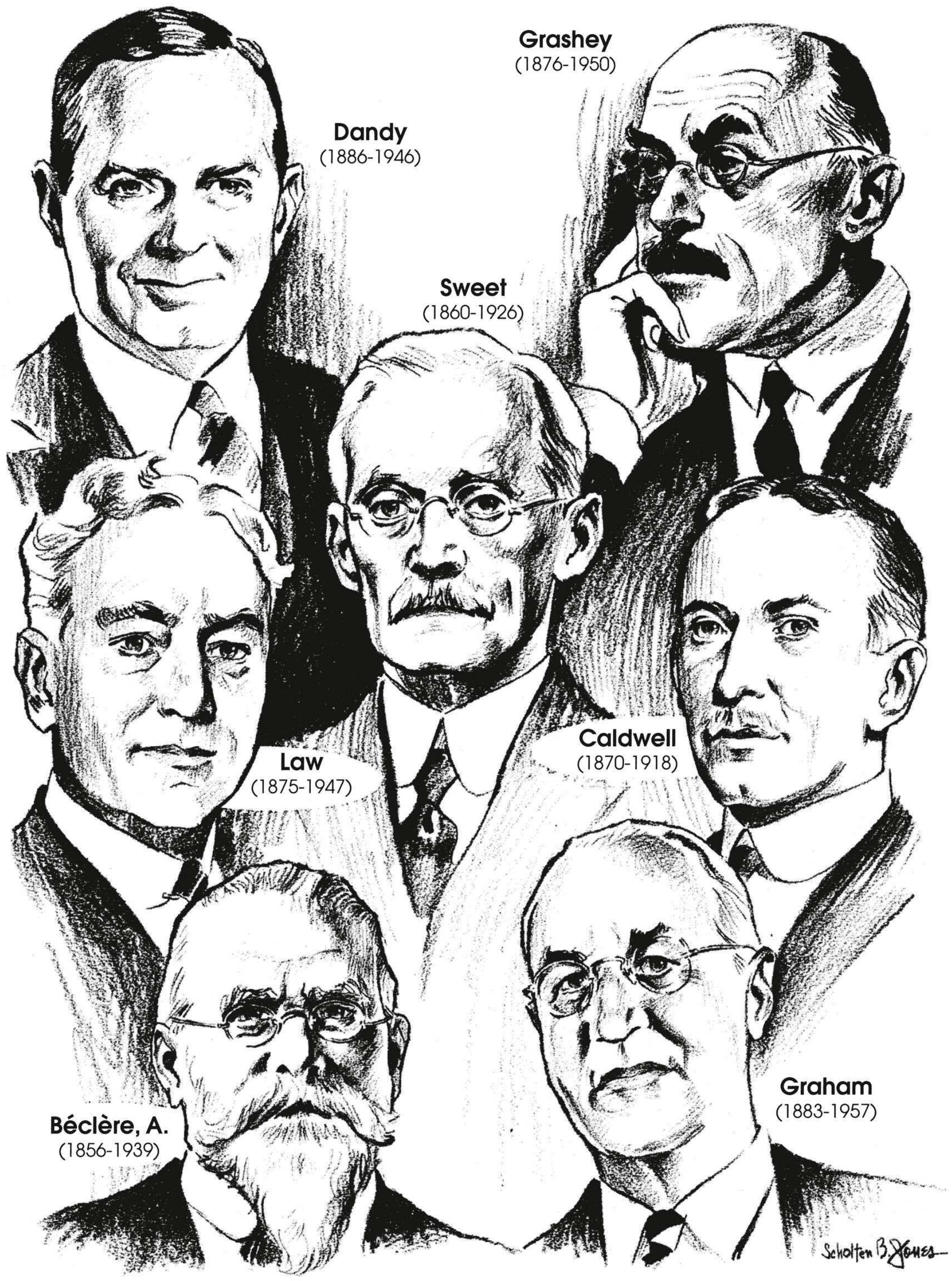
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Previous Authors

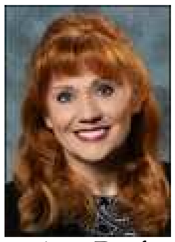
Vinita Merrill, **1905-1977**,Vinita Merrill was born in Oklahoma in 1905 and died in New York City in 1977. Vinita began compilation of *Merrill's* in 1936 while she worked as Technical Director and Chief Technologist in the Department of Radiology and Instructor in the School of Radiography at the New York Hospital. In 1949, while employed as Director of the Educational Department of Picker X-Ray Corporation, she wrote the first edition of the *Atlas of Roentgenographic Positions.* She completed three more editions from 1959 to 1975. Seventy-four years later, Vinita's work lives on in the fifteenth edition of *Merrill's Atlas of Radiographic Positioning & Procedures*.

Philip W. Ballinger, PhD, RT(R), FASRT, FAEIRS, became the author of *Merrill's Atlas* in its fifth edition, which was published in 1982. He served as author through the tenth edition, helping to launch successful careers for thousands of students who have learned radiographic positioning from *Merrill's*. Phil currently serves as Professor Emeritus in Radiologic Sciences and Therapy, Division of the School of Health and Rehabilitation Sciences, at The Ohio State University. In 1995, he retired after a 25-year career as Radiography Program Director and, after ably guiding *Merrill's Atlas* through six editions, he retired as *Merrill's* author. Phil continues to be involved in professional activities such as speaking engagements at state, national, and international meetings.

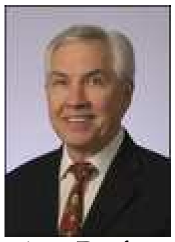
Eugene D. Frank, MA, RT(R), FASRT, FAEIRS, began working with Phil Ballinger on the eighth edition of *Merrill's Atlas* in 1995. He became the coauthor in its ninth, 50th anniversary edition, published in 1999. He served as lead author for the eleventh and twelfth editions and mentored three coauthors. Gene retired from the Mayo Clinic/Foundation in Rochester, Minnesota, in 2001 after 31 years of employment. He was Associate Professor of Radiology in the College of Medicine and Director of the Radiography Program. He also served as Director of the Radiography Program at Riverland Community College, Austin, Minnesota, for 6 years before fully retiring in 2007. He is a Fellow of the ASRT and AEIRS. In addition to *Merrill's*, he is the coauthor of two radiography textbooks, *Quality Control in Diagnostic Imaging* and *Radiography Essentials for Limited Practice.* He continues to help radiography programs by teaching courses for sabbaticals and helps equip x-ray departments in West Africa with equipment.

Barbara J. Smith, MS, RT(R)(QM), FASRT, FAEIRS, is an instructor in the Radiologic Technology program at Portland Community College, where she has taught for 34 years. The Oregon Society of Radiologic Technologists inducted her as a Life Member in 2003. She presents at state, regional, national, and international meetings, was a trustee with the American Registry of Radiologic Technologists (ARRT), and is involved in professional activities at these levels. Her publication activities include articles, book reviews, and chapter contributions. Currently, she serves as chair of the Oregon Radiation Advisory Committee. As coauthor for four editions, Barb's role with the *Merrill's* team was working with the contributing authors and editing Volume 3.

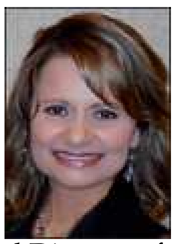
The Merrill's Team



Jeannean Hall Rollins, MRC, BSRT(R)(CV)(M), is an Associate Professor in the Medical Imaging and Radiation Sciences department at Arkansas State University, where she has taught for 30 years. She presents regularly at national meetings. Her publication activities include articles, book reviews, and chapter contributions. The fifteenth edition is Jeannean's first as the lead author and fifth time on the *Merrill's* team. She is also sharing responsibility for revising the workbook with Dr. Tammy Curtis on this edition. Her first contribution to *Merrill's Atlas* was on the tenth edition as coauthor of the trauma radiography chapter. Prior to becoming a coauthor on the textbook, Jeannean was responsible for revising the workbook, *Mosby's Radiography Online*, and the *Evolve Instructor Electronic Resources* that accompany *Merrill's Atlas*.



Bruce W. Long, MS, RT(R)(CV), FASRT, FAEIRS, is Associate Professor Emeritus of the Indiana University Radiologic and Imaging Sciences Programs, where he taught for 35 years. A Life Member of the Indiana Society of Radiologic Technologists, he frequently presented at state and national professional meetings. His publication activities include 28 articles in national professional journals and two books, *Orthopaedic Radiography* and *Radiography Essentials for Limited Practice*, in addition to being coauthor of the *Atlas*. The fifteenth edition is Bruce's fifth on the *Merrill's* team, with two editions as lead author.



Tammy Curtis, PhD, RT(R)(CT)(CHES), is a Professor and Director of the Radiologic Sciences Program at Northwestern State University, where she has taught for 20 years. She presents at the state, regional, and national levels and is involved in professional activities at the state and national levels. Her publication activities include articles, book reviews, and book contributions. Previously, Tammy served on the advisory board and submitted several projects to the *Atlas*. In particular, for the twelfth edition, Tammy submitted an updated photo and biography of the original author, Vinita Merrill, which she discovered after a 3-year search of historical records. The fifteenth edition is Tammy's first as a coauthor of the textbook and third time as part of the *Merrill's* team. In addition, she is sharing the workbook revision responsibilities with Jeannean Rollins for the fifteenth edition. Her previous role on the *Merrill's* team was to update the workbook and work with the coauthors of the textbook to review content for all three volumes.

Advisory Board

This edition of *Merrill's Atlas* benefits from the expertise of a special advisory board. The following board members have provided professional input and advice and have helped the authors make decisions about *Atlas* content throughout the preparation of the fifteenth edition.

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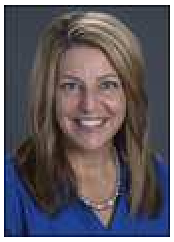

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Preface

Welcome to the fifteenth edition of *Merrill's Atlas of Radiographic Positioning & Procedures.* This edition continues the tradition of excellence begun in 1949, when Vinita Merrill wrote the first edition of what has become a classic text. For more than 70 years, *Merrill's Atlas* has provided a strong foundation in anatomy and positioning for thousands of students around the world who have gone on to successful careers as imaging technologists. *Merrill's Atlas* is also a mainstay for everyday reference in imaging departments all over the world. As the coauthors of the fifteenth edition, we are honored to follow in Vinita Merrill's footsteps.

Learning and Perfecting Positioning Skills

Merrill's Atlas has an established tradition of helping students learn and perfect their positioning skills. After covering preliminary steps in radiography, radiation protection, and terminology in the introductory chapters, the first two volumes of the *Atlas* teach anatomy and positioning in separate chapters for each bone group or organ system. The student learns to position the patient properly so that the resulting radiograph provides the information the physician needs to correctly diagnose the patient's problem. The *Atlas* presents this information for commonly requested projections as well as for those less commonly requested, making it the only reference of its kind in the world.

The third volume provides basic information about a variety of special imaging modalities, such as mobile and surgical imaging, pediatrics, geriatrics, computed tomography (CT), vascular radiology, magnetic resonance imaging (MRI), sonography, nuclear medicine technology, bone densitometry, and radiation therapy.

Merrill's Atlas is not only a comprehensive resource to help students learn but also an indispensable reference as they move into the clinical environment and ultimately into practice as imaging professionals.

New to This Edition

Since the first edition of *Merrill's Atlas* in 1949, many changes have occurred. This new edition incorporates many significant changes designed not only to reflect the technologic progress and advancements in the profession but also to meet the needs of today's radiography students. The major changes in this edition are highlighted as follows.

New Patient Photography

All patient positioning photographs have been replaced in Chapter 6. Additional new patient positioning photographs have been strategically added to replace or better illustrate diagrams. The new photographs show positioning detail to a greater extent and in some cases from a more realistic perspective. In addition, the equipment featured in the new photos is modern, thus providing students with a more realistic visual learning tool. The use of electronic central ray angle indicators enables a better understanding of where the central ray should enter the patient and the exact angle when required.

Updated gonadal shielding guidelines

The most significant recent change in our profession has been the American Association of Physicists in Medicine (AAPM) position statement entitled *AAPM Position Statement on the Use of Patient Gonadal and Fetal Shielding*. The author team, along with the help of the Advisory Board, have made every attempt to abide by this position statement while still considering state law that affect the practice of many technologists and students. The "*Shield gonads*" statement has been removed from Chapters 4 and 8 in accordance with the AAPM recommendations. Additionally, Chapter 1 has been revised to explain how to handle questions from patients regarding gonadal shielding.

Collimation and Exposure Field Size

Taking into consideration the recent recommendations to discontinue gonadal shielding for some exams, greater emphasis has been placed on collimation size and field light coverage as radiation protection measures. In addition, collimation parameters are increasingly important because many imaging departments use only a single, large image receptor (IR) size. Proper placement of the radiographic marker in the exposure field is described for routine projections.

Updates in this Edition

Color-coded anatomy diagrams have been added to enhance visual learning and better differentiate anatomic details. New charts have been added to Chapter 2 to assist students to master foundational terms more quickly. Essential projections have been revised to match 2022 ARRT Radiography Exam Content Specifications. Best practices that describe specific skills in each discipline were added to all advanced modality chapters, allowing students more insight into the unique environment of each modality. A new section was added to Chapter 21 regarding the O-arm mobile unit. Chapter 22 was expanded to include mobile radiography for neonates in the neonatal intensive care unit (NICU). NICU exam recommendations for performing routine projection and positions are described and supported with new images. In Chapter 24, three-dimensional (3D) advanced visualization was added to include 3D printing for demonstrating sectional anatomy. Chapter 27 has been significantly reorganized to reflect current practice in vascular, cardiac, and interventional radiography.

Learning Aids for the Student

Pocket Guide to Radiography

The new edition of *Merrill's Pocket Guide to Radiography* complements this revision of *Merrill's Atlas.* Instructions for positioning the patient and the body part for all of the essential projections are presented in a complete yet concise manner. The Coyle method for trauma elbow has been added to this edition. Tabs are included to help the user locate the beginning of each section. Space is provided for the user to write in specifics of department techniques.

Radiographic Positioning and Procedures Workbook

The new edition of this workbook features extensive review and self-assessment exercises that supplement the first 25 chapters in *Merrill's Atlas* in one convenient volume. Relevant material was updated to current practice and integrated into appropriate chapters. Terminology remains consistent to match the Content Specifications for the ARRT Radiography Examination, the ASRT Radiography Curriculum, and the evolution of digital imaging. New questions were developed to assess the newly added content in the textbook that reflects current ARRT content specifications. The features of the previous editions, including anatomy labeling exercises, positioning exercises, and self-tests, are still available. This edition features image evaluations to give students additional opportunities to evaluate radiographs for proper positioning and positioning questions to complement the workbook's strong anatomy review. The comprehensive multiple-choice tests at the end of each chapter help students assess their comprehension of the whole chapter. New exercises in this edition focus on improved understanding of essential projections and the need for appropriate collimated field sizes for digital imaging. Additionally, review and assessment exercises have been expanded for the chapters on pediatrics, reproductive system, mobile, surgical, geriatrics, sectional anatomy, vascular, and interventional radiography. Exercises in these chapters help students learn the theory and concepts of these special techniques with greater ease. Answers to the workbook questions are found on the Evolve website.

Teaching Aids for the Instructor

Evolve Instructor Electronic Resources

This comprehensive resource provides valuable tools such as lesson plans, PowerPoint slides, and an electronic test bank for teaching an anatomy and positioning class. The test bank includes more than 1500 questions, each coded by category and level of difficulty. Four exams are already compiled in the test bank to be used "as is" at the instructor's discretion. The instructor also has the option of building new tests as often as desired by pulling questions from the ExamView pool or using a combination of questions from the test bank and questions that the instructor adds.

Evolve may be used to publish the class syllabus, outlines, and lecture notes; set up "virtual office hours" and e-mail communication; share important dates and information through the online class calendar; and encourage student participation through chat rooms and discussion boards. Evolve allows instructors to post exams and manage their grade books online. For more information, visit www.evolve.elsevier.com or contact an Elsevier sales representative.

Mosby's Radiography Online

Mosby's Radiography Online: Merrill's Atlas of Radiographic Positioning & Procedures is a well-developed online course companion for the textbook and workbook. This online course includes animations with narrated interactive activities and exercises, as well as multiple-choice assessments that can be tailored to meet the learning objectives of your program or course. The addition of this online course to your teaching resources offers greater learning opportunities while accommodating diverse learning styles and circumstances. This unique program promotes problem-based learning with the goal of developing critical thinking skills that will be needed in the clinical setting.

Evolve—Online Course Management

Evolve is an interactive learning environment designed to work in coordination with *Merrill's Atlas.* Instructors may use Evolve to provide an Internet-based course component that reinforces and expands on the concepts delivered in class.

We hope you will find this edition of *Merrill's Atlas of Radiographic Positioning & Procedures* the best ever. Input from generations of readers has helped to keep the *Atlas* strong through 14 editions, and we welcome your comments and suggestions. We are constantly striving to build on Vinita Merrill's work, and we trust that she would be proud and pleased to know that the work she began 70 years ago is still so appreciated and valued by the imaging sciences community.

Jeannean Hall Rollins

Bruce W. Long

Tammy Curtis

Acknowledgments

In preparing for the fifteenth edition, our advisory board continually provided professional expertise and aid in the decision-making on the revision of this edition. The advisory board members are listed on p. ix. We are most grateful for their input and contributions to this edition of the *Atlas*.

Contributors

The group of radiography professionals listed here contributed to this edition of the *Atlas* and made many insightful suggestions. We are most appreciative of their willingness to lend their expertise.

The author team extends special recognition to Jennifer G. Chiu, EdD, MBA, RT(R)(CT)(ARRT), Associate Professor and Program Director at St. John's University in Queens, New York; and Zaidalynet Morales, MS, RT(R)(CT)(ARRT), Associate Professor, also at St. John's University. We are honored to have their expertise as reviewers of all three volumes of this edition. Additionally, they have undertaken the responsibility of revising and updating the *Evolve Instructor Electronic Resources* and *Mosby's Radiography Online: Merrill's Atlas of Radiographic Positioning & Procedures* for this fifteenth edition. We are very thankful and extremely blessed to have their expertise and assistance in maintaining the quality standard that defines *Merrill's Atlas*.

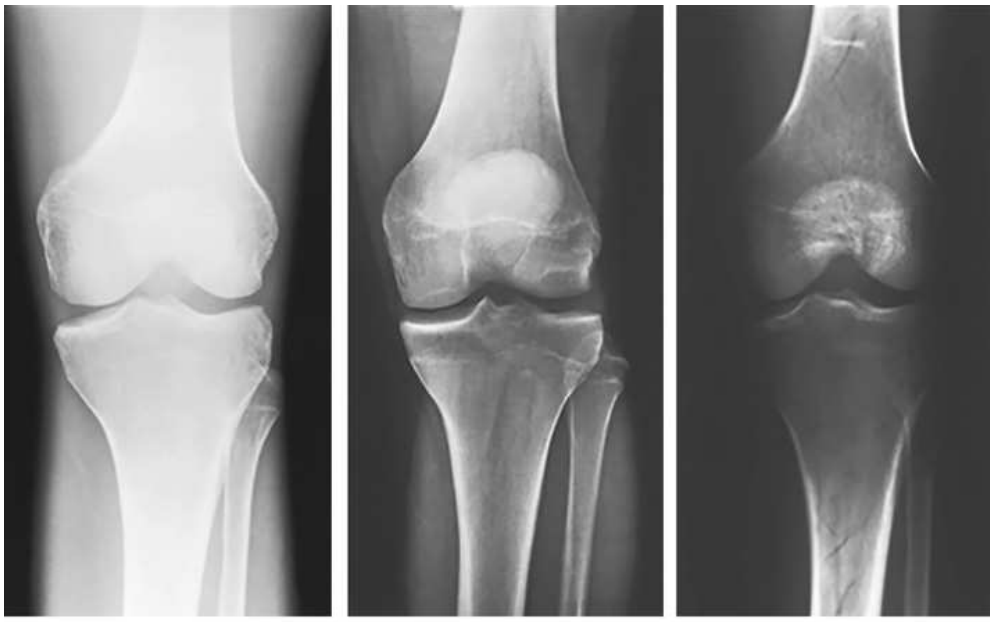
A very special "thank you" to Jon Rollins for agreeing to serve as a positioning model and photography reviewer and editor. Attempting to revise a major textbook during a national quarantine caused many delays, barriers, and obstacles. His willingness to pose for countless hours made the new positioning photos in Chapter 6 possible. Without your support, the team's goals for this fifteenth edition would have not been possible.

Our deepest appreciation to our faith, family, and colleagues, whose support and encouragement remain an indispensable part of this work. Finally, to all of our graduates and students, current and future, this edition is dedicated to you, our greatest teachers and inspiration. Thank you!

Volume One

OUTLINE

1: Preliminary Steps in Radiography



OUTLINE

The Radiographer

Radiologic technology is a health care profession that includes all diagnostic imaging technologists and radiation therapists. A radiographer is a radiologic technologist who administers ionizing radiation to perform radiographic procedures. The radiographer produces radiographic images at the request of a licensed medical practitioner, usually a physician.

Radiographers interact with patients to produce diagnostic images using technical skills combined with knowledge of physics, anatomy, physiology, and pathology. They must evaluate images for technical quality, accuracy, and appropriateness relative to the diagnosis or the reason for the procedure. This requires critical thinking and the application of professional judgment. A fundamental responsibility of the radiographer is to ensure that each radiation exposure is "as low as reasonably achievable," or *ALARA.*

Patient care responsibilities of the radiographer include communication, assessment, monitoring, and support. The patient is questioned to ensure that the procedure ordered is consistent with the clinical history. It is the patient's right to know what is to be done and to consent to the procedure. Patient assessment before the procedure and monitoring while the patient is under the care of the radiographer are essential to ensure the patient's safety and well-being. Both physical and emotional support may be necessary during the procedure and until the patient is released from the radiographer's care.

As members of the health care team, radiographers have a shared responsibility to support and advance the mission of the health care provider for whom they work. This includes continually assessing their professional performance, as well as actively participating in quality improvement initiatives. To ensure patient safety and quality of care, each radiographer must adhere to the moral and ethical code of the profession, as well as work within the practice standards that describe the scope of practice.

Radiography Practice Standards

The Radiography Practice Standards are written and maintained by the American Society of Radiologic Technologists (ASRT). They define the practice of radiography, describe necessary education and certification, and include the Radiographer Scope of Practice. In addition, the practice standards include Clinical Performance Standards, Quality Performance Standards, and Professional Performance Standards. The full text of the most current Radiography Practice Standards can be found on the ASRT website at ASRT.org.

Ethics in Radiologic Technology

Ethics is the term applied to a health professional's moral responsibility and the science of appropriate conduct toward others. The work of the medical professional requires strict rules of conduct. The physician, who is responsible for the welfare of the patient, depends on the absolute honesty and integrity of all health care professionals to carry out orders and report mistakes.

The American Registry of Radiologic Technologists (ARRT) created and maintains the Standards of Ethics that apply to all radiologic technologists who are certified by the organization. The purpose is to describe professional values that translate into practice that are in the best interests of patients. The Standards of Ethics include a Code of Ethics and Rules of Ethics.

The ARRT Code of Ethics serves as a professional behavior guide to which radiologic technologists may aspire. It is intended to assist in maintaining a high level of ethical conduct in the profession.

1. The radiologic technologist acts in a professional manner, responds to patient needs, and supports colleagues and associates in providing quality patient care.
2. The radiologic technologist acts to advance the principal objective of the profession: to provide services to humanity with full respect for the dignity of humankind.
3. The radiologic technologist delivers patient care and service unrestricted by concerns of personal attributes or the nature of the disease or illness and without discrimination on the basis of race, color, creed, religion, national origin, sex, marital status, status with regard to public assistance, familial status, disability, sexual orientation, gender identity, veteran status, age, or any other legally protected basis.
4. The radiologic technologist practices technology founded on theoretic knowledge and concepts, uses equipment and accessories consistent with the purpose for which they have been designed, and uses procedures and techniques appropriately.
5. The radiologic technologist assesses situations; exercises care, discretion, and judgment; assumes responsibility for professional decisions; and acts in the best interest of the patient.
6. The radiologic technologist acts as an agent through observation and communication to obtain pertinent information for the physician to aid in the diagnosis and treatment management of the patient and recognizes that interpretation and diagnosis are outside the scope of practice for the profession.
7. The radiologic technologist uses equipment and accessories; uses techniques and procedures; performs services in accordance with an accepted standard of practice; and demonstrates expertise in minimizing radiation exposure to the patient, self, and other members of the health care team.

8. The radiologic technologist practices ethical conduct appropriate to the profession and protects the patient's right to quality radiologic technology care.
9. The radiologic technologist respects confidences entrusted in the course of professional practice, respects the patient's right to privacy, and reveals confidential information only as required by law or to protect the welfare of the individual or the community.
10. The radiologic technologist continually strives to improve knowledge and skills by participating in educational and professional activities, sharing knowledge with colleagues, and investigating new and innovative aspects of professional practice.
11. The radiologic technologist refrains from the use of illegal drugs and/or legally controlled substances which result in impairment of professional judgment and/or ability to practice radiologic technology with reasonable skill and safety to practice to patients.

The ARRT Standards of Ethics also contains 22 Rules of Ethics that are "mandatory standards of minimally acceptable professional conduct for all Certificate Holders and Candidates. The Rules of Ethics are enforceable." [1] The full list and descriptions of the Rules of Ethics can be found on the ARRT website at ARRT.org.

The Canadian Association of Medical Radiation Technologists (CAMRT) Member Code of Ethics and Professional Conduct has been developed by members to articulate the ethical behavior expected of all medical radiation technologists and to serve as a means for reflection and self-evaluation. The code includes the following aspects of professional practice:

- Patient-centered care
- Maintaining competence
- Evidence-based and reflective practice
- Providing a safe environment
- Acting with professional integrity

The complete and current document can be found on the CAMRT website at CAMRT.ca.

Advanced Clinical Practice

In response to increased demands on the radiologist's time, a level of advanced clinical practice has developed for the radiographer. This advanced clinical role allows the radiographer to act as a radiologist extender, similar to the physician assistant for a primary care physician. These radiographers take a leading role in patient care activities, perform selected radiologic procedures under the radiologist's supervision, and may be responsible for making initial image observations that are forwarded to the supervising radiologist for incorporation into the final report. The titles of *radiologist assistant* (RA) and *radiology practitioner assistant* (RPA) are currently used to designate radiographers who provide these advanced clinical services in the diagnostic imaging department. Requirements for practice include certification as a radiographer by the ARRT, pertinent additional education, and clinical experience under the supervision of a radiologist preceptor. The title of RA or RPA may be used only after passing an advanced level certification examination.

Care of the Radiographic Room

The radiographic procedure room should be as scrupulously clean as any other room used for medical purposes. The mechanical parts of the x-ray machine, such as the table, supporting structure, and collimator, should be wiped daily with a clean, damp (not soaked) cloth. The metal parts of the machine should be periodically cleaned with a disinfectant. The overhead system, x-ray tube, and other parts that conduct electricity should be cleaned with alcohol or a clean, dry cloth. Water is never used to clean electrical parts.

The tabletop should be cleaned after each patient procedure with a department-approved disinfectant cleaner. Accessories, such as gonad shields and nonporous positioning devices, should be cleaned daily and after any contact with a patient. Adhesive tape residue left on image receptors (IRs) should be removed, and all surfaces should be disinfected. IRs should be protected from patients who are bleeding, and disposable protective covers should be manipulated so that they do not come in contact with ulcers or other discharging lesions, if possible. The use of stained or damaged IRs is inexcusable and does not represent professional practice.

The radiographic room should be prepared for the procedure before the patient arrives. The room should look clean and organized—not disarranged from the previous procedure (Fig. 1.1). A fresh pillowcase should be put on the pillow, and accessories needed during the procedure should be placed nearby. Performing these preprocedural steps requires only a few minutes but creates a positive, lasting impression on the patient.

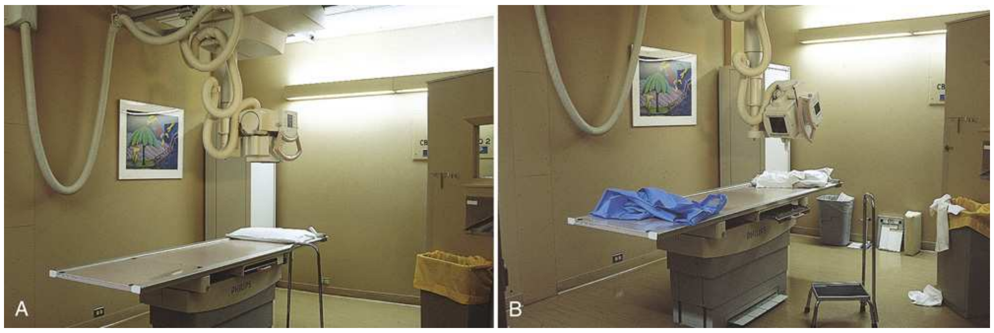


FIG. 1.1 (A) Radiographic room should always be clean and straightened before any examination begins. (B) This room is not ready to receive a patient. Note devices stored on the floor and previous patient's gowns and towels lying on the table. This room does not present a welcoming sight for a patient.

(A) A radiographic room has a radiographic table with a pillow on top. A trash can is on the side. The equipment are arranged and the room looks organized. (B) A radiographic room has a radiographic table with a gown and an unmade pillow on top of it. Towels are lying all over the room and on the floor. There is trash lying outside the trash can.

Control of Pathogen Contamination

For the protection of health care workers and patients, the US Centers for Disease Control and Prevention (CDC) provides directives for infection control. The foundation of infection control practices is included in the Standard Precautions for All Patient Care. "They're based on a risk assessment and make use of common-sense practices and personal protective equipment (PPE) use that protect health care providers from infection and prevent the spread of infection from patient to patient." [2] Standard precautions include the following aspects of professional practice:

- Perform hand hygiene (Fig. 1.2A).
- Use PPE whenever there is an expectation of possible exposure to infectious material (Box 1.1).
- Follow respiratory hygiene/cough etiquette principles.
- Ensure appropriate patient placement.
- Properly handle, clean, and disinfect patient care equipment and instruments/devices; clean and disinfect the environment appropriately (see Fig. 1.2B).
- Handle textiles and laundry carefully.
- Follow safe injection practices; wear a surgical mask when performing lumbar punctures.
- Ensure health care worker safety, including proper handling of needles and other sharps (Fig. 1.3).
- Transmission-based precautions are used in addition to standard precautions for patients with known or suspected infections.

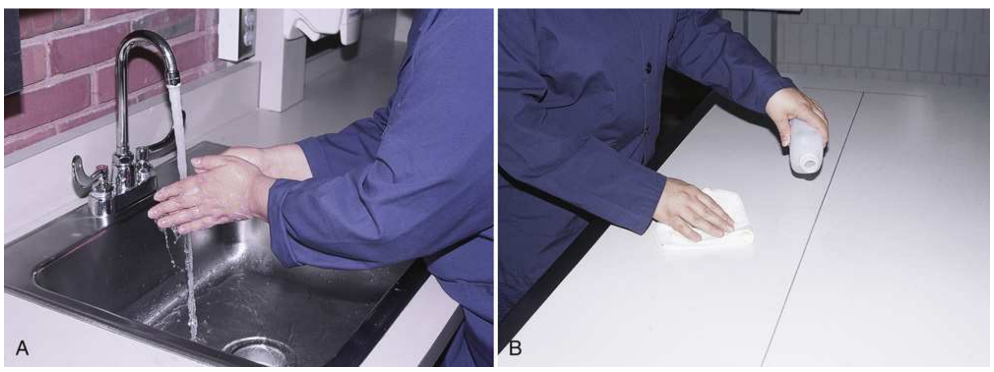


FIG. 1.2 (A) Radiographers should practice scrupulous cleanliness, which includes regular handwashing. (B) Radiographic tables and equipment should be cleaned with a disinfectant according to department policy.

(A) Close-up of hands of a radiographer washing hands by scrubbing both hands together under a running faucet of water. (B) Hands of a radiographer disinfecting the table using a bottle of disinfectant and a cloth.

BOX 1.1 Body fluids that may contain pathogenic microorganisms

Blood
Any fluid containing blood
Amniotic fluid
Pericardial fluid
Pleural fluid
Synovial fluid

Cerebrospinal fluid
Seminal fluid
Vaginal fluid
Urine
Sputum

FIG. 1.3 All needles should be discarded in puncture-resistant containers.

Standard Precautions

Radiographers are engaged in caring for sick patients and should be thoroughly familiar with *standard precautions*. They should know the way to handle patients who are on isolation status without contaminating their hands, clothing, or equipment, and radiographers must know the method of disinfecting these items when they become contaminated. Standard precautions are designed to reduce the risk of transmission of unrecognized sources of pathogens in health care institutions.

Handwashing is the easiest and most convenient method of preventing the spread of microorganisms (see Fig. 1.2A). Radiographers should wash their hands before and after working with each patient. Hands must always be washed, without exception, in the following specific situations:

- After examining patients with known communicable diseases
- After coming in contact with blood or body fluids
- Before beginning invasive procedures
- Before touching patients who are at risk for infection

As one of the first steps in the aseptic technique, radiographers' hands should be kept smooth and free from roughness or chapping by the frequent use of soothing lotions. All abrasions should be protected by bandages to prevent the entrance of bacteria.

For the protection of the health of radiographers and patients, the laws of asepsis and prophylaxis must be obeyed. Radiographers should practice scrupulous cleanliness when handling all patients, whether or not the patients are known to have an infectious disease. If a radiographer is to examine the patient's head, face, or teeth, the patient should ideally see the radiographer perform handwashing. If this is not possible, the radiographer should perform handwashing and then enter the room while drying the hands with a fresh towel. If the patient's face is to come in contact with the IR front or table, the patient should see the radiographer clean the device with a disinfectant or cover it with a clean drape. Under all circumstances, the radiographer must wear disposable gloves.

A sufficient supply of gowns and disposable gloves should be kept in the radiographic room to be used to care for infectious patients. After examining infectious patients, radiographers must wash their hands in warm, running water and soapsuds and rinse and dry them thoroughly. If the sink is not equipped with a knee control for the water supply, the radiographer opens the valve of the faucet with a paper towel. After proper handwashing, the radiographer closes the valve of the faucet with a paper towel.

Before bringing a patient from an isolation unit to the radiology department, the transporter should drape the stretcher or wheelchair with a clean sheet to prevent contamination of anything the patient might touch. When the patient must be transferred to the radiographic table, the table should be draped with a sheet. The edges of the sheet may be folded back over the patient so that the radiographer can position the patient through the clean side of the sheet without becoming contaminated.

When a free IR is used, it may be placed under the sheet. When possible, the gloved radiographer should position the patient using the sheet. If the radiographer must handle the patient directly, an assistant should position the tube and operate the equipment to prevent contamination. If a patient has any moisture or body fluids on the body surface that could come in contact with the IR, a nonporous cover should be placed over the IR before positioning under the patient.

When the examination is finished, the contaminated linen should be folded with the clean side out and disposed of according to the established policy of the institution. All radiographic tables must be cleaned after patients have touched them with their bare skin and after patients with communicable diseases have been on the table (see Fig. 1.2B).

Minor Surgical Procedures in the Radiology Department

Procedures that require a rigid aseptic technique, such as cystography, intravenous urography, spinal puncture, arthrography, and angiography, are performed in the radiology department (Fig. 1.4). Although the physician needs the assistance of a nurse in certain procedures, the radiographer can make the necessary preparations and provide assistance in many procedures.

For procedures that do not require a nurse, the radiographer should know which instruments and supplies are necessary and how to prepare and sterilize them. Radiographers may make arrangements with the surgical supervisor to acquire the education necessary to perform these procedures.

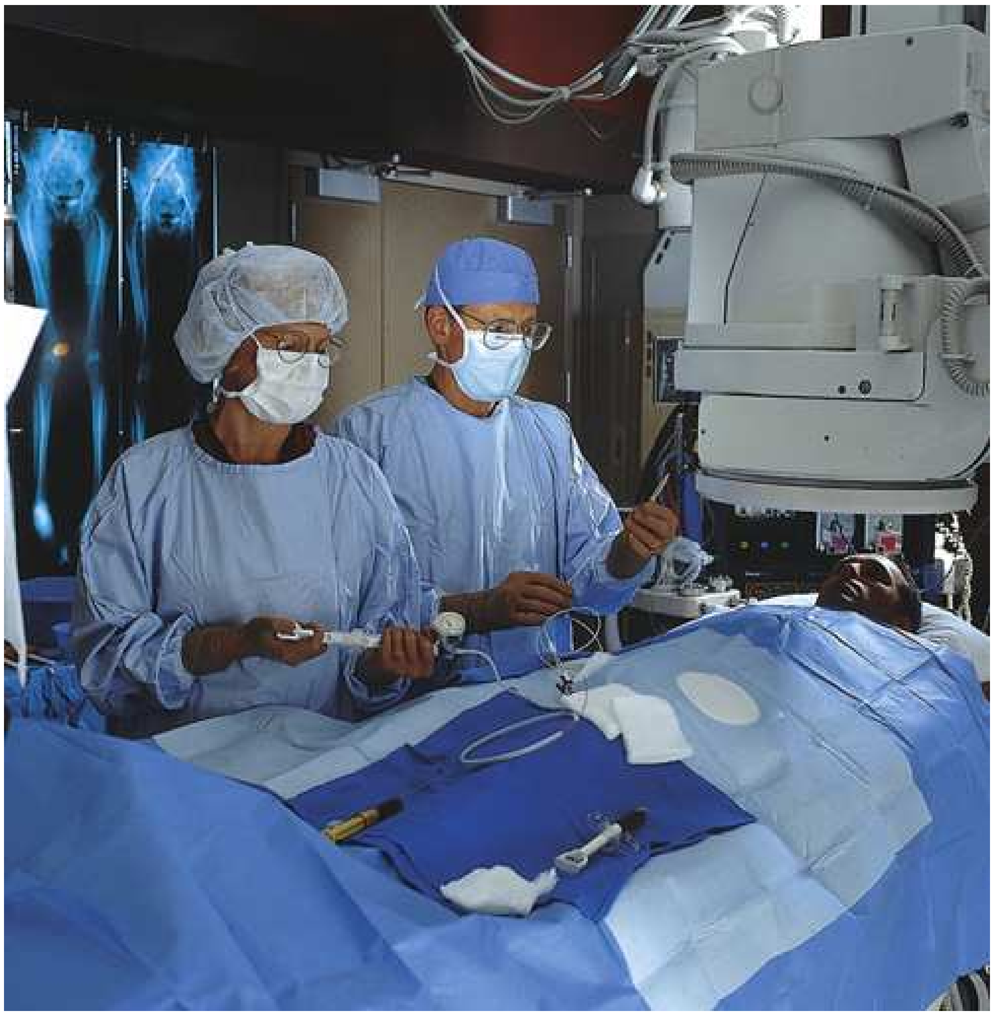


FIG. 1.4 Many radiographic procedures require strict aseptic technique, as seen in this procedure involving passing a catheter into the patient's femoral artery.

Control of Contamination Outside the Radiology Department

The radiographer is frequently required to provide imaging services to patients in hospital departments outside of radiology. These most often involve mobile radiography and C-arm fluoroscopy procedures in areas such as the emergency department (ED), intensive care units, medical-surgical units, and pain management clinics.

Strict adherence to standard precautions will help to ensure the safety of the radiographer, patients, and other health care workers. In addition to standard precautions, the radiographer must practice transmission-based precautions and isolation precautions when the situation warrants. Carelessness by the radiographer can result in the spread of infection to other health care workers or between patients. In the case of immunocompromised patients in a protective environment, failure of the radiographer to adhere to strict aseptic guidelines can result in a serious patient infection.

Providing imaging services in the operating room (OR) requires additional cleanliness considerations beyond those required in other hospital areas. The radiographer must safely enter and perform imaging procedures without contaminating the sterile surgical field. This requires experience and a high level of caution when moving imaging equipment in the surgical environment.

Chapter 21 of this atlas contains comprehensive information about the radiographer's work in the OR. A radiographer who has not had extensive patient care education must exercise extreme caution to prevent contaminating sterile objects in the OR. The radiographer should perform handwashing and wear scrub clothing, shoe covers, a scrub cap, and a mask and should survey the particular setup in the OR before bringing in the x-ray equipment. By taking this precaution, the radiographer can ensure that sufficient space is available to do the work without the danger of contamination. If necessary, the radiographer should ask the circulating nurse to move any sterile items. Because of the threat of contamination of the sterile field, sterile supplies, and persons scrubbed for the procedure, the radiographer should never approach the operative side of the surgical table unless directed to do so.

After checking the room setup, the radiographer should thoroughly wipe the x-ray equipment with a damp (not soaked) cloth before taking it into the OR. The radiographer moves the mobile machine, or C-arm unit, to the free side of the operating table—the side opposite the surgeon, scrub nurse, and sterile layout (Fig. 1.5). The machine should be maneuvered into a general position that makes the final adjustments easy when the surgeon is ready to proceed with the examination.

The IR is placed in a sterile covering for some procedures. The surgeon or one of the assistants holds the sterile case open while the radiographer gently drops the IR into it, being careful not to touch the sterile case. The radiographer may give directions for positioning and securing the IR for the exposure.

The radiographer should make the necessary arrangements with the OR supervisor when performing work that requires the use of a tunnel or other special equipment. When an IR is being prepared for the patient, any tunnel or grid should be placed on the table with the tray opening to the side of the table opposite the sterile field. With the cooperation of the surgeon and OR supervisor, a system can be developed for performing radiographic examinations accurately and quickly without moving the patient or endangering the sterile field (Fig. 1.6).

FIG. 1.5 Radiographer carefully positioning mobile x-ray tube during a surgical procedure. The sterile incision site is properly covered to maintain a sterile field. Note the sterile instruments in the foreground *(arrow)*. The radiographer should never move radiographic equipment over uncovered sterile instruments or an uncovered surgical site.

FIG. 1.6 Radiographer must exercise extreme caution to prevent contaminating sterile objects in the OR.

Interacting With Patients

Patients who are coherent and capable of understanding should be given an explanation of the procedure to be performed. Patients should understand exactly what is expected and be made comfortable. If patients are apprehensive about the examination, their fears should be alleviated. If the procedure will cause discomfort or be unpleasant, such as with cystoscopy and intravenous injections, the radiographer should calmly and truthfully explain the procedure. Patients should be told that it will cause some discomfort or be unpleasant, but because the procedure is a necessary part of the examination, full cooperation is necessary. Patients usually respond favorably if they understand that all steps are being taken to alleviate discomfort. Patients with special needs, such as autism or Alzheimer disease, may require specialized strategies to gain their cooperation during radiography procedures. See Chapters 22 and 23 for recommendations for effectively interacting with these patients.

Because the entire procedure may be a new experience, patients usually respond incorrectly when given more than one instruction at a time. For example, when instructed to get up on the table and lie on the abdomen, a patient may get onto the table in the most awkward possible manner and lie on his or her back. Instead of asking a patient to get onto the table in a specific position, the radiographer should first have the patient sit on the table and then give instructions on assuming the desired position. If the patient sits on the table first, the position can be assumed with less strain and fewer awkward movements. The radiographer should never rush a patient. If patients feel hurried, they will be nervous and less able to cooperate. When moving and adjusting a patient into position, the radiographer should manipulate the patient gently but firmly; a light touch can be as irritating as one that is too firm. Patients should be instructed and allowed to do as much of the moving as possible.

X-ray grids move under the radiographic table, and with floating or moving tabletops, patients may injure their fingers. To reduce the possibility of injury, the radiographer should inform patients to keep their fingers on top of the table at all times. Regardless of the part being examined, the patient's entire body must be adjusted with resultant motion or rotation to prevent muscle pull in the area of interest. When a patient is in an oblique (partially rolled to the side) position, the radiographer should use support devices and adjust the patient to relieve any strain. Immobilization devices should be used whenever necessary but not to the point of discomfort.

When making final adjustments to a patient's position, the radiographer should stand with the eyes in line with the position of the x-ray tube, visualize the internal structures, and adjust the part accordingly. Although there are a variety of ways to position patients, many repeat examinations can be eliminated by following these guidelines. (See Chapters 22 and 23 for specific recommendations for interacting with pediatric and geriatric patients.)

Ill or Injured Patients

Great care must be exercised in handling trauma patients, particularly patients with skull, spinal, and long bone injuries. A physician should perform any necessary manipulation to prevent the possibility of fragment displacement. The positioning technique should be adapted to each patient and should necessitate as little movement as possible. If the tube-body part-imaging plane relationship is maintained, the resultant projection is the same regardless of the patient's position.

When a patient who is too sick to move alone must be moved, the following considerations should be kept in mind:

1. The patient should be moved as little as possible.
2. The radiographer should never try to lift a helpless patient alone.
3. To prevent straining the back muscles when lifting a heavy patient, one should flex the knees, straighten the back, and bend from the hips.
4. When a patient's shoulders are lifted, the head should be supported. While holding the head with one hand, slide the opposite arm under the shoulders and grasp the axilla so that the head can rest on the bend of the elbow when the patient is raised.

5. When moving the patient's hips, the patient's knees are flexed first. In this position, patients may be able to raise themselves. If not, lifting the body when the patient's knees are bent is easier.
6. When a helpless patient must be transferred to the radiographic table from a stretcher or bed, he or she should be moved on a sheet or moving device by at least four and preferably six people. The stretcher is placed parallel to and touching the table. Under ideal circumstances, at least three people should be stationed on the side of the stretcher and two on the far side of the radiographic table to grasp the sheet at the shoulder and hip levels. One person should support the patient's head, and another person should support the feet. When the signal is given, all six people should *smoothly and slowly* lift and move the patient in unison (Fig. 1.7A). Often, radiographers use the three-person move for patients who are not in a critical condition (see Fig. 1.7B).

Many hospitals now have a specially equipped radiographic room adjoining the ED. These units often have special radiographic equipment and stretchers with radiolucent tops that allow severely injured patients to be examined on the stretcher and in the position in which they arrive. A mobile radiographic machine is often taken into the ED, and radiographs are exposed there. When this ideal emergency setup does not exist, trauma patients are often conveyed to the main radiology department. There they must be given precedence over nonemergency patients (see Chapter 12).

FIG. 1.7 (A) Technique for a six-person transfer of a patient who is unable to move from a cart to the procedure table. Note the person holding and supporting the head. (B) Three-person transfer of a patient back onto the cart. Note that two people are always on the side that is pulling the patient and one person is on the opposite side pushing the patient. Note also that the backs of the three people are straight, in accordance with correct lifting and moving practices.

(A) shows six people dressed in uniforms transferring a patient from the cart to the procedure table. One of them is holding the head. Three of them are holding the left side and the other two are holding the right side. (B) shows three people dressed in uniforms transferring a patient from the procedure table to the cart. One person is pushing the patient and the other two standing next to the cart are pulling the patient.

Age-Specific Competencies

Age-specific competence is defined as the knowledge, skills, ability, and behaviors that are essential for providing optimal care to defined groups of patients. Examples of defined groups include neonatal, pediatric, adolescent, and geriatric patients. Appropriate staff competence in working with these diverse patient groups is crucial in providing quality patient care. The Joint Commission [3] requires that age-specific competencies be written for all health care personnel who provide direct patient care. Radiographers are considered direct patient care providers. The Joint Commission requires radiology departments to document that radiographers maintain competency in providing radiologic examinations to defined groups of patients.

Age-specific competence is based on the knowledge that different groups of patients have special physical and psychosocial needs. Different types and levels of competence are required for specific patient populations. A radiographer who is obtaining radiographic images on a neonatal or pediatric patient must be skilled at interpreting nonverbal communication. Working with a geriatric patient requires the radiographer to have the knowledge and skills necessary to assess and maintain the integrity of fragile skin.

Health care facilities that provide patient care may classify the different age groups for which age-specific competence is defined. Some hospitals may classify patients by *chronologic* age, some may use *functional* age, and others may use *life stage* groupings.[4,5] Specialty organizations, such as pediatric hospitals, veterans' hospitals, psychiatric hospitals, or long-term care facilities, might use institution-specific criteria, such as premature or newborn, Vietnam veteran, closed ward, or Alzheimer disease.

The principle supporting age-related competencies is that staff involved in direct patient care who are not competent to provide care to patients in a specific age or functional groups can alter treatment, increase patient complaints about care, make serious medical errors, and increase operational costs. The Joint Commission looks for evidence of staff development programs that are effective and ongoing and serve to maintain and improve staff competence.

When The Joint Commission surveys organizations, it looks for evidence of competence assessment primarily in personnel records. The Joint Review Committee on Education in Radiologic Technology (JRCERT), the organization that accredits radiography programs, makes site visits of radiography programs and looks for evidence that students not only learn the basic theories supporting age-related competence but also are competent. Table 1.1 shows a checklist that can be used in a radiography program to document that a student has demonstrated basic competence in several different life stages. Box 1.2 provides examples of age-specific competencies that should be required of a radiographer. Health care facilities are required to prepare age-related competencies for all age groups, including neonates, infants, children, adolescents, adults, and geriatrics.

TABLE 1.1

Used with permission from The Joint Commission, Oakbrook Terrace, IL, 1998.

Merrill's Atlas essentially addresses the normal adult patient in the age group from approximately 18 to 60 years. Although an organization would have published age-specific competencies for this broad age group, this group could be considered the "standard group" for which radiologic procedures are standardized and written. Radiographers must learn the specifics of how to adapt and modify procedures for extreme groups, such as neonates (see Chapter 22) and geriatric patients (see Chapter 23), and for those in between, such as adolescents.

BOX 1.2 Age-specific competencies that should be required of a radiographer for two selected age groups

Neonate (1–30 days)

- Explain examination to the parents if present.
- Cover infant with a blanket to conserve body heat.
- Cover image receptor with a blanket or sheet to protect the skin from injury.
- Collimate to a specific area of interest only.
- Shield patient and any attendants.

Geriatric (68 years old or older)

- Speak clearly and do not raise your voice.
- Do not rush examination.
- Use positioning aids when possible.
- Ensure that patient is warm owing to decreased circulation.
- Do not leave the patient unattended on the x-ray table.

Note: This list is not inclusive for the two age groups listed. Age-related competencies are prepared for other age groups as well.

Clinical History

The radiographer is responsible for performing radiographic examinations according to the standard department procedure except when contraindicated by the patient's condition. The radiologist is a physician who is board certified to read or interpret diagnostic images. As the demand for the radiologist's time increases, less time is available to devote to the technical aspects of radiology. This situation makes the radiologist more dependent on the radiographer to perform the technical aspects of patient care. The additional responsibility makes it necessary for the radiographer to know the following:

- Normal anatomy and normal anatomic variations so that the patient can be accurately positioned
- The radiographic characteristics of numerous common abnormalities

Although the radiographer is not responsible for explaining the cause, diagnosis, or treatment of the disease, the radiographer's professional responsibility is to produce an image that clearly shows the abnormality.

When the physician does not see the patient, the radiographer is responsible for obtaining the necessary clinical history and observing any apparent abnormality that might affect the radiographic result (Fig. 1.8). Examples include noting jaundice or swelling, body surface masses possibly casting a density that could be mistaken for internal changes, tattoos that contain ferrous pigment, surface scars that may be visible radiographically, and some decorative or ornamental clothing. The physician should give specific instructions about what information is necessary if the radiographer assumes this responsibility.

The request for an imaging procedure received by the radiographer should clearly identify the exact region to be radiographed and the reason for the procedure. It is the radiographer's responsibility to determine whether the procedure ordered is consistent with the reason for the examination. The patient must be positioned and the exposure factors selected according to the region involved and the radiographic characteristics of the suspected abnormality. Radiographers must understand the rationale behind the examination; otherwise, radiographs of diagnostic value cannot be produced. This may result in a delayed or missed diagnosis. Having the information in advance prevents delay, inconvenience, and, more importantly, unnecessary radiation exposure for the patient.

With most institutions now using electronic medical records, the radiographer will likely be using the computer system to enter information about the patient. In many of these information systems, the full patient medical record may be accessed. The radiographer needs to observe rules of confidentiality, as required by the Health Insurance and Portability Act of 1996 (HIPAA), restricting access to that part of the patient's protected health information that is relevant to the current procedure.

Diagnosis and the Radiographer

A patient is naturally anxious about procedure results and is likely to ask questions. The radiographer should tactfully advise the patient that the referring physician will receive the report as soon as the radiographs have been interpreted by the radiologist. Referring physicians may also ask the radiographer questions, and they should be instructed to contact the interpreting radiologist. Interpretation of images, beyond the assessment of quality, is outside the scope of practice for a radiographer. However, it may be appropriate for a radiographer to notify the radiologist before the patient is released if something is seen on a radiograph that may indicate a potentially serious or life-threatening condition.

FIG. 1.8 Radiographer is often responsible for obtaining a clinical history from the patient.

A radiographer holding a clipboard is talking to an elderly man sitting in a wheelchair in front of her in the radiographic room. The procedure table and a mobile x-ray tube are next to them. Few gowns are hanging on the wall behind.

Bowel Preparation

Radiologic examinations involving the abdominal organs often require that the entire colon be cleansed before the examination so that diagnostic quality radiographs can be obtained. The patient's colon may be cleansed by one or any combination of the following:

- Limited diet
- Laxatives
- Enemas

The technique used to cleanse the patient's colon generally is selected by the medical facility or physician. The patient should be questioned about any bowel preparation that may have been completed before an abdominal procedure is begun. For additional information on bowel preparation, see Chapter 15.

Patient Clothing, Jewelry, and Surgical Dressings

The patient should be dressed in a gown that allows exposure of limited body regions under examination. A patient is never exposed unnecessarily; a sheet should be used when appropriate. If a region of the body needs to be exposed to complete the examination, only the area under examination should be uncovered while the rest of the patient's body is completely covered for warmth and privacy. When the radiographer is examining parts that must remain covered, disposable paper gowns or cotton cloth gowns without metal or plastic snaps are preferred (Fig. 1.9). If washable gowns are used, they should not be starched; starch is *radiopaque,* which means it cannot be penetrated easily by x-rays. Any folds in the cloth should be straightened to prevent confusing densities, or artifacts, on the radiograph. The length of exposure should also be considered. When a longer exposure or more radiation is used, such as that required for an adult abdomen, material that does not cast a density (artifact) may show clearly when less exposure is used, such as that used on a child's abdomen.

Any radiopaque object should be removed from the region to be radiographed. Zippers, necklaces, snaps, thick elastic, and buttons should be removed when radiographs of the chest and abdomen are produced (Fig. 1.10). When radiographing the skull, the radiographer must make sure that dentures, removable bridgework, earrings, necklaces, and all hairpins are removed.

When the abdomen, pelvis, or hips of an infant are radiographed, the diaper should be removed. Because some diaper rash ointments are radiopaque, the area may need to be cleansed before the procedure.

Surgical dressings, such as metallic salves and adhesive tape, should be examined for radiopaque substances. If permission to remove the dressings has not been obtained or the radiographer does not know how to remove them and the radiology department physician is not present, the nurse should be asked to accompany the patient to the radiology department to remove the dressings. When dressings are removed, the radiographer should always ensure that a cover of sterile gauze adequately protects open wounds.

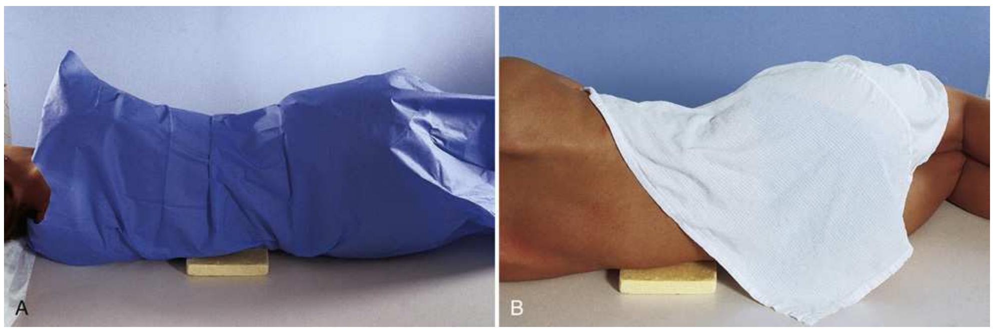


FIG. 1.9 (A) A female patient wearing a disposable paper gown and positioned for a lateral projection of the lumbar spine. Private areas are completely covered. The gown is smoothed around the contour of the body for accurate positioning. (B) The same patient wearing a traditional cloth hospital gown. The gown is positioned for maximal privacy.

(A) A patient lying in a lateral recumbent position on the procedure table is wearing a disposable paper gown. A support is placed above the hip. (B) A patient lying in a lateral recumbent position on the procedure table is wearing a traditional cloth and it covers the private parts. A support is placed above the hip.

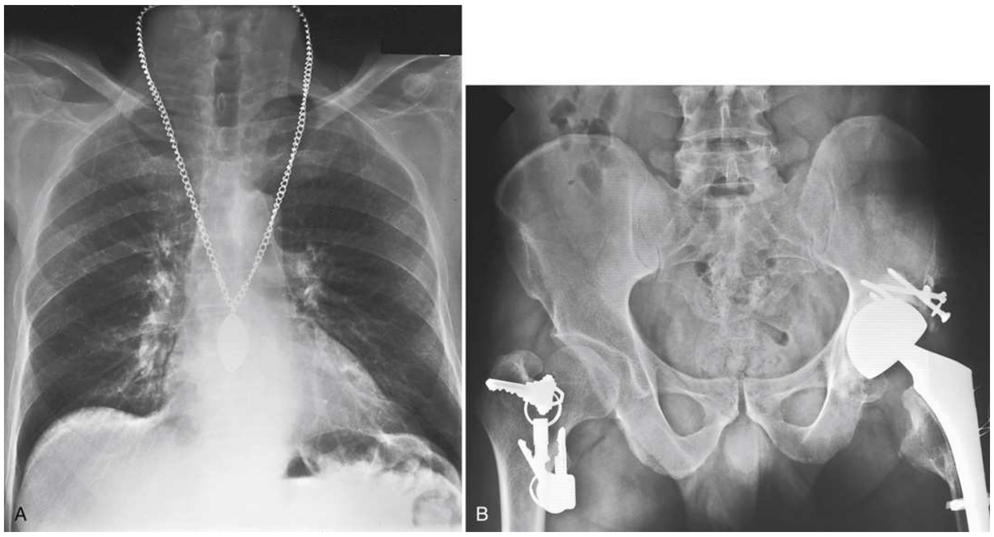


FIG. 1.10 (A) A necklace was left on for this chest radiograph. (B) Keys were left in the pocket of a lightweight hospital robe during the examination of this patient's pelvis. Both radiographs had to be repeated because the metal objects were not removed before the examination.

(A) An x-ray view of the chest shows a necklace around the neck area. It appears radiopaque. (B) An x-ray view of the pelvis shows a bunch of keys on the left and a fixation device with screws on the right near the femoral joint. It appears radiopaque.

Motion and Its Control

Patient motion plays a large role in radiography (Fig. 1.11). Because motion is the result of muscle action, the radiographer needs to have some knowledge about the functions of various muscles. The radiographer should use this knowledge to eliminate or control motion for the exposure time necessary to complete a satisfactory examination. The three types of muscular tissue that affect motion are the following:

- Smooth (involuntary)
- Cardiac (involuntary)
- Striated (voluntary)

FIG. 1.11 (A) Forearm radiograph of a patient who moved during the exposure. Note the fuzzy appearance of the edges of the bones. (B) Radiograph of patient without motion.

Involuntary Muscles

The visceral (organ) muscles are composed of *smooth* muscular tissue and are controlled partially by the autonomic nervous system and the muscles' inherent characteristics of rhythmic contractility. By their rhythmic contraction and relaxation, these muscles perform the movement of the internal organs. The rhythmic action of the muscular tissue of the alimentary tract, called *peristalsis,* is normally more active in the stomach (approximately three or four waves per minute) and gradually diminishes along the intestine. The specialized *cardiac* muscular tissue functions by contracting the heart to pump blood into the arteries and by expanding or relaxing to permit the heart to receive blood from the veins. The pulse rate of the heart varies with emotions, exercise, diet, size, age, and gender.

Involuntary motion is caused by the following:

- Heart pulsation
- Chill
- Peristalsis
- Tremor
- Spasm
- Pain

The primary method of reducing involuntary motion on radiographic images is to control the length of exposure time—the less exposure time, the better.

Voluntary Muscles

The voluntary, or skeletal, muscles are composed of *striated* muscular tissue and are controlled by the central nervous system. These muscles perform the movements of the body initiated by the individual. In radiography, the patient's body must be positioned in such a way that the skeletal muscles are relaxed. The patient's comfort level is a good guide in determining the success of the position.

Voluntary motion resulting from lack of control is caused by the following:

- Nervousness
- Discomfort
- Excitability
- Mental illness
- Fear
- Age
- Breathing

The radiographer can control voluntary patient motion on images by doing the following:

- Giving clear instructions
- Providing patient comfort
- Adjusting support devices
- Applying immobilization

Decreasing the length of exposure time is the best way to control voluntary motion for patients who are unable to cooperate, such as young children, the elderly, and those with mental illness. Immobilization for limb radiography can often be obtained for the duration of the exposure by having the patient phonate an *mmm* sound with the mouth closed or an *ahhh* sound with the mouth open. The radiographer should always be watching the patient during the exposure to ensure that the patient has complied with breathing instructions when an exposure is made. Radiolucent positioning sponges and sandbags are commonly used as immobilization devices (Fig. 1.12A). A leg holder is used to stabilize the opposite leg for lateral radiographs of the legs, knee, femur, and hip (Fig. 1.12B). A thin radiolucent mattress, called a *table pad,* may be placed on the radiographic table to reduce movement related to patient discomfort caused by lying on the hard surface. These table pads should not be used when the increased object-to-image receptor distance (OID) would result in unacceptable magnification, such as in radiography of the limbs. If possible, radiographers should use table pads under the patient in the body areas where the projections are not made.

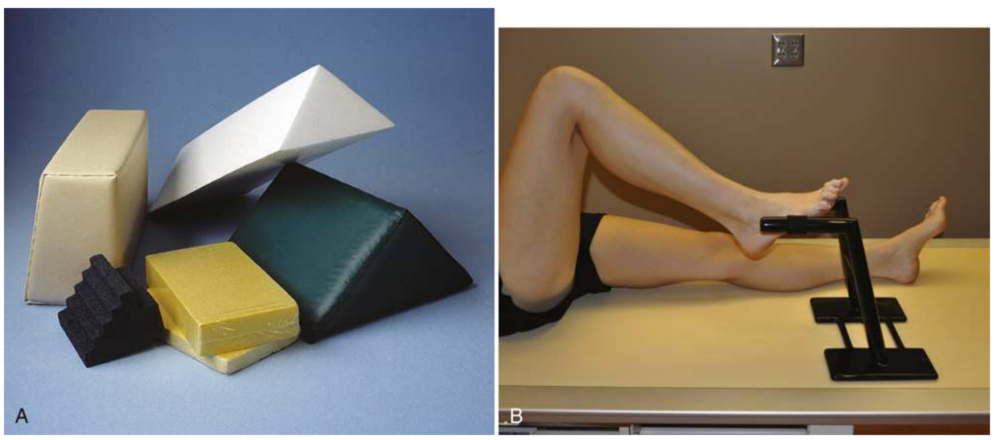


FIG. 1.12 (A) Positioning sponges and sandbags are commonly used as immobilization devices. (B) Ferlic leg holder and immobilization device. B, Courtesy Ferlic Filter Company, LLC, White Bear Lake, MN.

(A) A few radiolucent positioning sponges and sandbags of different shapes, sizes, and colors are next to each other. Two of them are triangular, two are rectangular, one of them is shaped like a pyramid with steps. (B) Close-up legs of a patient lying supine, resting her flexed knee on a ferlic leg holder placed on the radiographic table. The other leg is extended.

Preexposure Instructions

The radiographer should instruct the patient in the appropriate breathing method and should have the patient practice until the necessary actions are clearly understood. Most, but not all, radiographic projections require a breath hold in some phase of respiration. The most common are breath holds at the end of inspiration and at the end of expiration. The appropriate phase of breath hold or breathing technique is included in the positioning instructions for each projection in the text. A breathing technique is defined as instructing the patient to breathe during a long exposure time combined with a low mA technique setting. The breathing motion blurs overlying anatomic structures for demonstration of specific anatomy, such as the anteroposterior (AP) scapula and lateral thoracic vertebrae.

During trunk examination, the patient's phase of breathing is important. *Inspiration* (inhalation or breathing in) depresses the diaphragm and abdominal viscera, lengthens and expands the lung fields, elevates the sternum and pushes it anteriorly, and elevates the ribs and reduces their angle near the spine. *Expiration* (exhalation or breathing out) elevates the diaphragm and abdominal viscera, shortens the lung fields, depresses the sternum, and lowers the ribs and increases their angle near the spine. When exposures are to be made during shallow breathing, the patient should practice slow, even breathing, so that only the structures above the one being examined move.

After the patient is in position, but before the radiographer leaves to make the exposure, the radiographer should have the patient practice the appropriate breath hold once more. This step requires a few minutes, but it may prevent a repeat exposure. The eyes of the radiographer should always be on the patient when the exposure is made to ensure that an exposure is not made if the patient moves or breathes. This is particularly important when pediatric, trauma, unconscious, and some geriatric patients undergo radiography.

Image Receptor

In radiography, the *image receptor* is the device that receives the energy of the x-ray beam and forms the image of the body part. In diagnostic radiology, the IR is one of the following four devices:

1. *Solid-state digital detector:* Often referred to as digital radiography (DR); uses a flat-panel IR to convert x-ray energy into a digital signal. The digital signal converter may be a thin-film transistor (TFT) array or a charge-coupled device (CCD). The image capture system may be indirect, using a light-emitting scintillator coupled to the digital converter, or direct, consisting of a photoconductor integrated with the digital converter. These solid-state detectors may be built into the x-ray table or upright wall unit (Fig. 1.13A), or they may be housed in a cassette-like portable enclosure. The portable solid-state detectors may be wired, or tethered, directly to the digital imaging system computer (see Fig. 1.13B) or may be connected wirelessly (see Fig. 1.13C). The image is viewed on a computer monitor and may be downloaded to a compact disc (CD), or least commonly, printed on film. This is the fastest image acquisition system, with images available in 6 seconds or less.
2. *Photostimulable storage phosphor image plate* (PSP IP): A device, used for computed radiography (CR), similar in composition to a conventional intensifying screen that is housed in a specially designed cassette. The IP stores much of the x-ray energy it receives for later processing. After exposure, the cassette is inserted into a CR reader device, which scans the IP with a laser to release the stored x-ray energy pattern as light. The emitted light, constituting the radiographic image, is converted to digital format and viewed on a computer monitor, exported to a CD, or printed on film (see Fig. 1.13D).
3. *Fluoroscopic IR:* A fluoroscopic system is designed for real-time imaging, to guide procedures, or capture full-motion video. The IR may be a conventional image intensifier tube (see Fig. 1.13E), coupled to a video camera, or a solid-state flat-panel digital detector (see Fig. 1.13F). The resulting images are viewed on a monitor and may be saved as static images, video recordings, or video files.

TABLE 1.2

Most common computed radiography plate sizes

Inches	Centimeters
8 × 10	18 × 24
10 × 12	24 × 30
14 × 14	35 × 35
14 × 17	35 × 43
14 × 36	35 × 91

Some manufacturers build in inches and some in centimeters.

4. *Cassette with film:* A device that contains special intensifying screens that emit light when struck by x-rays and imprint the x-ray image on film. Use of a darkroom, where the film is developed in a processor, is required. Afterward, the radiographic film image is ready for viewing on an illuminator or a viewbox (Fig. 1.13G). Film-screen cassettes are the oldest type of IR and are rarely used in modern medical imaging.

IR Dimensions

Radiographic IR systems are manufactured in English and metric sizes. CR IPs are commonly manufactured in five sizes (Table 1.2). However, most departments use only the 10 × 12-inch (24 × 30-cm) and 14 × 17-inch (35 × 43-cm) plates for all routine images. The active surfaces of IRs used for DR are manufactured in approximately 10 × 12-inch (24 × 30-cm), 14 × 17-inch (35 × 43-cm), and 17 × 17-inch (43 × 43-cm) dimensions. The outer dimensions of these IRs are larger and vary in size depending on the manufacturer.

IR Dimensions in this Atlas

IR dimensions recommended in this atlas are for *adults*. These sizes are subject to modification as needed to fit the size of the body part. Both US and metric sizes are used in the atlas, as appropriate.

FIG. 1.13 Image receptors. (A) DR upright wall unit. A flat-panel digital detector is located behind the front cover *(arrow)*. (B) Tethered portable DR IR. (C) Wireless portable DR IR. (D) CR cassette. This contains a photostimulable storage phosphor image plate that stores the x-ray image. (E) Fluoroscopic image intensifier unit located under fluoroscopic tower *(arrow)* transmits x-ray image to a camera and then to a television for real-time viewing. (F) Fluoroscopic solid-state flat-panel digital detector transmits image directly to viewing monitor without the need for an intermediate video camera. (G) Conventional radiographic cassette, opened and showing a sheet of x-ray film. F, Courtesy Canon USA, Inc. G, Used with permission from Philips Healthcare, Bothell, WA.

(A) shows a D R upright wall unit with a front cover. A black arrow is pointed at the front cover. (B) shows a man wearing a coat holding a whiteboard. A horizontal and a vertical line in the middle divides the board into four quadrants. (C) shows a hand holding a whiteboard with a text that reads "D X-D 30 C." (D) shows a C R cassette with a digital screen on the top and three circular buttons around it. (E) shows a flat-panel digital detector. It has a tower on top and flat at the bottom. An arrow points at the flat bottom. (F) shows flat-panel equipment. It has a long rectangular grey-colored frame on it in the middle. (G) shows a hand pulling out a sheet of x-ray film from a radiographic cassette.

Radiographic Positioning and Procedure

The atlas contains all instructions and recommendations needed to perform any radiographic projection. Updates to this edition reflect changes in current practice. A total of 340 projections are included in Volumes 1 and 2, of which 210 are essential projections. An essential projection, also called a routine projection, is identified in the Summary of Projections in each chapter with the

symbol.

A procedure or protocol book covering each examination performed in the radiology department is important. Under the appropriate heading, each procedure should be outlined, and a list of all department-approved projections and positions for each procedure should be listed. For fluoroscopic procedures, the protocol should state the staff required and the duties of each team member. A listing of sterile and nonsterile items should also be included. A copy of the sterile instrument requirements should be given to the supervisor of the central sterile supply department to guide preparation of the trays for each procedure.

Initial or Routine Procedure

The radiographs obtained for the initial or routine procedure for each body part are based on the anatomy or function of the part and the type of abnormality indicated by the clinical history. These radiographs are usually the minimum required to detect any demonstrable abnormality in the region and are set by department protocol. They are usually the ones included in the radiology information system (RIS) worklist order set for the ordered procedure. Supplemental radiographs, for further investigation, are made as needed. This standard procedure saves time, eliminates unnecessary radiographs, and reduces patient exposure to radiation.

Common Steps for a Radiographic Procedure

Radiographers follow a set of common steps for each radiographic procedure. This improves efficiency, ensures patient safety, reduces mistakes, and minimizes patient radiation exposure. The order of these steps varies by the anatomy of interest, patient condition, type of equipment available, and by department protocol. More complex procedures, involving multiple body parts or fluoroscopy, may require additional steps. Table 1.3 lists recommended procedural steps for a radiographic procedure on a cooperative, uncomplicated patient.

TABLE 1.3

CR, Central ray; *HIPAA*, Health Insurance and Portability Act of 1996; *IR*, image receptor; *SID*, source-to-image receptor distance.

Accessory Equipment

Performance of radiographic procedures may require the use of equipment to ensure a body part remains in the appropriate posture during exposure. The most common positioning aids are radiolucent sponges of various shapes and sizes based on the anatomy of interest. Additional devices may be needed for special purposes by department protocol (see Fig. 1.12).

Other devices may be needed to enhance image quality. These devices are placed between the patient and the IR. These include grids, lead shields, and filters. Grids and lead shields reduce scattered radiation to the IR. For lateral projections of the thoracic and lumbar spine, sacrum, and coccyx, placement of a lead shield on the table posterior to the patient's back reduces the amount of scattered radiation reaching the IR (Fig. 1.14). Grids reduce scattered and off-focus radiation reaching the IR. They may be attached to the IR (Fig. 1.15) or may be built into the IR holder or Bucky tray (Fig. 1.16).

FIG. 1.14 When positioning for a lateral thoracic spine, a lead drape placed on the table in line with the back shadow will reduce the amount of scattered radiation reaching the IR.

The patient lying in the lateral recumbent position with his back facing front. A support is placed under the head to elevate it. A support is placed under the lower thoracic region. The side marker is in the collimated exposure field. The central ray is perpendicular to the center of the I R at the level of T 7.

FIG. 1.15 The IR is placed in a grid holder for this cross-table lateral cervical spine radiograph to reduce the amount of scatter radiation reaching the IR.

The patient is lying in a supine position against the I R in a grid holder. The arms are placed along the sides of the body and the shoulders lie in the same horizontal plane. The central ray is distal to the adjacent mastoid tip.

FIG. 1.16 A vertical Bucky unit contains a reciprocating grid to reduce scattered radiation reaching the IR.

The patient is in standing a true lateral position before a vertical bucky unit and is looking steadily in front. The adjacent shoulder is resting against the device. The chin is elevated slightly. The side marker is in the collimated exposure field. The central ray is horizontal and perpendicular to C4.

Compensating filters are designed to compensate for significantly varied tissue thickness and density within a body part. The filter results in a more uniform image brightness by varying the amount of radiation received by different parts of the anatomy when the filter is placed between the tube and patient. The resulting attenuated beam more appropriately exposes the various tissue densities of the anatomy and reveals greater anatomic detail. Equally important, the filter reduces the entrance skin exposure and, thus, the absorbed dose to some of the organs in the body (Fig. 1.17). Some of the most common filters currently in use are shown in Fig. 1.18. Without the use of filters, radiographs such as the AP projection of the thoracic spine (Fig. 1.19), the axiolateral projection (Danelius-Miller method) of the hip (Fig. 1.20), and the AP shoulder (Fig. 1.21) may demonstrate significant differences in brightness between anatomic structures of widely varying tissue densities, even with DR. Common projections for which filters improve image quality are listed in Table 1.4.

Compensating filters are manufactured in various shapes and are composed of several materials. The shape or material chosen is based on the particular body part to be imaged. The exact placement of the filter also varies, with most placed between the x-ray tube and the skin surface, although some are placed between the anatomy and IR. However, filters placed close to the IR often produce distinct outlines of the filter, which can be objectionable to the radiologist.

The *wedge* is the simplest and most common of the compensating filter shapes. It is used to improve the image quality of a wide variety of body parts. Various filters with more complex shapes, including the *trough, scoliosis, Ferlic,* [6] and *Boomerang,* [7] have been developed for technically challenging anatomic areas.

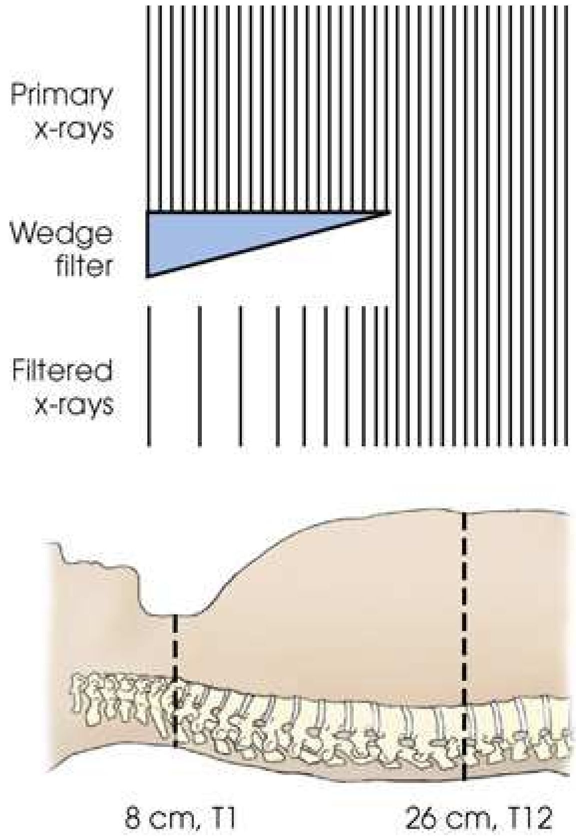


FIG. 1.17 Wedge filter in position for AP projection of thoracic spine. Note how the thick portion of the wedge partially attenuates the x-ray beam over the upper thoracic area while the nonfilter area receives full exposure to penetrate the thick portion of the spine. An even image density results.

Diagram shows a patient in a supine position and the vertebra is highlighted. It is divided into two by two dashed vertical lines. Above him are multiple vertical lines arranged close to each other. They are labeled as primary x-rays. A triangle is beneath the vertical lines on one side. They are labeled as wedge x-ray. Below it, the vertical lines are arranged next to each other and the space between them decreases. They are labeled as filtered x-rays.

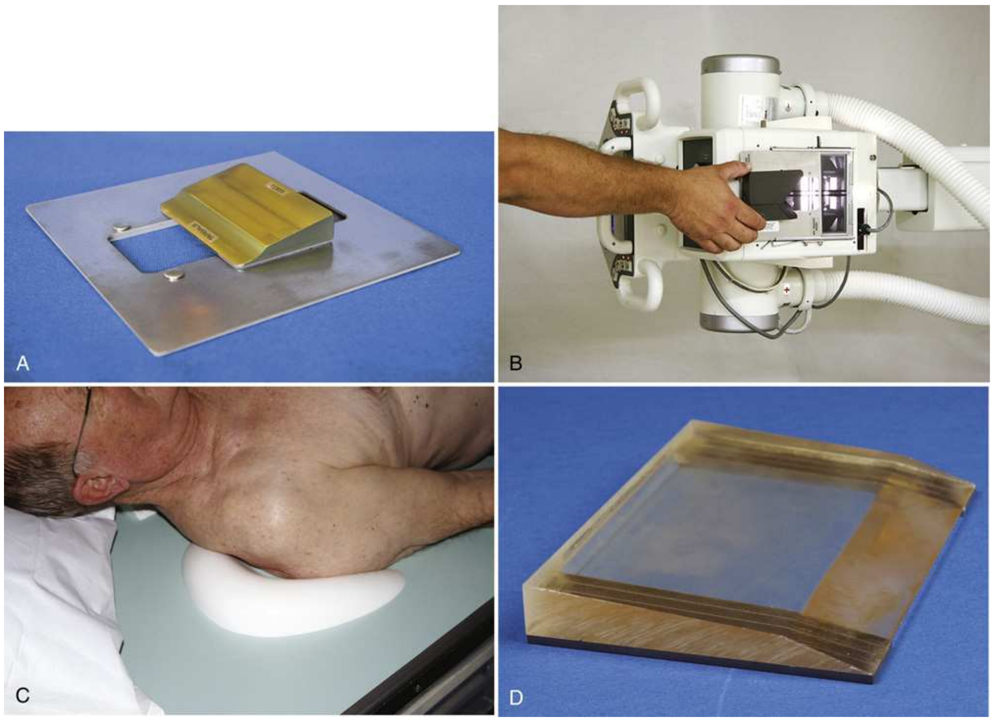


FIG. 1.18 Examples of compensating filters currently in use. (A) Ferlic collimator-mounted filter for AP axial projections of the foot. (B) Ferlic collimator-mounted filter positioned on collimator for AP projection of shoulder. (C) Boomerang contact filter in position for AP projection of shoulder. (D) Supertech wedge, collimator-mounted Clear Pb filter. B, Courtesy Scott Slinkard, College of Nursing and Health Sciences, Cape Girardeau, MO.

(A) shows a yellow wedge-shaped thing on top of a board. (B) shows a hand holding the collimator. (C) shows a boomerang contact filter placed next to a patient's shoulder. (D) shows a collimator on top is a wedge.

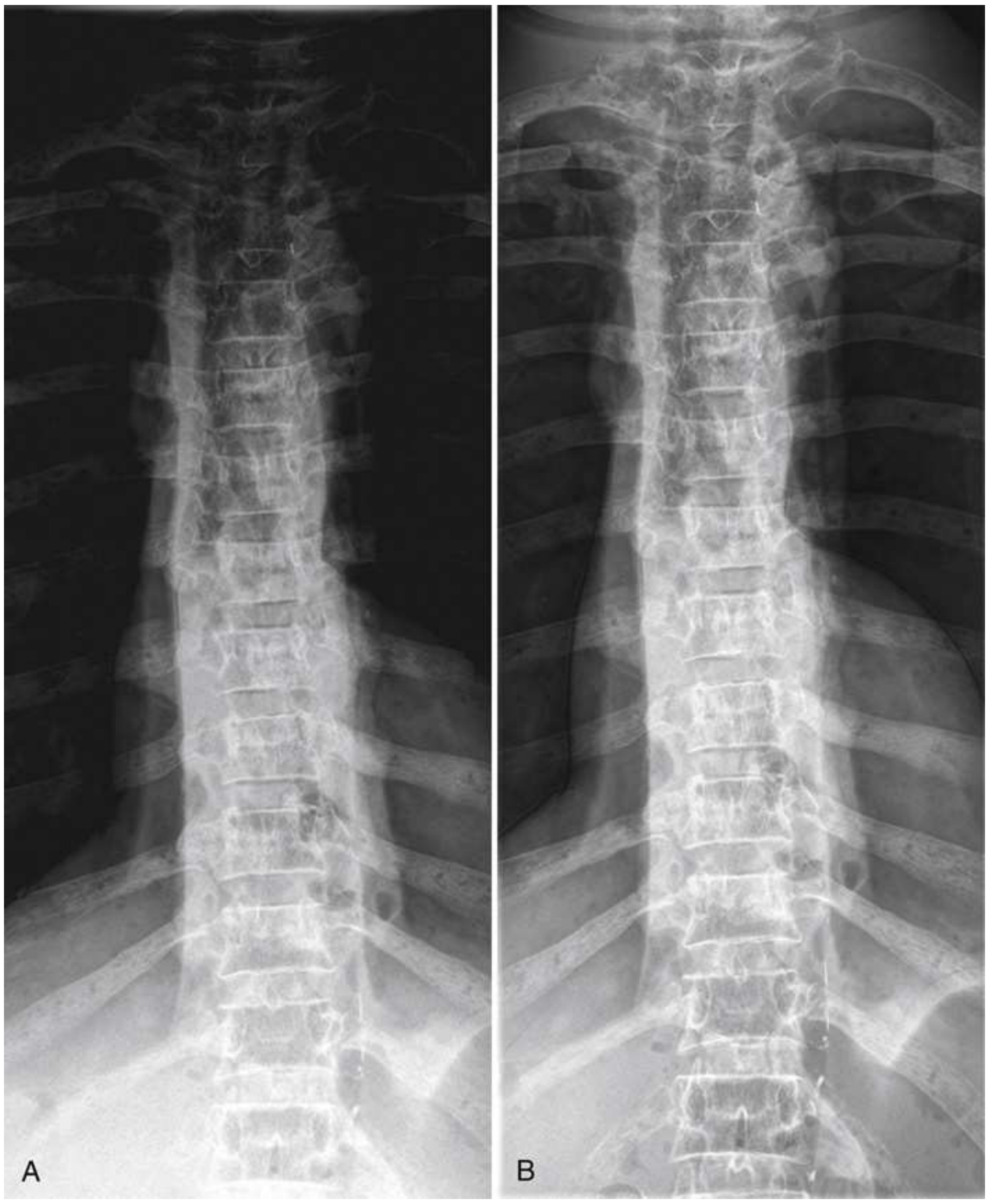


FIG. 1.19 (A) AP projection of thoracic spine without compensating filter. (B) Same projection with Ferlic wedge filter. Note more even brightness of spine, and all vertebrae are shown.

(A) shows an x-ray of the thoracic spine. The bottom region of the radiograph appears radiopaque. (B) shows an x-ray of the thoracic spine. The spines appear bright and the outlines of the vertebrae are defined.

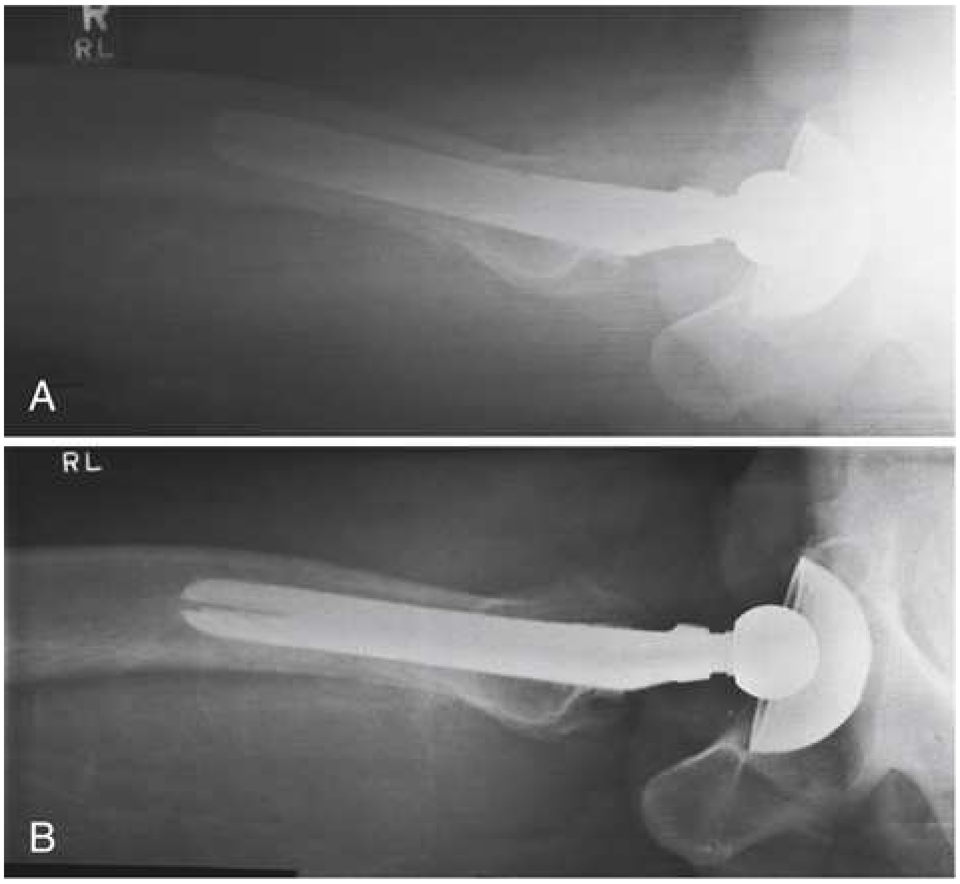


FIG. 1.20 (A) Axiolateral projection of hip (Danelius-Miller method) without compensating filter. (B) Same projection with Ferlic swimmer's filter. Note how the acetabulum and end of the metal shaft are seen in one image.

(A) shows an x-view of the hip containing a metal shaft. It appears blurry and radiopaque. (B) shows an x-ray view of the hip containing a metal shaft. The acetabulum is clearly visible. The metal shaft appears radiopaque and prominent.

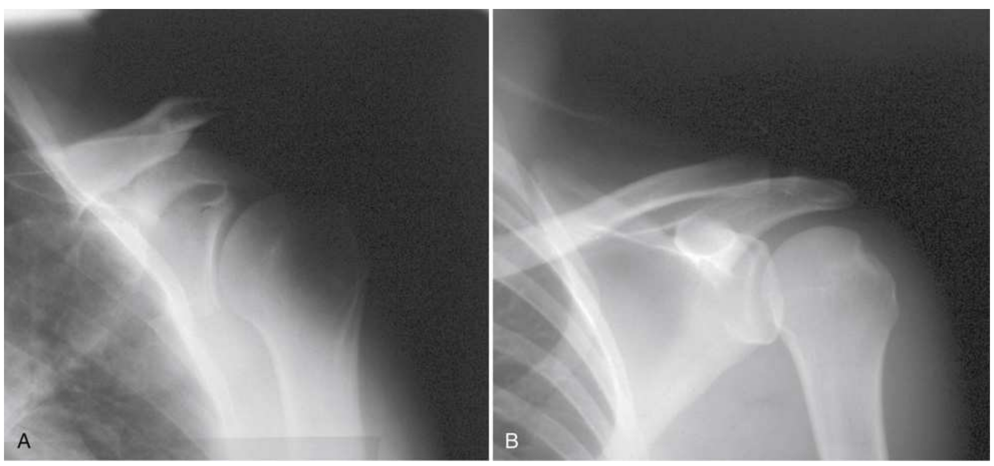


FIG. 1.21 (A) AP projection of shoulder without compensating filter. (B) Same projection using Boomerang contact filter.

TABLE 1.4

This table is not all-inclusive. Other body structures can be imaged, and other filters are available on the market.

AC, Acromioclavicular joint.

[a] Ferlic; Ferlic Filter Company, LLC, White Bear Lake, MN.

[b] Boomerang; Octostop, Inc., Laval, Canada.

[c] Supertech, Elkhart, IN.

Compensating filters are composed of a substance of sufficiently high atomic number to attenuate the x-ray beam. The most common filter materials are aluminum and high-density plastics. These are manufactured with varying thicknesses of material and are generally distributed in a smoothly graduated way that corresponds with the distribution of the different tissue densities of the anatomy (see Fig. 1.18A). Aluminum is an efficient attenuator and a common filter material.

Some manufacturers offer compensating filters made from clear leaded plastic, known as *Clear Pb,* [8] that allows the field light to shine through to the patient but still attenuates the x-ray beam (see Fig. 1.18D). However, this leaded plastic is inappropriate for all filter uses, such as in the extremely dense area of the shoulder during lateral spine radiography, because the thickness required to attenuate the beam sufficiently would result in a prohibitively heavy device. In these cases, aluminum is generally used. The Boomerang (see Fig. 1.18C) filter is composed of an attenuating silicon rubber compound, and some models of this filter have an embedded metal bead chain to mark the filter edge.

Compensating filters are most often placed in the x-ray beam between the x-ray tube and patient. Broadly, filters fall into two categories based on their location during use: *collimator-mounted* filters and *contact* filters. Collimator-mounted filters are mounted on the collimator, using rails installed on both sides of the window on the collimator housing or magnets. Contact compensating filters may be placed directly on the patient or between the anatomy and the IR.

In general, filters placed between the primary beam and the body provide the added benefit of a reduction in radiation exposure to the patient because of the beam-hardening effect of the filter, whereas filters placed between the anatomy and the IR have no effect on patient exposure. Measurements provided with Ferlic filters show radiation exposure reductions of 50% to 80%, depending on the kilovoltage peak (kVp), in the anatomic area covered by the filter. Measurements by Frank et al. [9] show exposure reductions of 20% to 69% to the thyroid, sternum, and breasts. Both types have the same effect on the finished image, which is visualization of all structures even though the tissue density varies greatly.

Compensating Filters in this Atlas

Body structures whose radiographic images can be improved through the use of compensating filters are identified throughout the atlas directly on the projection page. The special icon

identifies the use of a filter.

Technical Factors

Variation in electricity delivered to the x-ray tube permits the radiographer to control several prime technical factors: *milliamperage* (mA), *kilovolt peak* (kVp), and *exposure time* (seconds). The radiographer selects the specific factors required to produce a quality radiograph using the generator's control panel after consulting a technique chart. Manual and automatic exposure control (AEC) systems are used to set the factors.

Detailed aspects of each technical factor are presented in radiographic physics and principles courses. Because of the variety of exposure factors and equipment used in clinical practice, exact technical factors are not presented in this atlas. However, each positioning chapter contains a sample exposure technique chart for the essential projections described in the chapter. This chart is accurate for the equipment and IRs used to make the exposures. The exposure techniques listed may not be appropriate for general use because of the variability of x-ray generator output characteristics and because of the energy sensitivities of IR. However, these techniques can be used as a starting point for the development of charts for specific radiographic units. In addition, the accompanying radiation dose information can provide a general idea of the relative amount of exposure associated with particular projections. In addition, the companion *Merrill's Pocket Guide to Radiography* contains a recommended kVp for each projection and is designed with a blank table to allow students and radiographers to organize and write in the technical factors used in respective departments with different types of available equipment (Fig. 1.22).

Knee
AP

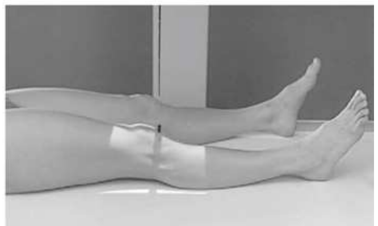
Patient Position
- Position patient supine with leg extended.
- Adjust patient's body so that pelvis is not rotated.

Part Position
- Center knee to IR at level ½ inch (1.3 cm) below patellar apex.
- Adjust leg so that femoral condyles are parallel to IR.

Central Ray
- Enters point ½ inch (1.3 cm) inferior to patellar apex
- Depending on ASIS-to-tabletop measurement, direct central ray as follows:

<19 cm	3 to 5 degrees *caudad* (thin pelvis)
19 to 24 cm	0 degrees
>24 cm	3 to 5 degrees *cephalad* (large pelvis)

Collimation:
Adjust to 10 × 12 inches (24 × 30 cm).



kVp: 70 (non-grid) 85 (grid) *Reference: 14th edition Atlas, p.344*

Manual Factors

Part Thickness (cm)	mA	kVp	Time	mAs	SID	Image Receptor Size	CR, DR Exposure Indicator	Grid	HF, 1Ø or 3Ø

AEC Factors

Part Thickness (cm)	mA	kVp	AEC Detector	mAs	Density Comp.	Image Receptor Size	CR, DR Exposure Indicator	Grid	HF, 1Ø or 3Ø

Notes: ______________________ Competency: ____/___/____

______________________ Instructor: ______________

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Lower Limb

FIG. 1.22 Exposure technique page from *Merrill's Pocket Guide to Radiography* showing how a specific department's manual techniques and AEC techniques can be written in for reference in setting optimal techniques. Note also patient photograph and radiograph. Quick reference can be made to the exact position of the patient, and the radiograph shows how the final image should appear. *AP*, anteroposterior; *IR*, image receptor.

A patient is supine with legs extended on the radiographic table. An x-ray below shows an x-ray view of the knee joint. The patella appears bright. The first table below is titled manual factors. It has ten columns and three rows. The columns are labeled as part thickness in centimeter, m A, k V p, Time, m A s, S I D, image receptor size, C R, D R exposure indicator, grid, H F 10 or 30. The second table below is titled A E C factors. It has ten columns and three rows. The columns are labeled as part thickness in centimeter, m A, k V p, A E C detector, m A s, density comp, image receptor size, C R, D R exposure indicator, grid, H F 10 or 30.

Foundation Exposure Techniques and Charts

An exposure technique chart should be placed in each radiographic room and on mobile units, including machines that use AEC.[10–12] A foundation technique chart is one made for all normal-size adults. A well-designed chart also includes suggested adjustments for pediatric, emaciated, and obese patients. The chart should be organized to display all radiographic projections performed in the room. Specific exposure factors for each projection should also be indicated (Fig. 1.23). A measuring caliper should be used to ascertain part thickness for accurate technique selection (Fig. 1.24).

A satisfactory technique chart can be established only by the radiographer's familiarity with the characteristics of the particular equipment and accessories used and the radiologist's preference in image quality. The following primary factors must be taken into account when the correct foundation technique is being established for each unit:

- Milliampere-seconds (mAs)
- kVp
- AECs

- Source-to-image receptor distance (SID)
- Relative patient or part thickness
- Grid
- CR/DR exposure indicators or other digital exposure value estimates
- IR or collimated exposure field dimensions
- Electrical supply characteristics (phase, frequency)

SAMPLE EXPOSURE TECHNIQUE CHART ESSENTIAL PROJECTIONS

These techniques were accurate for the equipment used to produce each exposure. However, use caution when applying them in your department. [1]

This chart was created in collaboration with Dennis Bowman, AS, RT(R), Clinical Instructor, Community Hospital of the Monterey Peninsula, Monterey, CA. http://digitalradiographysolutions.com/.

THORACIC VISCERA

Part	cm	kVp*	SID†	Collimation	CR‡ mAs	CR‡ Dose (mGy)‖	DR§ mAs	DR§ Dose (mGy)‖
Chest: Lungs and heart—*PA*¶	22	120	72″	14″ × 16″ (35 × 40 cm)	2.8**	0.188	1.4**	0.089
Chest: Lungs and heart—*Lateral*¶	33	120	72″	14″ × 17″ (35 × 43 cm)	7.1**	0.550	3.6**	0.273
Chest: Lungs and heart—*PA oblique*¶	25	120	72″	14″ × 17″ (35 × 43 cm)	3.6**	0.255	1.8**	0.124
Chest: Lungs and heart—*AP*††	22	90	40″	16″ × 14″ (40 × 35 cm)	4.0**	0.655		
Chest: Lungs and heart—*AP*††	22	105	40″	16″ × 14″ (40 × 35cm)			1.6**	0.340
Chest: Lungs and heart—*AP*¶	22	120	72″	14″ × 16″ (35 × 40 cm)	3.2**	0.217	1.6**	0.104
Pulmonary apices—*AP axial*¶	23	120	72″	14″ × 11″ (35 × 28 cm)	4.0**	0.198	2.0**	0.097
Lungs and pleurae—*Lateral decubitus*¶	22	120	72″	17″ × 14″ (43 × 35 cm)	4.0**	0.271	2.0**	0.133
Lungs and pleurae—*Dorsal/ventral decubitus*¶	33	120	72″	17″ × 14″ (43 × 35 cm)	9.0**	0.697	4.5**	0.344

[1]ACR-AAPM-SIMM Practice Parameter for Digital Radiography, revised 2017.
*kVp values are for a high-frequency generator.
†40 inch minimum; 44-48 inches recommended to improve spatial resolution (mAs increase needed, but no increase in patient dose will result).
‡AGFA CR MD 4.0 General IP, CR 75.0 reader, 400 speed class, with 6:1 (178LPI) grid when needed.
§GE Definium 8000, with 13:1 grid when needed.
‖All doses are skin entrance for average adult (160-200 pound male, 150-190 pound female) at part thickness indicated.
¶Bucky/Grid.
**Large focal spot.
††Nongrid.

FIG. 1.23 Radiographic exposure technique chart showing manual and AEC technical factors for the examinations identified.

A table is titled thoracic viscera. The table has nine columns and nine rows. From left to the right, the columns are labeled as part, centimeter, k V p asterisk, S I D cross, collimation, C R barred cross m A s, C R barred cross dose (m G y) to the power 11, D R section sign m S s, D R section sign dose (m G y) to the power 11. The row-wise entries of the table are as follows: Row 1: Chest lungs and heart P A pilcrow, 22, 120, 72 inches, 14 inches times 16 inches (35 times 40 centimeter), 2.8 double asterisks, 0.188, 1.4 double asterisks, 0.089. Row 2: Chest lungs and heart lateral pilcrow, 33, 120, 72 inches, 14 inches times 17 inches (35 times 43), 7.1 double asterisks, 0.550, 3.6 double asterisks, 0.273. Row 3: Chest lungs and heart P A oblique pilcrow, 25, 120, 73 inches, 14 inches times 12 inches (35 times 43 centimeter), 3.6 double asterisks, 0.255, 1.8 double asterisks, 0.124. Row 4: Chest lungs and heart A P double barred cross, 22, 90, 40 inches, 16 inches times 14 inches (40 times 35 centimeter), 4.0 double asterisk, 0.655, blank, blank. Row 5: Chest lungs and heart A P double barred cross, 22, 105, 40 inches, 16 inches times 14 inches (40 times 35 centimeter), blank, blank, 1.6 double asterisks, 0.340. Row 6: Chest lungs and heart A P pilcrow, 22, 120, 72 inches, 14 inches times 16 inches (35 times 40 centimeter), 3.2 double asterisks, 0.217, 1.6 double asterisks, 0.104. Row 7: Pulmonary apices A P axial pilcrow, 23, 120, 72 inches, 14 inches times 11 inches (35 times 28 centimeter), 4.0 double asterisk, 0.198, 2.0 double asterisk, 0.097. Row 8: Lungs and pleurae Lateral decubitus pilcrow, 22, 120, 72 inches, 17 inches times 14 inches (43 times 35 centimeter), 4.0 double asterisk, 0.271, 2.0 double asterisk, 0.133. Row 9: Lungs and pleurae dorsal or ventral decubitus pilcrow, 33, 120, 72 inches, 17 inches times 14 inches (45 times 35 centimeter), 9.0 double asterisk, 0.697, 4.5 double asterisks, 0.344. A note below reads, 1. A C R-A A P M-S I M M practice parameter for digital radiography, revised 20 17. Asterisk k V p values are for a high-frequency generator. Cross 40 inch minimum, 44-48 inches recommended to improve spatial resolution (m A s increase needed, but no increase in patient dose will result). Double barred cross A G F A C R M D 4.0 general I P, C R 75.0 reader, 400 speed class, with 6 by 1 (178 L P I) grid when needed. Section sign G E Definium 8000, with 13 by 1 grid when needed. Double line All doses are skin entrance for an average adult (160-200 pound male, 150-190 pound female) at part thickness indicated. Pilcrow Bucky or Grid. Double asterisk Large focal spot. Double barred cross Nongrid.

With this information available, the exposure factors can be selected for each region of the body that results in the best possible radiographic quality with minimal radiation exposure.

Modern x-ray generators have anatomic programmers that can store a wide range of radiographic exposure techniques for most body parts (Fig. 1.25). The radiographer simply selects the body part, and the technique is automatically set. However, it is the responsibility of all radiographers to ensure that the programmed techniques are appropriate and optimum for their particular patient.

Adaptation of Exposure Technique to Patients

The radiographer's responsibility is to select the combination of exposure factors that produce the desired quality of radiographs for each region of the body and to minimize radiation exposure to the patient. These foundation factors should be adjusted for every patient's size to maintain uniform radiation exposure to the IR. In addition, congenital and developmental factors, age, and pathologic changes must be considered. Some patients have fine, distinct bony trabecular markings, whereas others do not. Individual differences must be considered when the quality of the radiograph is judged.

Certain conditions require the radiographer to compensate when establishing an exposure technique. Conditions that require a decrease in technical factors include old age, pneumothorax, emphysema, emaciation, degenerative arthritis, and atrophy.

Some conditions require an increase in technical factors to penetrate the part to be examined. These include pneumonia, pleural effusion, hydrocephalus, enlarged heart, edema, and ascites.

Gonad Shielding

For several decades, education and clinical practice encouraged the routine use of gonadal shielding to reduce the risk of damage to fetuses and the reproductive cells. Recent research by the American Association of Physicists in Medicine (AAPM) resulted in their position statement, which states that gonadal shielding can negatively impact exam efficacy. This position statement has been endorsed by the American College of Radiology (ACR), the ASRT, the ARRT, and several other professional imaging organizations.[13] At the time of this publication, researchers are still weighing in on both sides of the effectiveness and practice of gonadal shielding.[14,15] Additionally, the National Council on Radiation Protection (NCRP) issued a statement in January 2021 recommending that gonad shielding be discontinued for abdomen and pelvis radiography.[16] In light of this most recent evidence, the "*Shield gonads*" statement has been removed from Chapters 4 and 8.

FIG. 1.24 Measuring caliper is used to measure the body part for accurate exposure technique selection.

FIG. 1.25 Anatomic programmer on x-ray generator. Technical exposure factors for most body parts are preprogrammed into the computer. The factors on this display are for a PA projection of the hand.

A computer screen titled Quantum medical imaging shows the anterior view of the human body in the middle and each part of the boy is circled. The left and right sides, and many tabs and options are in it.

Students and technologists must remain aware of these changes in the practice of gonadal shielding as they evolve in the coming months and years. In cases where patients or their caregivers express anxiety about having imaging studies without the use of gonadal shielding, technologists are advised to attempt to explain the latest AAPM research and the NCRP recommendations. Shielding may be used if the explanation fails to reduce anxiety. Students and technologists must also be aware that there are some states in the United States with specific gonadal shielding requirements and to abide by these guidelines. For this reason, gonadal shielding guidelines remain in place in most chapters and are illustrated in several positioning photos. The types of gonadal and large area shields are illustrated in Figs. 1.26 through 1.28. Shielding for the breasts and thyroid for pediatric patients are noted in Chapter 22.

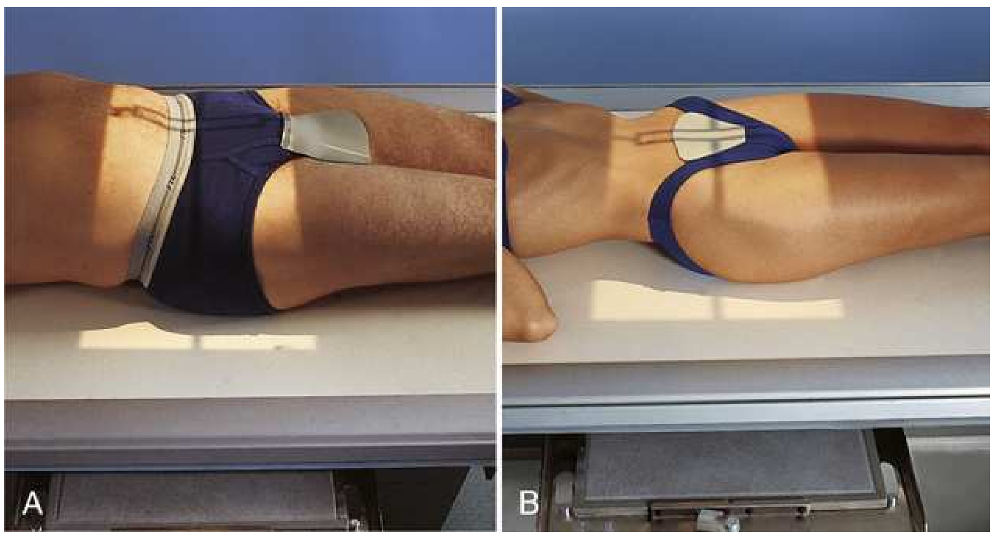

FIG. 1.26 (A) Contact shield placed over the gonads of a male patient. (B) Contact shield placed over the gonads of a female patient.

(A) shows a male patient lying on the radiographic table. A male shield gonad is placed on the gonads. (B) shows a female patient lying on the radiographic table. A female shield gonad is placed in the pelvic region.

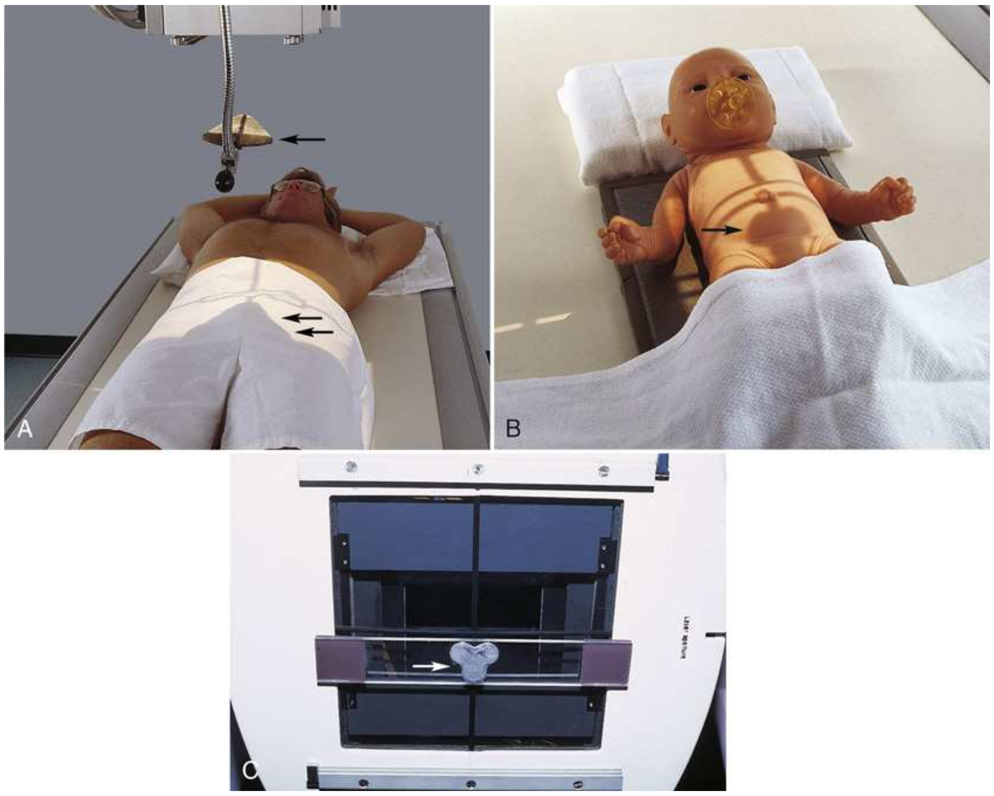

FIG. 1.27 (A) Shadow shield used on a male patient. Triangular lead device *(arrow)* is hung from the x-ray tube and is positioned so that its shadow falls on the gonads *(double arrows)*. (B) Shadow shield used on a female infant. Cloverleaf shield is positioned under the collimator with magnets so that its shadow falls over the gonads *(arrow)*. (C) Cloverleaf-shaped shadow shield *(arrow)* positioned under the collimator with magnets.

(A) A male patient is lying on the radiographic table with both his hands resting under his head. A shadow of a triangular lead device hung from the x-ray tube is on the gonads. The triangular lead device is marked by a black arrow. The shadow on the gonads is marked by two black arrows. (B) A female infant doll is on the radiographic table. A cloverleaf-shaped shadow is on the gonads. It is marked by a black arrow. (C) A cloverleaf-shaped shield is on the collimator. It is marked by a white arrow.

Placement and Orientation of Anatomy on the Image Receptor

The part to be examined is usually centered on the center point of the IR or at the position where the angulation of the central ray (CR) projects it to the center. The IR should be adjusted so that its long axis lies parallel to the long axis of the part being examined. Although a long bone angled across the radiograph does not impair the diagnostic value of the image, such an arrangement can be aesthetically distracting. The three general positions of the IR, lengthwise, crosswise, and diagonal, are shown in Fig. 1.29. These positions are named based on their position in relation to the long axis of the body. The lengthwise IR position is used most frequently.

Although the lesion may be known to be at the midbody (central portion) of a long bone, an IR large enough to include at least one joint should be used on all long bone studies (Fig. 1.30). This method is the only means of determining the precise position of the part and localizing the lesion. Many institutions require that both joints be shown when a long bone is initially radiographed. For tall patients, two exposures may be required—one for the long bone and joint closest to the area of concern and a second to show the joint at the opposite end.

An IR just large enough to cover the region being examined should be used when available. This aids in positioning and encourages proper collimation. This rule does not apply when a department has only one size detector available or for units where the IR is integrated into the housing, so it is a fixed size that cannot be changed. Regardless of the IR size, it is the radiographer's responsibility to collimate the exposure field to the body part dimensions regardless of its location on the detector.

A standard rule in radiography is that the body part must be placed as close to the IR as possible. However, in some situations, this rule is modified. For example, when lateral images of the middle and ring fingers are obtained, the radiographer increases the OID so that the part lies parallel to the IR. Although magnification is greater, less distortion occurs. The radiographer can increase the SID to compensate for the increase in OID, thereby reducing the magnification. In certain instances, intentional magnification is desirable and can be obtained by positioning and supporting the object between the IR and the focal spot of the tube. This procedure is known as magnification radiography.

Nearly all radiography is currently performed with one exposure for each IR. Multiple images in one image display field are not possible with DR, which captures one image at a time. However, with CR systems, bilateral examinations of small body parts may be placed on a single IR. Many IR cassettes have permanent markings on the edges to assist the radiographer in equally spacing multiple images on one IR. Depending on the size and shape of the body part being radiographed, the IR can be divided transversely or longitudinally.

FIG. 1.28 Large piece of flexible lead *(arrow)* is draped over this patient's pelvis to protect the gonads during the mobile radiographic examination of the chest.

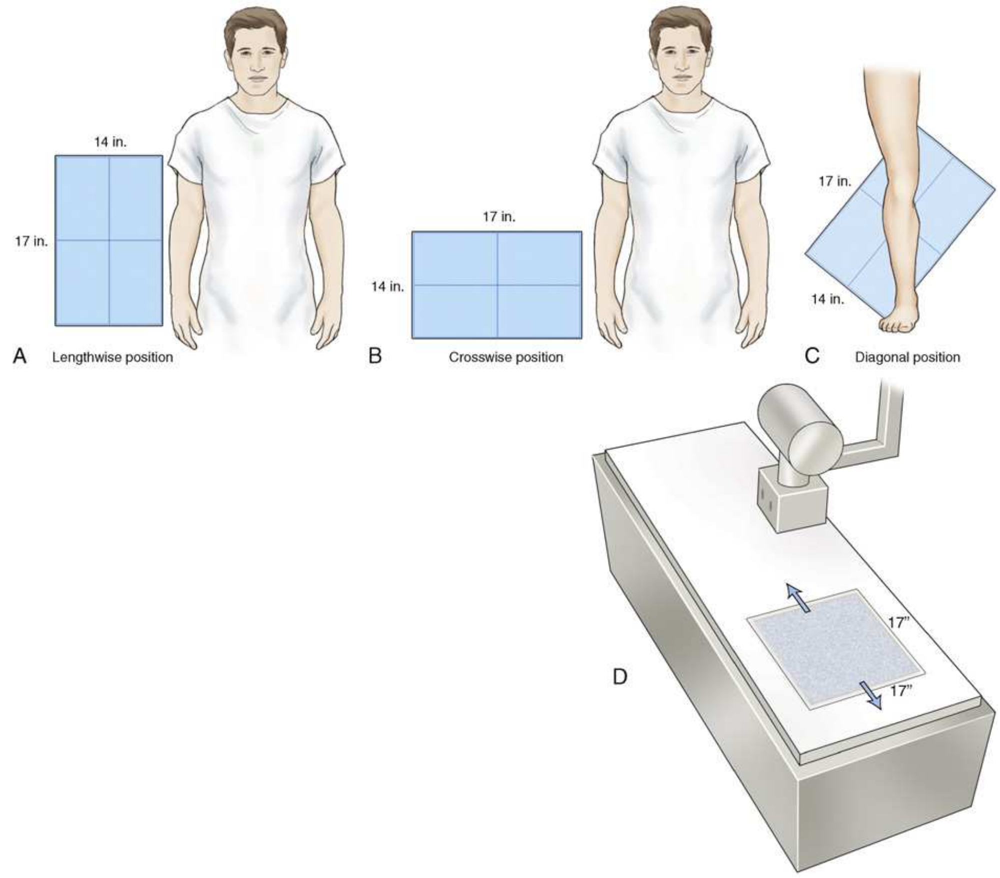

FIG. 1.29 (A) *Lengthwise* position of IR for AP projection of the abdomen. (B) *Crosswise* position of IR for AP projection of the pelvis. (C) *Diagonal* position of IR for AP projection of the leg to include the knee and ankle joints. (D) Position of built-in DR flat-panel IR detector at 17 × 17 inches (43 × 43 cm). Flat-panel detector is movable lengthwise with the grid under the table.

(A) A diagram shows an I R placed lengthwise next to a patient standing upright. The sides of the I R are labeled as 14 inches and 17 inches. (B) A diagram shows an I R placed crosswise next to a patient standing upright. The sides of the I R are labeled as 17 inches and 14 inches. (C) A diagram shows the I R placed diagonally behind the leg. The sides of the I R are labeled as 17 inches and 14 inches. (D) A diagram shows a radiographic table with a built-in D R flat panel I R detector. The sides of the I R are labeled as 17 inches and 17 inches.

FIG. 1.30 (A) AP projection of the leg showing the ankle joint included on the image. One joint should be shown on all images of long bones. (B) AP projection of the leg showing both the knee and ankle joints on the image.

Placement and Direction of the Central Ray

The central or principal beam of rays, simply referred to as the *central ray*, is always centered on the anatomy of interest and usually to the IR, when practical. The CR is angled through the part of interest under the following conditions:

- when overlying or underlying structures must not be superimposed
- when a curved structure, such as the sacrum or coccyx, must not be superimposed on itself
- when projection through angled joints, such as the knee joint and the lumbosacral junction, is necessary
- when projection through angled structures must be obtained without foreshortening or elongation, such as with a lateral image of the neck of the femur

The general goal is to place the CR perpendicular to the structure of interest. Accurate positioning of the part and accurate centering of the CR are of equal importance in obtaining a true structural projection with minimal distortion.

Source-to-Image Receptor Distance

SID is the distance from the anode focal spot inside the x-ray tube to the IR (Fig. 1.31). SID is an important technical consideration in the production of radiographs of optimal quality. This distance is a critical component of each radiograph because it directly affects the magnification of the anatomy on the image, the spatial resolution, and the dose to the patient. The greater the SID, the less the anatomy is magnified and the greater the spatial resolution. An SID of 40 inches (102 cm) has been used traditionally for most conventional examinations. In recent years, the SID has increased to 44 to 48 inches (112 to 122 cm) in many departments.[10, 11, 17–20] It has been determined that an increase in the SID when practical will result in reduced magnification and increased spatial resolution, with a reduction in patient dose of approximately 10%. SID must be established for each radiographic projection, and it must be indicated on the technique chart.

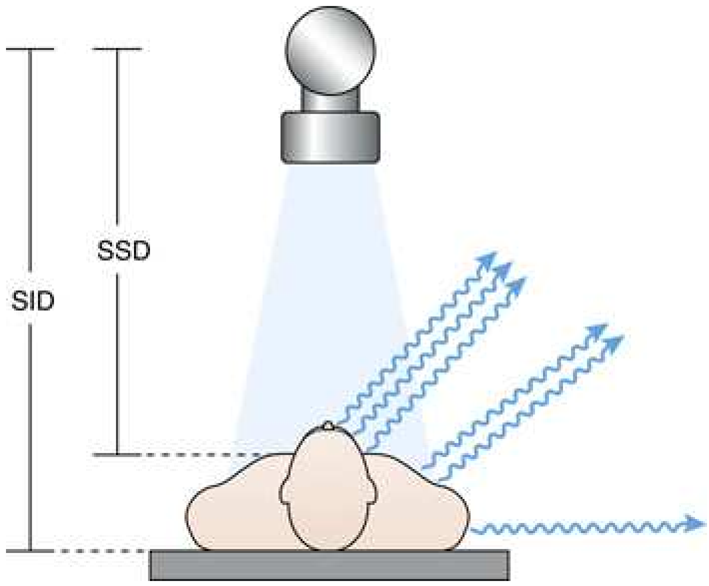

FIG. 1.31 Radiographic tube, patient, and table illustrate SID and SSD.

A patient is supine on the radiographic table. The x-ray tube is above him. The distance between the focal spot of the radiography tube and the skin of the patient is labeled as the S S D. The distance between the focal spot of the radiography tube and the skin touch the radiographic table is marked as S I D.

Outside the United States, the commonly used SID is 100 cm, instead of our customary 40 inches. For chest radiography, 180 cm is used instead of the 72 inches used in the United States. Other intermediate SIDs, such as 120 cm, may also be used.

For a few radiographic projections, a SID less than 40 inches (<102 cm) is desirable. In certain examinations, such as examination of the odontoid in the open mouth position, a short SID of 30 inches (76 cm) may be used. This shorter SID results in differentially greater magnification, in the direction of beam divergence, of the anatomic structures closest to the tube. This results in a greater field of view of the structures closest to the IR. At 30 inches, nearly 0.5 inches more anatomy is seen. The goal of these reduced SID projections is to demonstrate the body part with reduced superimposition of overlying structures. However, a slight increase in patient exposure will occur.

Conversely, a longer than standard SID is used for some radiographic projections. In chest radiography, a 72-inch (183-cm) SID is the minimum distance, and in many departments, a distance up to 120 inches (305 cm) is used. These long distances are necessary to ensure that the lungs fit onto the 14-inch (35-cm) width of the IR (via reduced magnification of the body part) and, most importantly, to ensure that the heart is minimally magnified to allow the diagnosis of cardiac enlargement.

Source-To-Image Receptor Distance in this Atlas

When a specific SID is necessary for optimal image quality, it is identified on the page of the specific projection. If not mentioned, it can be assumed that a *minimum* of 40 inches (102 cm) is recommended. Although sample exposure technique charts in each chapter identify the traditional SID of 40 inches (102 cm), this in no way implies that the authors advocate this distance when a greater SID from 44 to 48 inches (112 to 122 cm) may be obtained. Special SID projections vary from 30 inches (76 cm) to 120 inches (305 cm).

Source-to-Skin Distance

The distance between the focal spot of the radiography tube and the skin of the patient is termed the *source-to-skin distance* (SSD) (Fig. 1.31). This distance affects the dose to the patient and is addressed by the NCRP. Current NCRP recommendations state that the SSD *shall not* be less than 12 inches (<30 cm) and *should not* be less than 15 inches (<38 cm). [21] All modern radiographic and fluoroscopic equipment is constructed to prevent an SSD of less than 12 inches (30 cm).

Collimation of Radiation Field

The radiation field, also called the exposure field, must be restricted to irradiate only the anatomy of interest. This restriction of the radiation field, called *collimation,* serves two purposes. First, it minimizes the amount of radiation to the patient by restricting exposure to essential anatomy only. Second, it reduces the amount of scatter radiation that can reach the IR, which reduces the potential for a reduction in contrast resolution (Fig. 1.32). Many experts regard collimation as the most important aspect of producing an optimal image. This is true regardless of the type of IR used.

The area of the radiation field is reduced to the required size by using a collimator constructed of lead or other metal with high radiation absorption capability, attached to the tube housing and placed between the tube and the patient. Because of the metal attenuators of the beam restrictors, the peripheral radiation strikes and is absorbed by the collimator metal, and only x-rays in the exit aperture are transmitted as the exposure field.

For cassette-based or free detector IR systems, positive beam limitation (PBL), also called *automatic collimation,* is possible. The Bucky tray or other IR holder contains a mechanism that senses the dimensions of the IR and automatically collimates the beam to those dimensions. This prevents an exposure field larger than the IR when multiple IR sizes may be used. With fixed detector units that contain an enclosed IR, the system safeguards will not allow the exposure field to exceed the dimensions of the IR, but those dimensions may frequently exceed the dimensions of the anatomy to be imaged. In all cases, PBL is designed to limit only the exposure field to the dimensions of the IR. This does not take the place of proper collimation to the dimensions of the body part.

FIG. 1.32 Radiographs of the hip joint and acetabulum. (A) Collimator inadvertently opened to size 14 × 17 inches (35 × 43 cm). Scatter and secondary radiation have reduced radiographic contrast and poor-quality image results. (B) Collimator set correctly to 8 × 10 inches (18 × 24 cm), improving radiographic contrast and visibility of detail.

(A) An x-ray shows the hi[joint and the acetabulum. It appears blurry. (B) An x-ray shows the femoral head, penetrated and seen through the acetabulum. A concave area is in the fovea capitalis. The outlines are well defined.

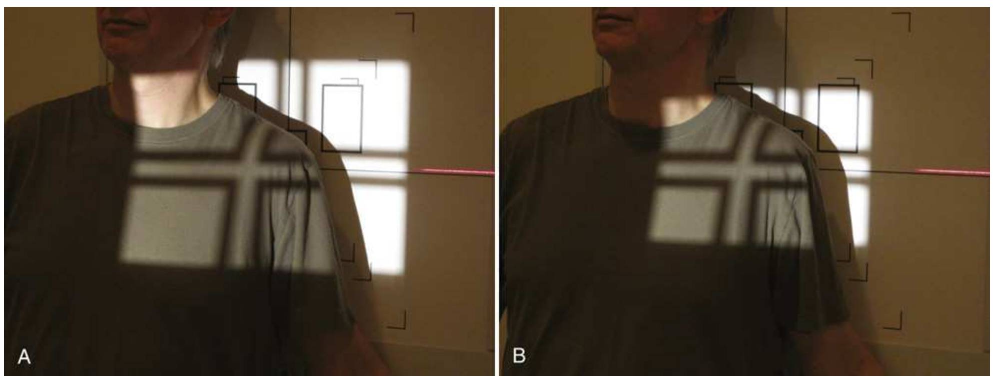

FIG. 1.33 (A) Collimation set too large for AP projection of the shoulder. Note unnecessary radiation of thyroid, sternum, and general thoracic tissues. With this large collimation, more than half of the radiation strikes the table directly, resulting in increased scatter. (B) Collimation set correctly to 10 × 12 inches (24 × 30 cm). Less tissue receives radiation, and less scatter is produced from the radiation striking the table.

(A) A patient is standing against the grid. The collimation is scattered on the patient's shoulder and divides it into four quadrants. It is equally scattered on the grid. (B) A patient is standing against the grid. The collimation is less scattered and it divides the patient's shoulder into four quadrants. It is less scattered on the grid.

It is a violation of the ARRT Code of Ethics and ASRT Practice Standards to collimate larger than the required radiation field size. When a larger than the required area is exposed, the patient receives unnecessary radiation to areas not needed on the image (Fig. 1.33A). In addition, the increased scatter radiation decreases the contrast resolution and spatial resolution in the image, reducing the ability to ensure an accurate diagnosis. The collimator should be manually adjusted to result in a field size that will include all anatomy pertinent to the radiographic procedure ordered (see Fig. 1.33B). These field dimensions and the extent of collimated field edges in relation to the anatomy of interest are included for all radiographic projections and positions included in the atlas.

The software included in the computers of DR systems allows for shuttering. Shuttering is used in DR to provide a black background around the original collimation edges. This black background eliminates the distracting clear areas and the associated brightness that comes through to the eyes. Radiographers may be tempted to open the collimator larger than is necessary and use the shuttering software to "crop-in" or mask unwanted peripheral image information and create the appearance of proper collimation. This technique irradiates patients unnecessarily, increases scatter radiation, and increases the radiation dose. In addition, the imaging team is exposed to legal liability because captured image information has been masked. ***If it is later determined that pathology in this obscured area of the image was missed, causing a missed or delayed diagnosis,***

the radiographer may be held liable . Shuttering is an image aesthetic only and should not serve as a substitute for proper and accurate collimation of the body part.

Anatomic Markers

Each radiograph must include an appropriate marker that clearly identifies the patient's right (R) or left (L) side. Medicolegal requirements mandate that these markers be present. Radiographers and physicians must see the markers to determine the correct side of the patient or the correct limb. Markers typically are made of lead and are placed directly on the IR or tabletop. The marker is seen on the image, along with the anatomic part (Fig. 1.34). Box 1.3 presents the specific rules of marker placement.

Basic marker conventions include the following:

- R or L markers must be placed on all radiographs.
- The marker should never obscure anatomy.
- The marker should always be placed in the exposure field on the edge of the collimation border.
- The marker should always be placed outside of any lead shielding.
- R and L markers must be used with CR and DR digital imaging.

The development of digital imaging and the use of CR and DR have enabled an environment in which the R and L markers can be annotated or placed on the image electronically after exposure at the computer workstation. *This is not recommended* because of the great potential for error, which has legal implications related to side identification. This practice is especially problematic when patients are examined in the prone position. Anatomic markers should be placed directly on the CR cassette or the DR table/wall unit prior to making the exposure. The exception to direct marker placement is in sterile (OR), trauma (ED), or infectious environments where marker placement may interfere with proper patient care. In addition, the practice of placing markers directly on the body part is not recommended because the marker is likely to be distorted on the image. This will make side identification difficult, thus defeating the purpose of using a marker.

BOX 1.3 Specific marker placement recommendations

1. For AP and PA projections that include R and L sides of the body (head, spine, chest, abdomen, and pelvis), the R marker is typically used.
2. For lateral projections of the head and trunk (head, spine, chest, abdomen, and pelvis), always mark the side closest to IR. If the left side is closest, use L marker. The marker is typically placed anterior to the anatomy.
3. For oblique projections that include R and L sides of the body (spine, chest, and abdomen), the side down, or nearest IR, is typically marked. For a right posterior oblique (RPO) position, mark R side.
4. For extremity projections, use appropriate R or L marker. The marker must be placed within the edge of the collimated x-ray beam.
5. For extremity projections that are done with two images on one IR, only one of the projections needs to be marked.
6. For extremity projections where R and L sides are imaged side by side on one IR (e.g., R and L, AP knees), R and L markers must be used to identify the two sides clearly.
7. For AP, PA, or oblique chest projections, a marker is placed on the upper-outer corner so that the thoracic anatomy is not obscured.
8. For decubitus positions of the chest and abdomen, R or L marker should always be placed on the side up (opposite the side laid on) and away from the anatomy of interest.

Note: No matter which projection is performed, and no matter what position the patient is in, if an R marker is used, it must be placed on the "right" side of the patient's body. If an L marker is used, it must be placed on the "left" side of the patient's body.

FIG. 1.34 (A) AP projection of the abdomen showing right *(R)* marker. (B) AP projection of the left limb showing left *(L)* marker on the outer margin of the image. (C) AP projection of the right and left knees on one image showing R and L markers. (D) AP projection of the chest performed in the left lateral decubitus position showing R marker on the "upper" portion of the IR.

(A) An x-ray shows the abdomen. (B) An x-ray shows the left limb including the hip joint. A small circular white area is near the femoral neck. (C) An x-ray shows the joint spaces of both knees. The patella appears radiopaque. (D) An x-ray shows the x-ray of the chest. The vertebrae lie horizontally. The upper part of the chest appears radiopaque.

The Radiograph

The image recorded by exposing any of the IR to x-rays is called a radiograph. Each step in performing a radiographic procedure must be completed accurately to ensure that the maximal amount of information is recorded on the image. The information that is obtained by performing the radiographic procedure generally shows the presence or absence of abnormality or trauma. This information assists in the diagnosis and treatment of the patient.

The radiographer must evaluate each radiograph to determine the acceptability of image features, proper radiation safety practices, and whether the objectives for performing the procedure have been met. Additional image evaluation criteria to be considered include the presence of patient identification, proper radiographic marker placement, proper collimation, evidence of required patient shielding, and absence of artifacts. This requires an understanding of anatomy, image geometry, image display characteristics, and image appearance of pathology. Figs. 1.35 through 1.38 are radiographs providing examples of image evaluation principles.

Display of Radiographs

Radiographs are generally oriented on the display device according to the preference of the interpreting physician. Because methods of displaying radiographic images have developed largely through custom, no fixed rules have been established. However, both the radiologist, who is responsible for making an interpretation based on the radiographic examination, and the radiographer, who performs the examination, follow traditional standards of practice regarding the orientation of radiographs on the display monitor.

Anatomic Position

Radiographs are usually oriented on the display monitor so that the person looking at the image sees the body part as though viewed facing the patient. This is called the *anatomic position*. When in the anatomic position, the patient stands erect with the face and eyes directed forward, arms extended by the sides with the palms of the hands facing forward, heels together, and toes pointing anteriorly (Fig. 1.39). When the radiograph is displayed in this manner, the patient's left side is on the viewer's right side and vice versa (Fig. 1.40). Medical professionals always describe the body, a body part, or a body movement as though it were in the anatomic position.

FIG. 1.35 AP oblique foot. All pertinent anatomy is included and demonstrated with good image quality. Optimum appearance and relationships of all-important anatomy. Evidence of collimation and appropriately placed side marker. The long axis of the foot is slightly angled in relation to the exposure field resulting in a collimated field slightly larger than necessary.

FIG. 1.36 PA wrist. All pertinent anatomy is included and demonstrated with good image quality. Optimum appearance and relationships of all-important anatomy. Evidence of collimation and appropriately placed side marker. Exposure field and anatomy are angled on the display, which is common with DR but not ideal.

FIG. 1.37 Lateral knee. All pertinent anatomy is included and demonstrated with good image quality. The relationship of femoral condyles indicates slight over-rotation of the knee because the medial condyle (identified as the larger, less distinct condyle) is anterior to the lateral condyle. Evidence of collimation. The appearance of the side marker indicates it was likely added by annotation rather than placed on the IR prior to exposure, which is not recommended.

FIG. 1.38 AP lumbar spine. All pertinent anatomy is included and demonstrated with good image quality. Optimum appearance and relationships of all-important anatomy. The slight rotation of the lumbar spine is related to mild scoliosis, so not related to a positioning error. Evidence of collimation. The side marker is appropriately placed but is not oriented correctly. Metallic artifacts, probably bra hooks, are superimposed with the lower thoracic spine.

Posteroanterior and anteroposterior radiographs

Fig. 1.41A illustrates the anterior (front) aspect of the patient's chest placed closest to the IR for a *posteroanterior* (PA) projection. Fig. 1.41B illustrates the posterior (back) aspect of the patient's chest placed closest to the IR for an *anteroposterior* projection. Regardless of whether the anterior or posterior body surface was closest to the IR during the exposure, the radiograph is usually oriented in the anatomic position (Fig. 1.42). (Positioning terminology is fully described in Chapter 2.)

Exceptions to these guidelines include the hands, fingers, wrists, feet, and toes. Hand, finger, and wrist radiographs are routinely displayed with the digits (fingers) pointed to the ceiling. Foot and toe radiographs are displayed with the toes pointed to the ceiling. Hand, finger, wrist, toe, and foot radiographs are viewed from the perspective of the x-ray tube or exactly as the anatomy was projected onto the IR (Fig. 1.43). This perspective means that the individual looking at the radiograph is in the same position as the x-ray tube.

Lateral radiographs

Lateral radiographs are obtained with the patient's right or left side placed against the IR. Lateral images are displayed in the same orientation as though the viewer were looking at the patient from the perspective of the x-ray tube at the side where the x-rays first enter the patient—exactly like radiographs of the hands, wrists, feet, and toes. Another way to describe this is to display the radiograph so that the side of the patient closest to the IR during the procedure is also the side in the image closest to the monitor screen. A patient positioned for a left lateral chest radiograph is depicted in Fig. 1.44. The resulting left lateral chest radiograph is displayed, as shown in Fig. 1.45. A right lateral chest position and its accompanying radiograph would be positioned and displayed as the opposite of that shown in Figs. 1.44 and 1.45.

Oblique radiographs

Oblique radiographs are obtained when the patient's body is rotated so that the projection obtained is not frontal, posterior, or lateral (Fig. 1.46). These radiographs are viewed with the patient's anatomy placed in the anatomic position (Fig. 1.47).

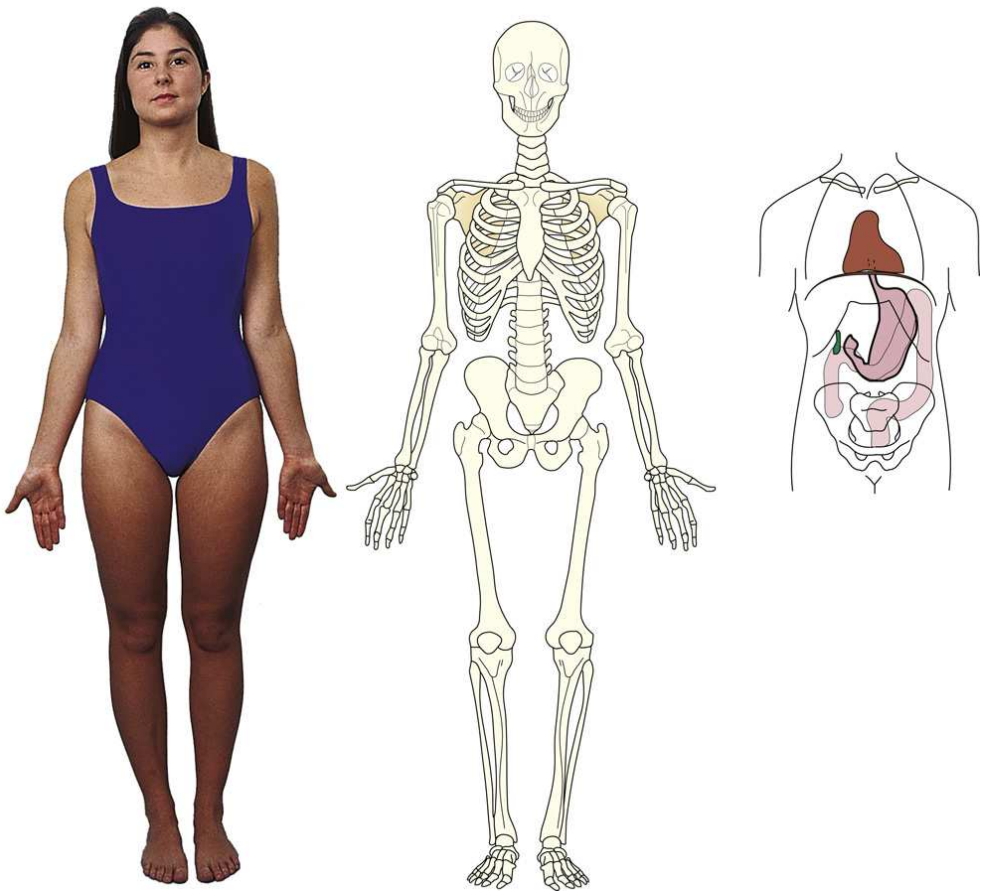

FIG. 1.39 Patient in anatomic position. Most radiographs are displayed on the monitor. with the body part matching this position.

A patient is standing upright with palms of the hands facing front. A skeletal view of a human body standing upright with the palmar surface facing front. A diagram next to it shows the front view of the body showing all the organs.

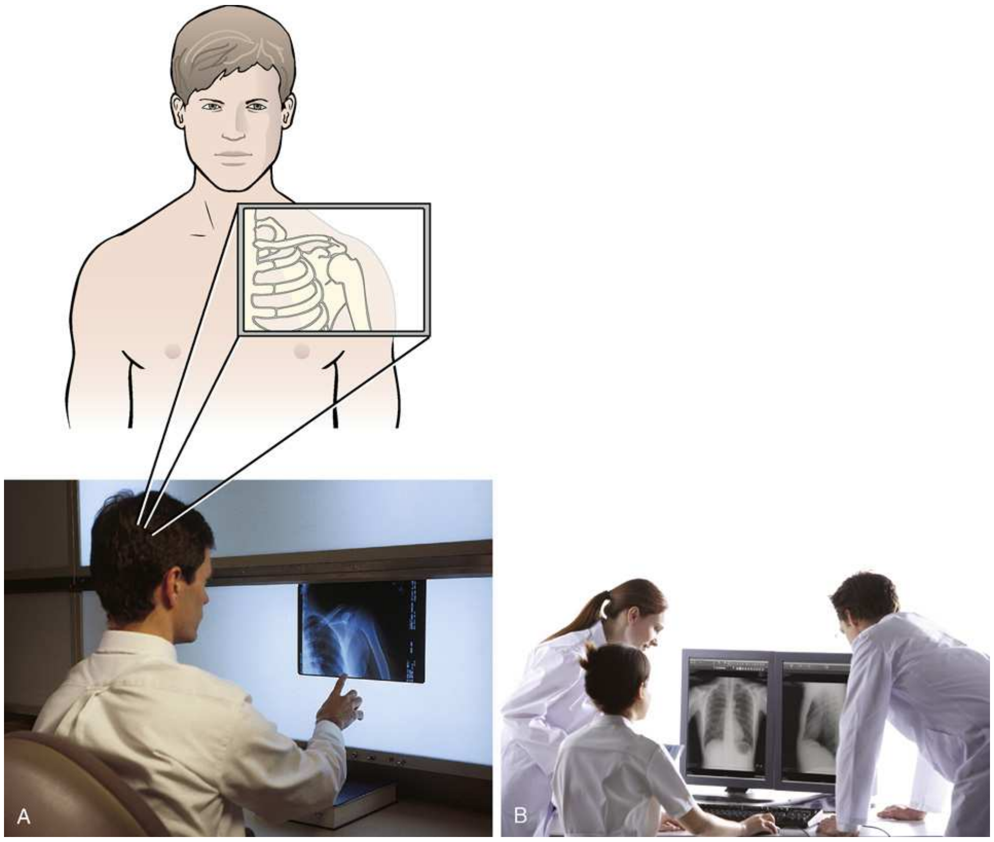

FIG. 1.40 (A) Radiologist interpreting radiograph of a patient's left shoulder. A radiograph is placed on the illuminator with the patient's left side on the viewer's right side. The radiologist spatially pictured the patient's anatomy in the anatomic position and placed the radiograph on the illuminator in that position. (B) Radiographs displayed correctly on a digital display. The same orientation rules apply to digital imaging. B, Courtesy Canon USA, Inc.

(A) A radiologist is reading the x-ray sheet showing the shoulder joint placed on the illuminator. A diagram projected above shows the anterior view of a human body highlighting the shoulder joint. (B) Three people are looking at the radiograph displayed on the screen.

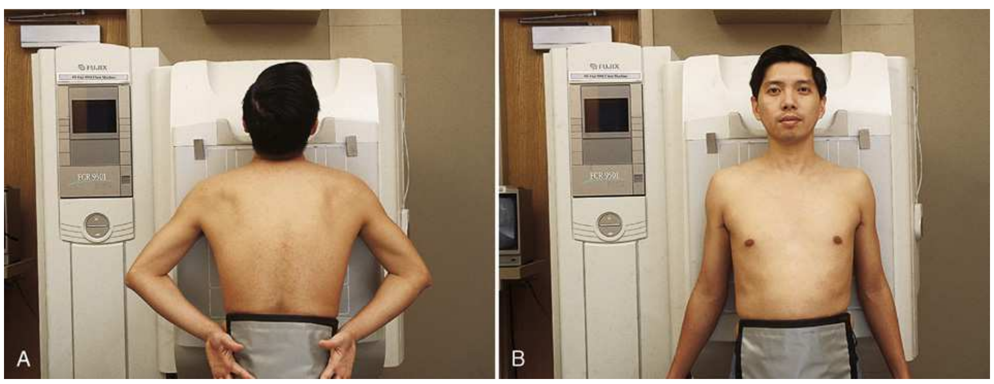

FIG. 1.41 (A) Patient positioned for PA projection of the chest. The anterior aspect of the chest is closest to IRs. (B) Patient positioned for AP projection of the chest. The posterior aspect of the chest is closest to IRs.

(A) A patient is standing upright with the anterior aspect of his chest facing the I R. His hands are resting on either side of his hips. (B) A patient is standing upright with the posterior aspect of his chest facing the I R. Both his hands are abducted.

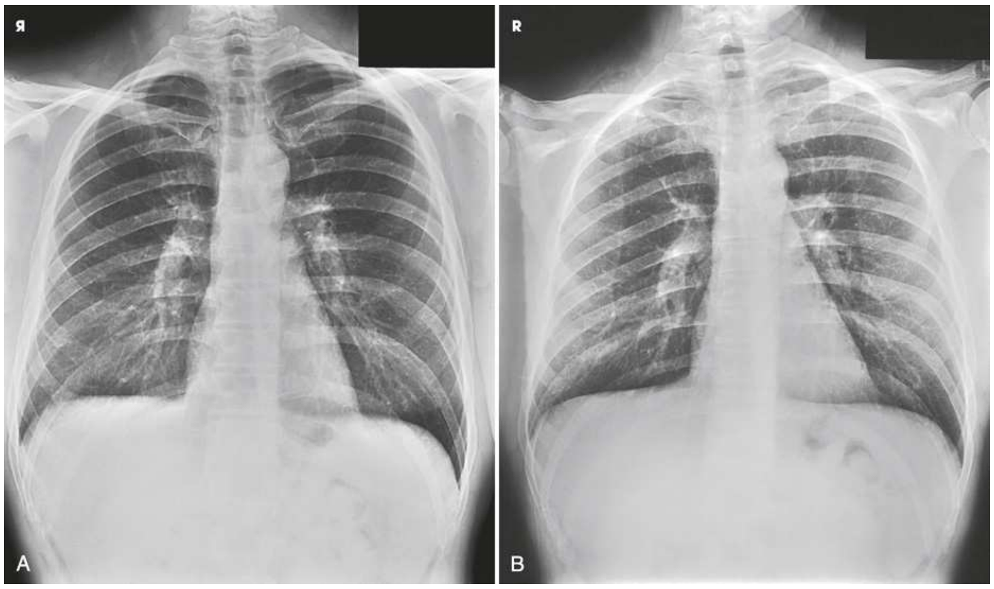

FIG. 1.42 (A) PA projection of the chest. (B) AP projection of the chest. Both radiographs are correctly displayed with the anatomy in the anatomic position even though the patient was positioned differently. Note that the patient's left side is on your right, as though the patient were facing you.

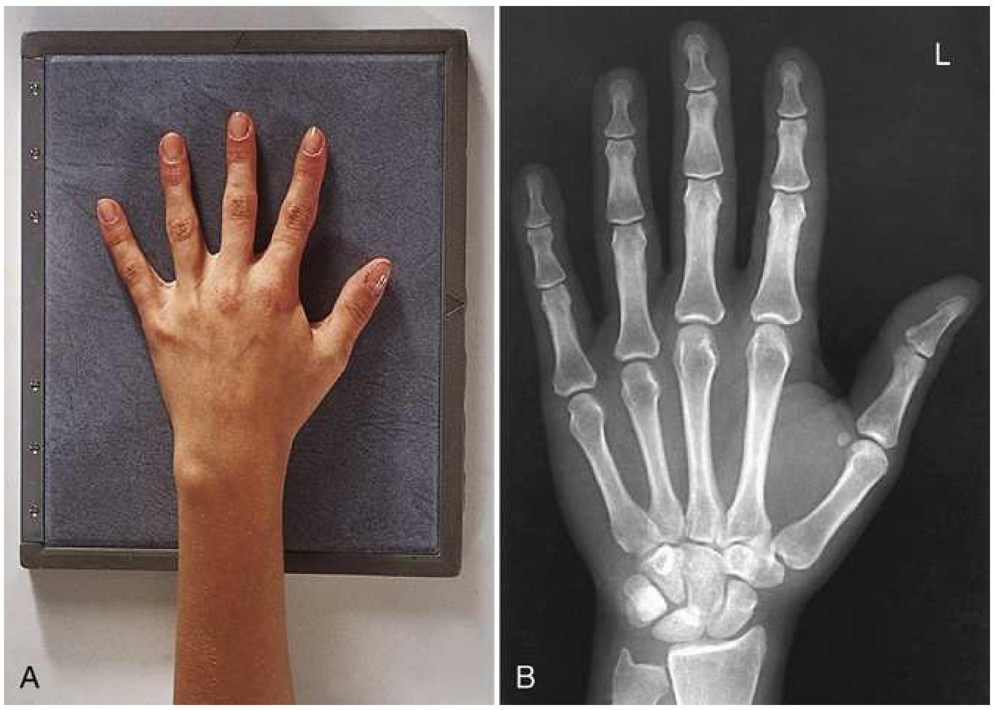

FIG. 1.43 (A) Left hand positioned on IR. This view is from the perspective of the x-ray tube. (B) Radiograph of the left hand is displayed on the monitor in the same manner, with the digits pointed upward.

FIG. 1.44 Proper patient position for a left lateral chest radiograph. The left side of the patient is placed against the IR.

FIG. 1.45 Left lateral chest displayed with the anatomy seen from the perspective of the x-ray tube.

FIG. 1.46 A patient placed in the LAO position for PA oblique projection of the chest.

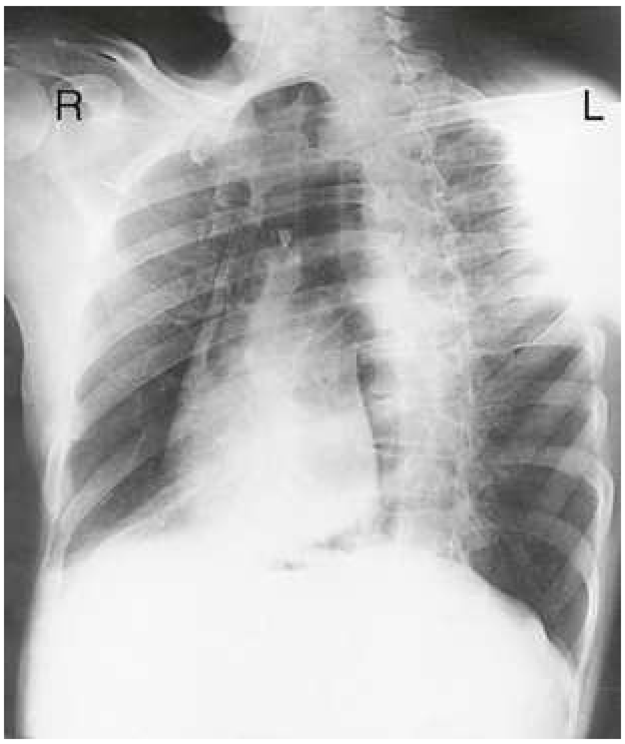

FIG. 1.47 PA oblique chest radiograph is displayed with the anatomy in the anatomic position. The patient's left side is on your right, as though the patient were facing you.

Other radiographs

Many other less commonly performed radiographic projections are described throughout this atlas. The most common method of displaying the radiograph that is used in the radiology department and in most clinical practice areas is generally in the anatomic position or from the perspective of the x-ray tube; however, there are exceptions. Some physicians prefer to view all radiographs from the perspective of the x-ray tube rather than in the anatomic position. A neurosurgeon operates on the posterior aspect of the body and does not display spine radiographs in the anatomic position or from the perspective of the x-ray tube. The radiographs are displayed with the patient's right side on the surgeon's right side as though looking at the posterior aspect of the patient. What the surgeon sees on the radiograph is exactly what is seen in the open body part during surgery.

Identification of Radiographs

All radiographs must include the patient and procedure information required by institutional policy. This information customarily includes (Fig. 1.48A):

- Date
- Patient's name or identification number
- Right or left marker
- Institution identity

Correct identification is vital and should always be confirmed. Identification is absolutely vital in comparison studies, on follow-up examinations, and in medicolegal cases. Radiographers should develop the habit of rechecking the identification side marker just before placing it on the IR. The radiographer associates the patient's identification and other data with each radiograph via the computer workstation (see Fig. 1.48B). However, side markers should still be physically placed on the IR. The workstation should not be used to add, or annotate, *right* and *left* markers to the image.

Other patient identification information includes the patient's age or date of birth, the time of day, and the name of the radiographer or attending physician. For certain examinations, the radiograph should include such information as cumulative time after the introduction of contrast medium (e.g., 5 minutes post injection), the position of the patient (e.g., upright, decubitus), or with other markings specified by the institution. This additional information is usually added by annotation of the completed radiograph during postexposure evaluation.

Working Effectively With Obese Patients

Radiology departments are having a difficult time acquiring and interpreting images of obese patients. One study found that the number of radiology procedures that were difficult to interpret because of obesity doubled over the previous 15 years. [22] According to the CDC, approximately 71% of Americans are overweight, obese, or morbidly obese (Fig. 1.49). [23] The prevalence of obesity in children has been steadily increasing. Over the past 25 years, the number of obese children has nearly tripled. Approximately 18% of children and adolescents, ages 2 to 19 years old, are obese. [24] *Obesity* is defined as an increase in body weight caused by excessive accumulation of fat. More specifically, obesity is quantified by the body mass index (BMI). [25] A BMI of 30 to 39.9 is classified as obese. A BMI greater than 40 is classified as morbidly obese, or approximately 100 lb overweight. The BMI is not of primary importance when radiographic examinations are performed; the patient's *body diameter* and *weight* are the two important considerations. One or both of these factors can determine whether a radiographic examination can be performed.

Obese patients have an effect on the functionality of the imaging equipment, and many obese patients cannot be placed onto radiographic or computed tomography (CT) tables. Patient transportation to the imaging department, as well as transfer to and from imaging equipment, are more challenging. The increased body size and weight of obese patients have a negative impact on image quality and create technical challenges for the imaging professional. However, these challenges must be met because the popularity of bariatric surgery has increased the demand for radiographic procedures in obese patients.

Equipment

Manufacturers of imaging equipment have defined weight limits. The structural integrity and function of equipment and motors are typically warrantied by manufacturers up to the stated weight only. Radiographic table weight limits cannot be exceeded without voiding the warranty. Fluoroscopy towers have a maximum diameter, and many obese patients cannot fit under the tower of those with under-table units. Over-table IR units have a much greater distance between the tube and the table, making them popular for use with obese patients (Fig. 1.50); CT and magnetic resonance imaging (MRI) scanners have gantry and bore diameters that cannot accommodate some obese patients. Table 1.5 lists the current industry-standard weight limits and maximum aperture diameters. For CT and MRI, the aperture diameter is accurate in the horizontal plane. The vertical plane must take into consideration the table thickness entering the gantry or bore. The table takes up 15 to 18 cm of the stated vertical diameter; this limits many obese patients from having CT or MRI examinations. Radiology departments without appropriate equipment cannot perform examinations on patients who weigh more than 350 to 450 lb. Radiographers must be aware of the weight and aperture limits of the radiographic equipment in their department. The radiology department should have a protocol for working with obese patients, and all equipment should be marked with the limits.

FIG. 1.48 (A) All radiographs must be permanently identified and should contain a minimum of four identification markings. Note the L side marker bearing the radiographer's initials. (B) Radiographer entering a patient's identification data into a computer. (C) Enlarged image of three of the four required identification markings from A: facility name, date, and patient name and ID number. A and C, Courtesy of and used with permission of Jon Rollins.

(A) An x-ray shows the femoral condyles, patella, tibial condyles, and head of the fibula. The knee joints are open and the joint space is prominent and dark. (B) A woman is typing on a keyboard. A computer screen is in front of her. (C) shows four identification markings. The text on it reads X Y Z imaging. Rollins, Jon. Hashtag 1 11 October 20 17 07:55. I D: 0000109727. A c: 00100855874. Series: 1.

FIG. 1.49 (A) Obese patient. (B) Morbidly obese patient.

FIG. 1.50 Over-table digital fluoroscopy unit. Note the increased source-to-skin distance achievable with these units. Used with permission from Philips Healthcare, Bothell, WA.

TABLE 1.5

Industry-standard weight limit and maximum aperture diameter by imaging technique

Imaging technique	Weight limit	Maximum aperture diameter (cm)
Fluoroscopy	350 lb (159 kg)	45
4- to 16-multidetector CT	450 lb (205 kg)	70 [a]
Cylindrical bore MRI, 1.5–3.0 T	350 lb (159 kg)	60 [a]
Vertical field MRI, 0.3–1.0 T	550 lb (250 kg)	55 [a]

CT, Computed tomography; *MRI*, magnetic resonance imaging.

[a] Aperture is accurate in the horizontal plane only. For the vertical plane, approximately 15 to 18 cm must be subtracted from diameter to account for table thickness.

TABLE 1.6

Advances in weight limit and maximum aperture diameter by imaging technique

Imaging technique	Weight limit	Maximum aperture diameter (cm)
Fluoroscopy	700 lb (318 kg)	60
16-multidetector CT	680 lb (308 kg)	90 [a]
Cylindrical bore MRI, 1.5 T	550 lb (250 kg)	70 [a]
Vertical field MRI, 0.3–1.0 T	550 lb (250 kg)	55 [a]

CT, Computed tomography; *MRI*, magnetic resonance imaging.

[a] Aperture is accurate in the horizontal plane only. For the vertical plane, about 15 to 18 cm must be subtracted from diameter to account for table thickness.

To accommodate obese patients, most radiography equipment manufacturers are redesigning their equipment and increasing table weights and aperture dimensions. Table 1.6 shows the limits of the current equipment modified for obese patients. Radiographic and fluoroscopic table weight limits have doubled to 700 lb. CT and MRI table weights and aperture openings have also increased.

Transportation

The transportation of obese patients may be difficult with standard equipment. Obese patients require larger wheelchairs (Fig. 1.51) and larger transport beds or stretchers. Some hospitals have installed larger doorways to accommodate larger transportation equipment. The availability of these special chairs and beds may be limited and may affect the scheduling of these patients. One manufacturer [26] has designed a special cart that can hold patients weighing 750 lb; this cart has a 34-inch pad width. Many obese patients, unless they are hospitalized, are able to walk around and access clinics and imaging centers. However, their weight becomes an issue when they have to lie on an imaging table. For this reason, morbidly obese patients who can stand are often imaged in an upright position. If images are to be produced using an upright radiographic-fluoroscopic table, the footboard should be removed, allowing the patient to stand directly on the floor. Under these circumstances, it is recommended that a large, sturdy bench be kept available in case the patient becomes unstable and needs to sit during the radiographic or fluoroscopic procedure.

An important consideration during transportation and transfer of obese patients is the potential risk of injury to the radiographer and other health care workers during movement and positioning of patients. Radiographic examinations of obese patients who are hospitalized must be coordinated carefully between the radiology department and the patient's nursing section. Appropriate measurements must be made in the patient's room in advance by trained radiology personnel. An obese patient should not be transported to the radiology department and find on arrival that he or she cannot be accommodated.

An appropriate number of staff members must be available to ensure that moving assistance is appropriate. Transfer of a patient from the cart to the radiographic table may require a greater number of personnel, up to 8 to 10 individuals, than is specified by department policy. Obese patients are not manually lifted; they are moved by sliding. Although traditional sliding equipment is not sufficiently wide or sturdy, newer sliding technology that rides on a thin film of air is allowing safer and easier movement of obese patients with fewer personnel (Fig. 1.52). In addition, creative use of high-capacity power lifts allows transfer of obese patients in situations where sliding is not practical (Fig. 1.53). Regardless of the transfer method used, it is imperative that proper body mechanics be used by all personnel moving these patients.

If a morbidly obese patient falls or collapses to the floor, procedures must be predetermined to move the patient to a stretcher or cart for transportation to an appropriate location for evaluation and possible treatment. Hospitals treating significant numbers of morbidly obese bariatric surgery patients have developed such procedures. For example, St. Vincent Carmel Hospital, a bariatric center of excellence in Indianapolis, Indiana, has developed a "code lift" process. Appropriate personnel from a variety of departments respond with appropriate equipment to safely move the fallen patient, with minimal risk to staff.

Communication

For the most part, communications with obese patients are no different than with nonobese patients. However, communication with obese patients may require personnel to be more aware of the issues of obesity. The radiographer must be able to assess the difficulties created by the limitations of equipment in handling an obese patient and must be able to communicate with the patient without offending him or her. The dignity of the patient must be kept in mind. Sensitivity training should be provided by the hospital or clinic. Reference to the patient's weight should never be made. The radiographer should be sensitive and display compassion. This can be accomplished by clearly explaining the procedure to gain the patient's confidence and trust. After the patient's trust and cooperation have been obtained, it is easier to communicate effectively if any problems or concerns with the examination arise.

There should never be any discussion about the patient in the radiographic room and no discussion within the hearing distance of the patient about poor image quality or the difficulty involved in obtaining images. If the radiologist and patient's physician together determine that the patient's weight allows radiographic images to be made, the examination should proceed in the same manner as with any other patient. Although more staff may be needed for transfer or positioning purposes, communications and performance of the examination should remain the same.

Imaging Challenges

When the patient is on the imaging table, it is imperative that he or she is centered accurately on the table. This is necessary because it may be impossible to palpate traditional landmarks such as the anterior superior iliac spine (ASIS) and the iliac crest (see Chapter 2 for positioning landmarks). One of the most important considerations in positioning an obese patient is the need to recognize that the bony skeleton and most organs have not changed in position and the organs are not larger. Most of what is seen physically on these patients is fat. In Fig. 1.54, although the soft tissue dimensions of patient B are much greater than those of patient A, the skeleton of patient B is approximately the same size as that of patient A, and most organs are located in their normal positions. The only exception would be seen in morbidly obese patients, in whom the width of the thoracic cage and ribs may be expanded by 2 inches, the stomach may be slightly larger, and the colon may be spread out more across the width of the abdomen (Fig. 1.55). Most positioning landmarks used on obese patients will serve as reference points in the midsagittal plane of the patient.

FIG. 1.51 Wheelchairs: extra-large for morbidly obese patients *(left)*, large for obese patients *(center)*, and standard for smaller patients. Courtesy Department of Radiology, St. Vincent Carmel Hospital, Carmel, IN.

FIG. 1.52 A patient-moving device that rides on a thin film of air. The straps and convenient handholds allow only a few people to securely move very large patients. Courtesy Department of Radiology, St. Vincent Carmel Hospital, Carmel, IN.

FIG. 1.53 Twin 500-lb capacity power lifts, attached to a ceiling-mounted rail system, allow very large patients to be safely lifted from a bed or a stretcher to the 650-lb capacity CT table. Interdepartmental cooperation is essential because the hoist sling is usually positioned under the patient before transport to the CT suite. Courtesy Department of Radiology, St. Vincent Carmel Hospital, Carmel, IN.

Radiographic projections of the skull, cervical spine, and upper limb are obtainable on all obese patients, as are projections of the lower limb from the knee distally. Shoulder and femur projections may be difficult to position but are usually obtainable. All projections of the thorax including lungs, abdomen, thoracic and lumbar spines, pelvis, and hips are very challenging to position and may be impossible to obtain in morbidly obese patients. The patient's lack of mobility makes lateral hip projections virtually impossible. Fig. 1.56 shows that most fat accumulates around the trunk, particularly around the abdomen, pelvis, and hips. Imaging of organs such as the stomach, small bowel, and colon may be very difficult, if not impossible, on morbidly obese patients. CT may be the only imaging alternative if the equipment can support the weight and girth of these patients.

Landmarks

Finding traditional positioning landmarks may be possible in some obese patients and impossible in morbidly obese patients. It is appropriate to enlist the patient's assistance in identifying landmarks if possible. This gives patients a sense of being involved in their examination. In some obese patients, the abdominal fat is very soft, movable, and layered in "folds." For these patients, the radiographer can gently move or push the folds of skin out of the way to palpate the ASIS or iliac crest. The patient should be informed of what the radiographer is doing every step of the way. The *jugular notch* may be the only palpable landmark on morbidly obese patients. Traditional landmarks such as the xiphoid, ASIS, iliac crest, pubic symphysis, and greater trochanter may be impossible to palpate. The radiographer should not attempt to push and prod to find these landmarks. Fig. 1.57 illustrates that, although traditional landmarks would be difficult to palpate because of excess body fat, if the patient's chin is raised, the jugular notch can be palpated.

The jugular notch is an essential landmark when obese patients are imaged. Most projections of the thorax, abdomen, and pelvis can be obtained using only this landmark to perform the following localization procedure. Two items should be available in the radiographic room—tongue depressors and a tape measure. When the jugular notch is found, a tongue depressor should be placed on the notch. With the tape measure kept horizontal, the radiographer measures straight down the midsagittal plane, from the jugular notch point to the pubic symphysis (Fig. 1.58). The pubic symphysis is found at the following distances from the jugular notch:

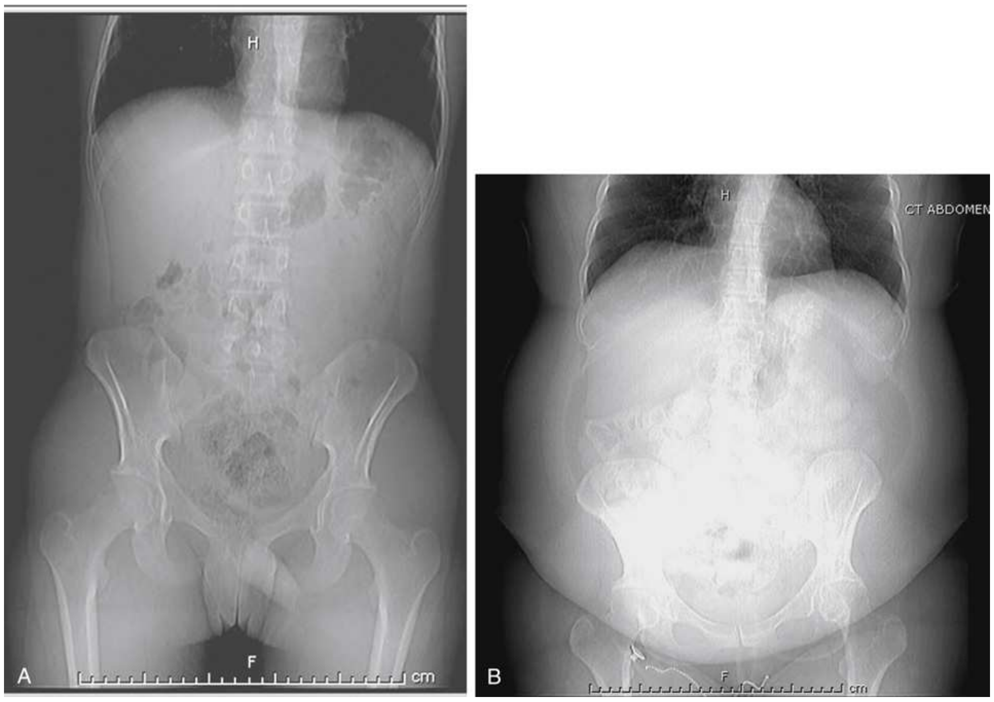

FIG. 1.54 CT abdomen scouts of (A) nonobese patient and (B) obese patient. Note the similar skeletal size and organ locations, although patient B has much greater external dimensions.

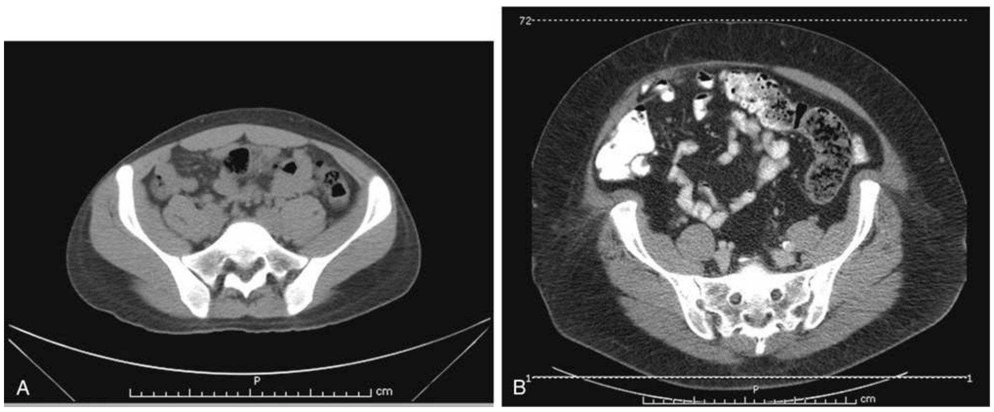

FIG. 1.55 (A) Axial CT image of the abdomen on an average-size patient. (B) Axial CT image of the abdomen on an obese patient demonstrating anterior and lateral displacement of colon and small bowel. However, note that the colon is still well within the skin margins.

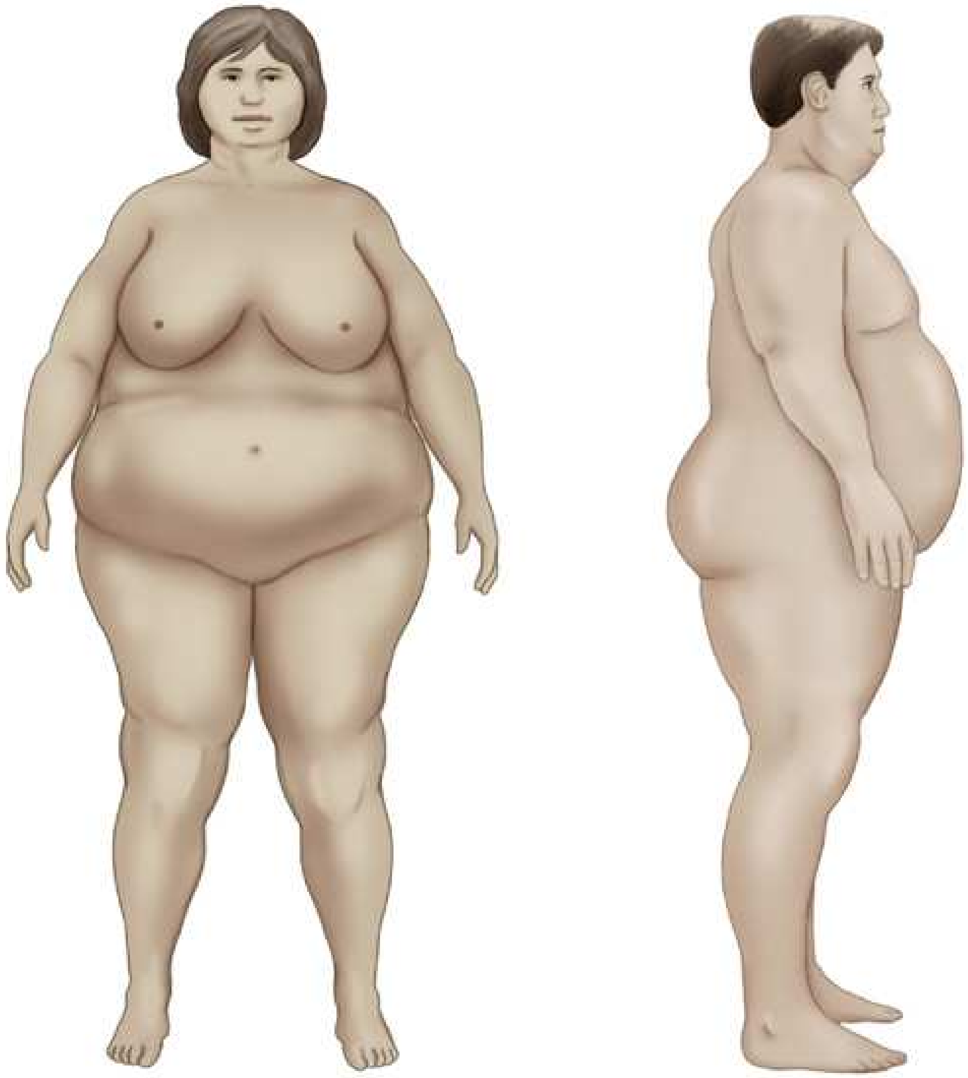

FIG. 1.56 Large amount of body fat that surrounds the abdomen, pelvis, hips, and upper femora on obese patients. The dimensions shown are from actual patient measurements.

(A) The anterior view of an obese woman shows a large amount of fat surrounding the abdomen, pelvis, hips, and upper femora. (B) The lateral view of an obese man shows a large amount of fat surrounding the abdomen, pelvis, hips, and upper femora.

Patient height: Less than 5 ft: 21 inches
5 to 6 ft: 22 inches
Greater than 6 ft: 24 inches

The second tongue depressor is placed at the level of the pubic symphysis. The two depressors present a visual indication of the superior and inferior boundaries of the trunk of the body. Note that the symphysis will not be palpated because of the pendiculum (the fat skirt that hangs down over the symphysis). The indicators presented will determine its location. When the radiographer knows where these two anatomic points are, nearly all projections of the trunk can be obtained with moderate accuracy. The bottom edge of a 14 × 17-inch (35 × 43-cm) IR placed lengthwise at the pubic symphysis shows the abdomen and lumbar spine. If the bottom edge of the IR is placed crosswise, it shows the pelvis and hips. The first thoracic vertebra (T1) is located approximately 2 inches (5 cm) above the jugular notch. An understanding of the landmarks related to body structures described in Chapter 2 enables the radiographer to position for nearly all projections of the trunk.

Oblique and lateral projections

Caution should be used when turning patients on their side for oblique and lateral projections. Turning should always be done with the assistance of the patient and with an appropriate number of additional personnel. Positioning aids or equipment should be used to prevent injury to the patient and personnel. Before the patient is turned, measurements should be taken of the body part width to determine whether the exposure technique can be made. Oblique and lateral projections of the hips, lumbar spine, lumbosacral area, sacrum, coccyx, and, in some patients, the thoracic spine may be prohibited because of x-ray tube limits. Oblique and lateral projections may be impossible to obtain on a morbidly obese patient. Cross-table projections also may be impossible because of the patient's size and the very large amount of scatter radiation produced. Lower grid ratios in grid holders are typically used for these exposures and may not aid in improving image quality. In limited instances, two exposures can be made in rapid succession. However, the patient must be able to hold very still, and this works only on bone projections.

Image receptor sizes and collimation

Based on the exterior dimensions of obese patients, it may seem that larger IRs are needed to image these patients. In most instances, this is not the case. If care is taken to find landmarks, in particular, the jugular notch and the pubic symphysis, relatively accurate positioning can be accomplished. Collimation is one of the most important considerations when obese patients are imaged. Setting the collimator to the smallest dimensions possible reduces scatter radiation. The reduced scatter increases contrast, which enables improved visibility of the structures (Fig. 1.59). The use of standard-size IRs and standard collimation settings for DR keeps scatter radiation to low levels, and scatter radiation fog on the image is reduced. *The collimator should never be set larger than the size of the IR.* This requires referring to the field size indicators on the collimator, rather than using the projected light field size as an indicator of size at the IR.

With DR and the availability of the 17 × 17-inch (43 × 43-cm) flat-panel detector built into the table (see Fig. 1.29D), the radiographer may be tempted to use the maximum size of this field on large patients. *This temptation should be avoided.* This very large collimator setting produces more scatter, which degrades overall image quality. Collimating larger than the traditional 14 × 17 inches (35 × 43 cm) for body parts that require this dimension images only more fat. Recall from Fig. 1.54 that within the large body are a standard-size skeletal frame and organs. A significantly improved diagnostic image is obtained on obese patients when IRs and collimation settings of appropriate size are used. For colon and other abdominal images, it may be necessary to take multiple images on quadrants of the body [24] using smaller collimation settings. When DR is used to image obese patients, radiographers should use collimation settings for the various projections, as indicated in this atlas.

FIG. 1.57 Obese patient. Traditional landmarks would be impossible to palpate. With the chin raised, the jugular notch can be palpated. Used with permission from Philips Healthcare, Bothell, WA.

FIG. 1.58 Radiographer measuring jugular notch–to–pubic symphysis plane.

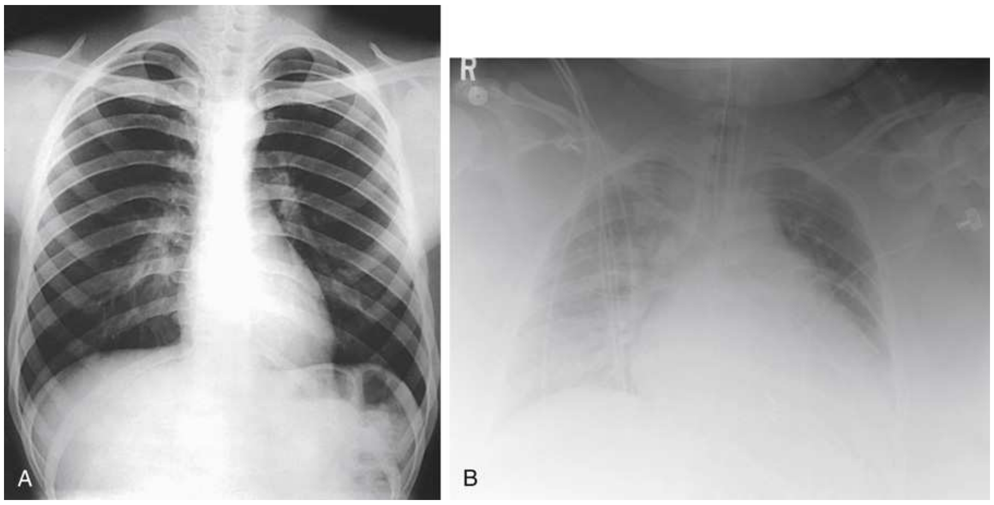

FIG. 1.59 (A) Chest radiograph on a 160-lb patient. Note very good contrast and visibility of structures. (B) Chest radiograph on a 360-lb patient. Note reduced contrast and fogging on the image. However, a reasonable image was obtained.

(A) An x-ray shows anterior ribs with more details above the diaphragm and posterior ribs with fewer details. A radiopaque area is aligned towards the right side of the radiograph towards the bottom. (B) An x-ray shows the chest. It appears foggy.

Field light size

When the collimator size is set automatically for IRs in the Bucky or manually on the collimator for DR equipment, the field light is visible on a nonobese patient's body relatively close to the actual dimensions of the IR (Fig. 1.60A). This light gives the radiographer an accurate visual indication of where the radiation field falls. On obese patients, in whom the vertical dimension of the thorax and abdomen is very large (see Fig. 1.49B), the field light visible on top of the patient appears much smaller than the IR size because the abdomen is closer to the collimator bulb and less light divergence occurs (see Fig. 1.60B). The natural tendency may be to open the collimator when this small field is seen. *The collimator should not be opened larger than the size of the IR or the stated collimator dimensions for DR.* The radiographer must understand that although the field size visually appears small on top of the patient, the radiation field diverges to expose the entire IR size.

Exposure Factors

Modified x-ray exposure techniques need to be used for obese patients. The main factors have to be increased, including mA, kVp, and exposure time. The major limitation in obtaining images of obese patients is inadequate penetration of the body part. This situation results in increased quantum mottle (noise) and decreased contrast resolution. The increased exposure time required for these patients can also contribute to motion artifacts in the image. The most important adjustment that should be made is an increase in the kVp. Increasing the kVp increases the penetration of the x-ray beam. Although mA and exposure time (mAs) have to be increased, caution should be used in increasing the mA. Greater exposures can be obtained safely by using lower mA settings and longer exposure times. (Refer to a tube rating chart in a physics text.)

Body motion is not a major problem in imaging obese patients because the weight of the patient prevents most body parts from moving, and mA settings of approximately 320 can be used. Although this setting may increase the exposure time, most obese patients can hold their breath with an explanation of the importance of doing so. With repeated use of high-exposure factors, the x-ray tube can become very hot. Radiographers should ensure that adequate cooling of the anode and tube as a whole occurs; this can be accomplished by simply taking more time between exposures.

Focal spot

The focal spot in the x-ray tube is controlled by the mA that is selected. The mA for obese patient radiographs may be higher than 250 to 320 mA, which may automatically engage the large focus. Use of the small focal spot, which enables greater spatial resolution, may be restricted to the distal limbs because of the higher exposure techniques. Radiographers must have a full understanding of the focal spot limits for the machines they use. These should be posted for use with obese patient projections.

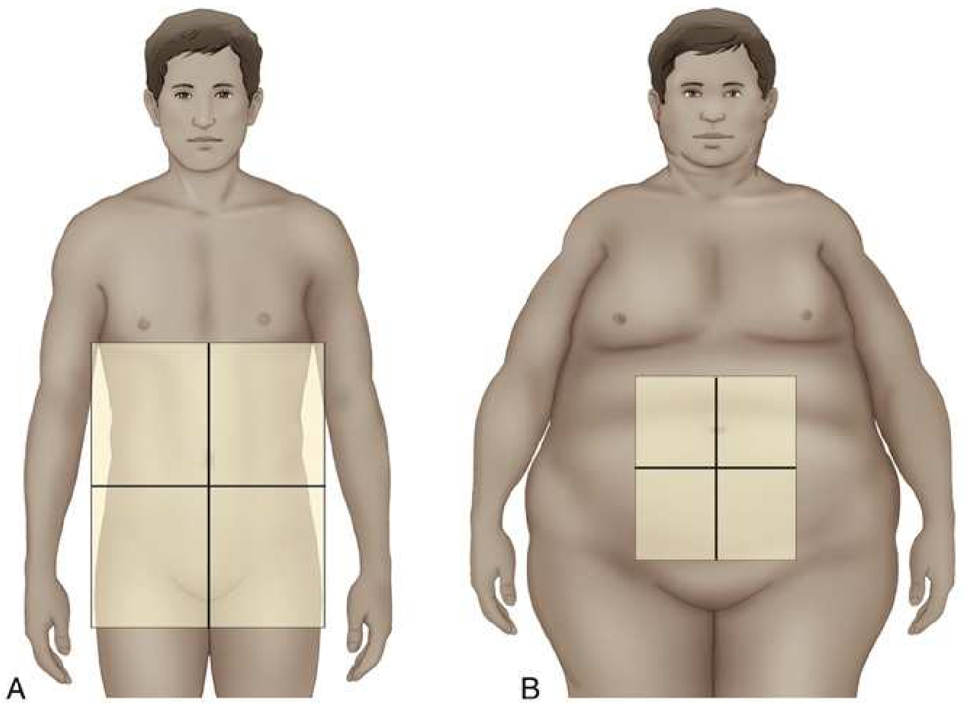

FIG. 1.60 (A) Illustration of how collimator light for 14 × 17-inch (43 × 43-cm) IR appears on a normal-size patient with 21-cm abdomen measurement. The light is very close in dimension to IR size. (B) Collimator light shown for same-size IR on an obese patient with 45-cm vertical abdomen measurement. Although the collimator is set to the same dimensions, the light field appears small on top of the patient.

(A) shows the anterior view of a normal-sized patient. The I R covers the abdomen and divides it into four quadrants. (B) shows the anterior view of an obese patient. The I R appears small on the abdomen and covers only a small portion.

Bucky and grid

The use of a Bucky grid or a mobile grid can minimize scatter radiation significantly. The grid is automatically used when standard projections are obtained on the x-ray table and for some cross-table lateral images of limbs. Although a grid is never used for elbow, ankle, and leg projections on nonobese patients, it can significantly improve image quality on obese patients, in particular on morbidly obese patients (Fig. 1.61). Radiology departments should have a high-ratio mobile grid available for use with obese patients.

Automatic exposure control and anatomically programmed radiography systems

AEC and anatomically programmed radiography (APR) systems are widely used in radiology departments to control technical factors automatically. Machine-set exposure factors are frequently inappropriate for obese patients, so kVp, mA, exposure time, AEC detectors, and focal spot should be *manually adjusted.* With AEC, the radiographer should ensure that a high kVp and a moderate mA are used. In addition, a backup time greater than the customary 150% of anticipated mAs will likely be required. The radiology department should maintain a special exposure technique chart for obese patients, similar to a special chart used for pediatric patients. When possible, all three AEC detectors should be activated.

Mobile radiography

Mobile radiography machines may be used for imaging obese patients; however, their use is very limited. Because the x-ray tubes on these machines have limited ratings, exposures high enough to penetrate these patients can be difficult to obtain. However, the greater dynamic range of digital IRs is allowing all but the largest patients to be imaged. Depending on the size of the patient, mobile projections may be restricted to the chest and limbs only. The mobile machine should have a special technique chart outlining the technical factors used for this group of patients.

Radiation dose

Radiographers must use caution in all aspects of working with obese patients, including keeping repeat exposures to a minimum. A study of radiation doses to obese patients having bariatric surgery showed a fourfold dose increase compared with nonobese patients having the same examinations.[27] Doses to these patients reached 45 mSv (4500 mrem). Precautions must be taken to minimize patient dose. The radiologist should be involved in evaluating the justification of any radiologic procedure on an obese patient. Radiographers should be especially cautious when holding a limb or an IR during an x-ray exposure on an obese patient. The increased exposure techniques prompt increased scatter, which reaches the person holding the patient. If someone has to hold an obese patient, when possible, the person should stand at a right angle (90 degrees) to the CR for maximum scatter protection. (See Chapter 20 for further information.)

Special technical considerations must be followed when working with obese and morbidly obese patients. Box 1.4 summarizes these technical considerations.

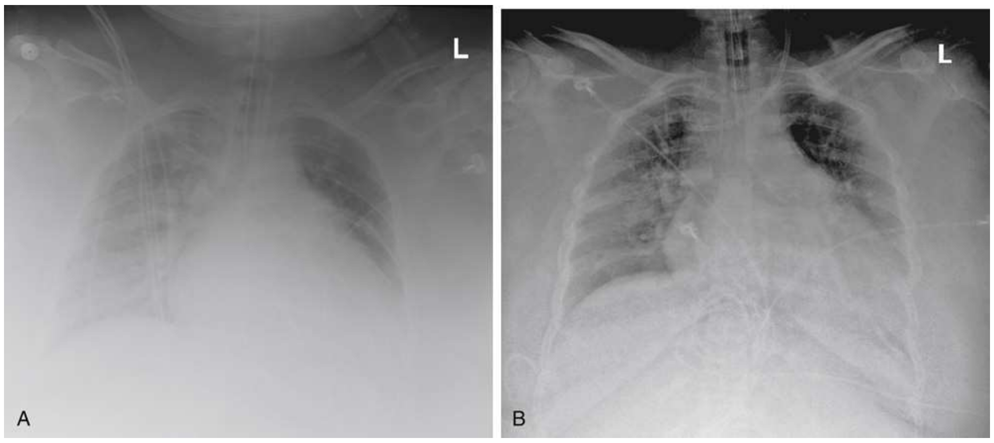

FIG. 1.61 Mobile chest radiographs of an obese patient. (A) AP projection with no grid. (B) AP projection of the same patient using a grid. Note increased contrast resolution in image B.

BOX 1.4 Technical considerations for working effectively with obese patients

- Warm up the x-ray tube before making any exposures.
- Use lower mA settings (<320).
- Use higher kVp settings.
- Do not make repeated exposures near the x-ray tube loading limit.
- Use the large focal spot for all but distal limbs.
- Do not use APR systems to determine exposure technique.
- When using AEC systems, ensure kVp is high enough and mA is moderate.
- Collimate to the size of IR or smaller.
- With DR, collimate to suggested field size for the projection.
- Avoid collimating to the maximum 17 × 17-inch (43 × 43-cm) size of the flat-panel DR detector.
- Maintain special exposure technique chart for obese patient projections.
- Stand at right angles (90 degrees) to the central ray when holding an obese patient.

AEC, Automatic exposure control; *APR,* anatomically programmed radiography; *kVp*, kilovoltage peak.

Abbreviations used in Chapter 1

AAPM	American Association of Physicists in Medicine
ACR	American College of Radiology
AEC	automatic exposure control
ALARA	as low as reasonably achievable
AP	anteroposterior
APR	anatomically programmed radiography
ARRT	American Registry of Radiologic Technologists
ASIS	anterior superior iliac spine
ASRT	American Society of Radiologic Technologists
BMI	body mass index
CAMRT	Canadian Association of Medical Radiation Technologists
CCD	charge-coupled device
CDC	Centers for Disease Control and Prevention
cm	centimeter
CR [a]	central ray
CR [a]	computed radiography
CT	computed tomography
DR	digital radiography
ED	emergency department
IP	image plate
IR	image receptor
JRCERT	Joint Review Committee on Education in Radiologic Technology
kVp	kilovolt peak
L	left
LAO	left anterior oblique
mA	milliamperage
mAs	milliampere second
MRI	magnetic resonance imaging
NCRP	National Council on Radiation Protection
OID	object-to-image receptor distance
OR	operating room
PA	posteroanterior
PBL	positive beam limitation
PPE	personal protective equipment
PSP	photostimulable storage phosphor
R	right
RA	radiologist assistant
RPA	radiology practitioner assistant
RPO	right posterior oblique
SID	source-to-image receptor distance
SSD	source-to-skin distance

TFT	thin-film transistor

[a] Note that there are two different abbreviations for CR.
See Addendum A for a summary of all abbreviations used in Volume 1.

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2: General Anatomy and Radiographic Positioning Terminology

OUTLINE

General Anatomy

Radiographers must possess a thorough knowledge of anatomy, physiology, and osteology to obtain radiographs that show the desired body part. *Anatomy* is the term applied to the science of the structure of the body. *Physiology* is the study of the function of the body organs. *Osteology* is the detailed study of the body of knowledge related to the bones of the body.

Radiographers also must have a general understanding of all body systems and their functions. Particular attention must be given to gaining a thorough understanding of the skeletal system and the surface landmarks used to locate different body parts. The radiographer must be able to visualize mentally the internal structures that are to be radiographed. By using external landmarks, the radiographer should be able to properly position body parts to obtain the best diagnostic radiographs possible.

Body Planes

The full dimension of the human body as viewed in the *anatomic position* (see Chapter 1) can be effectively subdivided through the use of imaginary body planes. These planes slice through the body at designated levels from all directions. The following four fundamental body planes referred to regularly in radiography are illustrated in Fig. 2.1A:

- Sagittal
- Coronal
- Horizontal
- Oblique

Sagittal plane

A sagittal plane divides the entire body or a body part into right and left segments. The plane passes vertically through the body from front to back (see Fig. 2.1A and B). The *midsagittal plane* is a specific sagittal plane that passes through the midline of the body and divides it into equal right and left halves (see Fig. 2.1C).

Coronal plane

A coronal plane divides the entire body or a body part into anterior and posterior segments. The plane passes through the body vertically from one side to the other (see Fig. 2.1A and B). The *midcoronal plane* is a specific coronal plane that passes through the midline of the body, dividing it into equal anterior and posterior halves (see Fig. 2.1C). This plane is sometimes referred to as the *midaxillary plane*.

Horizontal plane

A *horizontal plane* passes crosswise through the body or a body part at right angles to the longitudinal axis. It is positioned at a right angle to the sagittal and coronal planes. This plane divides the body into superior and inferior portions. Often it is referred to as an *axial*, *transverse,* or *cross-sectional plane* (see Fig. 2.1A).

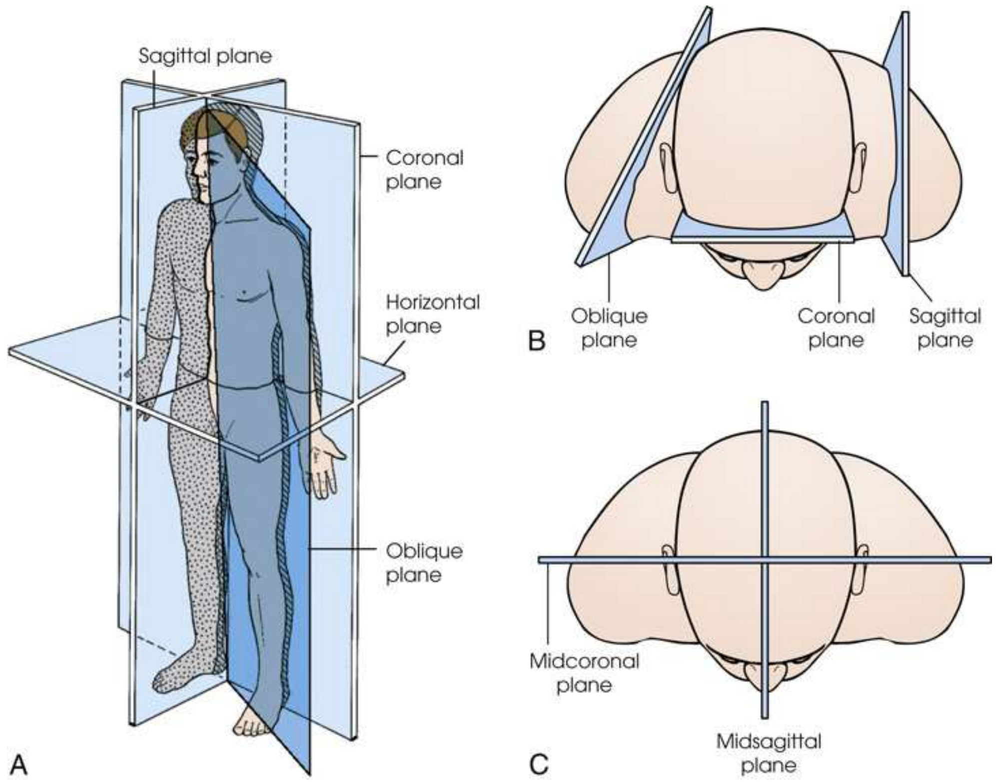


FIG. 2.1 Planes of the body. (A) A patient in anatomic position with four planes identified. (B) Top-down perspective of patient's body showing sagittal plane through left shoulder, coronal plane through anterior head, and oblique plane through right shoulder. (C) Midsagittal plane dividing body equally into right and left halves and midcoronal plane dividing body equally into anterior and posterior halves. Sagittal, coronal, and horizontal planes are always at right angles to one another.

(A) The sagittal plane, coronal plane, horizontal plane, and oblique plane are marked on the human body. A vertical plane running from front to back and divides the body into left and right side median vertical longitudinal plane divides the body into right and left halves. A vertical line runs from side to side and divides the body into anterior and posterior portions. A horizontal plane divides the body into upper and lower parts. (B) The top-down view of a human body shows the sagittal plane through the left shoulder, the coronal plane through the anterior head, and the oblique plane through the right shoulder. (C) The top-down view of a human body shows the Midsagittal plane dividing body equally into right and left halves and the midcoronal plane dividing body equally into anterior and posterior halves.

Oblique plane

An oblique plane can pass through a body part at any angle among the three previously described planes (see Fig. 2.1A and B). Planes are used in radiographic positioning to center a body part to the image receptor (IR) or central ray and to ensure that the body part is properly oriented and aligned with the IR. For example, the midsagittal plane may be centered and perpendicular to the IR, with the long axis of the IR parallel to the same plane. Planes can also be used to guide projections of the central ray. The central ray for an anteroposterior (AP) projection passes through the body part parallel to the sagittal plane and perpendicular to the coronal plane. Quality imaging requires attention to all relationships among body planes, the IR, and the central ray.

Body planes are used in computed tomography (CT), magnetic resonance imaging (MRI), and ultrasound (US) to identify the orientation of anatomic cuts or slices shown in the procedure (Fig. 2.2). Imaging in several planes is often used to show large sections of anatomy (Fig. 2.3).

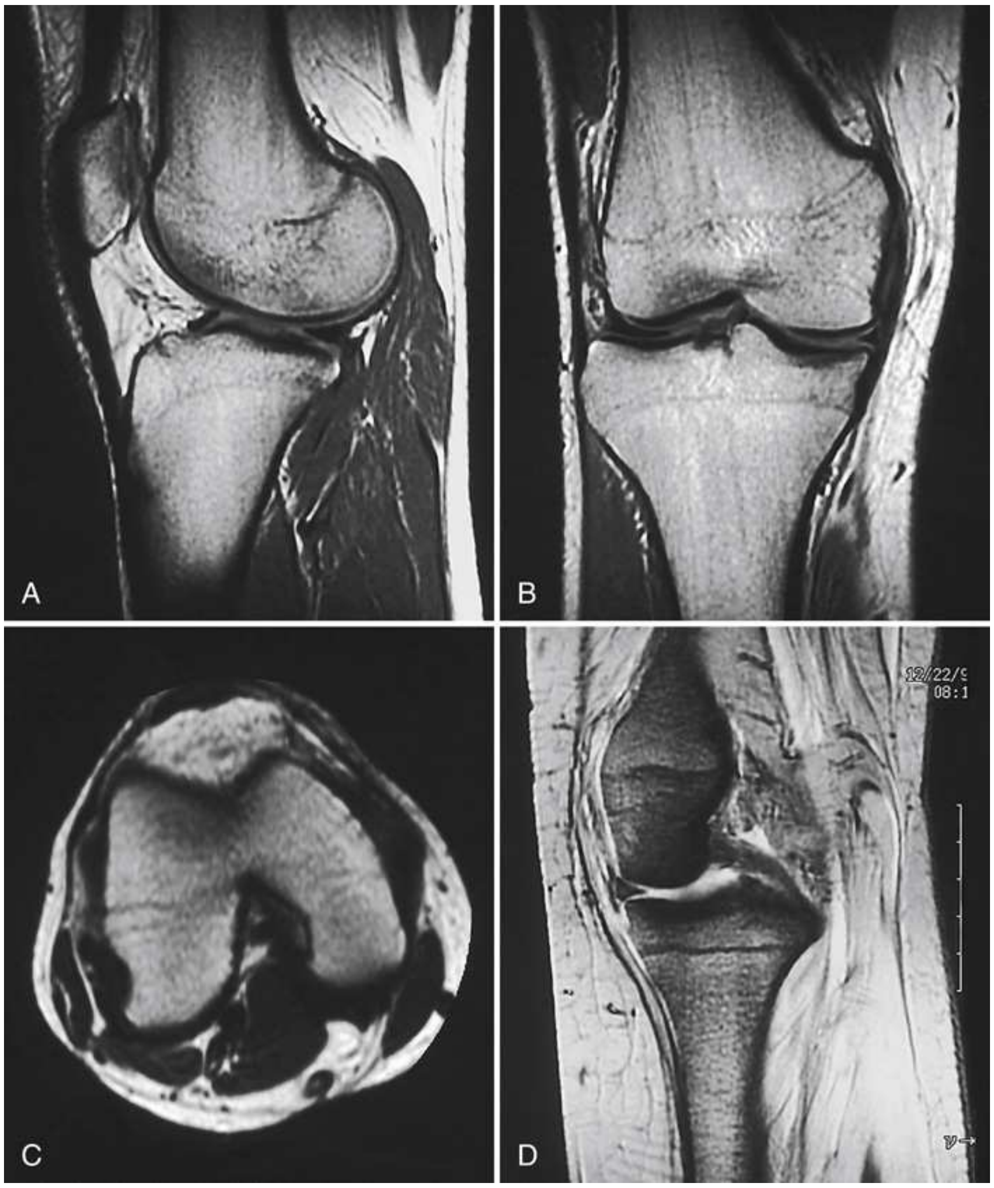


FIG. 2.2 MRI of the knee in four planes. (A) Sagittal. (B) Coronal. (C) Horizontal. (D) Oblique, 45 degrees.

(A) An M R I shows the sagittal plane of the knee joint. The femur head has a well-defined outline. (B) An M R I shows the horizontal plane of the knee joint. The intercondylar fossa and posteroinferior articular surfaces of the condyles of the femur are visible. The open joint space is dark. (C) An M R I shows the oblique plane of the knee joint. It is M Shaped. (D) An M R I shows the oblique plane of the knee joint. The soft tissues appear white and the bony elements appear dark and grainy.

FIG. 2.3 Large sections of anatomy are often imaged in different planes. (A) Coronal plane of abdomen and lower limb. (B) Sagittal plane of abdomen and lower limb at level of left kidney, left acetabulum, and left knee.

(A) An M R I shows the abdomen and the lower limb including the kidney, acetabulum, and knee. They appear white. (B) An M R I shows the abdomen and the lower limb including the left kidney, left acetabulum, and left knee.

Special Planes

Two special planes are used in radiographic positioning. These planes are localized to a specific area of the body only.

Interiliac plane

The interiliac plane transects the pelvis at the top of the iliac crests at the level of the fourth lumbar spinous process (Fig. 2.4A). It is used in positioning the lumbar spine, sacrum, and coccyx.

Occlusal plane

The occlusal plane is formed by the biting surfaces of the upper and lower teeth with the jaws closed (see Fig. 2.4B). It is used in positioning of the odontoid process and in some head projections.

Body Cavities

The two great cavities of the torso are the *thoracic* and *abdominal cavities* (Fig. 2.5). The thoracic cavity is subdivided into a pericardial segment and two pleural portions. Although the abdominal cavity has no intervening partition, the lower portion is called the *pelvic cavity*. Some anatomists combine the abdominal and pelvic cavities and refer to them as the *abdominopelvic cavity*. The principal structures located in the cavities are listed on the following page.

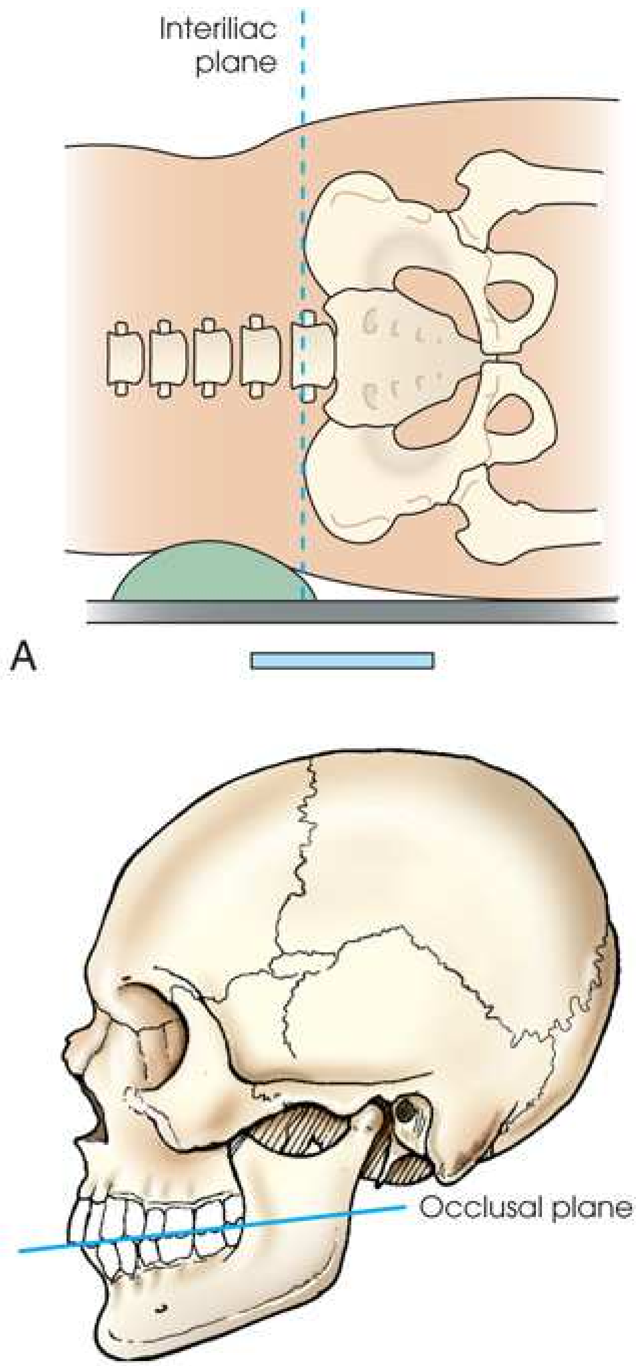


FIG. 2.4 Special planes. (A) Interiliac plane transecting trunk at tops of iliac crests. (B) Occlusal plane formed by biting surfaces of teeth.

(A) Diagram shows the lateral surface of the body placed on the I R with a support under the body. A horizontal dashed line labeled interillac plane passes through the body. (B) Diagram shows the lateral view of the skull. A dashed line touches the incisal edges of the incisors and tips of the occluding surfaces of the posterior teeth.

Thoracic cavity

- Pleural membranes
- Lungs
- Trachea
- Esophagus
- Pericardium
- Heart and great vessels

Abdominal cavity

- Peritoneum
- Liver
- Gallbladder
- Pancreas
- Spleen
- Stomach
- Intestines
- Kidneys
- Ureters
- Major blood vessels
- **Pelvic portion**—rectum, urinary bladder, and parts of the reproductive system

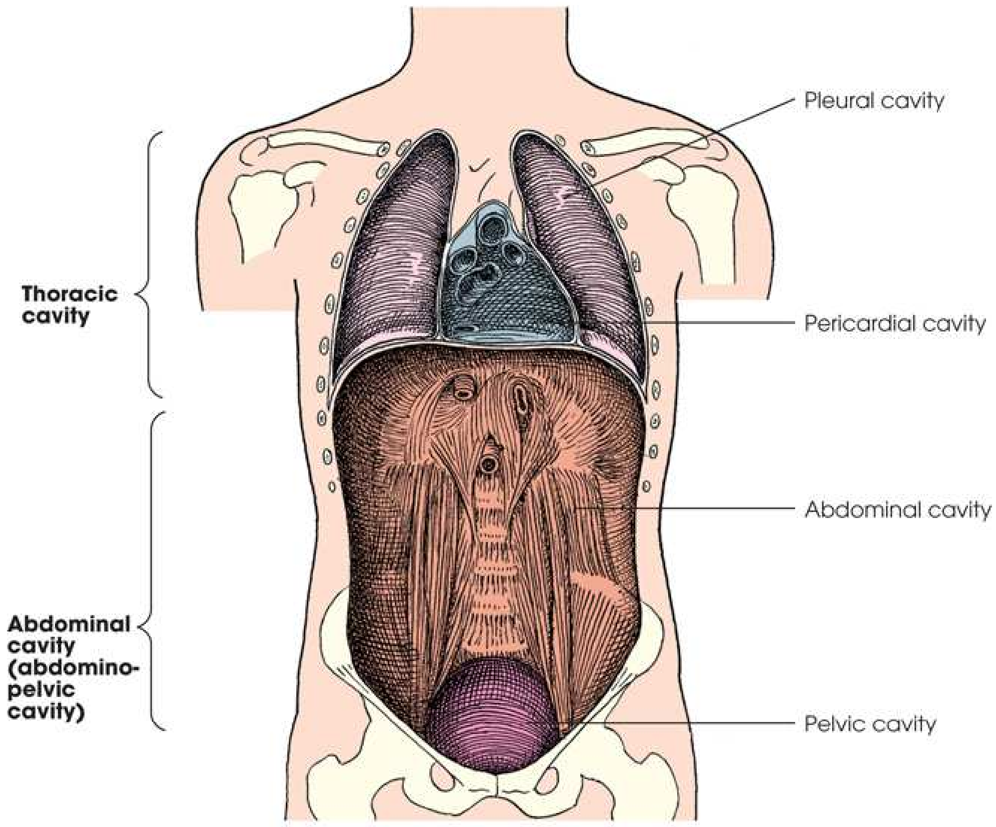


FIG. 2.5 Anterior view of torso showing two great cavities: thoracic and abdominopelvic.

An anterior view of the human body shows two cavities. The lungs, heart, abdomen, and pelvis are highlighted. The parts labeled are the thoracic cavity (including pleural cavity and pericardial cavity) and abdominal cavity (abdominopelvic cavity) including abdominal cavity and pelvic cavity.

Divisions of the Abdomen

The abdomen is the portion of the trunk that is bordered superiorly by the diaphragm and inferiorly by the superior pelvic aperture (pelvic inlet). The location of organs or an anatomic area can be described by dividing the abdomen according to one of two methods: four quadrants or nine regions.

Quadrants

The abdomen is often divided into four clinical divisions called *quadrants* (Fig. 2.6). The midsagittal plane and a horizontal plane intersect at the umbilicus and create the boundaries. The quadrants are named as follows:

- Right upper quadrant (RUQ)
- Right lower quadrant (RLQ)
- Left upper quadrant (LUQ)
- Left lower quadrant (LLQ)

Dividing the abdomen into four quadrants is useful for describing the location of the various abdominal organs. For example, the spleen can be described as being located in the LUQ.

Regions

Some anatomists divide the abdomen into nine regions by using four planes (Fig. 2.7). These anatomic divisions are not used as often as quadrants in clinical practice. The nine regions of the body, divided into three groups, are named as follows:

Superior

- Right hypochondrium
- Epigastrium
- Left hypochondrium

Middle

- Right lateral
- Umbilical
- Left lateral

Inferior

- Right inguinal
- Hypogastrium
- Left inguinal

In the clinical setting, a patient could be described as having "epigastric" pain. A patient with discomfort in the right lower abdomen could be described as having "RLQ" pain. Sometimes a quadrant term is used, and other times a region term is used.

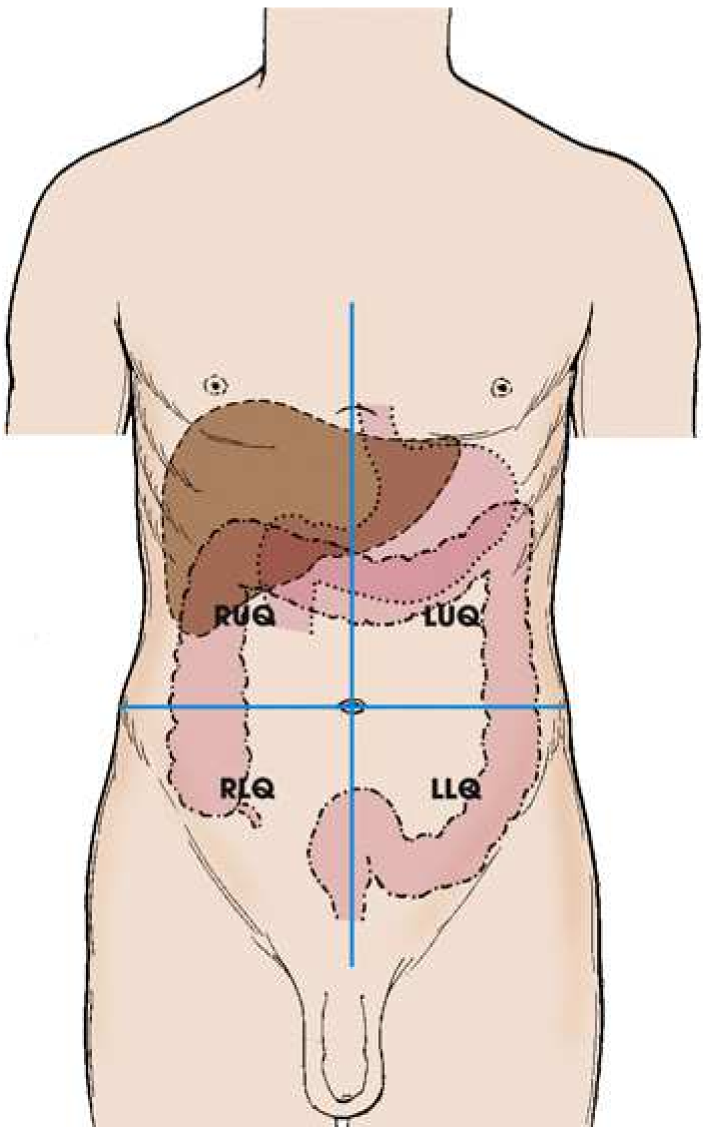


FIG. 2.6 Four quadrants of abdomen.

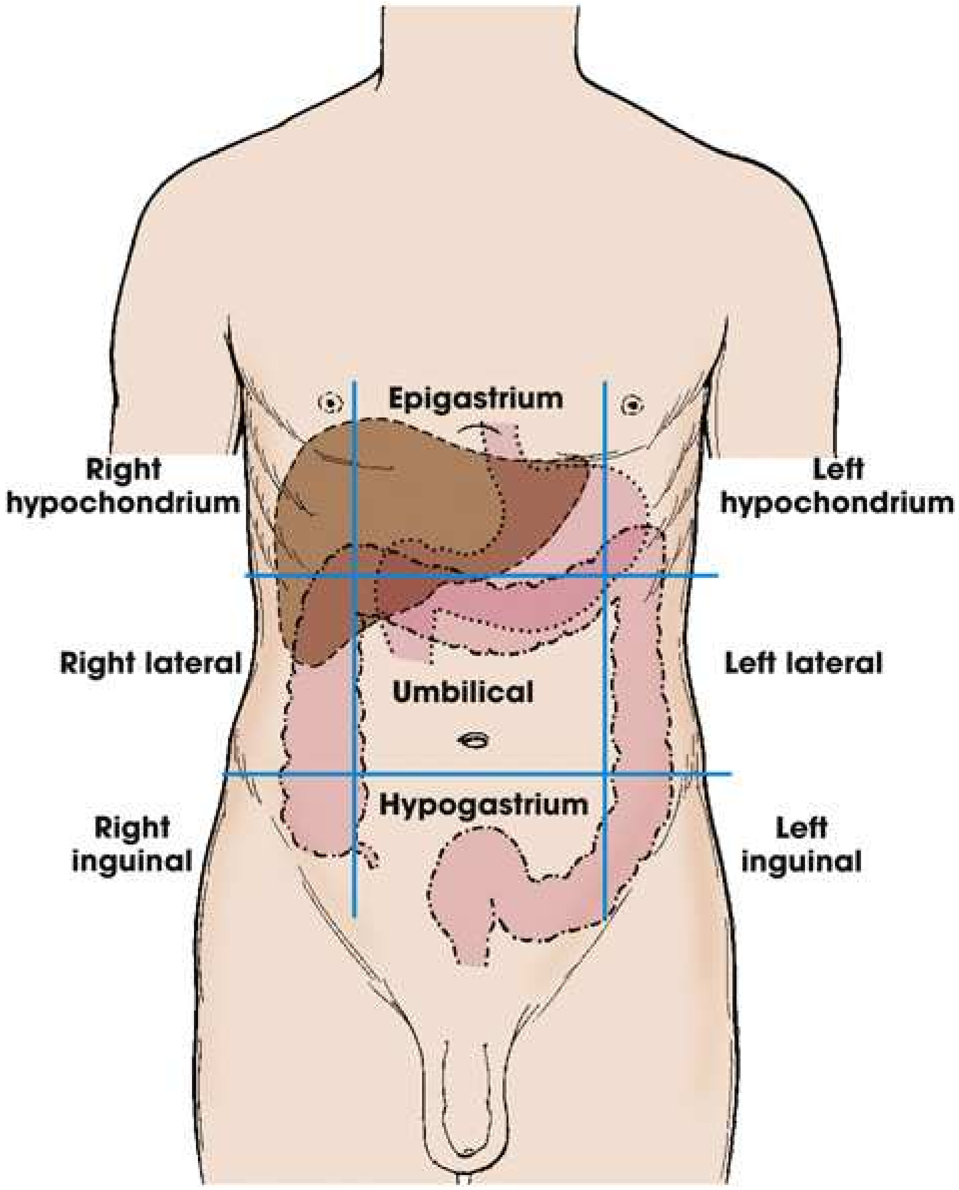


FIG. 2.7 Nine regions of abdomen.

Cutaway model of the human body shows regions of abdomen divided into a 3-by-3 matrix, marked left to right in each region as follows: Upper region: Right hypochondriac, epigastric, and left hypochondriac. Middle region: Right lumbar, umbilical, and left lumbar. Lower region: Right iliac, hypogastric, and left iliac.

Surface Landmarks

Most anatomic structures cannot be visualized directly; the radiographer must use various protuberances, tuberosities, and other external indicators to position the patient accurately. These surface landmarks enable the radiographer to obtain radiographs of optimal quality consistently for a wide variety of body types. If surface landmarks are not used for radiographic positioning or if they are used incorrectly, the chance of having to repeat the radiograph greatly increases.

Many commonly used landmarks are listed in Table 2.1 and diagrammed in Fig. 2.8. These landmarks are accepted averages for most patients and should be used only as guidelines. Variations in anatomic build or pathologic conditions may warrant positioning compensation on an individual basis. The ability to compensate is gained through experience. In the *Atlas*, positioning instructions based on external landmarks are for average-sized adults.

TABLE 2.1

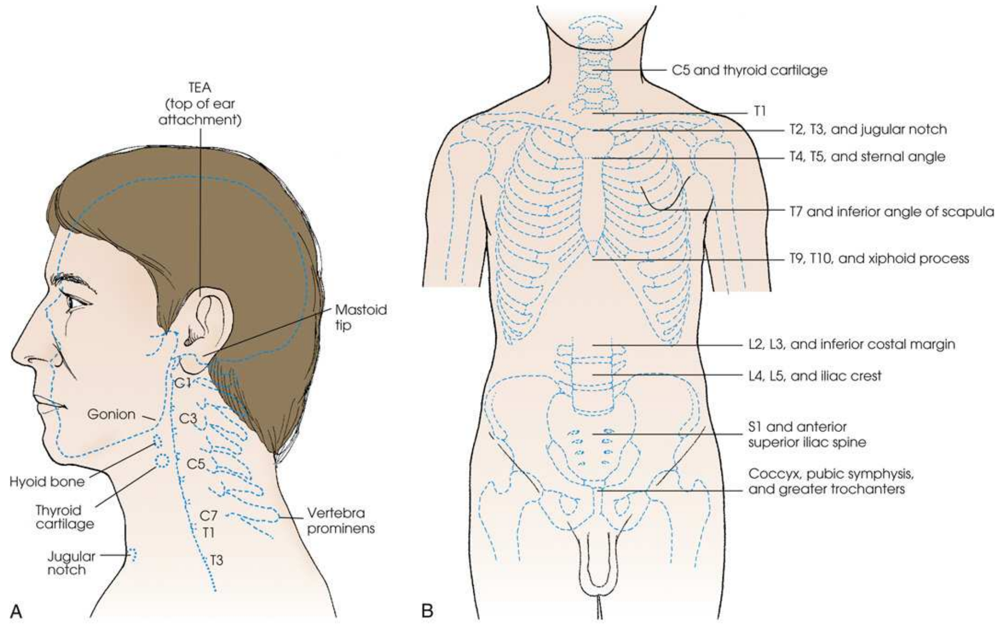


FIG. 2.8 Surface landmarks. (A) Head and neck. (B) Torso.

(A) Diagram shows the lateral view of the head. The commonly used landmarks are labeled as follows: T E A (top of ear attachment), gonion, mastoid tip, vertebra prominens, C 1, C 3, C 5, C 7, T 1, T 3, hyoid bone, thyroid cartilage, and jugular notch. (B) Diagram shows the anterior view of the human body or the torso. The commonly used landmarks labeled are marked from top to bottom as follows: C 5 and thyroid cartilage, T 1, T2, T3, and jugular notch, T 4, T 5, and sternal angle, T7 and inferior angle of the scapula, T 9, T 10, and xiphoid process, L 2, L 3, and inferior costal margin, L 4, L 5, and the iliac crest, S 1 and anterior superior iliac spine, and coccyx, pubic symphysis, and greater trochanters.

Body Habitus

Common variations in the shape of the human body are termed the *body habitus*. Mills [1] determined the primary classifications of body habitus based on his study of 1000 patients. The specific type of body habitus is important in radiography because it determines the size, shape, and position of the organs of the thoracic and abdominal cavities.

Body habitus directly affects the location of the following:

- Heart
- Lungs
- Diaphragm
- Stomach
- Colon
- Gallbladder

An organ such as the gallbladder may vary in position by 8 inches, depending on the body habitus. The stomach may be positioned horizontally, high, and in the center of the abdomen for one type of habitus and may be positioned vertically, low, and to the side of the midline in another type. Fig. 2.9 shows an example of the placement, shape, and size of the lungs, heart, and diaphragm in patients with four different body habitus types.

Body habitus and placement of the thoracic and abdominal organs are also important in the determination of technical and exposure factors. The standard placement and size of the IR may have to be changed because of body habitus. The selection of kilovolt (peak) and milliampere-second exposure factors may also be affected by the type of habitus because of wide variations in physical tissue density. These technical considerations are described in greater detail in radiography physics and imaging texts.

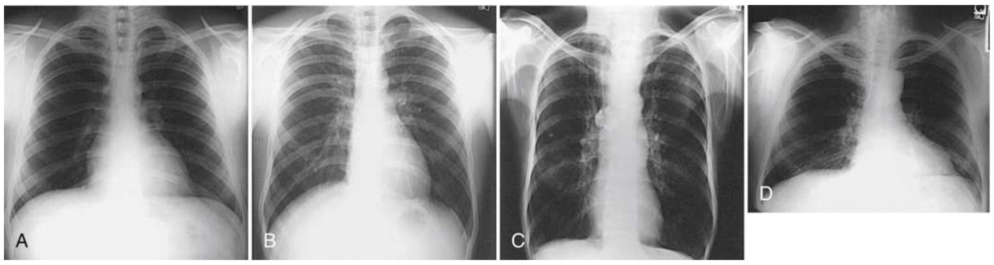


FIG. 2.9 Placement, shape, and size of lungs, heart, and diaphragm in patients with four different body habitus types. (A) Sthenic. (B) Hyposthenic. (C) Asthenic. (D) Hypersthenic (crosswise exposure field).

(A) An x-ray shows the lungs in full inspiration. The lungs filled with air appear radiolucent. The heart and the region below the diaphragm appear radiopaque. (B) An x-ray shows the lungs in full expiration. The lungs appear darker than in (A). The diaphragm is depressed. (C) A diagram shows the anterior view of the human body with the lungs highlighted. The diaphragm is positioned lower. An x-ray shows the anterior view of the human body and the lungs appear radiolucent. The diaphragm is positioned lower. The anterior ends of the ribs are less sharply visualized. (D) An x-ray shows the anterior view of the human body and the lungs appear radiolucent. The diaphragm arches posteriorly from the level of about the sixth or seventh costal cartilage to the level of the ninth or tenth thoracic vertebra. The left side of the diaphragm lies at a slightly lower level.

Box 2.1 describes specific characteristics of the four types of body habitus and outlines their general shapes and variations. The four major types of body habitus and their approximate frequency in the population are identified as follows:

- Sthenic—50%
- Hyposthenic—35%
- Asthenic—10%
- Hypersthenic—5%

More than 85% of the population has either a *sthenic* or *hyposthenic* body habitus. The sthenic type is considered the predominant type of habitus. The relative shape of patients with a sthenic or hyposthenic body habitus and the position of their organs are referred to in clinical practice as *ordinary* or *average*. All standard radiographic positioning and exposure techniques are based on these two groups. Radiographers must become thoroughly familiar with the characteristics and organ placement of these two body types.

BOX 2.1 Four types of body habitus: prevalence, organ placement, and characteristics

Sthenic, 50%

Organs

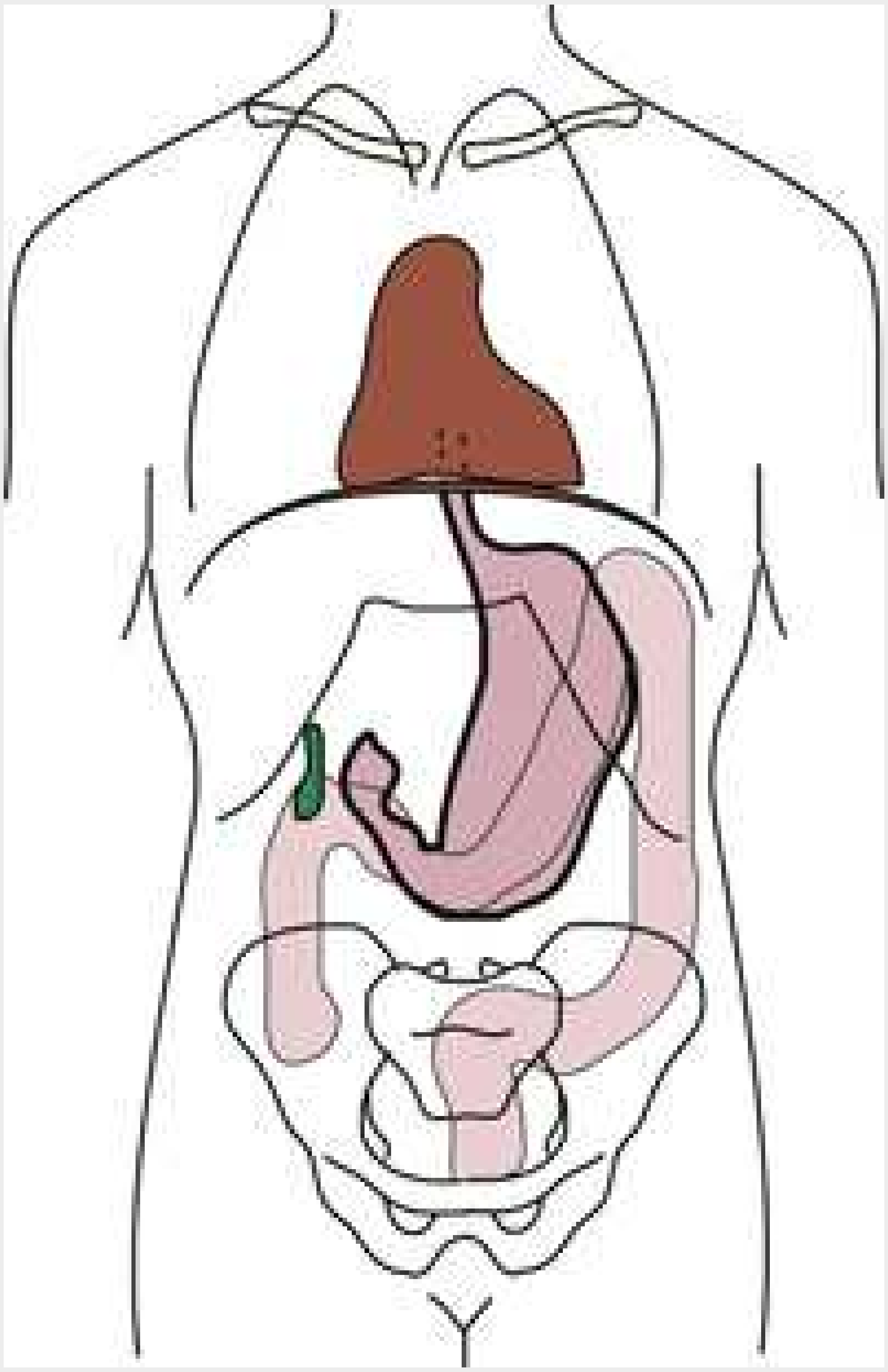


Diagram shows an anterior view of a moderately heavy body titled sthenic 50 percent. Heart: Moderately transverse. Lungs: Moderate length. Diaphragm: Moderately high. Stomach: High, upper left. Colon: Spread evenly; slight dip in the transverse colon. Gallbladder: Centered on the right side, upper abdomen. Abdomen: Moderately long. Thorax: Moderately short, broad, and deep. Pelvis: Relatively small.

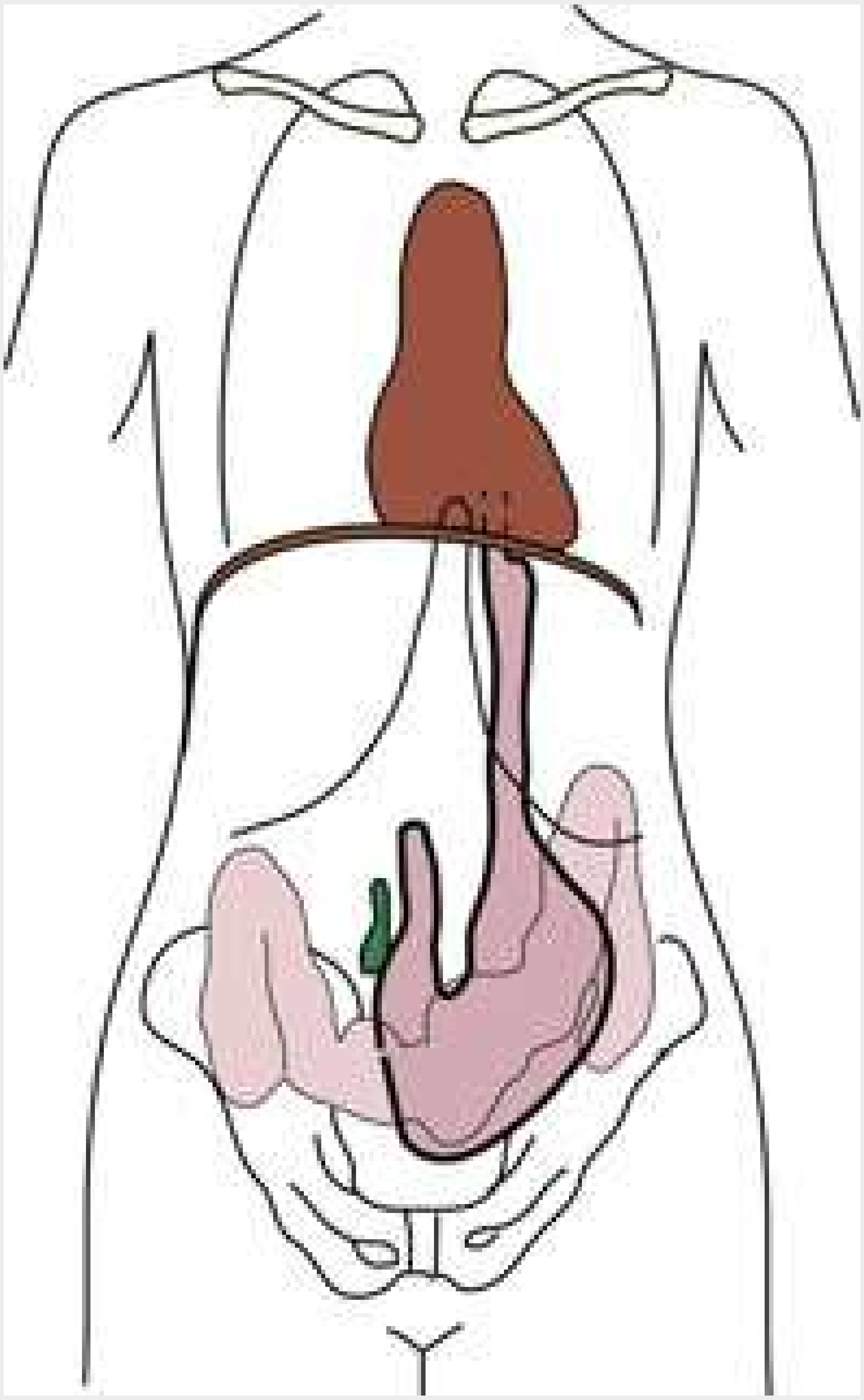
Heart: Moderately transverse
Lungs: Moderate length
Diaphragm: Moderately high
Stomach: High, upper left
Colon: Spread evenly; slight dip in transverse colon
Gallbladder: Centered on right side, upper abdomen

Characteristics

Build: Moderately heavy
Abdomen: Moderately long
Thorax: Moderately short, broad, and deep
Pelvis: Relatively small

Asthenic, 10%

Organs



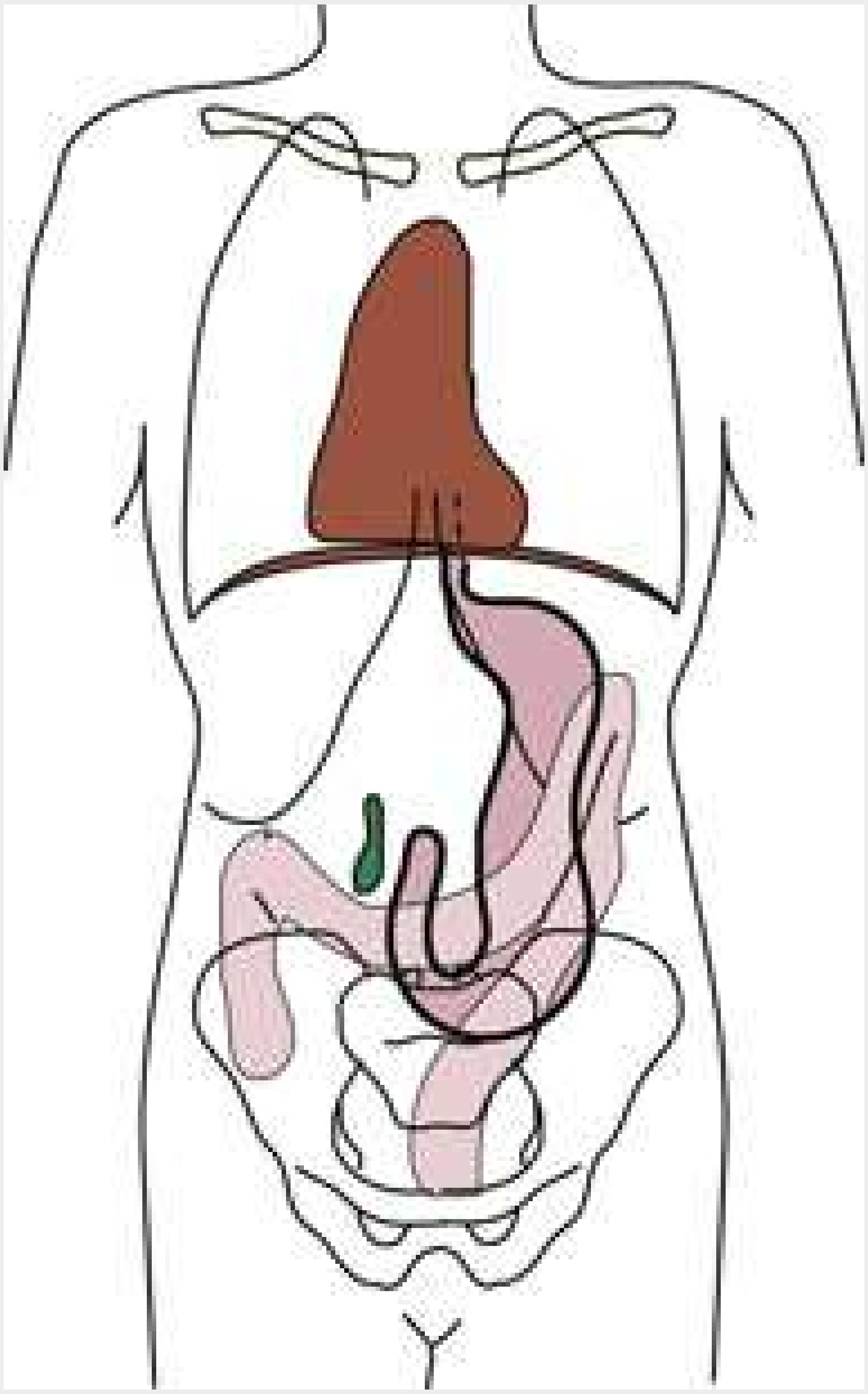
Heart: Nearly vertical and at midline
Lungs: Long, apices above clavicles, may be broader above base
Diaphragm: Low
Stomach: Low and medial, in the pelvis when standing
Colon: Low, folds on itself
Gallbladder: Low and nearer the midline

Characteristics

Build: Frail
Abdomen: Short

Thorax: Long, shallow
Pelvis: Wide

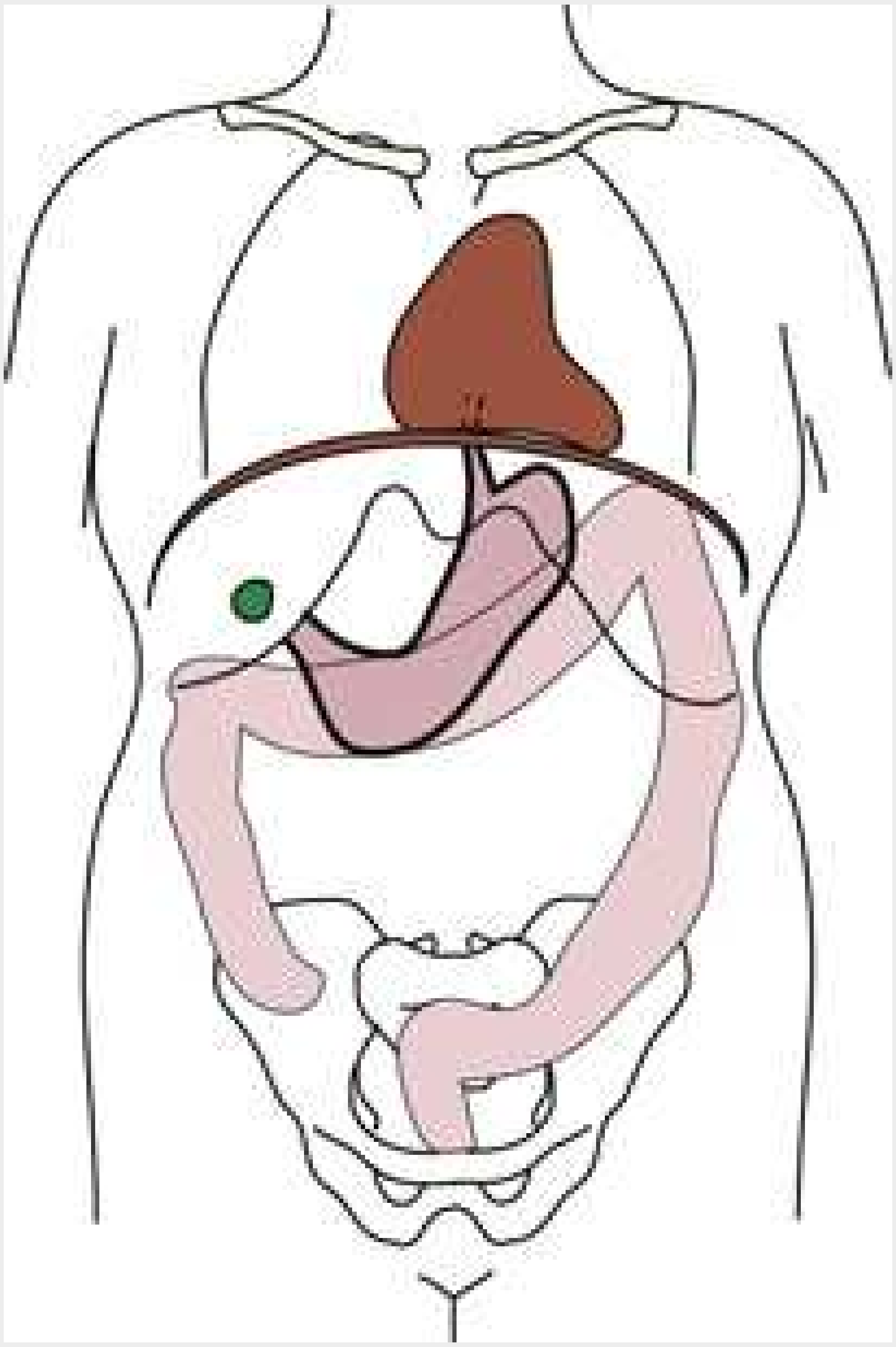
Hyposthenic, 35%



Organs and characteristics for this habitus are intermediate between sthenic and asthenic body habitus types; this habitus is the most difficult to classify.

Hypersthenic, 5%

Organs



Heart: Axis nearly transverse
Lungs: Short, apices at or near clavicles
Diaphragm: High
Stomach: High, transverse, and in the middle
Colon: Around periphery of abdomen
Gallbladder: High, outside, lies more parallel

Characteristics

Build: Massive
Abdomen: Long
Thorax: Short, broad, deep
Pelvis: Narrow

Note the significant differences between the two extreme habitus types (i.e., asthenic and hypersthenic). The differences between sthenic and hyposthenic types are less distinct.

Radiographers must also become familiar with the two extreme habitus types: *asthenic* and *hypersthenic*. In these two small groups (15% of the population), placement and size of the organs significantly affect positioning and the selection of exposure factors. Consequently, radiography of these patients can be challenging. Experience and professional judgment enable the radiographer to determine the correct body habitus and to judge the specific location of the organs.

Body habitus is not an indication of disease or other abnormality, and it is not determined by body fat or by the physical condition of the patient. Habitus is simply a classification of the four general shapes of the *trunk* of the human body. When positioning patients, the radiographer should be conscious that habitus is not associated with height or weight. Four patients of equal height could have four different trunk shapes (Fig. 2.10).

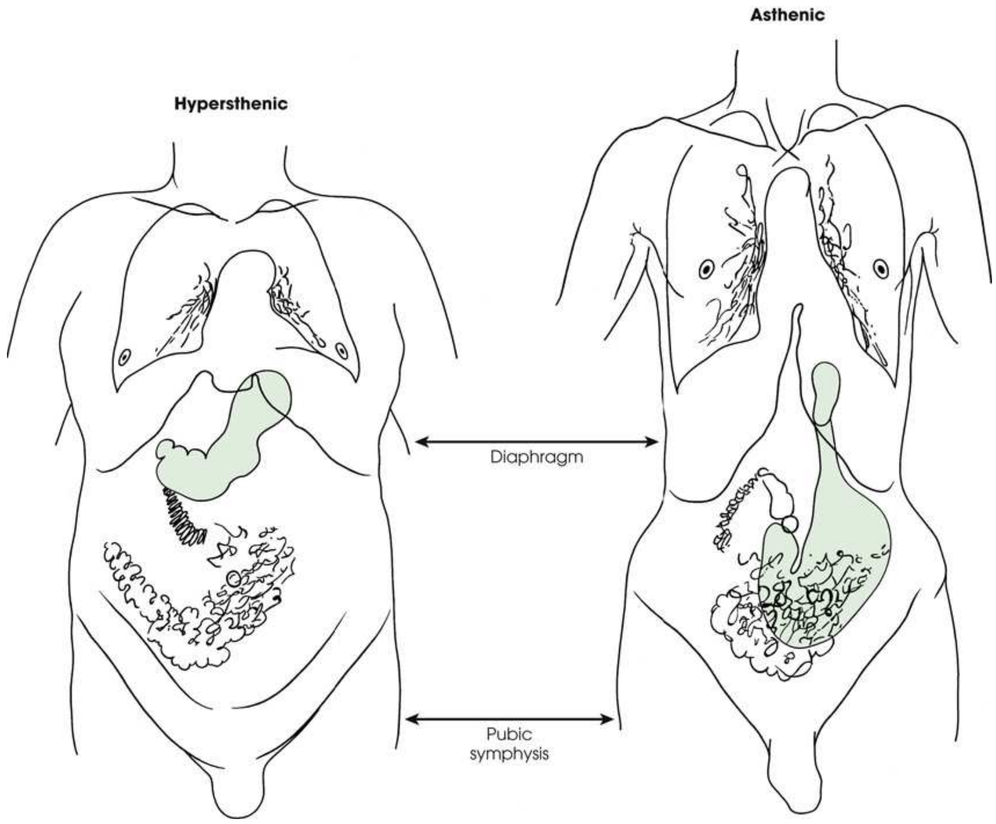


FIG. 2.10 Different trunks are shown for asthenic and hypersthenic habitus, the two extremes. The abdomen is the same length in both patients (diaphragm-to-pubic symphysis). The abdominal organs are in completely different positions. Note high stomach in hypersthenic habitus *(green color)* and low stomach in asthenic habitus. Art is based on actual autopsy findings by R. Walter Mills, MD.

Diagram shows an anterior view of a human body titled hypersthenic on the left and an anterior view of a human body titled asthenic on the right. The abdominal organs are in completely different positions. The diaphragm and the pubic symphysis are the same lengths in both patients. The stomach is shaded in green color. It is high in hypersthenic and low in asthenic.

Osteology

The adult human skeleton is composed of 206 primary bones. Ligaments unite the bones of the skeleton. Bones provide the following:

- Attachment for muscles
- Mechanical basis for movement
- Protection of internal organs
- A frame to support the body
- Storage for calcium, phosphorus, and other salts
- Production of red and white blood cells

The 206 bones of the body are divided into two main groups:

- Axial skeleton
- Appendicular skeleton

The axial skeleton supports and protects the head and trunk with 80 bones (see Table 2.2). The appendicular skeleton allows the body to move in various positions and from place to place with its 126 bones (Table 2.3). Fig. 2.11 identifies these two skeletal areas.

TABLE 2.2

[a] Auditory ossicles are small bones in the ears. They are not considered official bones of the axial skeleton but are placed here for convenience.

TABLE 2.3

Appendicular skeleton: 126 bones

Area	Bones	Number
Shoulder girdle	Clavicles	2
	Scapulae	2
Upper limbs	Humeri	2
	Ulnae	2
	Radii	2
	Carpals	16
	Metacarpals	10
	Phalanges	28
Lower limbs	Femora	2
	Tibias	2
	Fibulae	2
	Patellae	2
	Tarsals	14
	Metatarsals	10
	Phalanges	28
Pelvic girdle	Hip bones	2

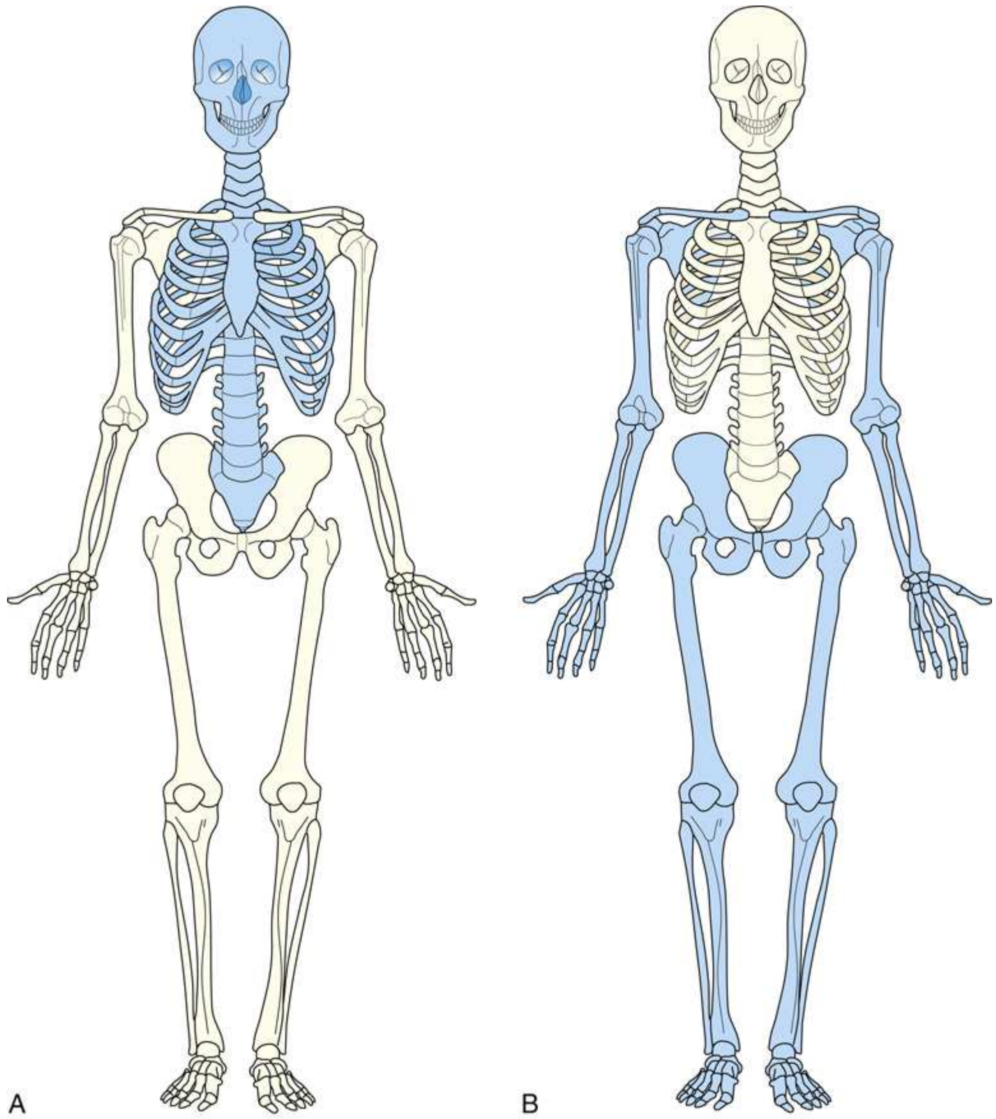


FIG. 2.11 Two main groups of bones. (A) Axial skeleton. (B) Appendicular skeleton.

(A) shows a skeletal view of the human body. The skull, neck, thorax, and vertebral column are highlighted in blue. (B) shows the skeletal view of the human body. The shoulder girdle, upper limbs, lower limbs, and pelvic girdle are highlighted in blue.

General Bone Features

The general features of most bones are shown in Fig. 2.12. All bones are composed of a strong, dense outer layer called the *compact bone* and an inner portion of less dense *spongy bone*. The hard outer compact bone protects the bone and gives it strength for supporting the body. The softer spongy bone contains a spiculated network of interconnecting spaces called the *trabeculae* (Fig. 2.13). The trabeculae are filled with red and yellow marrow. Red marrow produces red and white blood cells, and yellow marrow stores adipose (fat) cells. Long bones have a central cavity called the *medullary cavity,* which contains trabeculae filled with yellow marrow. In long bones, the red marrow is concentrated at the ends of the bone and not in the medullary cavity.

A tough, fibrous connective tissue called the *periosteum* covers all bony surfaces except the articular surfaces, which are covered by the articular cartilage. The tissue lining the medullary cavity of bones is called the *endosteum*. Bones contain various knob-like projections called *tubercles* and *tuberosities,* which are covered by the periosteum. Muscles, tendons, and ligaments attach to the periosteum at these projections. Blood vessels and nerves enter and exit the bone through the periosteum.

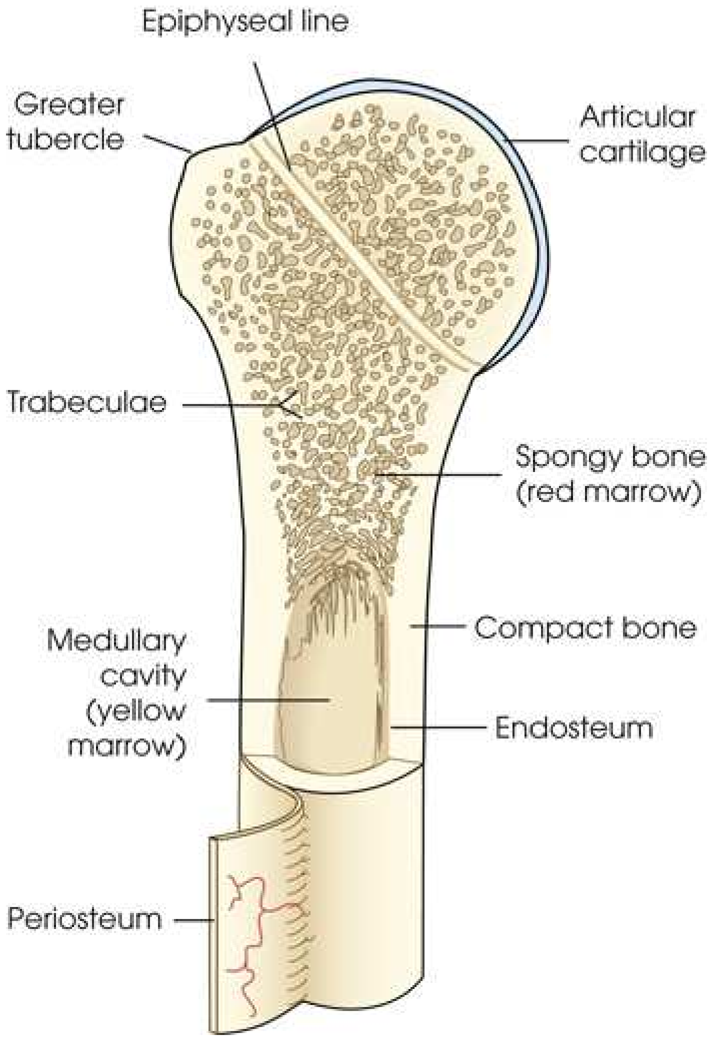


FIG. 2.12 General bone features and anatomic parts.

The general features of the bones are labeled as follows: epiphyseal line, articular cartilage, spongy bone (red marrow), compact bone, endosteum, greater tubercle, trabeculae, medullary cavity (yellow marrow), and periosteum. The trabeculae are filled with red and yellow marrow. The medullary cavity contains trabeculae filled with yellow marrow.

FIG. 2.13 Radiograph of distal femur and condyles showing bony trabeculae within entire bone.

Bone Vessels and Nerves

Bones are live organs that must receive a blood supply for nourishment or they die. Bones also contain a supply of nerves. Blood vessels and nerves enter and exit the bone at the same point, through openings called the *foramina*. Near the center of all long bones is an opening in the periosteum called the *nutrient foramen*. The nutrient artery of the bone passes into this opening and supplies the cancellous bone and marrow. The epiphyseal artery separately enters the ends of long bones to supply the area, and periosteal arteries enter at numerous points to supply the compact bone. Veins exiting the bones carry blood cells to the body (Fig. 2.14).

Bone Development

Ossification is the term given to the development and formation of bones. Bones begin to develop in the second month of embryonic life. Ossification occurs separately by two distinct processes: *intermembranous ossification* and *endochondral ossification*.

Intermembranous ossification

Bones that develop from fibrous membranes in the embryo produce the flat bones—bones of the skull, clavicles, mandible, and sternum. Before birth, these bones are not joined. As flat bones grow after birth, they join and form sutures. Other bones in this category merge and create the various *joints* of the skeleton.

Endochondral ossification

Bones created by endochondral ossification develop from hyaline cartilage in the embryo and produce short, irregular, and long bones. Endochondral ossification occurs from two distinct centers of development called *primary* and *secondary centers of ossification*.

Primary ossification

Primary ossification begins before birth and forms the entire bulk of the short and irregular bones. This process forms the long central shaft in long bones. During development only, the long shaft of the bone is called the *diaphysis* (Fig. 2.15A).

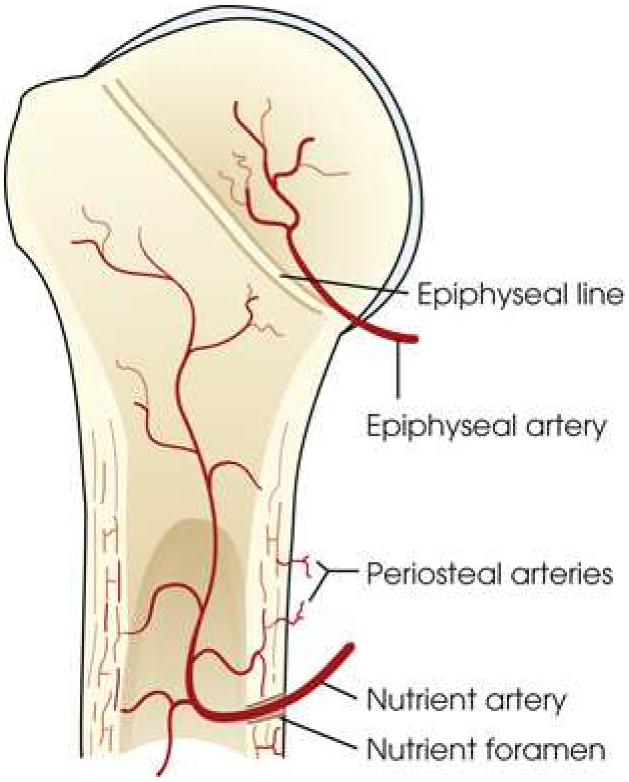


FIG. 2.14 Long bone end showing its rich arterial supply. Arteries, veins, and nerves enter and exit bone at the same point.

Diagram shows the veins in the long bone. The parts labeled are as follows: epiphyseal line, epiphyseal artery, periosteal arteries, nutrient artery, and nutrient foramen. The epiphyseal artery separately enters the ends of long bones. The periosteal arteries enter at numerous points.

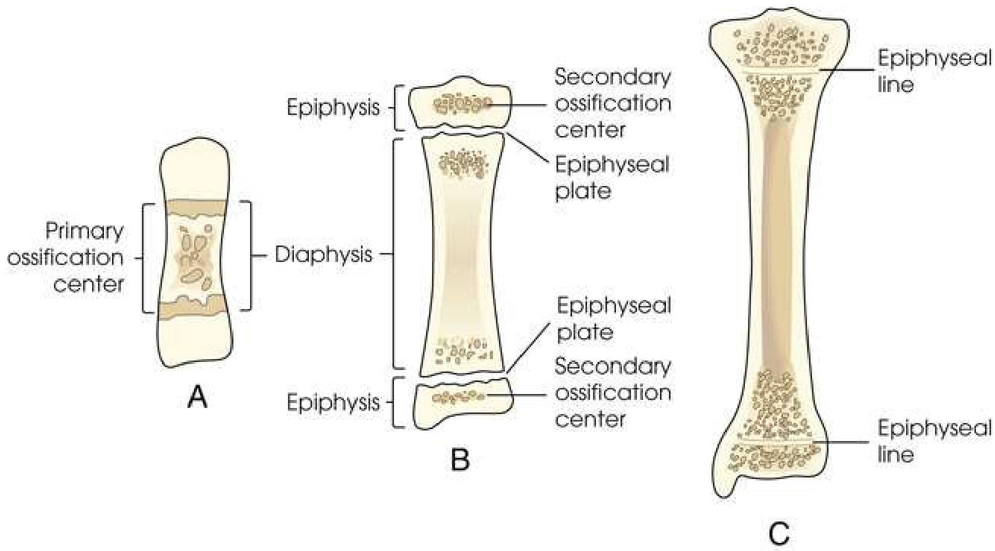


FIG. 2.15 Primary and secondary ossification of bone. (A) Primary ossification of tibia before birth. (B) Secondary ossification, which forms two *epiphyses* after birth. (C) Full growth into single bone, which occurs by age 21 years.

Diagram (A) shows a short central shaft. The parts labeled are the primary ossification center and the diaphysis. Irregular circular patches are between two horizontal lines. Diagram (B) shows a shaft of a bone and the secondary ossification center on the top and the bottom. The parts labeled on the left are epiphysis, diaphysis, and epiphysis. The parts labeled on the right side are the secondary ossification center, epiphyseal plate, epiphyseal plate, and secondary ossification center. A separate bone begins to develop at both ends of each long bone. Diagram (Co shows a plate of cartilage called the epiphyseal plate develops between the two areas. The parts labeled are the epiphyseal line on top and the epiphyseal line at the bottom. It divides the ends of the epi[hysis into two parts.

Secondary ossification

Secondary ossification occurs after birth when a separate bone begins to develop at both ends of each long bone. Each end is called the *epiphysis* (see Fig. 2.15B). At first, the diaphysis and the epiphysis are distinctly separate. As growth occurs, a plate of cartilage called the *epiphyseal plate* develops between the two areas (see Fig. 2.15C). This plate is seen on long bone radiographs of all pediatric patients (Fig. 2.16A). The epiphyseal plate is important radiographically because it is a common site of fractures in pediatric patients. Near age 21 years, full ossification occurs, and the two areas become completely joined; only a moderately visible *epiphyseal line* appears on the bone (see Fig. 2.16B).

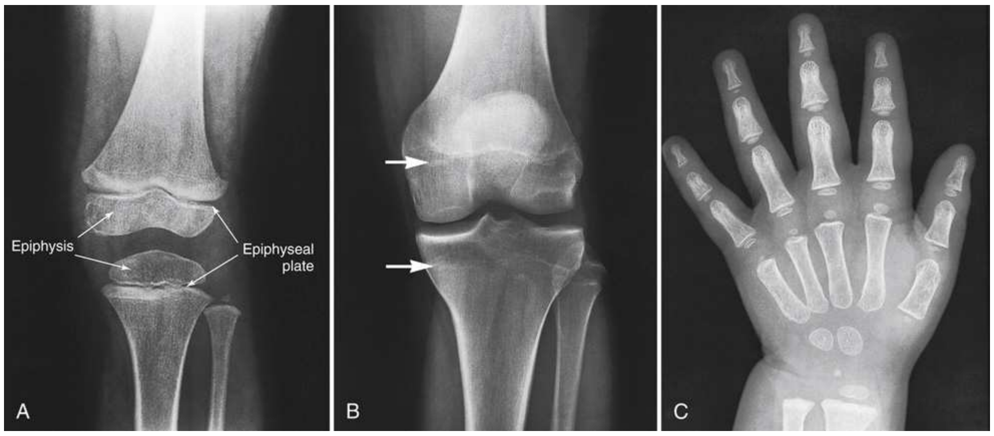


FIG. 2.16 (A) Radiograph of a 6-year-old child. Epiphysis and epiphyseal plate shown on knee radiograph *(arrows)*. (B) Radiograph of same area in a 21-year-old adult. Full ossification has occurred, and only subtle epiphyseal lines are seen *(arrows)*. (C) PA radiograph of hand of a 2½-year-old child. Note early stages of ossification in epiphyses at proximal ends of phalanges and first metacarpal, distal ends of other metacarpals, and radius. C, From Standring S. *Gray's Anatomy*. 40th ed. New York: Churchill Livingstone; 2009.

(A) An x-ray shows the knee joint. The epiphysis and the epiphysial plate are clearly visible. There are open intraarticular joint spaces. (B) An x-ray shows the knee joint. The epiphysial lines are slightly visible. They appear white. Two white arrows point at the lines. (C) An x-ray shows a hand. There are gaps between the proximal ends of phalanges and first metacarpal, distal ends of other metacarpals, and radius.

Classification of Bones

Bones are classified by shape, as follows (Fig. 2.17):

- Long
- Short
- Flat
- Irregular
- Sesamoid

Long bones

Long bones are found only in the limbs. They consist primarily of a long cylindric shaft called the *body* and two enlarged, rounded ends that contain a smooth, slippery articular surface. A layer of articular cartilage covers this surface. The ends of these bones all articulate with other long bones. The femur and the humerus are typical long bones. The phalanges of the fingers and toes are also considered long bones. A primary function of long bones is to provide support.

Short bones

Short bones consist mainly of cancellous bone containing red marrow and have a thin outer layer of compact bone. The carpal bones of the wrist and the tarsal bones of the ankles are the only short bones. They are varied in shape and allow minimum flexibility of motion in a short distance.

Flat bones

Flat bones consist largely of two tables of compact bone. The narrow space between the inner and outer tables contains cancellous bone and red marrow, or *diploë,* as it is called in flat bones. The bones of the cranium, sternum, and scapula are examples of flat bones. The flat surfaces of these bones provide protection, and their broad surfaces allow muscle attachment.

Irregular bones

Irregular bones are so termed because their peculiar shapes and variety of forms do not place them in any other category. The vertebrae and the bones in the pelvis and face fall into this category. Similar to other bones, they have compact bone on the exterior and cancellous bone containing red marrow in the interior. Their shape serves many functions, including attachment for muscles, tendons, and ligaments, or they attach to other bones to create joints.

Sesamoid bones

Sesamoid bones are small and oval. They develop inside and beside tendons. Their precise role is not understood. Experts believe that they alter the direction of muscle pull and decrease friction. The largest sesamoid bone is the patella, or the kneecap. Other sesamoids are located beneath the first metatarsophalangeal articulation of the foot and on the palmar aspect of the thumb at the metacarpophalangeal joint of the hand. Two small but prominent sesamoids are located beneath the base of the large toe. Similar to all other bones, they can be fractured.

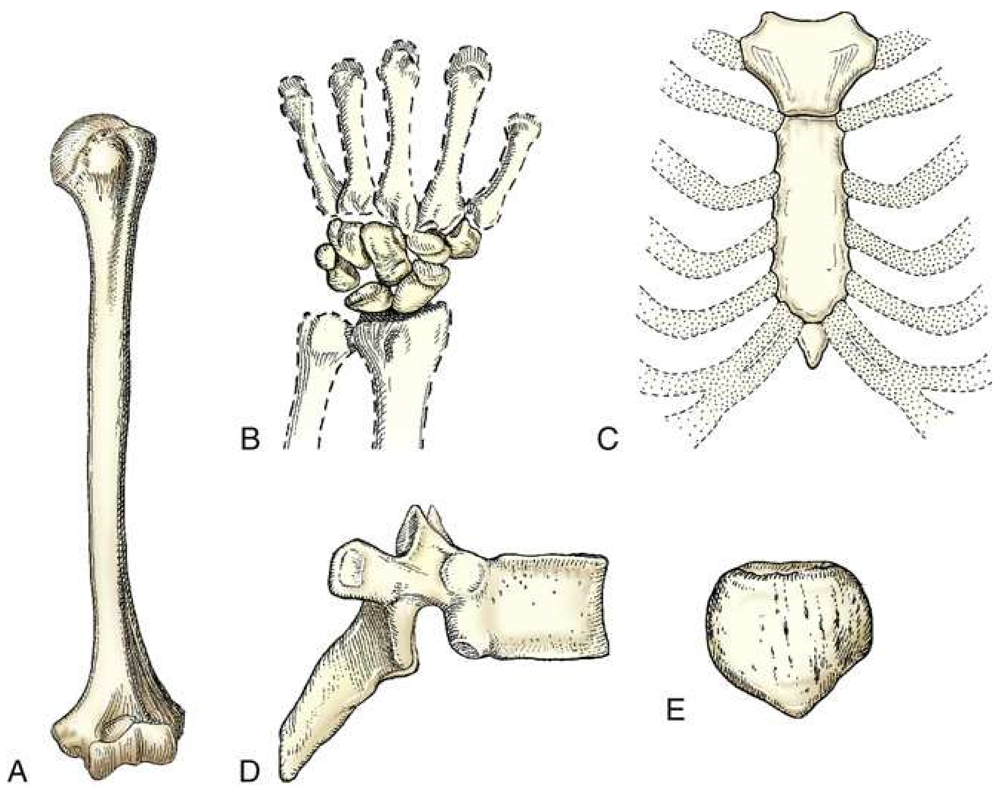


FIG. 2.17 Bones are classified by shape. (A) Humerus is a long bone. (B) Carpals of the wrist are short bones. (C) Sternum is a flat bone. (D) Vertebra is an irregular bone. (E) Patella is a sesamoid bone.

Diagram (A) shows a long, narrow, and cylindrical bone. Diagram (B) shows cancellous bones. They are varied in shape. Diagram (C) shows the flat bone called sternum in the middle and the ribs rise from it. Diagram (D) shows an irregularly shaped bone. Diagram (E) shows a small and oval-shaped bone.

TABLE 2.4

Arthrology

Arthrology is the study of the joints, or articulations between bones. Joints make it possible for bones to support the body, protect internal organs, and create movement. Various specialized articulations are necessary for these functions to occur.

The two classifications of joints described in anatomy books are *functional* and *structural*. Studying both classifications can be confusing. The most widely used and primary classification is the structural classification, which is used to describe all the joints in this atlas. This is also the classification recognized by *Nomina Anatomica*. For academic interest, a brief description of the functional classification is provided.

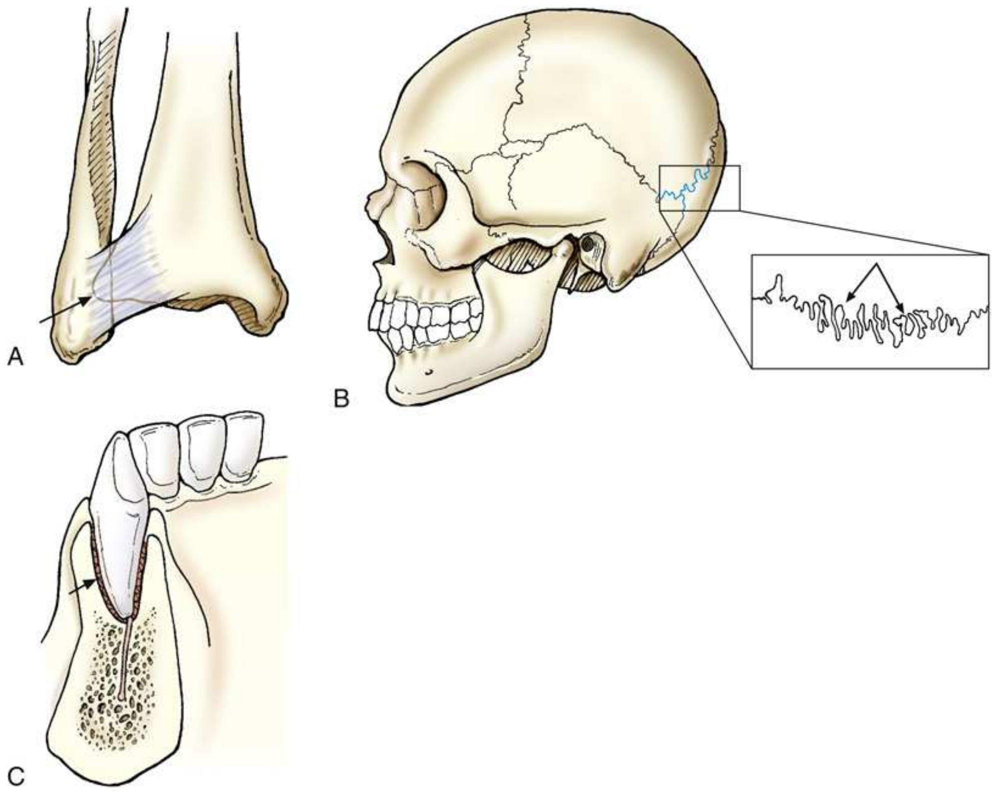


FIG. 2.18 Examples of three types of fibrous joints. (A) *Syndesmosis:* Inferior tibiofibular joint. (B) *Suture:* Sutures of skull. (C) *Gomphosis:* Roots of teeth in alveolus.

Diagram (A) shows inferior tibiofibular joint. The sheets of fibrous tissue are highlighted and are marked by an arrow. Diagram (B) shows the lateral view of the skull. The sutures are highlighted. An enlarged image shows the sutures of the skull. Diagram (C) shows the roots of teeth in the alveolus. The fibrous periodontal ligaments underlying the tooth are highlighted. The alveolus appears grainy.

Functional Classification

When joints are classified as functional, they are broken down into three classifications. These classifications are based on the mobility of the joint, as follows:

- Synarthroses—immovable joints
- Amphiarthroses—slightly movable
- Diarthroses—freely movable

Structural Classification

The structural classification of joints is based on the types of tissues that unite or bind the articulating bones. A thorough study of this classification is easier if radiographers first become familiar with the terminology and breakdown of the structural classification identified in Table 2.4.

Structurally, joints are classified into three distinct groups on the basis of their connective tissues: fibrous, cartilaginous, and synovial. Within these three broad categories are the 11 specific types of joints. They are numbered in the text for easy reference to Table 2.4.

Fibrous joints

Fibrous joints do not have a joint cavity. They are united by various fibrous and connective tissues or ligaments. These are the strongest joints in the body because they are virtually immovable. The three types of fibrous joints are as follows:

1. *Syndesmosis:* An immovable joint or slightly movable joint united by sheets of fibrous tissue. The inferior tibiofibular joint is an example (Fig. 2.18A).
2. *Suture:* An immovable joint occurring only in the skull. In this joint, the interlocking bones are held tightly together by strong connective tissues. The sutures of the skull are an example (see Fig. 2.18B).
3. *Gomphosis:* An immovable joint occurring only in the roots of the teeth. The roots of the teeth that lie in the alveolar sockets are held in place by fibrous periodontal ligaments (see Fig. 2.18C).

Cartilaginous joints

Cartilaginous joints are similar to fibrous joints in two ways: (1) They do not have a joint cavity, and (2) they are virtually immovable. Hyaline cartilage or fibrocartilage unites these joints. The two types of cartilaginous joints are as follows:

4. *Symphysis:* A slightly movable joint. The bones in this joint are separated by a pad of fibrocartilage. The ends of the bones contain hyaline cartilage. A symphysis joint is designed for strength and shock absorbency. The joint between the two pubic bones (pubic

symphysis) is an example of a symphysis joint (Fig. 2.19A). Another example of a symphysis joint is the joint between each vertebral body. These joints all contain a fibrocartilaginous pad or disk.

5. *Synchondrosis:* An immovable joint. This joint contains a rigid cartilage that unites two bones. An example is the epiphyseal plate found between the epiphysis and diaphysis of a growing long bone (see Fig. 2.19B). Before adulthood, these joints consist of rigid hyaline cartilage that unites two bones. When growth stops, the cartilage ossifies, making this type of joint a temporary joint.

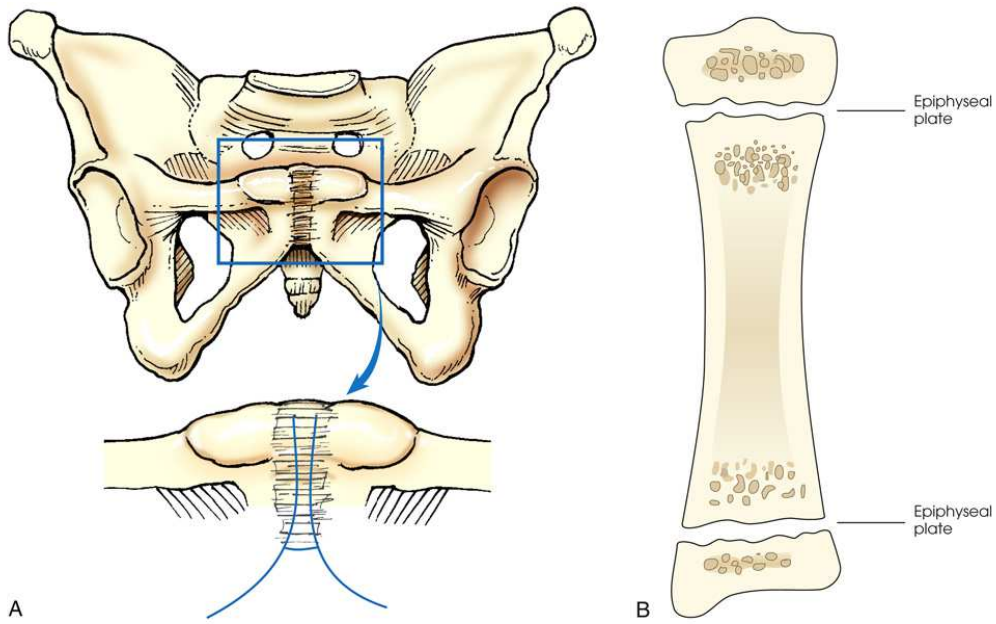


FIG. 2.19 Examples of two types of cartilaginous joints. (A) *Symphysis:* Pubic symphysis. (B) *Synchondrosis:* Epiphyseal plate found between epiphysis and diaphysis of growing long bones.

Diagram (A) shows the pubic symphysis highlighted on the pubic bones. An enlarged image below shows the pubic symphysis marked by two blue curves. Diagram (B) shows the epiphyseal plate found between epiphysis and diaphysis of a bone. They are granulated at the ends.

Synovial joints

Synovial joints permit a wide range of motion, and they all are freely movable. These joints are the most complex joints in the body. Fig. 2.20 shows their distinguishing features.

An articular capsule completely surrounds and enfolds all synovial joints to join the separate bones together. The outer layer of the capsule is called the *fibrous capsule,* and its fibrous tissue connects the capsule to the periosteum of the two bones. The *synovial membrane,* which is the inner layer, surrounds the entire joint to create the joint cavity. The membrane produces a thick, yellow, viscous fluid called *synovial fluid*. Synovial fluid lubricates the joint space to reduce friction between the bones. The ends of the adjacent bones are covered with articular cartilage. This smooth and slippery cartilage permits ease of motion. The two cartilages do not actually touch because they are separated by a thin layer of synovial membrane and fluid.

Some synovial joints contain a pad of fibrocartilage called the *meniscus,* which surrounds the joint. Specific menisci intrude into the joint from the capsular wall. They act as shock absorbers by conforming to and filling in the large gaps around the periphery of the bones. Some synovial joints also contain synovial fluid-filled sacs outside the main joint cavity, which are called the *bursae*. Bursae help to reduce friction between skin and bones, tendons and bones, and muscles and bones. Menisci, bursae, and other joint structures can be visualized radiographically by injecting iodine-based contrast medium and/or air directly into the synovial cavity. This procedure, called *arthrography,* is detailed in Chapter 13.

The six synovial joints complete the 11 types of joints within the structural classification. They are listed in order of increasing movement. The most common name of each joint is identified, and the less frequently used name is given in parentheses.

6. *Gliding (plane):* Uniaxial movement. This is the simplest synovial joint. Joints of this type permit slight movement. They have flattened or slightly curved surfaces, and most glide slightly in only one axis. The intercarpal and intertarsal joints of the wrist and foot are examples of gliding joints (Fig. 2.21A).
7. *Hinge (ginglymus):* Uniaxial movement. A hinge joint permits only flexion and extension. The motion is similar to that of a door. The elbow, knee, and ankle are examples of this type of joint (see Fig. 2.21B).
8. *Pivot (trochoid):* Uniaxial movement. These joints allow only rotation around a single axis. A rounded or pointed surface of one bone articulates within a ring formed partially by the other bone. An example of this joint is the articulation of the atlas and axis of the cervical spine. The atlas rotates around the dens of the axis and allows the head to rotate to either side (see Fig. 2.21C).
9. *Ellipsoid (condyloid):* Biaxial movement, primary. An ellipsoid joint permits movement in two directions at right angles to each other. The radiocarpal joint of the wrist is an example. Flexion and extension occur along with abduction and adduction. Circumduction, a combination of both movements, can also occur (see Fig. 2.21D).
10. *Saddle (sellar):* Biaxial movement. This joint permits movement in two axes, similar to the ellipsoid joint. The joint is so named because the articular surface of one bone is saddle shaped and the articular surface of the other bone is shaped like a rider sitting in a saddle. The two saddle-like structures fit into each other. The carpometacarpal joint between the trapezium and the first metacarpal is the

only saddle joint in the body. The face of each bone end has a concave and a convex aspect. The opposing bones are shaped in a manner that allows side-to-side and up-and-down movement (see Fig. 2.21E).

11. *Ball and socket (spheroid):* Multiaxial movement. This joint permits movement in many axes, including flexion and extension, abduction and adduction, circumduction, and rotation. In a ball-and-socket joint, the round head of one bone rests within the cup-shaped depression of the other bone. The hip and the shoulder are examples (see Fig. 2.21F).

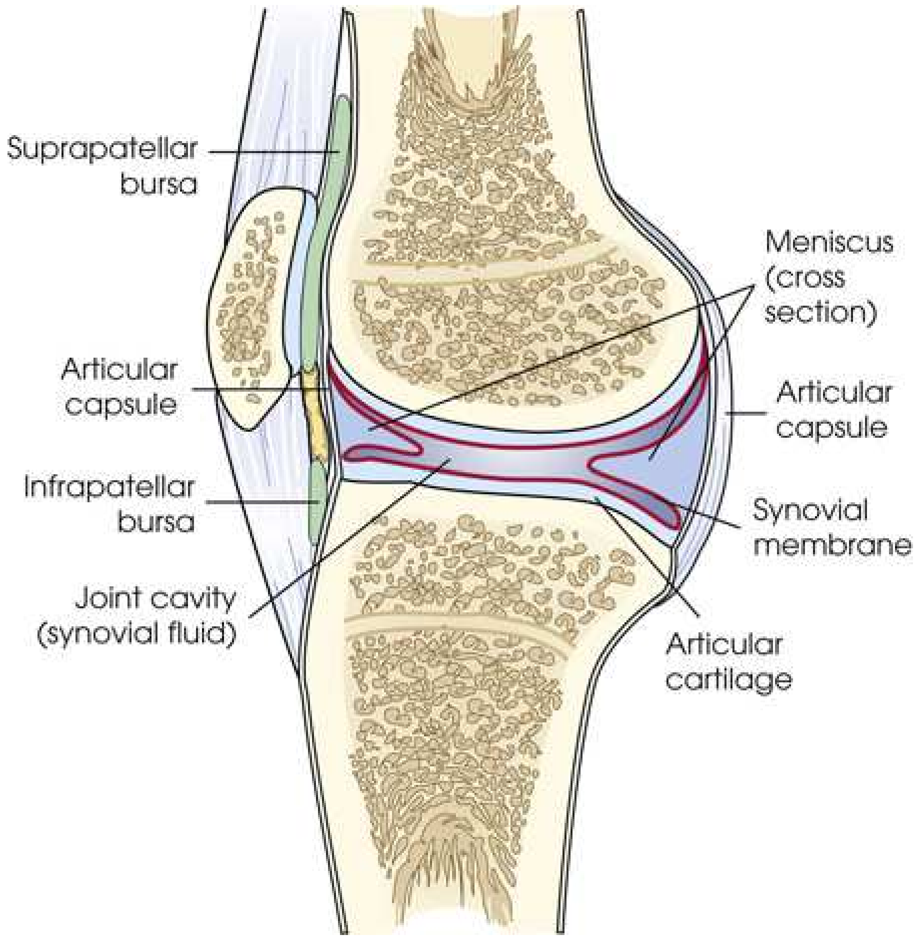


FIG. 2.20 Lateral cutaway view of knee showing distinguishing features of a synovial joint.

A cross-sectional diagram of bone shows labels marked from top to bottom as follows: suprapatellar bursa, articular capsule, infrapatellar bursa, joint cavity (synovial fluid), meniscus (cross-section), articular capsule, synovial membrane, and articular cartilage.

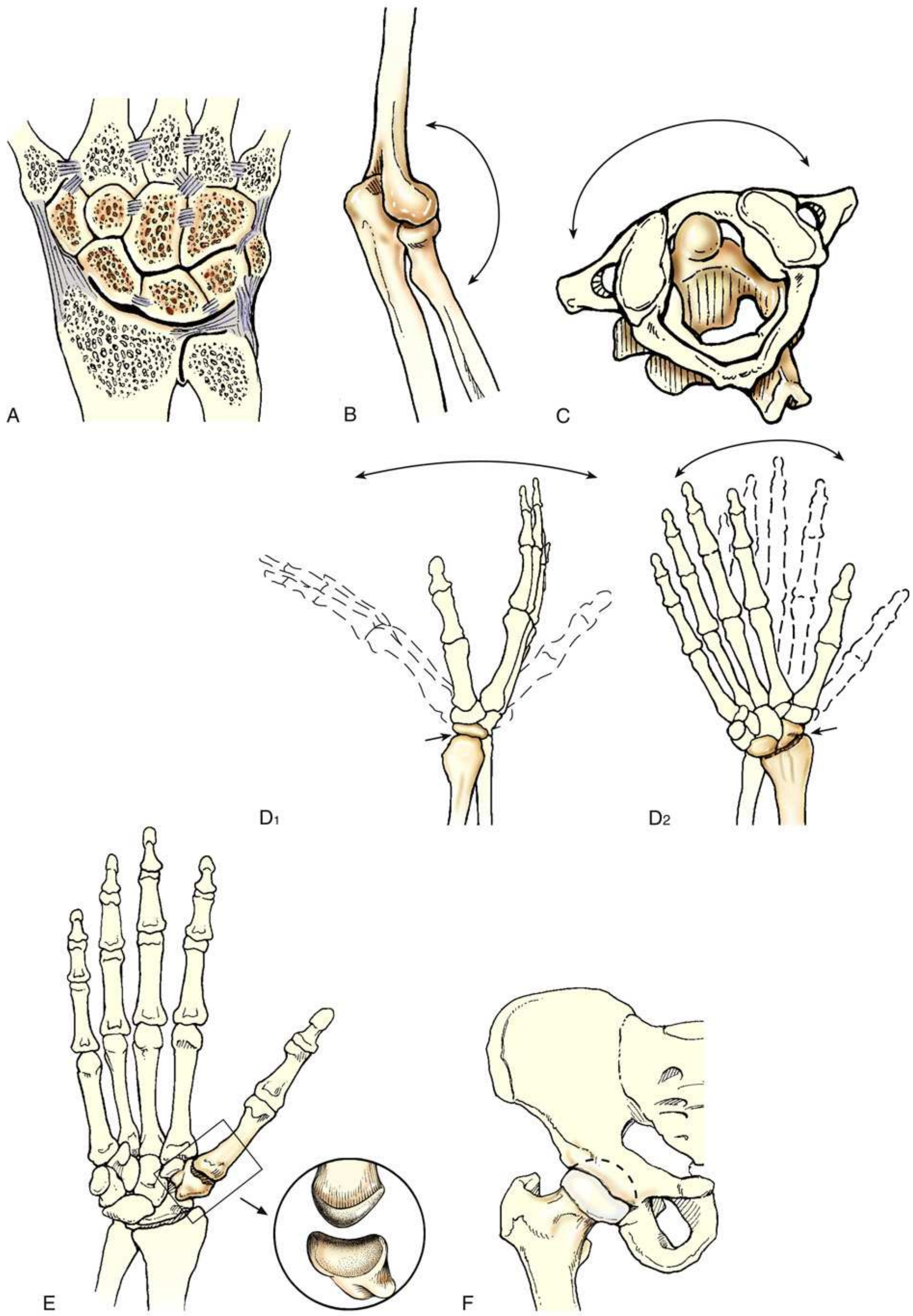


FIG. 2.21 Examples of six types of synovial joints. (A) *Gliding:* Intercarpal joints of wrist. (B) *Hinge:* Elbow joint. (C) *Pivot:* Atlas and axis of cervical spine (viewed from above). (D) *Ellipsoid:* Radiocarpal joint of wrist. (E) *Saddle:* Carpometacarpal joint. (F) *Ball and socket:* Hip joint.

Diagram (A) shows the Intercarpal joints of the wrist. The carpals have yellow granules on them. The cartilages are shaded. Diagram (B) shows the elbow joint. An arrow indicates flexion and extension. Diagram (C) shows the top view of the atlas and axis of the cervical spine. An arrow points at the ends projecting at the ends. Diagram (D 1, D 2) shows joints of the wrist. An arrow indicates movement in two directions at right angles to each other. Diagram (E) shows the carpometacarpal joint. The face of each bone end has a concave and a convex aspect. An enlarged image of the carpometacarpal joint shows a gap between the two ends. Diagram (F) shows the hip joint. The ball and socket area is highlighted using a dashed line.

Bone Markings and Features

The following anatomic terms are used to describe either processes or depressions on bones.

Processes or Projections

Processes or projections extend beyond or project out from the main body of a bone and are designated by the following terms:

condyle—rounded process at an articular extremity

coracoid or coronoid—beak-like or crown-like process
crest—ridge-like process
epicondyle—projection above a condyle
facet—small, smooth-surfaced process for articulation with another structure
hamulus—hook-shaped process
head—expanded end of a long bone
horn—horn-like process on a bone
line—less prominent ridge than a crest; a linear elevation
malleolus—club-shaped process
protuberance—projecting part or prominence
spine—sharp process
styloid—long, pointed process
trochanter—either of two large, rounded, and elevated processes (greater or major and lesser or minor) located at junction of neck and shaft of femur
tubercle—small, rounded, and elevated process
tuberosity—large, rounded, and elevated process

Depressions

Depressions are hollow or depressed areas and are described by the following terms:

fissure—cleft or deep groove
foramen—hole in a bone for transmission of blood vessels and nerves
fossa—pit, fovea, or hollow space
groove—shallow linear channel
meatus—tube-like passageway running within a bone
notch—indentation into border of a bone
sinus—recess, groove, cavity, or hollow space, such as (1) recess or groove in bone, as used to designate a channel for venous blood on inner surface of cranium; (2) air cavity in bone or hollow space in other tissue (used to designate a hollow space within a bone, as in paranasal sinuses); or (3) fistula or suppurating channel in soft tissues
sulcus—furrow, trench, or fissure-like depression

Fractures

A fracture is a break in the bone. Fractures are classified according to the nature of the break. Several general terms can pertain to them:

closed—fracture that does not break through the skin
displaced—serious fracture in which bones are not in anatomic alignment
nondisplaced—fracture in which bone retains its normal alignment
open—serious fracture in which broken bone or bones project through the skin

Common classifications of fractures are listed as follows and identified in Fig. 2.22:

- Compression
- Open or compound
- Simple
- Greenstick
- Transverse
- Spiral or oblique
- Comminuted
- Impacted

Many fractures fall into more than one category. A fracture could be spiral, closed, *and* nondisplaced.

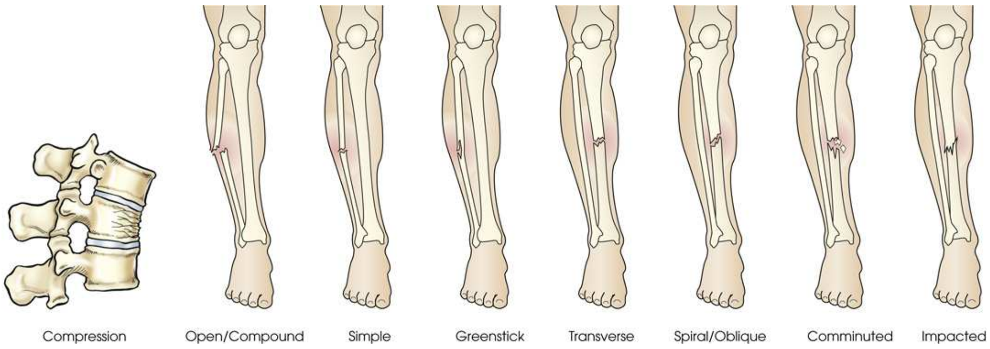


FIG. 2.22 Common classifications of fractures.

Eight diagrams show the classification of the fractures. The first diagram shows compression between the vertebral column. The second diagram shows a leg with an open or compound fracture. A fragment of bone breaking through the skin. The third diagram shows a leg with a simple fracture. A fracture of the bone only, without damage to the surrounding tissue. The fourth diagram shows a leg with a greenstick fracture. There is a crack or break on one side of a long bone. The fifth diagram shows a leg with a transverse fracture. The bone breaks at a 90-degree angle to the long axis. The sixth diagram shows a leg with a spiral or oblique fracture. The break has a curved or sloped pattern. The seventh diagram shows a leg with a comminuted fracture. There is a break in the bone into more than two fragments. The eighth diagram shows a leg with an impacted fracture. The fracture shows bone fragments driven into each other.

Anatomic Relationship Terms

Various terms are used to describe the relationship of parts of the body in the anatomic position. Radiographers should be thoroughly familiar with these terms, which are commonly used in clinical practice. Most of the following positioning and anatomic terms are paired as opposites. Fig. 2.23 illustrates two commonly used sets of terms.

anterior (ventral) refers to forward or front part of body or forward part of an organ
posterior (dorsal) refers to back part of body or organ (however, note that the superior surface of the foot is referred to as the dorsal surface)
caudad refers to parts away from the head of the body
cephalad refers to parts toward the head of the body
inferior refers to nearer the feet or situated below
superior refers to nearer the head or situated above
central refers to middle area or main part of an organ
peripheral refers to parts at or near the surface, edge, or outside of another body part
contralateral refers to part or parts on opposite side of body
ipsilateral refers to part or parts on same side of body
lateral refers to parts away from median plane of body or away from the middle of another body part to the right or left
medial refers to parts toward median plane of body or toward the middle of another body part
deep refers to parts far from the surface
superficial refers to parts near skin or surface
distal refers to parts farthest from point of attachment, point of reference, origin, or beginning; away from center of body
proximal refers to parts nearer point of attachment, point of reference, origin, or beginning; toward center of body
external refers to parts outside an organ or on outside of body
internal refers to parts within or on the inside of an organ
parietal refers to the wall or lining of a body cavity
visceral refers to the covering of an organ
dorsum refers to the top or anterior surface of the foot or to the back or posterior surface of the hand
palmar refers to the palm of the hand
plantar refers to the sole of the foot

Radiographic Positioning Terminology

Radiography is the process of recording an image of a body part using one or more types of IRs (PSP plate, digital detector, or fluoroscopic image intensifier). The terminology used to position the patient and to obtain the radiograph was developed through convention. Attempts to analyze usage often led to confusion because the manner in which the terms are used does not follow one specific rule. During the preparation of this chapter, contact was maintained with the American Registry of Radiologic Technologists (ARRT) and the Canadian Association of Medical Radiation Technologists (CAMRT). The ARRT first distributed the "Standard Terminology for Positioning and Projection" in 1978 [2]; it has not been substantially revised since initial distribution. [3] Despite its title, the ARRT document did not actually define selected positioning terms. [4] Terms not defined by the ARRT are defined in this atlas.

Approval of Canadian positioning terminology is the responsibility of the CAMRT Radiography Council on Education. This council provided information used in the development of this chapter and clearly identified terminology differences between the United States and Canada. [5]

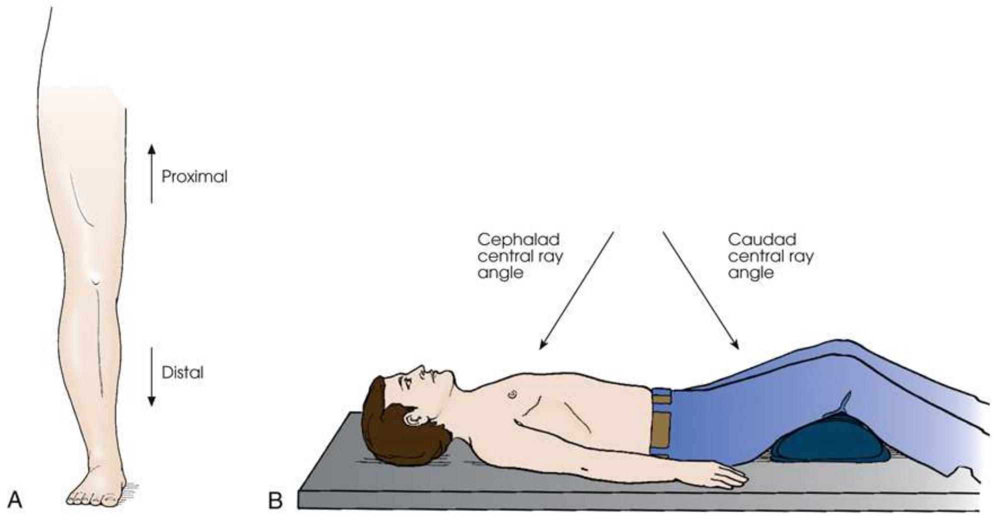


FIG. 2.23 (A) Use of common radiology terms *proximal* and *distal*. (B) Use of common radiology terms *caudad angle* and *cephalad angle*.

Diagram (A) shows the anterior surface of the leg. An arrow pointing upwards is labeled proximal and an arrow pointing downwards is labeled distal. Diagram (B) shows a patient lying on the radiographic table in a supine position. The legs are elevated by placing a pillow under the knee joints. His arms are placed along the sides of his body. An arrow pointing towards the chest is labeled as cephalad central ray angle and an arrow pointing towards the thighs is labeled as caudad central ray angle.

The terminology used by ARRT and CAMRT is consistent overall with that used in this atlas.

The following are the four positioning terms most commonly used in radiology:

- Projection
- Position
- View
- Method

Projection

The term *projection* is defined as the path of the central ray as it exits the x-ray tube and goes through the patient to the IR. Most projections are defined by entrance and exit points in the body and are based on the *anatomic position*. When the central ray enters anywhere in the front (anterior) surface of the body and exits the back (posterior), an *AP projection* is obtained. Regardless of which body position the patient is in (e.g., supine, prone, upright), if the central ray enters the anterior body surface and exits the posterior body surface, the projection is termed an *AP projection* (Fig. 2.24).

Projections can also be defined by the relationship formed between the central ray and the body as the central ray passes through the entire body or body part. Examples include *axial* and *tangential projections*.

All radiographic examinations described in this atlas are standardized and titled by their x-ray projection. The x-ray projection accurately and concisely defines each image produced in radiography. Table 2.5 provides a summary view of the most common radiographic projections linked to the body positions. The essential radiographic projections follow.

Anteroposterior projection

In Fig. 2.25, a perpendicular central ray enters the anterior body surface and exits the posterior body surface. This is an *AP projection*. The patient is shown in the supine or dorsal recumbent body position. AP projections can also be achieved with upright, seated, or lateral decubitus positions.

Posteroanterior projection

In Fig. 2.26, a perpendicular central ray is shown entering the posterior body surface and exiting the anterior body surface. This illustrates a *posteroanterior (PA) projection* with the patient in the upright body position. PA projections can also be achieved with seated, prone (ventral recumbent), and lateral decubitus positions.

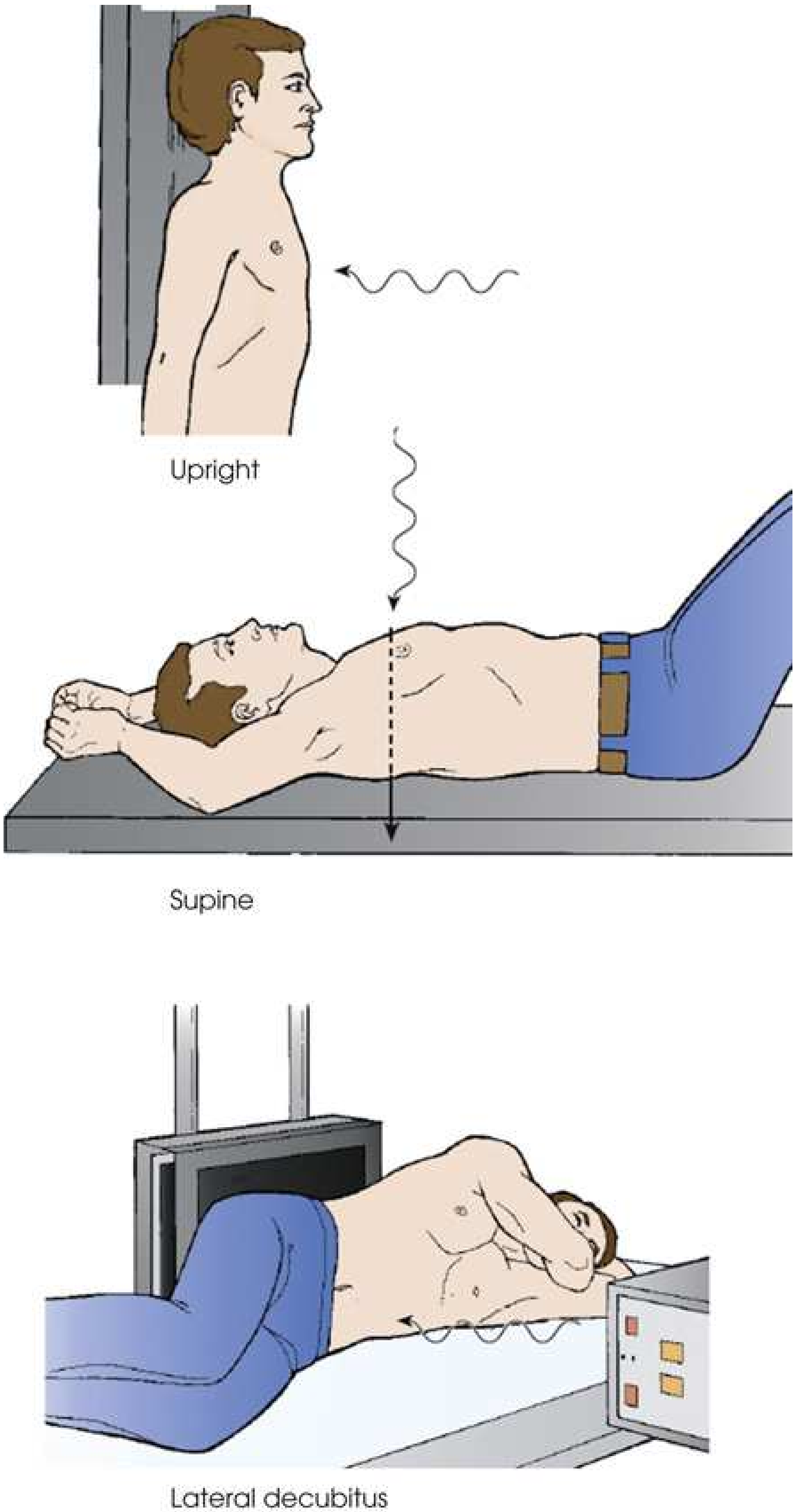


FIG. 2.24 All three body positions produce AP projections.

The first diagram shows a patient standing in an upright position against the radiographic table. The perpendicular C R enters the anterior surface. The second diagram shows a patient in a supine position on the radiographic table. The perpendicular C R enters the posterior surface. The third diagram shows a patient's lateral decubitus. A support is placed under the head. The perpendicular C R enters the lateral surface.

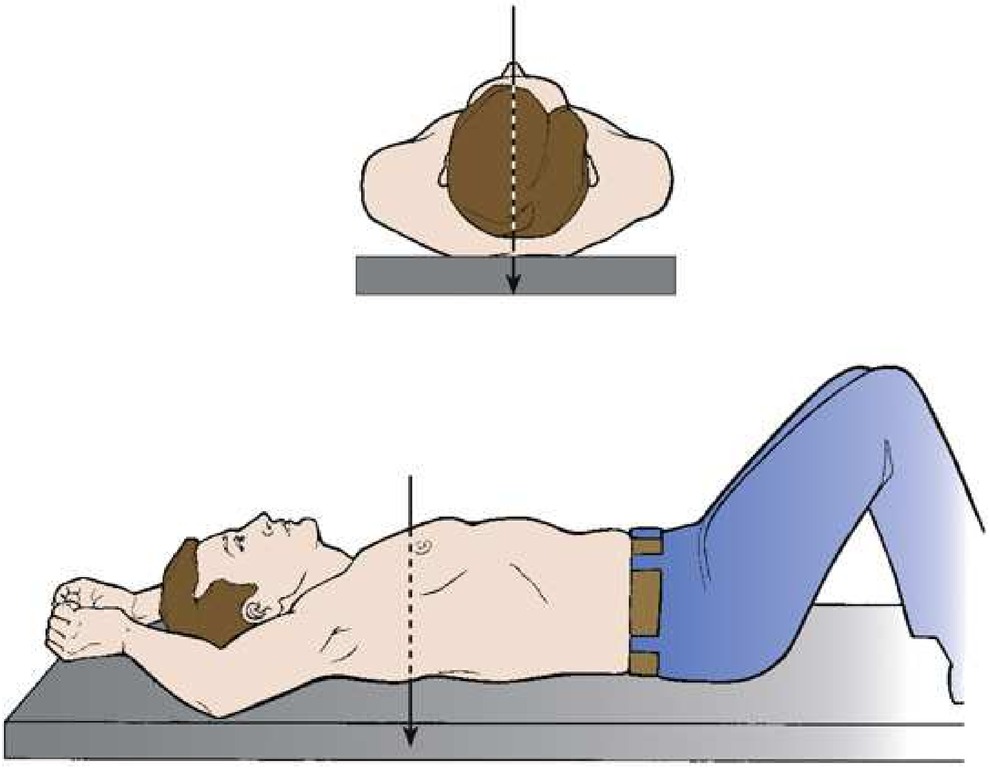


FIG. 2.25 AP projection of chest. Central ray enters anterior aspect and exits posterior aspect.

The first diagram shows the top view of a patient in a supine position on the radiographic table. The central ray enters the anterior aspect and exits posteriorly. The second diagram shows a patient in a supine position on the radiographic table. The central ray enters the anterior aspect and exits posteriorly.

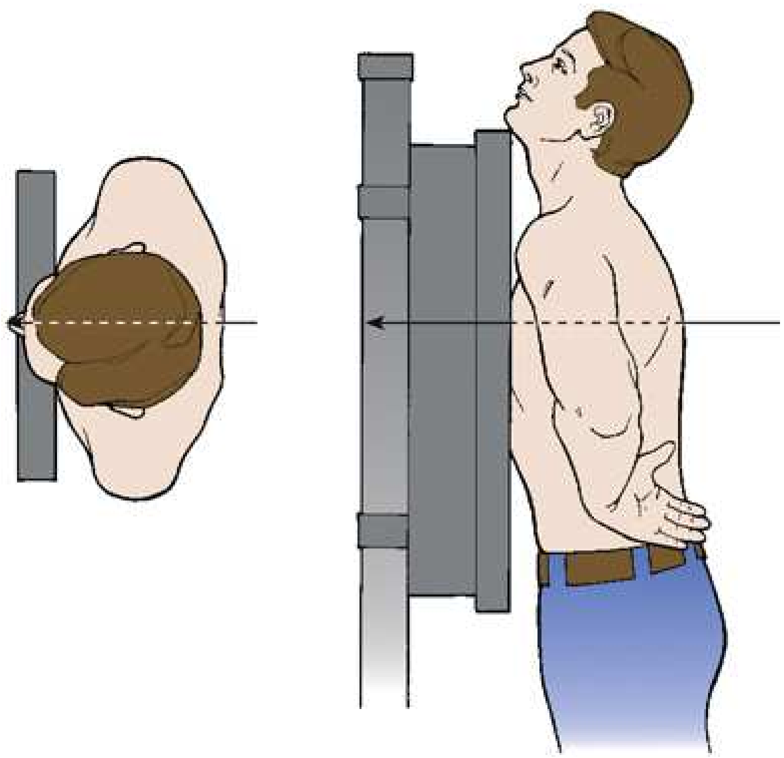


FIG. 2.26 PA projection of chest. Central ray enters posterior aspect and exits anterior aspect. Patient is in upright position.

The first diagram shows the top view of a patient standing with his chest against the I R. The central ray enters the anterior aspect and exits posteriorly. The second diagram shows a patient standing with his chest against the I R. The central ray enters the anterior aspect and exits posteriorly.

TABLE 2.5

Axial projection

In an axial projection (Fig. 2.27), there is *longitudinal angulation* of the central ray with the long axis of the body or a specific body part. This angulation is based on the anatomic position and is most often produced by angling the central ray cephalad or caudad. The longitudinal angulation in some examinations is achieved by angling the entire body or body part while maintaining the central ray perpendicular to the IR.

The term *axial,* as used in this atlas, refers to all projections in which the longitudinal angulation between the central ray and the long axis of the body part is *10 degrees or more*. When a range of central ray angles (e.g., 5 to 15 degrees) is recommended for a given projection, the term *axial* is used because the angulation could exceed 10 degrees. Axial projections are used in a wide variety of examinations and can be obtained with the patient in virtually any body position.

Tangential projection

Occasionally the central ray is directed toward the outer margin of a curved body surface to profile a body part just under the surface and project it free of superimposition. This is called a *tangential projection* because of the tangential relationship formed between the central ray and the entire body or body part (Fig. 2.28).

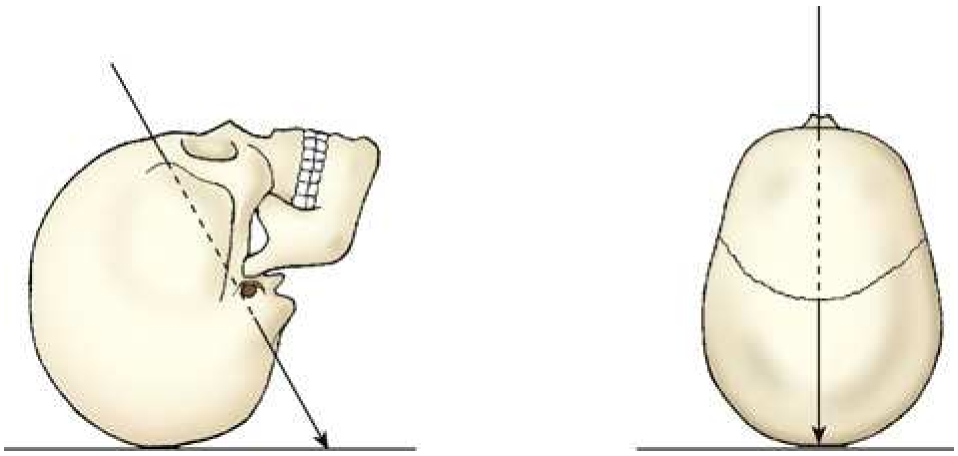


FIG. 2.27 AP axial projection of skull. Central ray enters anterior aspect at an angle and exits posterior aspect.

The first diagram shows a skull is on a plane with its anterior surface facing up. The central ray is angled 5 to 15 degrees enters the anterior aspect at an angle and exits the posterior aspect. The second diagram shows the top view of a skull on a plane. The central ray enters the anterior aspect at an angle and exits the posterior aspect.

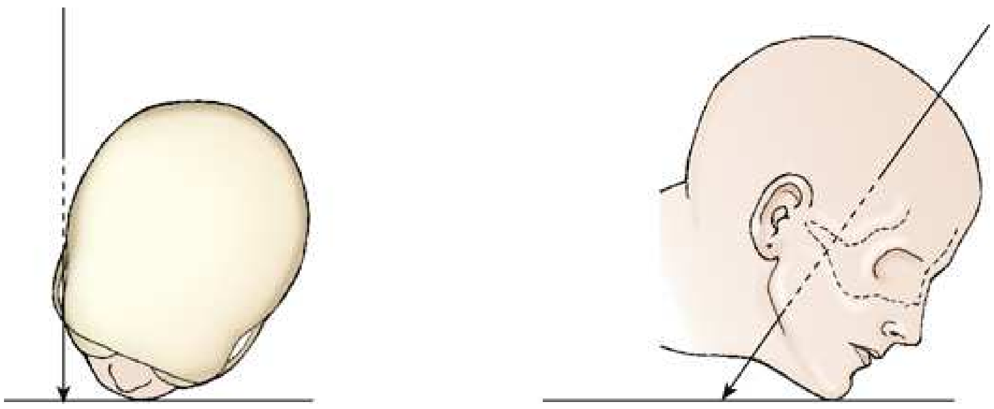


FIG. 2.28 Tangential projection of zygomatic arch. Central ray skims surface of the skull.

The first diagram shows the dorsal surface of a slight head on the plane. The central ray skims the surface of the skull. The second diagram shows the chin placed on the plane. The central ray is angled 5 to 15 degrees enters the anterior aspect at an angle and exits the posterior aspect.

Lateral projection

For a lateral projection, a perpendicular central ray enters one side of the body or body part, passes transversely along the coronal plane, and exits on the opposite side. Lateral projections can enter from either side of the body or body part as needed for the examination. This can be determined by the patient's condition or ordered by the physician. When a lateral projection is used for head, chest, or abdominal radiography, the direction of the central ray is described with reference to the associated radiographic position. A left lateral position or right lateral position specifies the *side of the body closest to the IR* and corresponds with the side exited by the central ray (Fig. 2.29). For a right lateral position, the central ray enters the left side of the body and exits the right side (see Fig. 2.29). Lateral projections of the limbs are clarified further by the terms *lateromedial* and *mediolateral* to indicate the sides entered and exited by the central ray (Fig. 2.30). The *transthoracic projection* is a unique lateral projection used for shoulder radiography and is described in Chapter 6.

Oblique projection

During an oblique projection, the central ray enters the body or body part from a side angle following an oblique plane. Oblique projections may enter from either side of the body and from anterior or posterior surfaces. If the central ray enters the anterior surface and exits the opposite posterior surface, it is an *AP oblique projection;* if it enters the posterior surface and exits anteriorly, it is a *PA oblique projection* (Fig. 2.31).

Most oblique projections are achieved by rotating the patient with the central ray perpendicular to the IR. As in the lateral projection, the direction of the central ray for oblique projections is described with reference to the associated radiographic position. A right posterior oblique (RPO) position places the right posterior surface of the body closest to the IR and corresponds with an AP oblique projection exiting through the same side. This relationship is discussed later. Oblique projections can also be achieved for some examinations by angling the central ray diagonally along the horizontal plane rather than rotating the patient.

Complex projections

For additional clarity, projections may be defined by entrance and exit points and by the central ray relationship to the body at the same time. In the PA axial projection, the central ray enters the posterior body surface and exits the anterior body surface following an axial or angled trajectory relative to the entire body or body part. Axiolateral projections also use angulations of the central ray, but the ray enters and exits through lateral surfaces of the entire body or body part. Table 2.6 summarizes the special or complex projections.

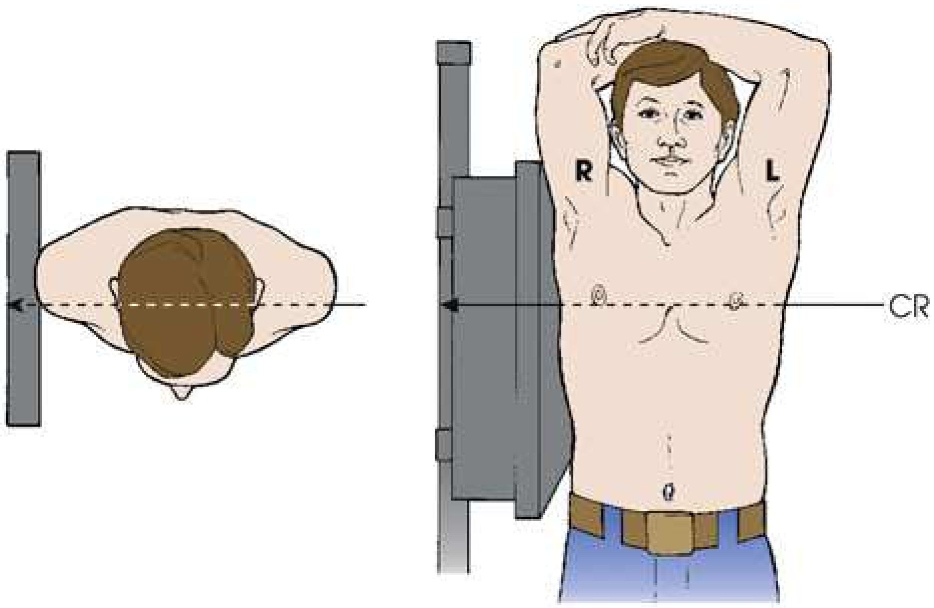


FIG. 2.29 Lateral projection of chest. The patient is placed in right lateral position. Right side of the chest is touching IR. Central ray (CR) enters left or opposite side of body.

The first diagram shows the top view of a patient standing with his lateral arm against the I R. The central ray (C R) enters the right and exits through the opposite side of the body. The second diagram shows a patient standing with his lateral arm against the I R with both his arms abducted and extended above and resting on his head. The central ray (C R) enters the right and exits through the opposite side of the body.

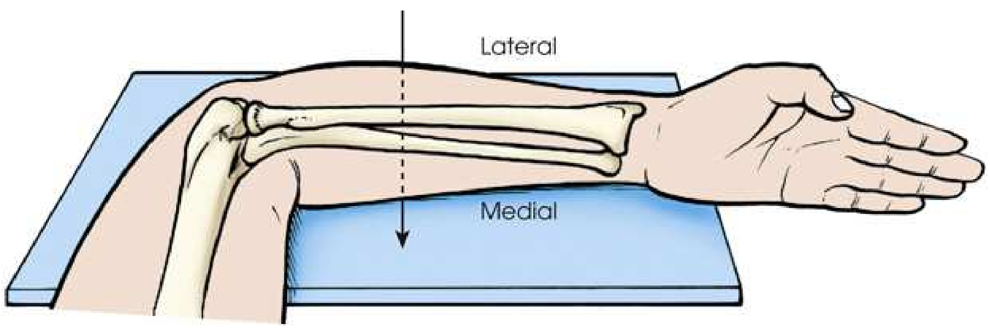


FIG. 2.30 Lateromedial projection of forearm. Central ray enters lateral aspect of forearm and exits medial aspect.

The humerus and the forearm are placed in contact with the table. The long axis of the elbow joint is parallel with the long axis of the forearm. The central ray enters the lateral aspect of the forearm and exits the medial aspect.

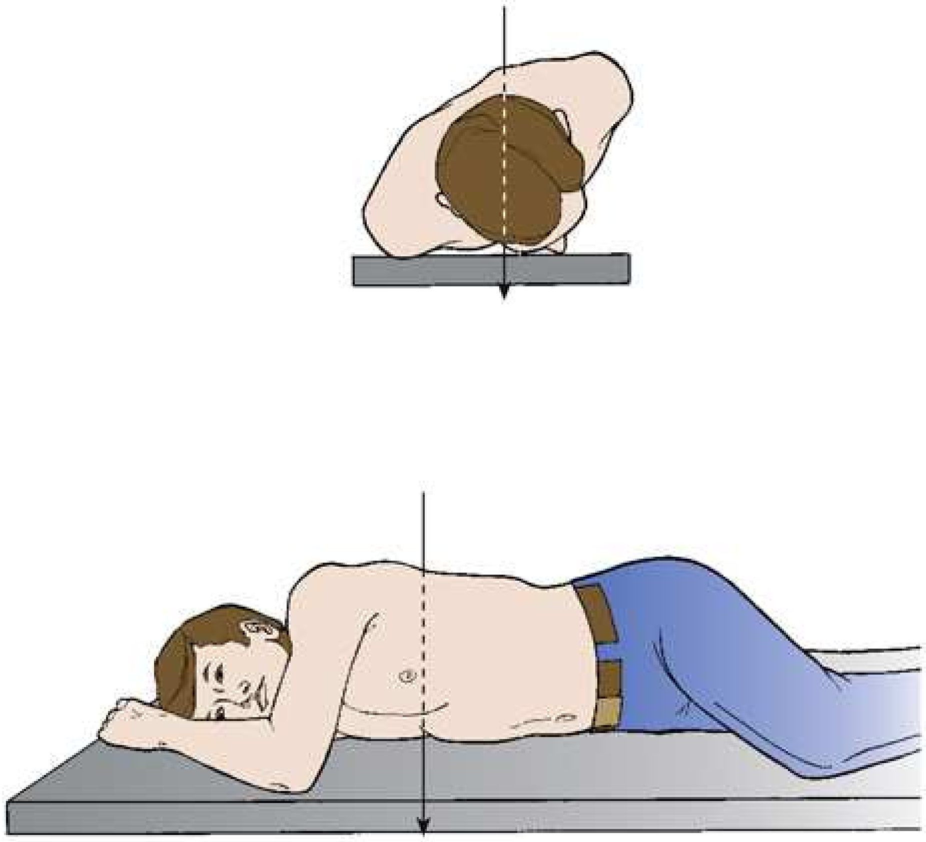


FIG. 2.31 PA oblique projection of chest. Central ray enters posterior aspect of body (even though it is rotated) and exits anterior aspect.

The first diagram shows the top view of a patient standing with his body rotated and the right side of the anterior body surface is against the I R. The central ray enters the posterior aspect of the body and exits the anterior aspect. The second diagram shows a patient lying in a lateral recumbent position. The central ray enters the posterior aspect of the body and exits the anterior aspect.

TABLE 2.6

Special projections summary

Projections	Definition
Axiolateral	Angled CR enters and exits lateral surfaces of the body/part
Axiolateral oblique	Angled CR enters and exits lateral surfaces of a rotated (oblique) body/part
Transthoracic	CR passes through the thorax
Craniocaudal	CR enters the cranial surface of a part and exits the caudal surface of a part; commonly used in mammography
Tangential	CR skims curved surface of part to project it free of superimposition
Inferosuperior	CR enters inferior surface and exits superior surface of the part
Superoinferior	CR enters superior surface and exits inferior surface of the part
Plantodorsal	Specific to the foot; CR enters plantar and exits dorsum surfaces
Dorsoplantar	Specific to the foot; CR enters dorsum and exits plantar surfaces
Lateromedial	CR passes through a part in the lateral position, entering the lateral and exiting the medial surfaces
Mediolateral	CR passes through a part in the lateral position, entering medial and exiting lateral surfaces
Submentovertical	Specific to the head; CR enters the inferior surface of the mandible (mentum) and exits the cranial vertex
Acanthoparietal	Specific to the head; CR enters the acanthion and exits the parietal bones
Parietoacanthial	Specific to the head; CR enters the parietal bones and exits the acanthion

True projections

The term *true* (*true AP, true PA,* and *true lateral*) [6] is often used in clinical practice. *True* is used specifically to indicate that the body part must be placed exactly in the anatomic position.

A true AP or PA projection is obtained when the central ray is perpendicular to the coronal plane and parallel to the sagittal plane. A true lateral projection is obtained when the central ray is parallel to the normal plane and perpendicular to the sagittal plane. When a body part is rotated for an AP or PA oblique projection, a true AP or PA projection cannot be obtained. In this atlas, the term *true* is used only when the body part is placed in the anatomic position.

In-profile

In-profile is an outlined or silhouette view of an anatomic structure that has a distinctive shape. The distinctive aspect is not superimposed. The view is frequently seen from the side.

Position

The term *position* is used in two ways in radiology. One way identifies the overall posture of the patient or the general body position. The patient may be described as upright, seated, or supine. The second use of *position* refers to the specific placement of the body part in relation to the radiographic table or IR during imaging. This is the radiographic position and may be a right lateral, left anterior oblique (LAO), or other position depending on the examination and anatomy of interest. A list of all general body positions and radiographic positions is provided in Box 2.2.

During radiography, general body positions are combined with radiographic positions to produce the appropriate image. For clarification of positioning for an examination, it is often necessary to include references to both because a particular radiographic position, such as right lateral, can be achieved in several general body positions (e.g., upright, supine, lateral recumbent) with differing image outcomes. Specific descriptions of general body positions and radiographic positions follow.

BOX 2.2 **Body positions**

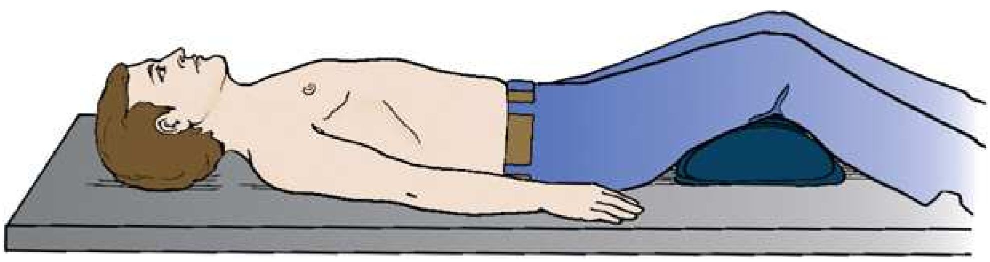


FIG. 2.32 Supine position of body, also termed *dorsal recumbent position*. The patient's knees are flexed for comfort.

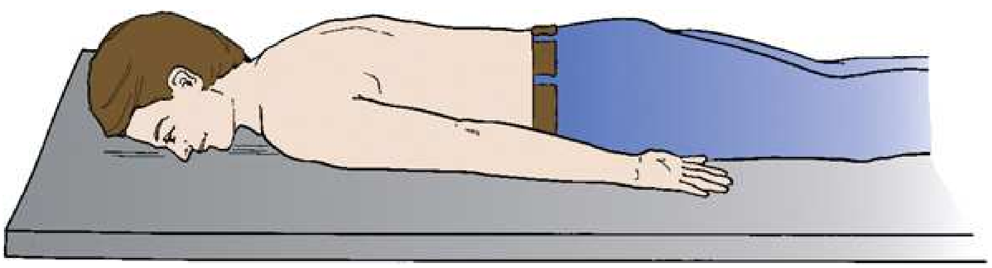


FIG. 2.33 Prone position of body, also termed *ventral recumbent position*.

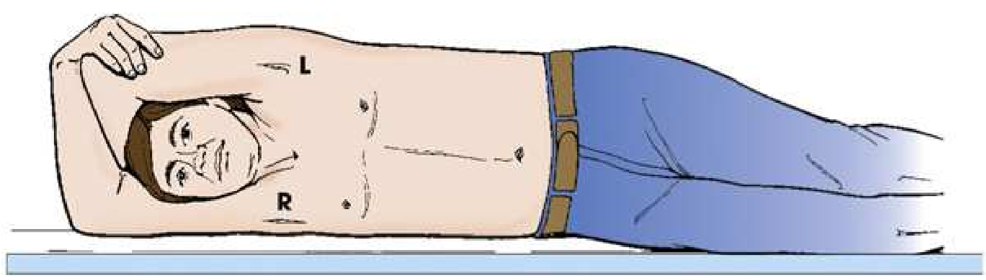


FIG. 2.34 Recumbent position of body, specifically *right lateral recumbent position*.

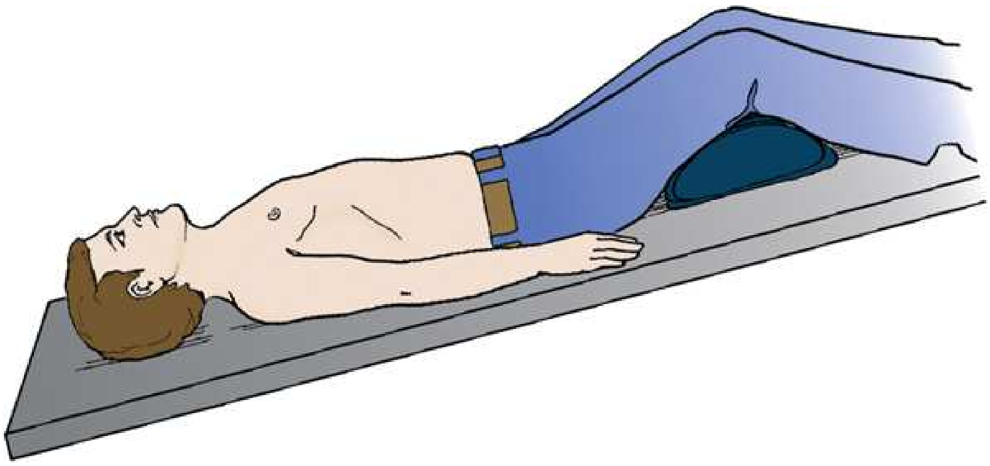


FIG. 2.35 Trendelenburg position of body. Feet are higher than the head.

A patient is in a supine position on the radiographic table with their head tilted downward. His arms are placed along the sides of his body. The legs are elevated by placing a pillow under the knee joints.

General body positions

The following list describes the general body positions. All are commonly used in radiography practice.

upright—erect or marked by a vertical position (see Fig. 2.26)
seated—upright position in which the patient is sitting on a chair or stool
recumbent—general term referring to lying down in any position, such as dorsal recumbent (Fig. 2.32), ventral recumbent (Fig. 2.33), or lateral recumbent (Fig. 2.34)
supine—lying on the back (see Fig. 2.32)
prone—lying face down (see Fig. 2.33)
Trendelenburg position—supine position with head tilted downward (Fig. 2.35)
Fowler position—supine position with head higher than the feet (Fig. 2.36)
Sims position—recumbent position with the patient lying on the left anterior side (semiprone) with left leg extended and right knee and thigh partially flexed (Fig. 2.37)
lithotomy position—supine position with knees and hip flexed and thighs abducted and rotated externally, supported by ankle or knee supports (Fig. 2.38)

Lateral position

Lateral radiographic positions are always named according to the side of the patient that is placed closest to the IR (Figs. 2.39 and 2.40). In this atlas, the right and left lateral positions are indicated as subheadings for all lateral x-ray projections of the head, chest, and abdomen in which either the left or the right side of the patient is placed adjacent to the IR. The specific side selected depends on the condition of the patient, the anatomic structure of clinical interest, and the purpose of the examination. In Figs. 2.39 and 2.40, the x-ray projection for the positions indicated is lateral projection.

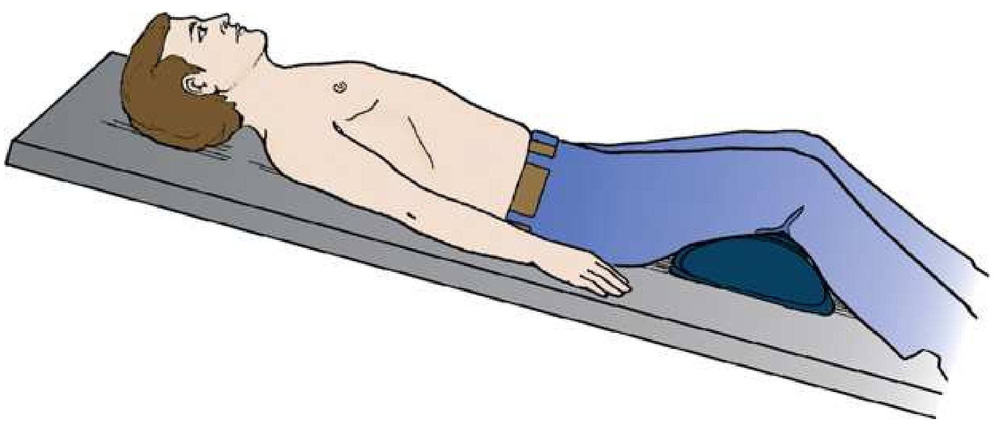


FIG. 2.36 Fowler position of the body. Head is higher than the feet.

A patient is in a supine position on the radiographic table with a head higher than the feet. His arms are placed along the sides of his body. The legs are elevated by placing a pillow under the knee joints.

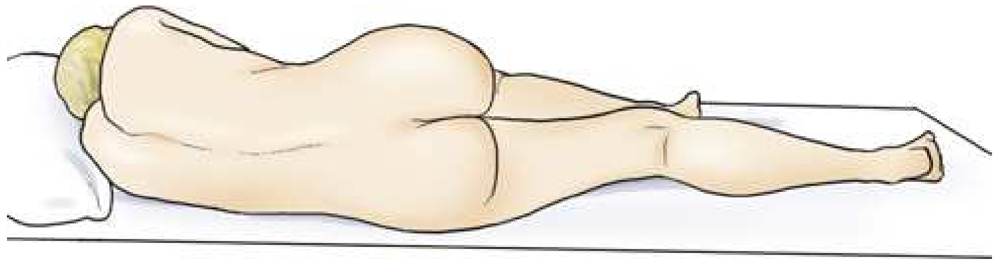


FIG. 2.37 Sims position of body. The patient is on the left side in recumbent oblique position.

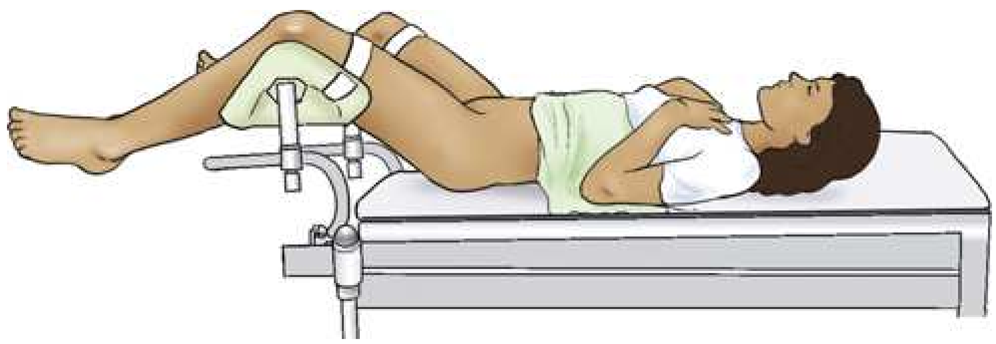


FIG. 2.38 Lithotomy position of body. Knees and hips are flexed, and thighs are abducted and rotated laterally.

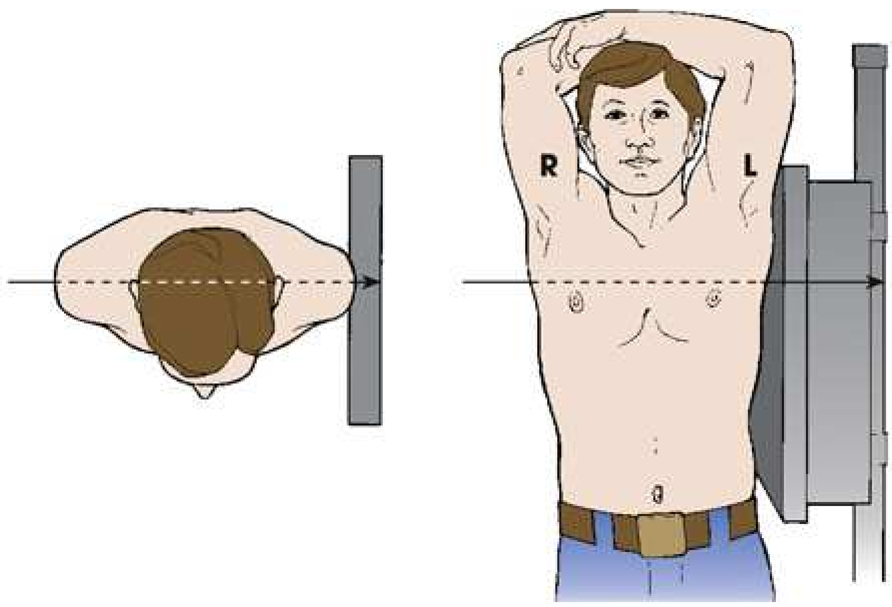


FIG. 2.39 Left lateral radiographic position of chest results in lateral projection.

The first diagram shows the top view of a patient standing with his lateral arm against the I R. The central ray (C R) enters the right and exits through the opposite side of the body. The second diagram shows a patient standing with his lateral arm against the I R with both his arms abducted and extended above and resting on his head. The central ray (C R) enters the right and exits through the opposite side of the body.

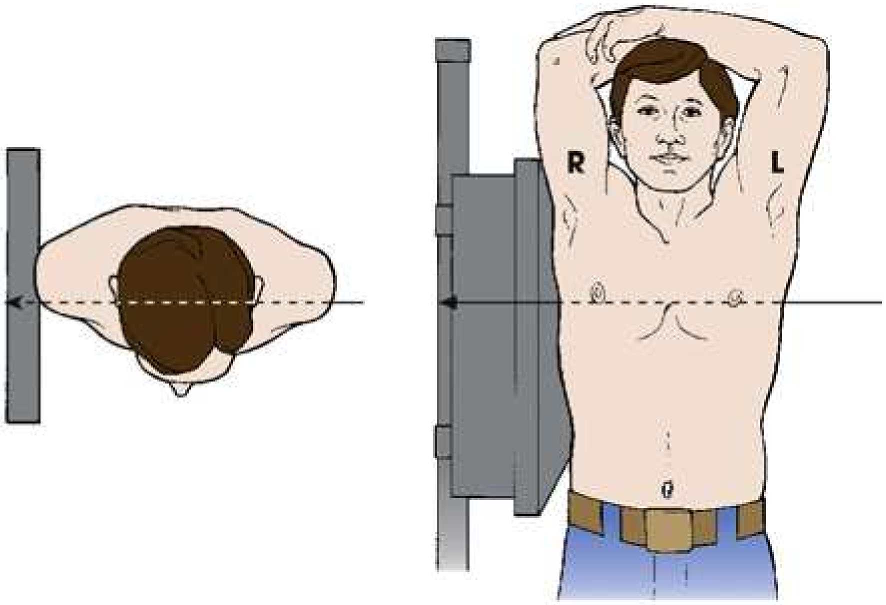


FIG. 2.40 Right lateral radiographic position of chest results in lateral projection.

The first diagram shows the top view of a patient standing with his lateral arm against the I R. The central ray (C R) enters the left and exits through the opposite side of the body. The second diagram shows a patient standing with his lateral arm against the I R with both his arms abducted and extended above and resting on his head. The central ray (C R) enters the left and exits through the opposite side of the body.

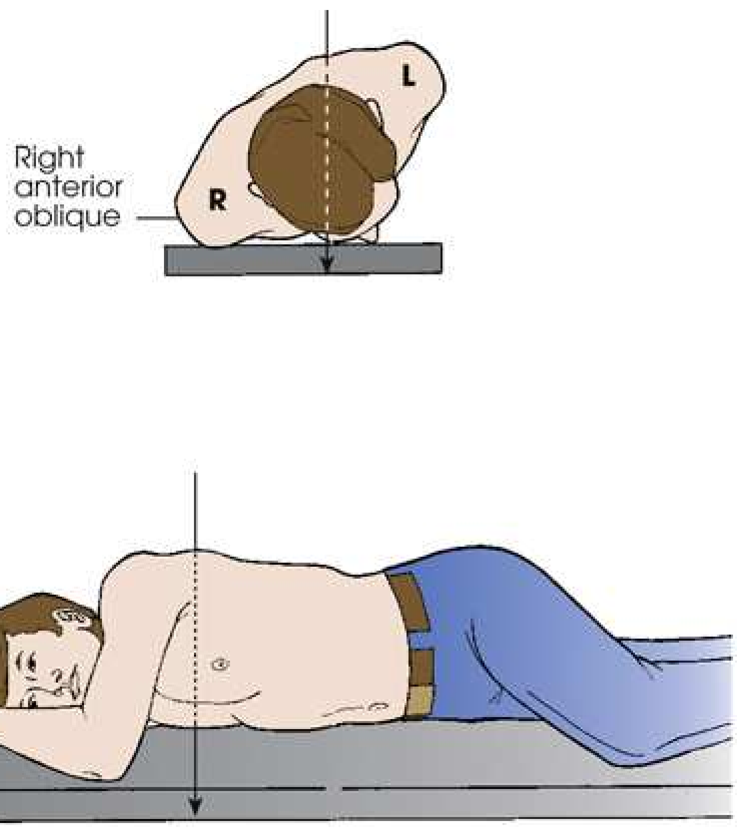
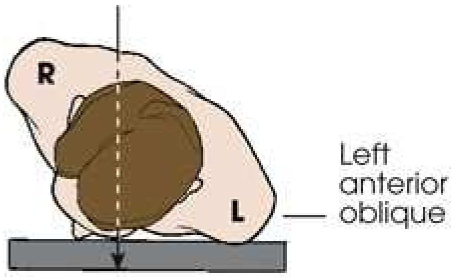


FIG. 2.41 RAO radiographic position of chest results in PA oblique projection.

The first diagram shows the top view of a patient standing with his body rotated and the right side of the anterior body surface is against the I R. The central ray enters the posterior aspect of the body and exits the anterior aspect. The second diagram shows a patient lying in a lateral recumbent position. The central ray enters the posterior aspect of the body and exits the anterior aspect.



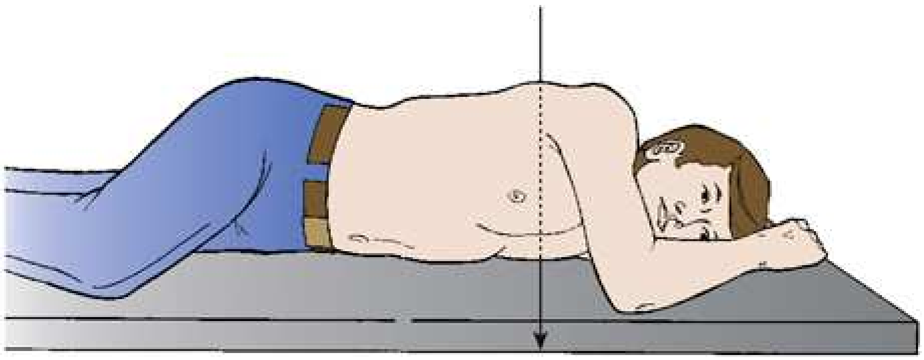


FIG. 2.42 LAO radiographic position of chest results in PA oblique projection.

The first diagram shows the top view of a patient standing with his body rotated and the left side of the anterior body surface is against the I R. The central ray enters the posterior aspect of the body and exits the anterior aspect. The second diagram shows a patient lying in a lateral recumbent position. The central ray enters the posterior aspect of the body and exits the anterior aspect.

Oblique position

An oblique radiographic position is achieved when the entire body or body part is rotated so that the coronal plane is not parallel with the radiographic table or IR. The angle of oblique rotation varies with the examination and structures to be shown. In this atlas, an angle is specified for each oblique position (e.g., rotated 45 degrees from the prone position).

Oblique positions, similar to lateral positions, are always named according to the side of the patient that is placed closest to the IR. In Fig. 2.41, the patient is rotated with the right anterior body surface in contact with the radiographic table. This is a *right anterior oblique (RAO) position* because the right side of the anterior body surface is closest to the IR. Fig. 2.42 shows the patient placed in an *LAO position*.

The relationship between oblique position and oblique projection can be summarized simply. Anterior oblique positions result in PA oblique projections, as shown in Figs. 2.41 and 2.42. Similarly, posterior oblique positions result in AP oblique projections, as illustrated in Figs. 2.43 and 2.44.

The oblique positioning terminology used in this atlas has been standardized using RAO and LAO or RPO and LPO positions along with the appropriate PA or AP oblique projection. For oblique positions of the limbs, the terms *medial rotation* and *lateral rotation* have been standardized to designate the direction in which the limbs have been turned from the anatomic position (Fig. 2.45).

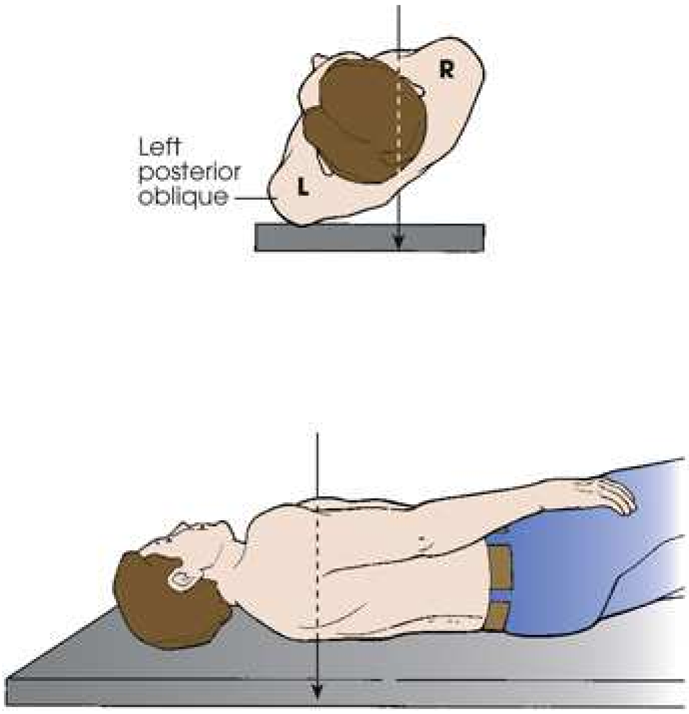


FIG. 2.43 LPO radiographic position of chest results in AP oblique projection.

The first diagram shows the top view of a patient standing with his body rotated and the left side of the posterior body surface is against the I R. The central ray enters the posterior aspect of the body and exits the anterior aspect. The second diagram shows a patient lying in a lateral recumbent position. The central ray enters the posterior aspect of the body and exits the anterior aspect.

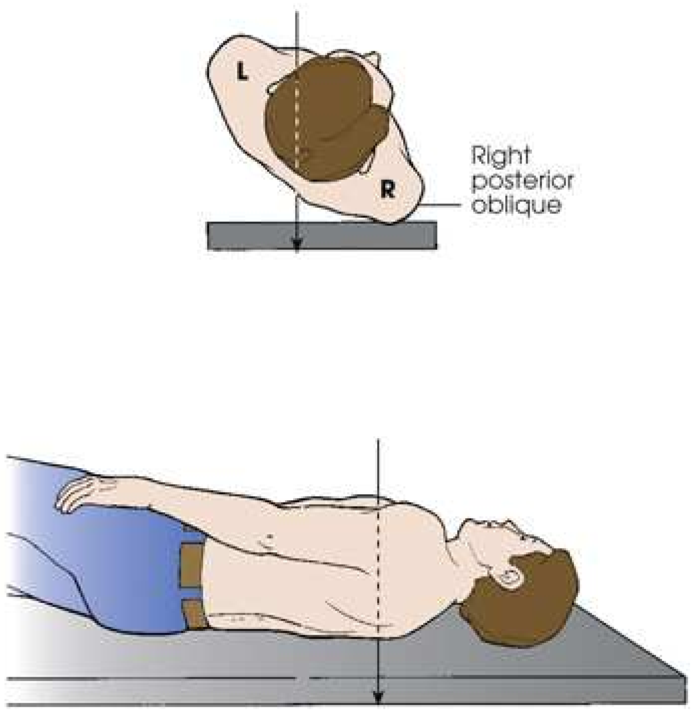


FIG. 2.44 RPO radiographic position of chest results in AP oblique projection.

The first diagram shows the top view of a patient standing with his body rotated and the right side of the posterior body surface is against the I R. The central ray enters the posterior aspect of the body and exits the anterior aspect. The second diagram shows a patient lying in a lateral recumbent position. The central ray enters the posterior aspect of the body and exits the anterior aspect.

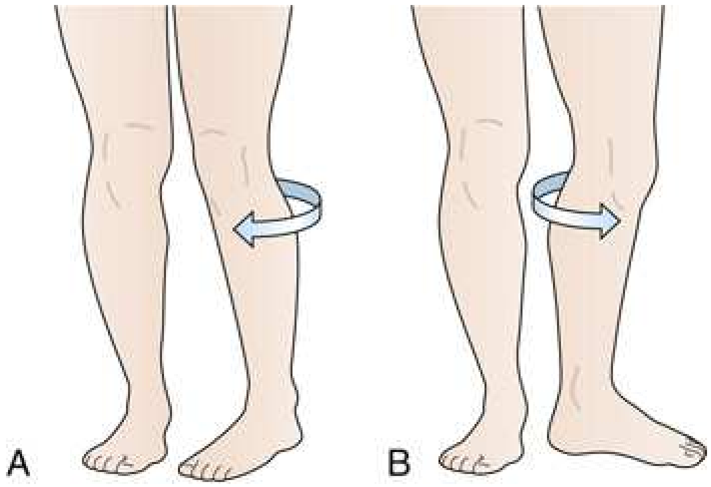


FIG. 2.45 (A) Medial rotation of knee. (B) Lateral rotation of knee.

(A) shows two legs with one leg turned inwards. It is indicated by an arrow pointing towards the other knee. (B) shows two legs with one leg turned outward. It is indicated by an arrow pointing outside.

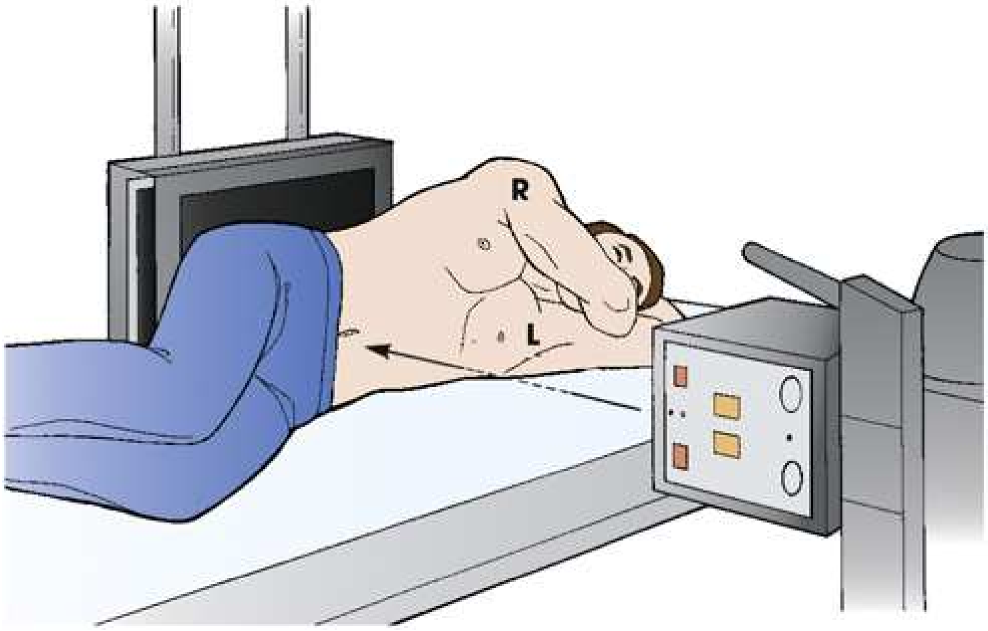


FIG. 2.46 Left lateral decubitus radiographic position of abdomen results in AP projection. Note horizontal orientation of central ray.

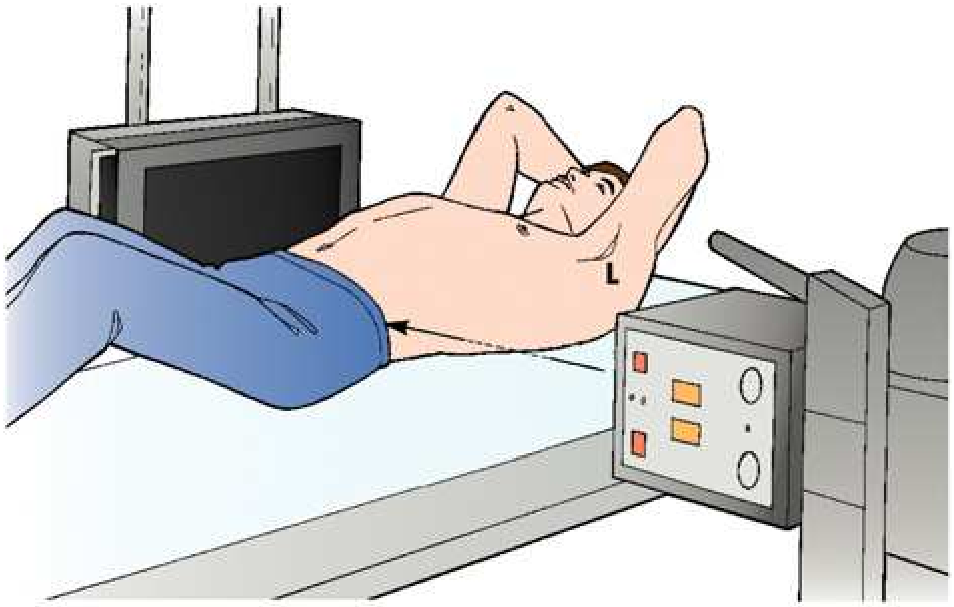


FIG. 2.47 Right dorsal decubitus radiographic position of abdomen results in right lateral projection. Note horizontal orientation of central ray.

A patient is placed in a dorsal decubitus radiographic position with one side of the body next to the I R. The patient's arms are extended to the vertical position, supporting his head. The central ray is directed horizontally.

Decubitus position

In radiographic positioning terminology, the term *decubitus* indicates that the patient is lying down and that the central ray is horizontal and parallel with the floor. Three primary decubitus positions are named according to the body surface on which the patient is lying: *lateral decubitus (left or right), dorsal decubitus,* and *ventral decubitus*. Of these, the lateral decubitus position is used most often to show the presence of air-fluid levels or free air in the chest and abdomen.

In Fig. 2.46, the patient is placed in the left lateral decubitus radiographic position with the back (posterior surface) closest to the IR. In this position, a horizontal central ray provides an AP projection. Fig. 2.46 is accurately described as an AP projection with the body in the left lateral decubitus position. Alternatively, the patient may be placed with the front of the body (anterior surface) facing the IR, resulting in a PA projection. This would be correctly described as a PA projection of the body in the left lateral decubitus position. Right lateral decubitus positions may be necessary with AP and PA projections, depending on the examination.

In Fig. 2.47, the patient is shown in a dorsal decubitus radiographic position with one side of the body next to the IR. The horizontal central ray provides a lateral projection. This is correctly described as a lateral projection with the patient placed in the dorsal decubitus position. Either side may face the IR, depending on the examination or the patient's condition.

The ventral decubitus radiographic position (Fig. 2.48) also places a side of the body adjacent to the IR, resulting in a lateral projection. Similar to the earlier examples, the accurate terminology is lateral projection with the patient in the ventral decubitus position. Either side may face the IR.

Lordotic position

The lordotic position is achieved by having the patient lean backward while in the upright body position so that only the shoulders are in contact with the IR (Fig. 2.49). An angulation forms between the central ray and the long axis of the upper body, producing an AP axial projection. This position is used for visualization of pulmonary apices (see Chapter 3) and clavicles (see Chapter 6).

Note to educators, students, and clinicians

In clinical practice, the terms *position* and *projection* are often incorrectly used. These are two distinct terms that should not be interchanged. Incorrect use leads to confusion for the student who is attempting to learn the correct terminology of the profession. Educators and clinicians are encouraged to use the term *projection* generally when describing any examination performed. The word *projection* is the only term that accurately describes how the body part is being examined. The term *position* should be used only when referring to placement of the patient's body. Correct examples are, "We are going to perform a PA projection of the chest with the patient in the upright position," and "We are going to perform an AP oblique projection of the lumbar spine in the left posterior oblique (LPO) position."

View

The term *view* is used to describe the body part as seen by the IR. Use of this term is restricted to the general discussion of a finished radiograph or image. *View* and *projection* are exact opposites. For many years, *view* and *projection* were often used interchangeably, which led to confusion. In the United States, *projection* has replaced *view* as the preferred terminology for describing radiographic images. For consistency, this atlas refers to all views as *images* or *radiographs*.

In clinical practice, it is common to see the term *view* used in radiology procedure orders. For example, a radiology procedure order pulled from the radiology information system (RIS) worklist may state "3 view shoulder." This should be interpreted as an order for three radiographic projections or positions. The radiology department protocol manual will indicate which three projections are routine for that procedure.

Method

Some radiographic projections and procedures are named after individuals (e.g., Waters, Towne) in recognition of their development of a method to show a specific anatomic part. *Method,* which was first described in the fifth edition of this atlas, describes the specific radiographic projection that the individual developed. Most methods are named after an individual; however, a few are named for unique projections. The method specifies the x-ray projection and body position, and it may include specific items such as IR, CR, or other unique aspects. In this atlas, standard projection terminology is used first, and a named method is listed secondarily (e.g., AP axial projection; Towne method). ARRT and CAMRT use standard anatomic projection terminology and list the originator in parentheses.

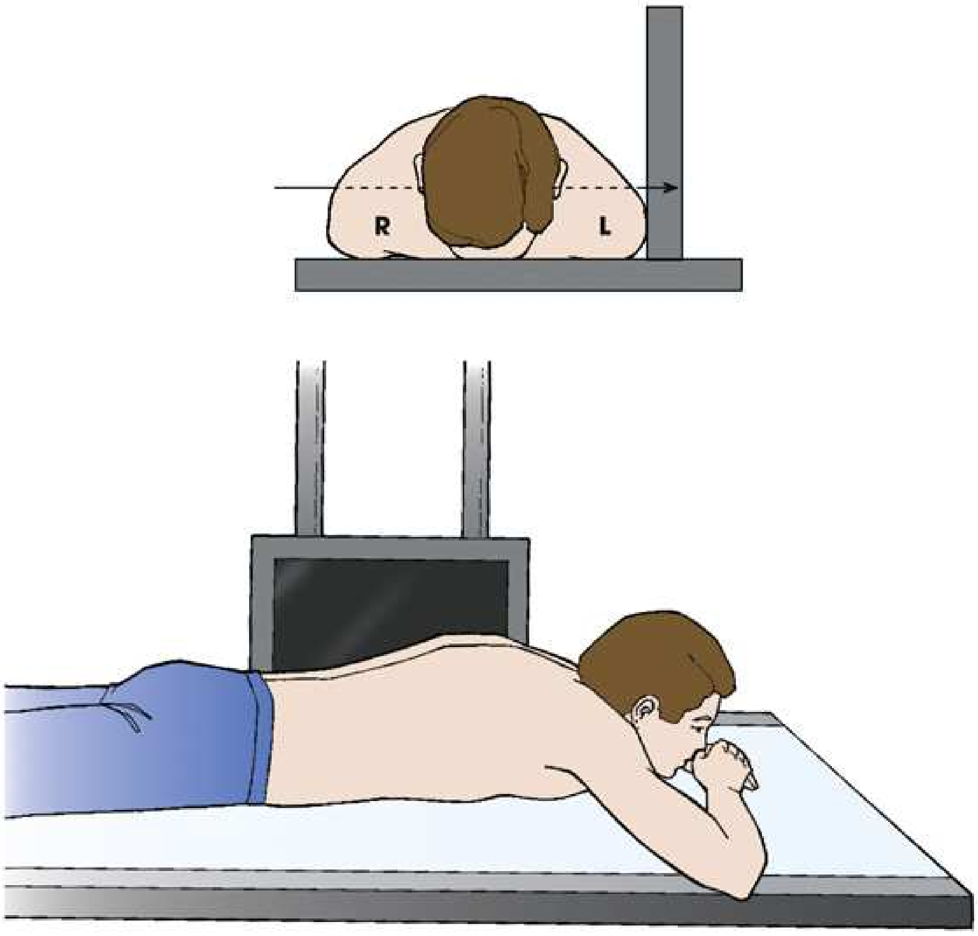


FIG. 2.48 Left ventral decubitus radiographic position of abdomen results in left lateral projection. Note horizontal orientation of central ray.

The diagram on top shows the top view of a patient with his anterior surface against the table. The side of the body is adjacent to the I R. His arms are placed along the sides of his body. The central ray is directed horizontally. The second diagram shows a patient in a prone position. The side of the body is adjacent to the I R. Both his arms are placed in front of his face. The central ray is directed horizontally.

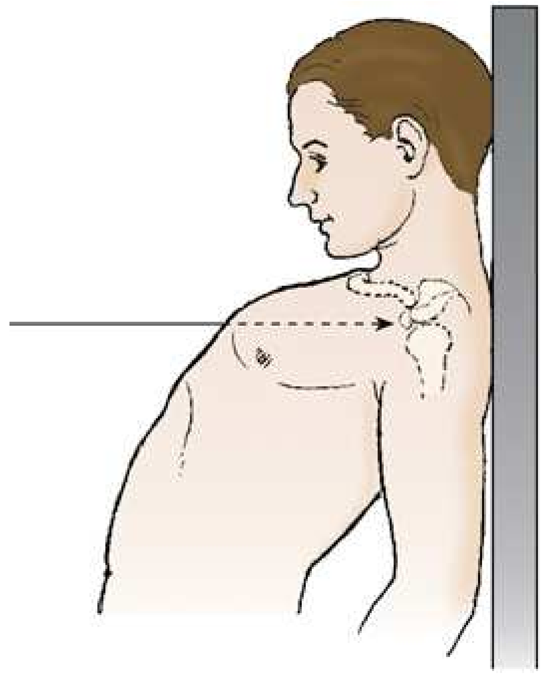


FIG. 2.49 Lordotic radiographic position of chest results in AP axial projection. Central ray is not angled; however, it enters chest axially as a result of body position.

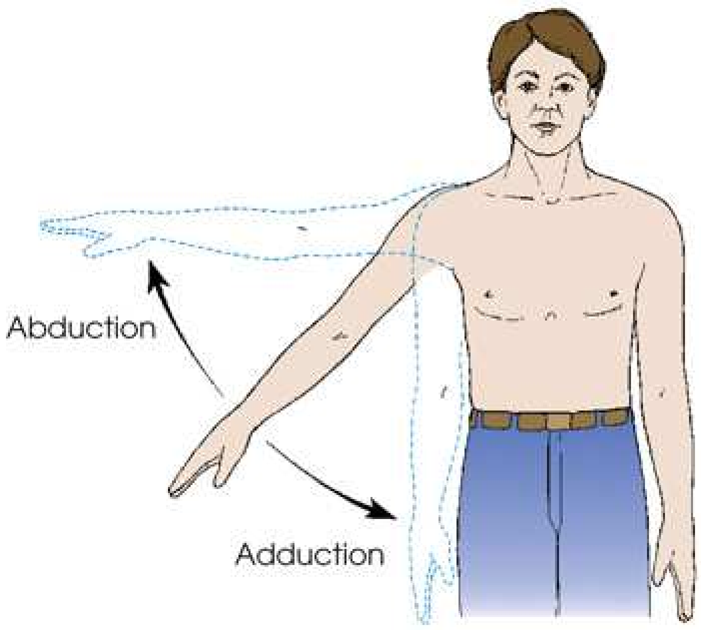


FIG. 2.50 Abduction and adduction of arm.

A patient is standing upright with his right arm extended to his side. An arrow pointing up indicates the movement of the arm from the central axis of the body or body part. An arrow pointing down indicates the movement of the arm toward the central axis of the body or body part.

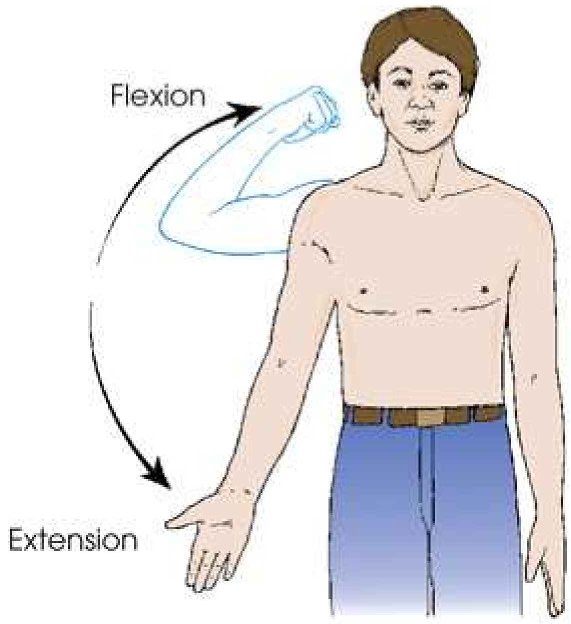


FIG. 2.51 Extension of arm (anatomic position) and flexion (bending).

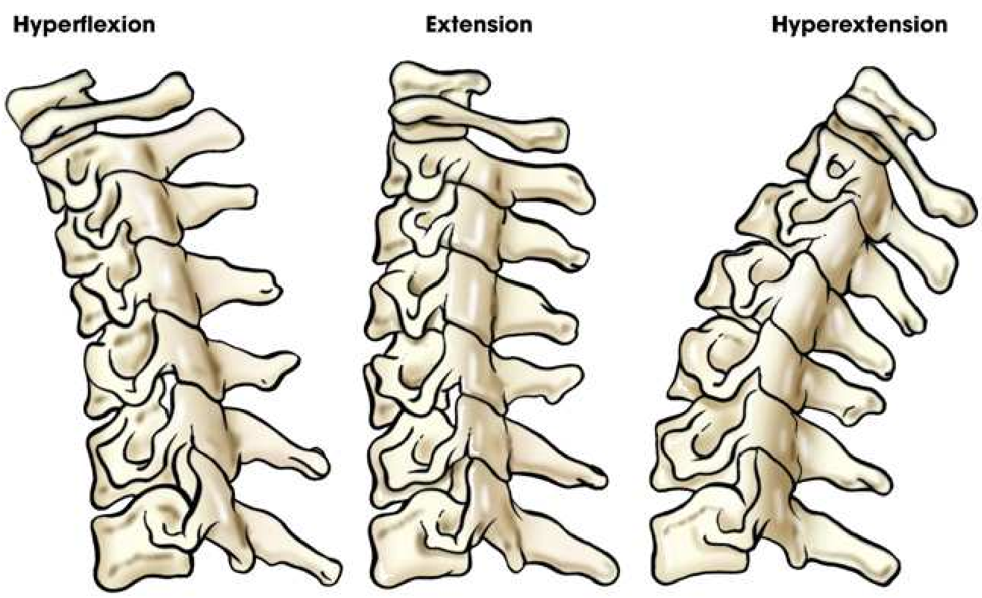


FIG. 2.52 Hyperextension, extension, and hyperflexion of neck.

Body Movement Terminology

The following terms are used to describe movement related to the limbs. These terms are often used in positioning descriptions and in the patient history provided to the radiographer by the referring physician. They must be studied thoroughly.

abduct or abduction—movement of a part away from the central axis of the body or body part
adduct or adduction—movement of a part toward the central axis of the body or body part (Fig. 2.50)
extension—straightening of a joint; when both elements of the joint are in the anatomic position; normal position of a joint (Fig. 2.51)
flexion—act of bending a joint; opposite of extension (Fig. 2.52)
hyperextension—forced or excessive extension of a limb or joints
hyperflexion—forced overflexion of a limb or joints (see Fig. 2.52)
evert/eversion—outward turning of the foot at the ankle (Fig. 2.53)

FIG. 2.53 Eversion and inversion of foot at ankle joint.

invert/inversion—inward turning of the foot at the ankle (Fig. 2.53)
pronate/pronation—rotation of the forearm so that the palm is down
supinate/supination—rotation of the forearm so that the palm is up (in the anatomic position) (Fig. 2.54)
rotate/rotation—turning or rotating of the body or a body part around its axis (Fig. 2.55A); rotation of a limb can be medial (toward the midline of the body from the anatomic position [see Fig. 2.55B]) or lateral (away from the midline of the body from the anatomic position [see Fig. 2.55C])
circumduction—circular movement of a limb (Fig. 2.56)
tilt—tipping or slanting a body part slightly; tilt is in relation to the long axis of the body (Fig. 2.57)
deviation—turning away from the regular standard or course (Fig. 2.58)
dorsiflexion—flexion or bending of the foot toward the leg (Fig. 2.59)
plantar flexion—flexion or bending of the foot downward toward the sole (see Fig. 2.59)

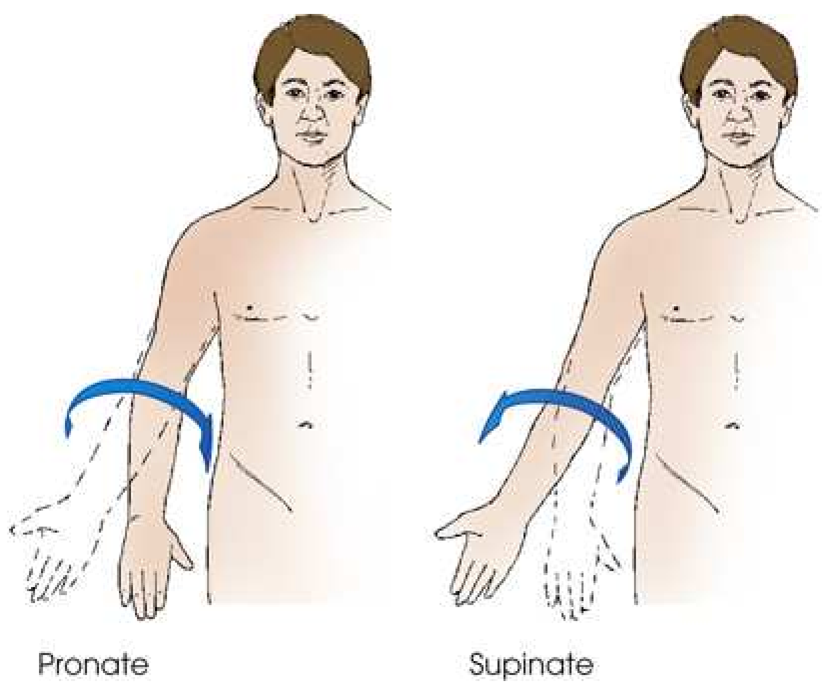


FIG. 2.54 Pronation and supination of forearm.

A man standing in an upright position is rotating the forearm so that the palm is down. It is indicated by an arrow pointing inwards. A man standing in an upright position is rotating the forearm so that the palm is up. It is indicated by an arrow pointing outside.

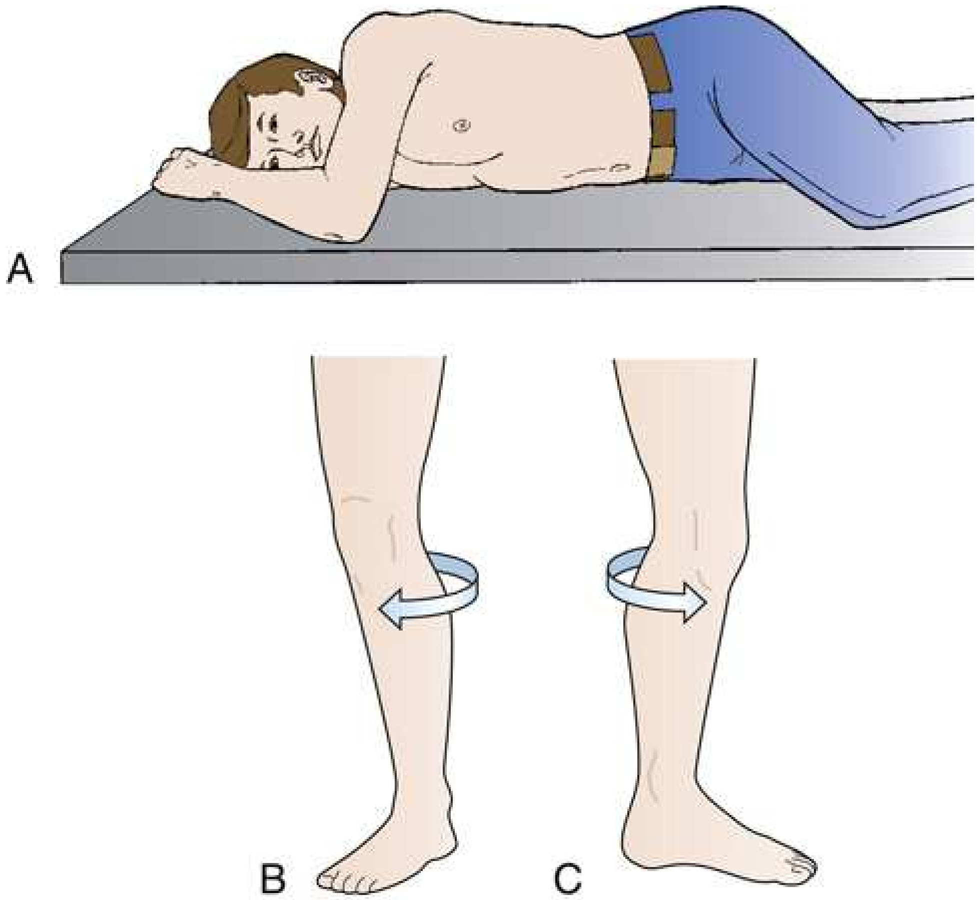


FIG. 2.55 (A) Rotation of chest and abdomen. The patient's arm and knee are flexed for comfort. (B) Medial rotation of left leg. (C) Lateral rotation of left leg.

(A) A patient is on the radiographic table by rotating the body around its axis. His knees and elbow are flexed. (B) A leg is rotated toward the midline of the body. It is indicated by an arrow. (C) A leg is rotated away from the midline of the body. It is indicated by an arrow.

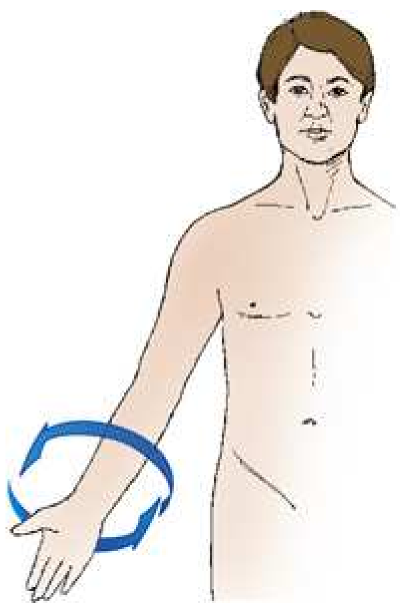


FIG. 2.56 Circumduction of arm.

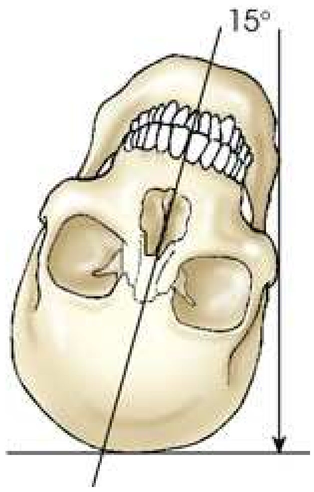


FIG. 2.57 Tilt of skull is 15 degrees from long axis.

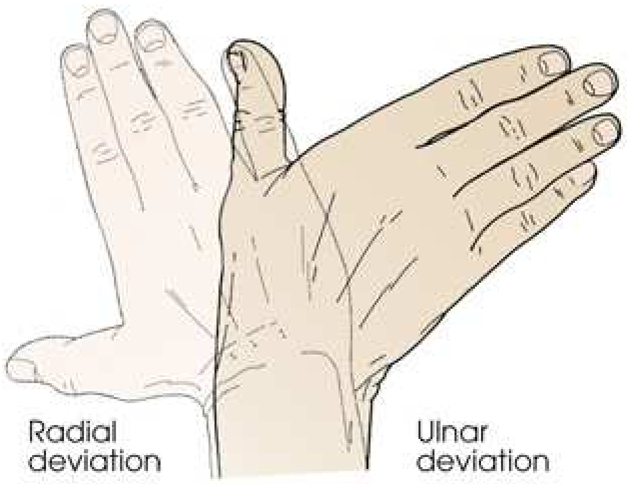


FIG. 2.58 Radial deviation of hand (turned to radial side) and ulnar deviation (turned to ulnar side).

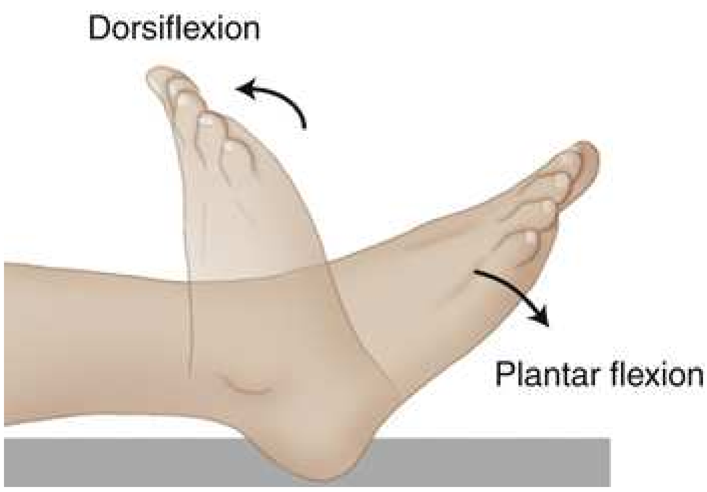


FIG. 2.59 Foot in dorsiflexion and plantar flexion. Note movement is at ankle joint.

TABLE 2.7

Greek and Latin nouns: common singular and plural forms

Singular	Plural	Examples: singular—plural
-a	-ae	maxilla—maxillae
-ex	-ces	apex—apices
-is	-es	diagnosis—diagnoses
-ix	-ces	appendix—appendices
-ma	-mata	fibroma—fibromata
-on	-a	ganglion—ganglia
-um	-a	antrum—antra
-us	-i	ramus—rami

TABLE 2.8

Medical Terminology

Single and plural word endings for common Greek and Latin nouns are presented in Table 2.7. Single and plural word forms are often confused. Examples of commonly misused word forms are listed in Table 2.8; the singular form generally is used when the plural form is intended.

Abbreviations used in Chapter 2

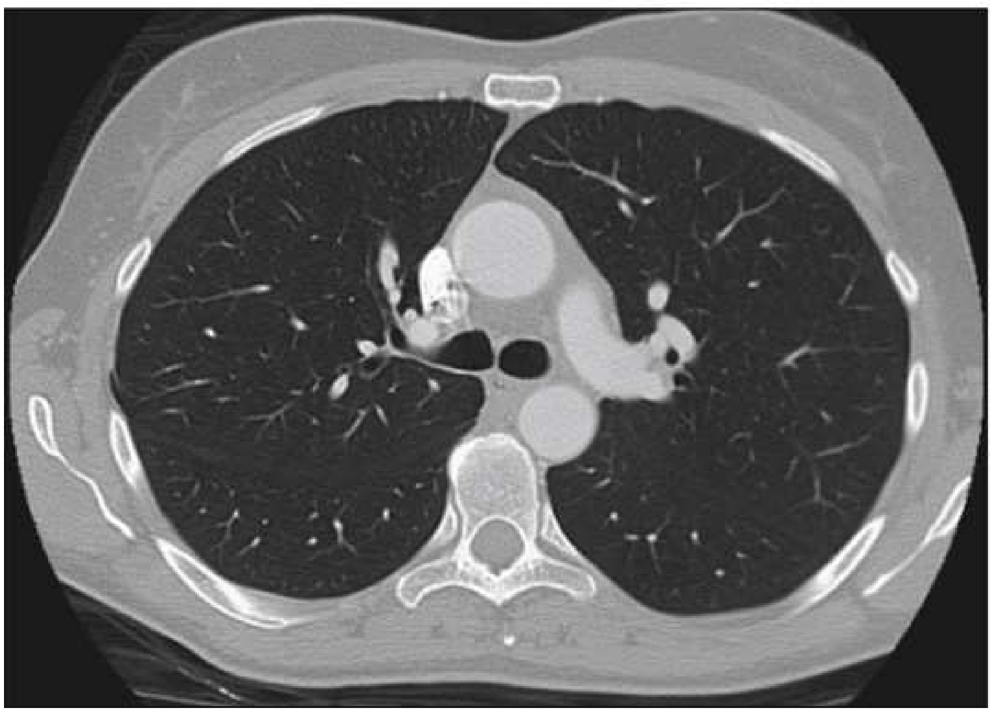
ARRT	American Registry of Radiologic Technologists
ASIS	Anterior superior iliac spine
CT	Computed tomography
LAO	Left anterior oblique
LLQ	Left lower quadrant
LPO	Left posterior oblique
LUQ	Left upper quadrant
MRI	Magnetic resonance imaging
RAO	Right anterior oblique
RLQ	Right lower quadrant
RPO	Right posterior oblique
RUQ	Right upper quadrant
US	Ultrasound

See Addendum A for a summary of all abbreviations used in Volume 1.

References

1. Mills W.R. The relation of bodily habitus to visceral form, position, tonus, and motility. *AJR* . 1917;4:155.
2. *ARRT educator's handbook* . ARRT; 1990.
3. *ARRT educator guide* . Spring; 2010.
4. *AART. Personal communication and permission* . May 2006.
5. CAMRT, Radiography Council on Education, . *Personal communication* . July 1993.
6. Bontrager K.L. In: *Textbook of radiographic positioning* . St Louis: Mosby; 2009.

3: Thoracic Viscera



Chest and Upper Airway

OUTLINE

Summary of Projections

Projections, Positions, and Methods					
Page	**Essential**	**Anatomy**	**Projection**	**Position**	**Method**
99		Soft tissue neck	AP		
101		Soft tissue neck	Lateral	R or L	
107		Chest: *Lungs and heart*	PA		
110		Chest: *Lungs and heart*	Lateral	R or L	
113		Chest: *Lungs and heart*	PA oblique	RAO and LAO	
117		Chest: *Lungs and heart*	AP oblique	RPO and LPO	
119		Chest	AP		
121		Pulmonary apices	AP axial	Lordotic	LINDBLOM
123		Pulmonary apices	AP axial		
124		Pulmonary apices	PA axial		
125		Lungs and pleurae	AP or PA	R or L lateral decubitus	
127		Lungs and pleurae	Lateral	R or L, ventral or dorsal decubitus	

Icons in the Essential column indicate projections frequently performed in the United States and Canada. Students should be competent in these projections.

AP, Anteroposterior; *L,* left; *LAO,* left anterior oblique; *LPO,* left posterior oblique; *PA,* posteroanterior; *R,* right; *RAO,* right anterior oblique; *RPO,* right posterior oblique.

Anatomy

Body Habitus

The general shape of the human body, or the *body habitus*, determines the size, shape, position, and movement of the internal organs. Fig. 3.1 outlines the general shape of the thorax in the four types of body habitus and shows how each appears on radiographs of the thoracic area.

Thoracic Cavity

The *thoracic cavity* is bounded by the walls of the thorax and extends from the *superior thoracic aperture*, where structures enter the thorax, to the *inferior thoracic aperture*. The *diaphragm* separates the thoracic cavity from the abdominal cavity. The anatomic structures that pass from the thorax to the abdomen go through openings in the diaphragm (Fig. 3.2).

The thoracic cavity contains the *lungs* and *heart*; organs of the *respiratory*, *cardiovascular*, and *lymphatic* systems; the *inferior portion of the esophagus*; and the *thymus gland*. Within the cavity are three separate chambers: a single *pericardial cavity* and the *right* and *left pleural cavities*. These cavities are lined by shiny, slippery, and delicate *serous membranes*. The space between the two pleural cavities is called the *mediastinum*. This area contains all thoracic structures except the lungs and pleurae.

Respiratory System

The *respiratory system* consists of the pharynx, trachea, bronchi, and two lungs. The air passages of these organs communicate with the exterior through the pharynx, mouth, and nose, each of which, in addition to serving other described functions, is considered a part of the respiratory system.

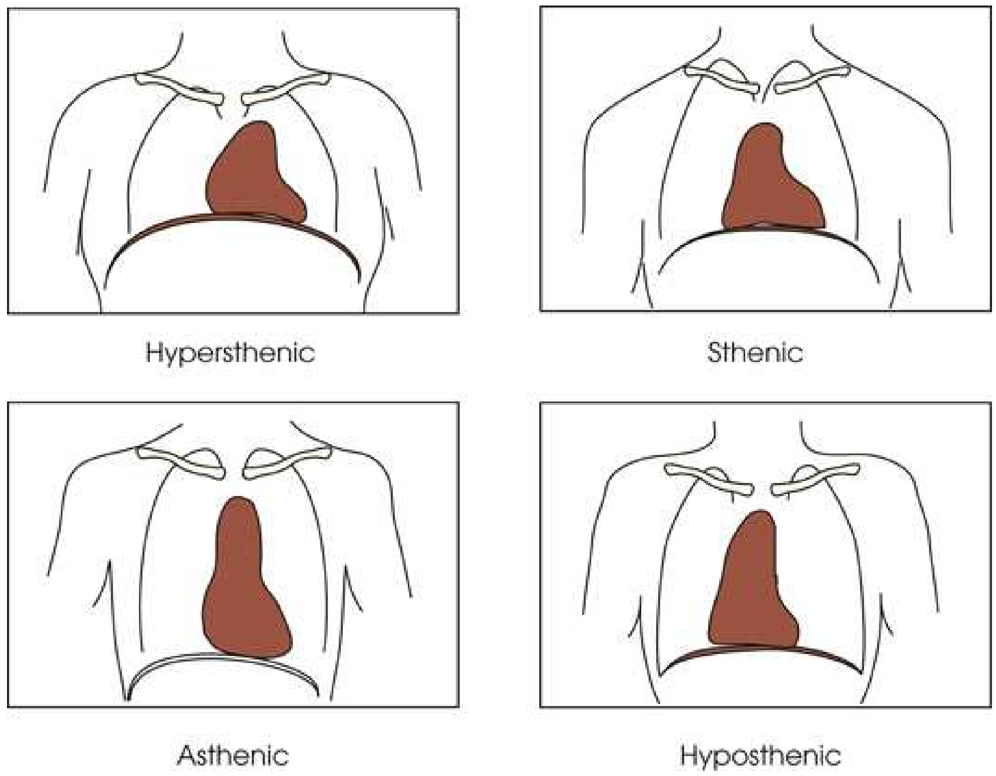


FIG. 3.1 Four types of body habitus. Note general shape of thorax, size and shape of lungs, and position of heart. Knowledge of this anatomy is helpful in positioning accurately for projections of the thorax.

Diagram on the top-left shows an anterior view of the chest and is labeled hypersthenic. The heart is highlighted and its axis is nearly transverse. The lungs are short and have apices at or near clavicles. The diaphragm is high. The thorax is short, broad, and deep. Diagram on the top-right shows an anterior view of the chest and is labeled sthenic. The heart is highlighted and is moderately transverse. The lungs are of moderate length. The diaphragm is moderately high. The thorax is moderately short, broad, and deep. Diagram at the bottom-left shows an anterior view of the chest and is labeled asthenic. The heart is highlighted and it is nearly vertical and at the midline. The lungs are long and apices above clavicles may be broader above the base. The thorax is long and shallow. Diagram at the bottom-right shows an anterior view of the chest and is labeled hyposthenic. The heart is highlighted. Organs and characteristics for this habitus are intermediate between sthenic and asthenic body habitus types.

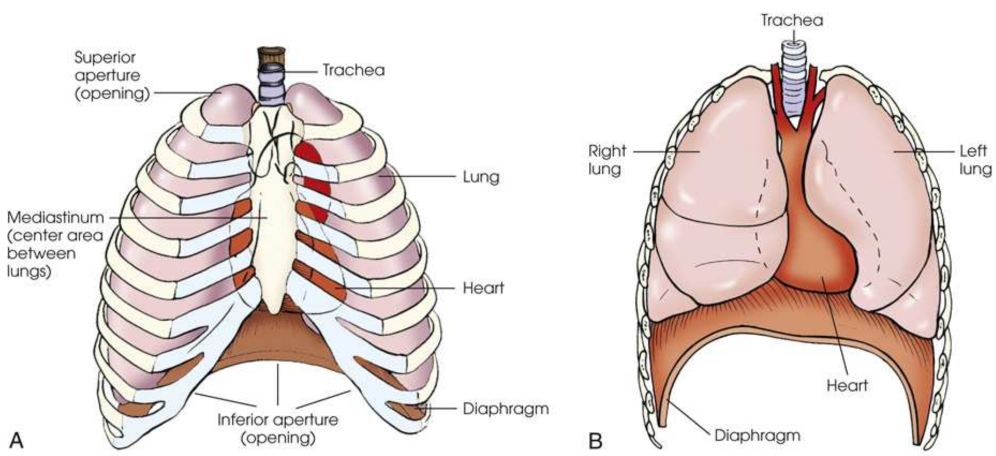


FIG. 3.2 (A) Thoracic cavity. (B) Thoracic cavity with anterior ribs removed.

Diagram (A) shows the anterior view of the thoracic cavity. The parts labeled in the diagram are as follows: superior aperture (opening), mediastinum (center area between lungs), inferior aperture (opening), trachea, lung, heart, and diaphragm. Diagram (B) shows the thoracic cavity with anterior ribs removed. The parts labeled in the diagram are as follows: right lung, diaphragm, trachea, heart, and left lung

Trachea

The *trachea* is a fibrous, muscular tube with 16 to 20 C-shaped cartilaginous rings embedded in its walls for greater rigidity (Fig. 3.3A). It measures approximately ½ inch (1.3 cm) in diameter and 4½ inches (11 cm) in length, and its posterior aspect is flat. The cartilaginous rings are incomplete posteriorly and extend around the anterior two-thirds of the tube. The trachea lies in the midline of the body, anterior to the esophagus in the neck. In the thorax, the trachea is shifted slightly to the right of the midline as a result of arching of the aorta. The trachea follows the curve of the vertebral column and extends from its junction with the larynx at the level of the sixth cervical vertebra inferiorly through the mediastinum to about the level of the space between the fourth and fifth thoracic vertebrae. The last tracheal cartilage is elongated and has a hook-like process, the *carina*, which extends posteriorly on its inferior surface. At the carina, the trachea divides, or bifurcates, into two lesser tubes—the primary bronchi. One of these bronchi enters the right lung, and the other enters the left lung.

The *primary bronchi* slant obliquely inferiorly to their entrance into the lungs, where they branch out to form the right and left bronchial branches (see Fig. 3.3B). The *right primary bronchus* is shorter, wider, and more vertical than the *left primary bronchus*. Because of the more vertical position and greater diameter of the right main bronchus, foreign bodies entering the trachea are more likely to pass into the right bronchus than the left bronchus.

After entering the lung, each primary bronchus divides, sending branches to each lobe of the lung: three to the right lung and two to the left lung. These *secondary bronchi* divide further and decrease in caliber. The bronchi continue dividing into *tertiary bronchi*, then into smaller *bronchioles*, and end in minute tubes called the *terminal bronchioles* (see Fig. 3.3). The extensive branching of the trachea is commonly referred to as the *bronchial tree* because it resembles a tree trunk (see box).

Subdivisions of the bronchial tree

- Trachea
  - Primary bronchi
    - Secondary bronchi
      - Tertiary bronchi
        - Bronchioles
          - Terminal bronchioles

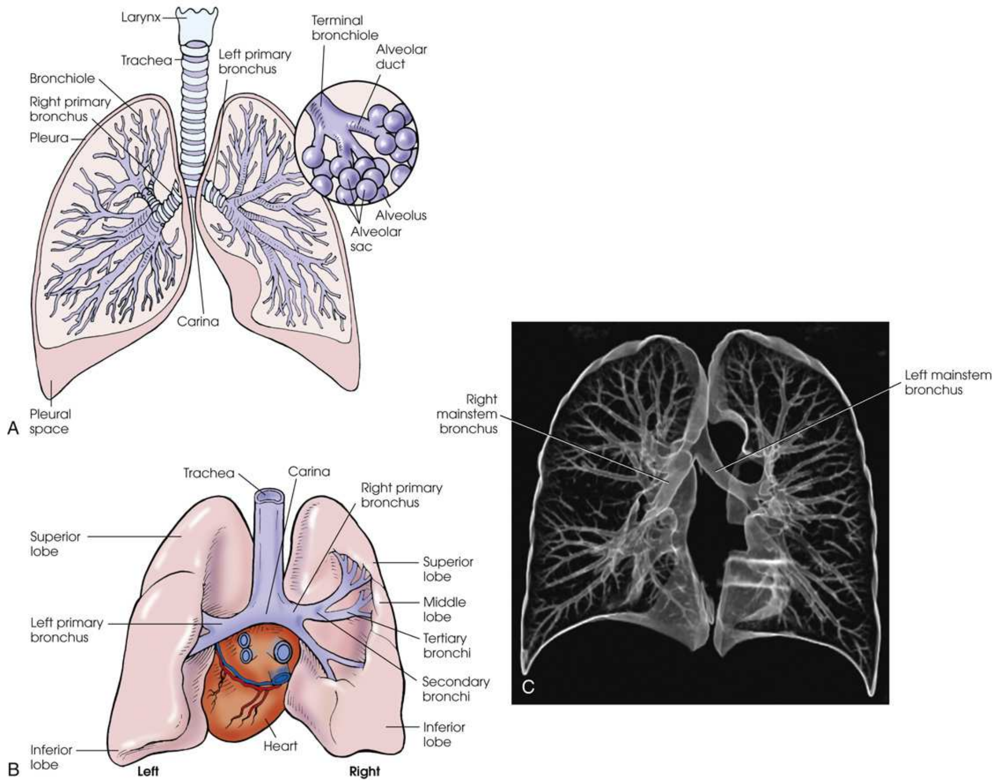


FIG. 3.3 (A) Anterior aspect of respiratory system. (B) Posterior aspect of heart, lungs, trachea, and bronchial trees. (C) Coronal, three-dimensional CT image of central and peripheral airways. C, From Kelley LL, Petersen CM. *Sectional Anatomy for Imaging Professionals*. 2nd ed. St Louis: Mosby; 2007.

Diagram (A) shows the anterior view of the respiratory system. The trachea has 16 to 20 C-shaped cartilaginous rings embedded in its walls. The last tracheal cartilage is elongated and has a hook-like process. At the carina, the trachea divides into two lesser tubes. One of these bronchi enters the right lung, and the other enters the left lung. The parts labeled in the diagram are as follows: larynx, trachea, bronchiole, right primary bronchus, pleura, pleural space, carina, left primary bronchus, terminal bronchiole, alveolar duct, alveolus, and alveolar sac. Diagram (B) shows the posterior view of the heart, lungs, trachea, and bronchial trees. The right primary bronchus is shorter, wider, and more vertical than the left primary bronchus. The parts labeled in the diagram on the left lung are as follows: superior lobe, left primary bronchus, inferior lobe, In the middle: trachea, carnia, heart. On the right: right primary bronchus, superior lobe, middle lobe, tertiary bronchi, secondary bronchi, and inferior lobe. (C) shows an C T view of the lungs. The parts labeled are right mainstem bronchus and left mainstem bronchus. The bronchus and the bronchioles appear white. A box is titled subdivisions of the bronchial tree. The contents of the box are as follows: trachea, primary bronchi, secondary bronchi, tertiary bronchi, bronchioles, terminal bronchioles.

Alveoli

The terminal bronchioles communicate with *alveolar ducts*. Each duct ends in several *alveolar sacs*. The walls of the alveolar sacs are lined with *alveoli* (see Fig. 3.3A). Each lung contains millions of alveoli. Oxygen and carbon dioxide are exchanged by diffusion within the walls of the alveoli.

Lungs

The *lungs* are the organs of respiration (Fig. 3.4). They provide the mechanism for introducing oxygen into the blood and removing carbon dioxide from the blood. The lungs are composed of a light, spongy, highly elastic substance, the *parenchyma,* and they are covered by a layer of serous membrane. Each lung presents a rounded *apex* that reaches above the level of the clavicles into the root of the neck and a broad *base* that, resting on the obliquely placed diaphragm, reaches lower in back and at the sides than in front. The right lung is approximately 1 inch (2.5 cm) shorter than the left lung because of the large space occupied by the liver, and it is broader than the left lung because of the position of the heart. The lateral surface of each lung conforms to the shape of the chest wall. The inferior surface of the lung is concave, fitting over the diaphragm, and the lateral margins are thin. During respiration, the lungs move inferiorly for inspiration and superiorly for expiration (Fig. 3.5). During inspiration, the lateral margins descend into the deep recesses of the parietal pleura. In radiology, this recess is called the *costophrenic angle* (see Fig. 3.5B). The mediastinal surface is concave with a depression called the *hilum* that accommodates the bronchi, pulmonary blood vessels, lymph vessels, and nerves. The inferior mediastinal surface of the left lung contains a concavity called the *cardiac notch*. This notch conforms to the shape of the heart.

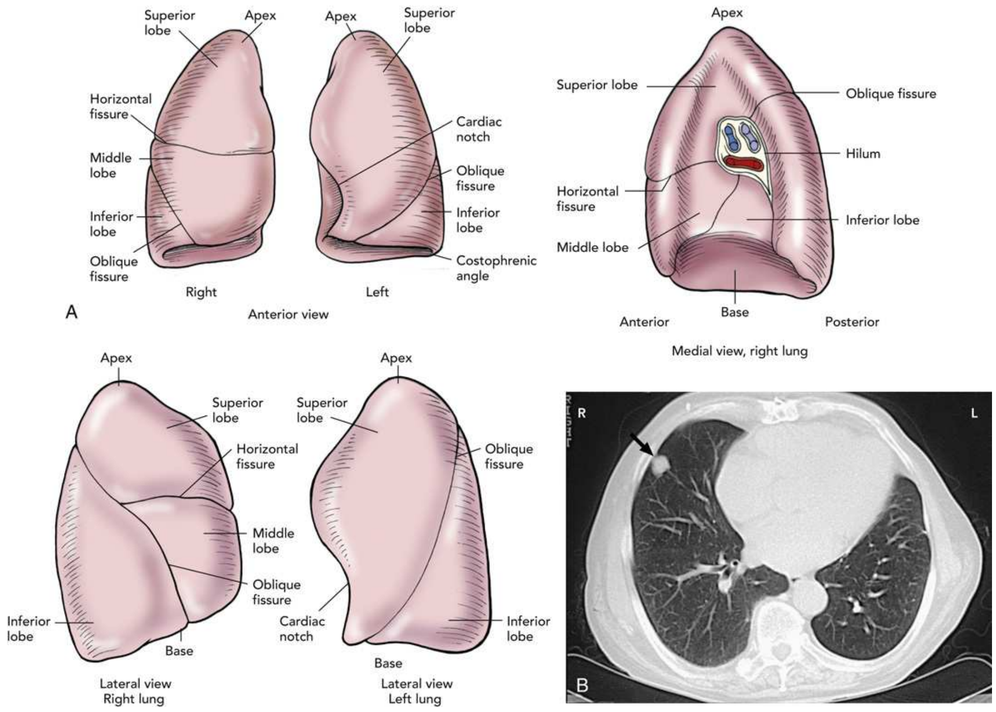


FIG. 3.4 (A) Three views of the lung. (B) CT axial image through the thorax. Right and left lungs are shown in actual position within thorax and in relation to heart. Note nodule in right anterior lung *(arrow)*.
B, Courtesy Siemens Medical Systems, Iselin, NJ.

Diagram (A) shows the three views of the lungs. The parts labeled in the anterior view are as follows. On the right lung: superior lobe, horizontal fissure, middle lobe, inferior lobe, oblique fissure, apex. On the left lung: apex, superior lobe, cardiac notch, inferior lobe, oblique fissure, costophrenic angle. The parts labeled in the lateral view are as follows. On the right lateral lung: apex, inferior lobe, base, superior lobe, horizontal fissure, middle lobe, oblique fissure. On the left lateral lung: apex, superior lobe, oblique fissure, cardiac notch, inferior lobe, base. The parts labeled in the medial view of the right lung are as follows. On the anterior side: superior lobe, horizontal fissure, middle lobe. In the middle: apex, base. On the posterior side: oblique fissure, hilum, inferior lobe. (B) shows the C T image of the thorax. The right lung appears big and the left lung is smaller. The heart and the other soft tissues appear white. A small circular nodule in the right lung is marked by an arrow.

Each lung is enclosed in a double-walled, serous membrane sac called the *pleura* (see Fig. 3.3A). The inner layer of the pleural sac, called the *visceral pleura*, closely adheres to the surface of the lung, extends into the interlobar fissures, and is contiguous with the outer layer at the hilum. The outer layer, called the *parietal pleura*, lines the wall of the thoracic cavity occupied by the lung and closely adheres to the upper surface of the diaphragm. The two layers are moistened by serous fluid so that they move easily on each other. The serous fluid prevents friction between the lungs and chest walls during respiration. The space between the two pleural walls is called the *pleural cavity*. Although the space is termed a cavity, the layers are actually in close contact.

Each lung is divided into *lobes* by deep fissures. The fissures lie in an oblique plane inferiorly and anteriorly from above, so that the lobes overlap each other in the anteroposterior (AP) direction. The *oblique fissures* divide the lungs into *superior* and *inferior lobes*. The superior lobes lie above and are anterior to the inferior lobes. The right superior lobe is divided further by a *horizontal fissure*, creating a *right middle lobe* (see Fig. 3.4). The left lung has no horizontal fissure and no middle lobe. The portion of the left lobe that corresponds in position to the right middle lobe is called the *lingula*. The lingula is a tongue-shaped process on the anteromedial border of the left lung. It fills the space between the chest wall and the heart.

Each of the five lobes divides into *bronchopulmonary segments* and subdivides into smaller units called *primary lobules*. The primary lobule is the anatomic unit of lung structure and consists of a terminal bronchiole with its expanded alveolar duct and alveolar sac.

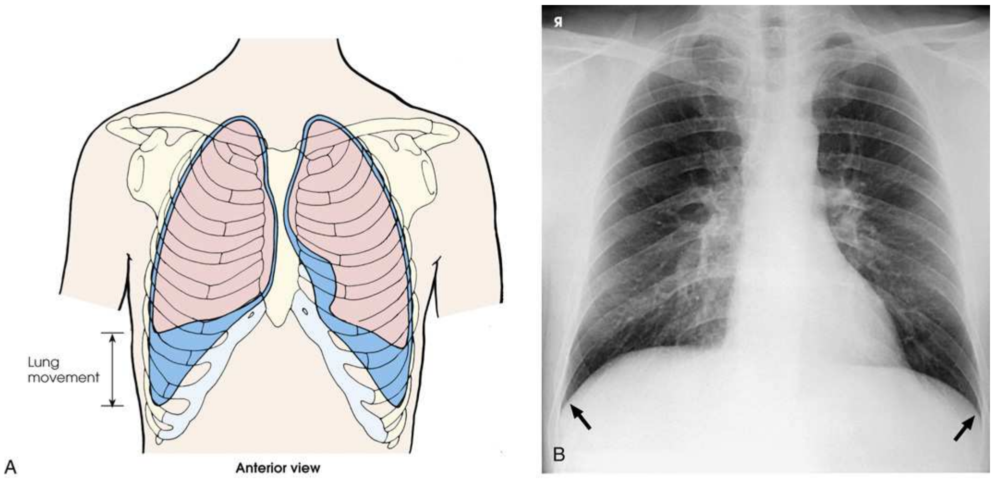


FIG. 3.5 (A) Movement of lungs during inspiration and expiration. (B) Costophrenic angles shown *(arrows)* on PA projection of chest.

(A) shows the anterior view of the lung. During respiration. The lung is enclosed in a double-walled, serous membrane sac called the pleura. The pleura is shaded in blue and the lung is shaded in pink. The lung movement is marked. (B) An x-ray view of the chest shows the mediastinal surface is concave with a depression. The inferior mediastinal surface of the left lung contains a concavity that conforms to the shape of the heart. It appears radiopaque.

Neck

The *neck* occupies the region between the skull and the thorax (Figs. 3.6 and 3.7). For radiographic purposes, the neck is divided into posterior and anterior portions in accordance with tissue composition and function of the structures. The procedures that are required to show the osseous structures occupying the posterior division of the neck are described in the discussion of the cervical vertebrae in Chapter 9. The portions of the central nervous system and circulatory system that pass through the neck are described in Chapters 14 and 27.

The portion of the neck that lies in front of the vertebrae is composed of largely soft tissues. The upper parts of the respiratory and digestive systems are the principal structures. The thyroid and parathyroid glands and the larger part of the submandibular glands are also located in the anterior portion of the neck.

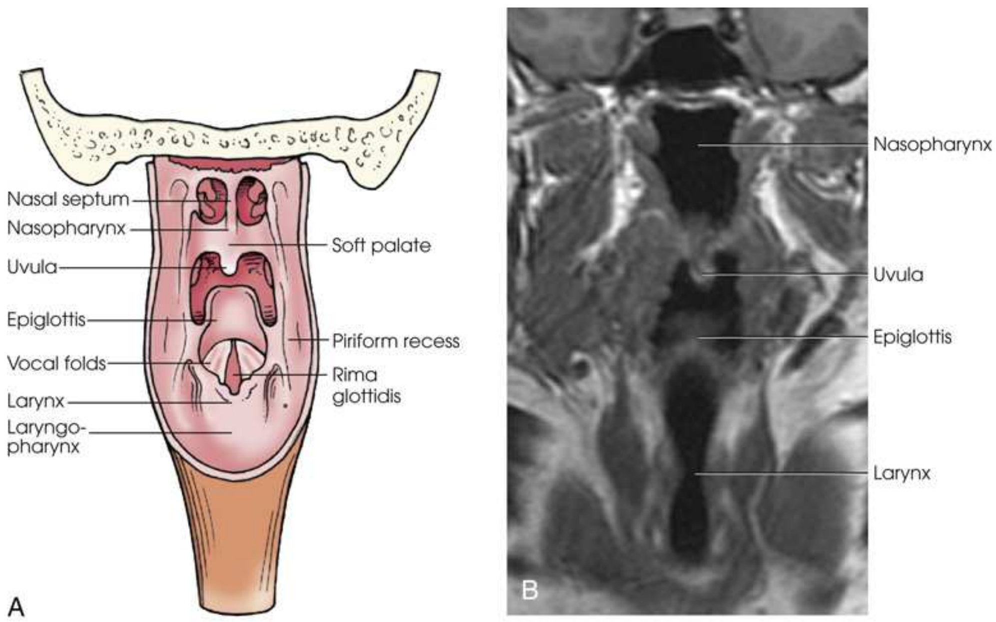


FIG. 3.6 (A) Interior posterior view of neck. (B) Coronal MRI of neck. B, Courtesy J. Louis Rankin, BS, RT[R][MR].

Diagram (A) shows the inferior posterior view of the neck. It is shaped like a horn. The parts labeled in the diagram are as follows: nasal septum, nasopharynx, uvula, epiglottis, vocal folds, larynx, laryngopharynx, soft palate, piriform recess, and rima glottidis. (B) shows the M R I of the neck. The nasopharynx appears radiolucent. The uvula is teardrop-shaped. The epiglottis is leaf-shaped and the larynx is dumbbell-shaped.

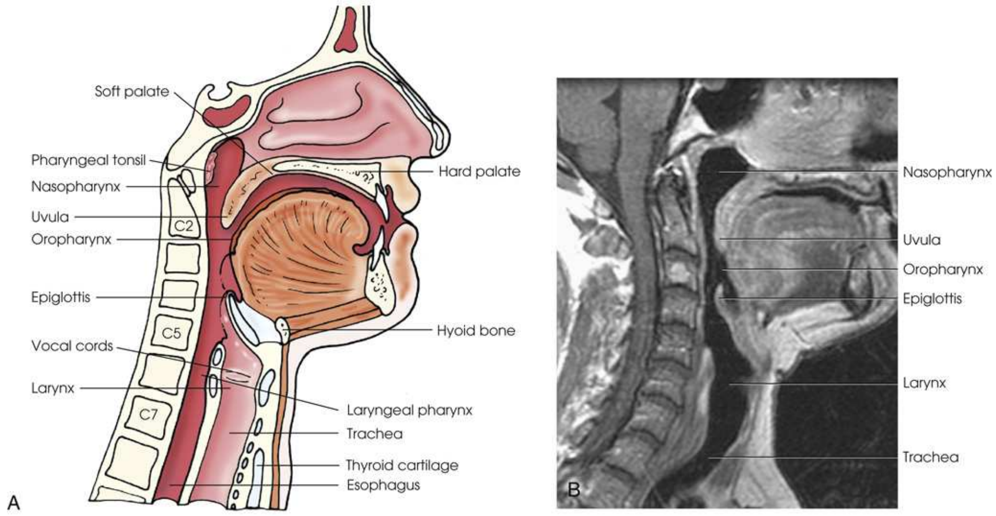


FIG. 3.7 (A) Sagittal section of face and neck. (B) Sagittal MRI of neck. B, Courtesy J. Louis Rankin, BS, RT[R][MR].

Diagram (A) shows the sagittal section of the face and neck. The parts labeled in the diagram are as follows: soft palate, pharyngeal tonsil, nasopharynx, uvula, oropharynx, epiglottis, vocal cords, larynx, C 2, C 5, C 7, hard palate, hyoid bone, laryngeal pharynx, thyroid cartilage, and esophagus, trachea. (B) shows a sagittal M R I of the neck. The parts labeled are as follows: nasopharynx, uvula, oropharynx, epiglottis, larynx, and trachea. They all appear radiolucent.

Thyroid Gland

The *thyroid gland* consists of two lateral lobes connected at their lower thirds by a narrow median portion called the *isthmus* (Fig. 3.8). The lobes are approximately 2 inches (5 cm) long, 1½ inches (3.2 cm) wide, and ¾ inch (1.9 cm) thick. The isthmus lies at the front of the upper part of the trachea, and the lobes lie at the sides. The lobes reach from the lower third of the thyroid cartilage to the level of the first thoracic vertebra. Although the thyroid gland is normally suprasternal in position, it occasionally extends into the superior aperture of the thorax.

Parathyroid Glands

The *parathyroid glands* are small ovoid bodies—two on each side, *superior* and *inferior*. These glands are situated one above the other on the posterior aspect of the adjacent lobe of the thyroid gland.

Pharynx

The *pharynx* serves as a passage for air and food and is common to the respiratory and digestive systems (see Fig. 3.7). The pharynx is a musculomembranous, tubular structure situated in front of the vertebrae and behind the nose, mouth, and larynx. Approximately 5 inches (13 cm) in length, the pharynx extends from the undersurface of the body of the sphenoid bone and the basilar part of the occipital bone inferiorly to the level of the disk between the sixth and seventh cervical vertebrae, where it becomes continuous with the esophagus. The pharyngeal cavity is subdivided into nasal, oral, and laryngeal portions.

The *nasopharynx* lies posteriorly above the *soft* and *hard* palates. (The upper part of the hard palate forms the floor of the nasopharynx.) Anteriorly, the nasopharynx communicates with the posterior apertures of the nose. Hanging from the posterior aspect of the soft palate is a small conical process, the *uvula*. On the roof and posterior wall of the nasopharynx, between the orifices of the auditory tubes, the mucosa contains a mass of lymphoid tissue known as the *pharyngeal tonsil* (or *adenoids* when enlarged). Hypertrophy of this tissue interferes with nasal breathing and is common in children. This condition is well shown in a lateral radiographic image of the nasopharynx.

The *oropharynx* is the portion extending from the soft palate to the level of the *hyoid bone*. The base, or root, of the tongue forms the anterior wall of the oropharynx. The *laryngeal pharynx* lies posterior to the larynx, its anterior wall being formed by the posterior surface of the larynx. The laryngeal pharynx extends inferiorly and is continuous with the esophagus.

The air-containing nasal and oral pharynges are well visualized in lateral images, except during the act of phonation, when the soft palate contracts and tends to obscure the nasal pharynx. An opaque medium is required to show the lumen of the laryngeal pharynx, although it can be distended with air during the *Valsalva maneuver* (an increase in intrathoracic pressure produced by forcible expiration effort against the closed glottis).

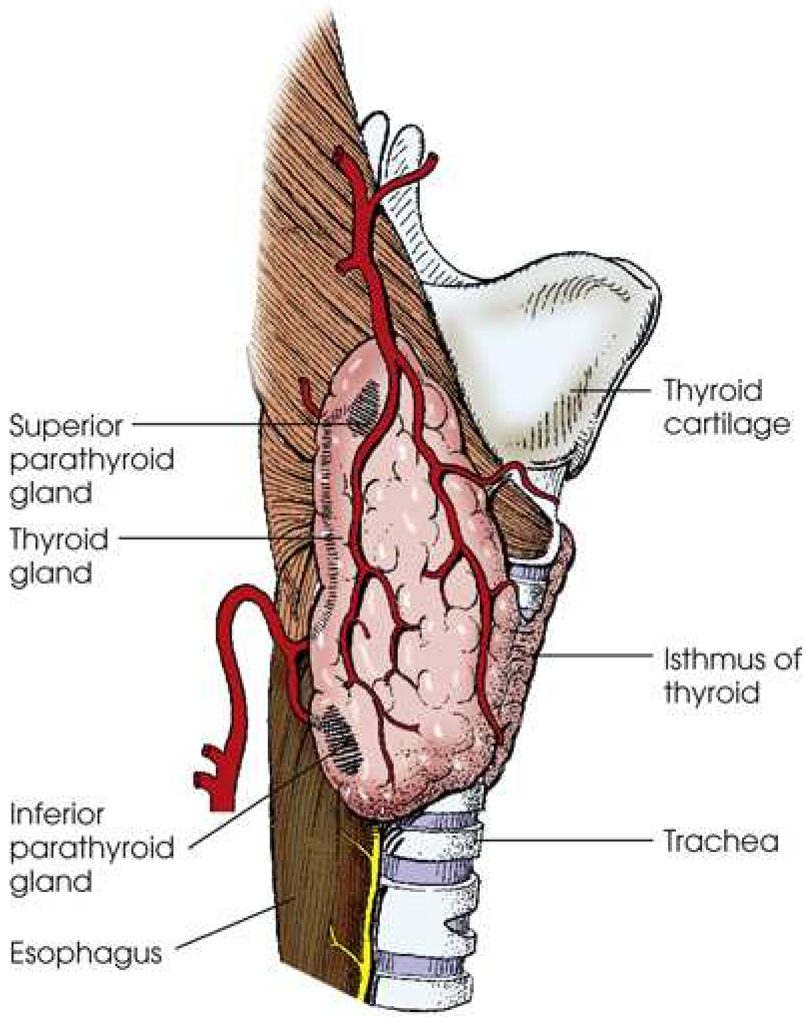


FIG. 3.8 Lateral aspect of laryngeal area showing thyroid gland and isthmus that connects its two lobes.

Diagram shows the lateral aspect of the laryngeal area. The parts labeled in the diagram are as follows: superior parathyroid gland, thyroid gland, inferior parathyroid gland, esophagus, thyroid cartilage, isthmus of thyroid, trachea.

Larynx

The larynx is the organ of voice (Figs. 3.9 and 3.10; see Figs. 3.6 through 3.8). Serving as the air passage between the pharynx and the trachea, the larynx is also one of the divisions of the respiratory system.

The larynx is a movable, tubular structure; is broader above than below; and is approximately 1½ inches (3.8 cm) in length. Situated below the root of the tongue and in front of the laryngeal pharynx, the larynx is suspended from the hyoid bone and extends from the level of the superior margin of the fourth cervical vertebra to its junction with the trachea at the level of the inferior margin of the sixth cervical vertebra. The thin, leaf-shaped *epiglottis* is situated behind the root of the tongue and the hyoid bone and above the laryngeal entrance. It has been stated that the epiglottis serves as a trap to prevent leakage into the larynx between acts of swallowing. The *thyroid cartilage* forms the laryngeal prominence, or *Adam's apple*.

The inlet of the larynx is oblique, slanting posteriorly as it descends. A pouch-like fossa called the *piriform recess* is located on each side of the larynx and external to its orifice. The piriform recesses are well shown as triangular areas on frontal projections when insufflated with air (Valsalva maneuver) or when filled with an opaque medium.

The entrance of the larynx is guarded superiorly and anteriorly by the epiglottis and laterally and posteriorly by folds of mucous membrane. These folds, which extend around the margin of the laryngeal inlet from their junction with the epiglottis, function as a sphincter during swallowing. The *laryngeal cavity* is subdivided into three compartments by two pairs of mucosal folds that extend anteroposteriorly from its lateral walls. The superior pairs of folds are the *vestibular folds*, or false vocal cords. The space above them is called the *laryngeal vestibule*. The lower two folds are separated from each other by a median fissure called the *rima glottidis*. They are known as the *vocal folds*, or true vocal folds (see Fig. 3.10). The vocal cords are vocal ligaments that are covered by the vocal folds. The ligaments and the rima glottidis constitute the vocal apparatus of the larynx. Collectively, these structures are referred to as the *glottis*.

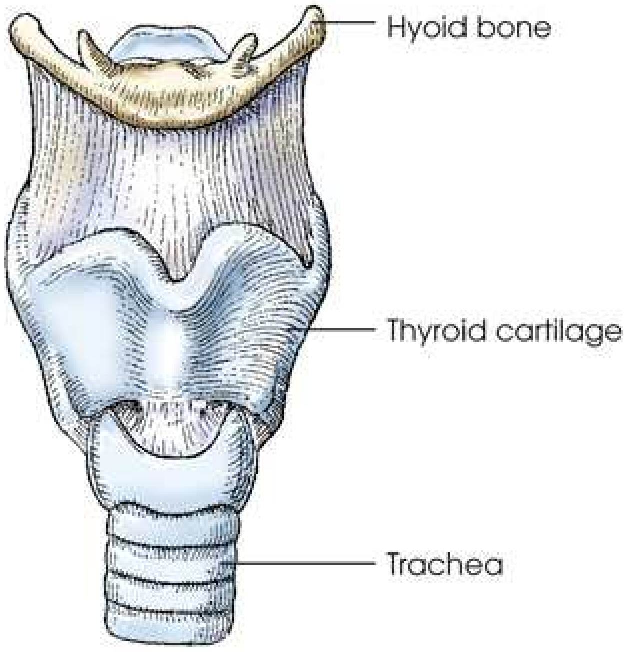


FIG. 3.9 Anterior aspect of larynx.

Diagram shows the anterior aspect of the larynx. The larynx is a movable, tubular structure and is broader above than below. The parts labeled in the diagram are as follows: hyoid bone, thyroid cartilage, and trachea.

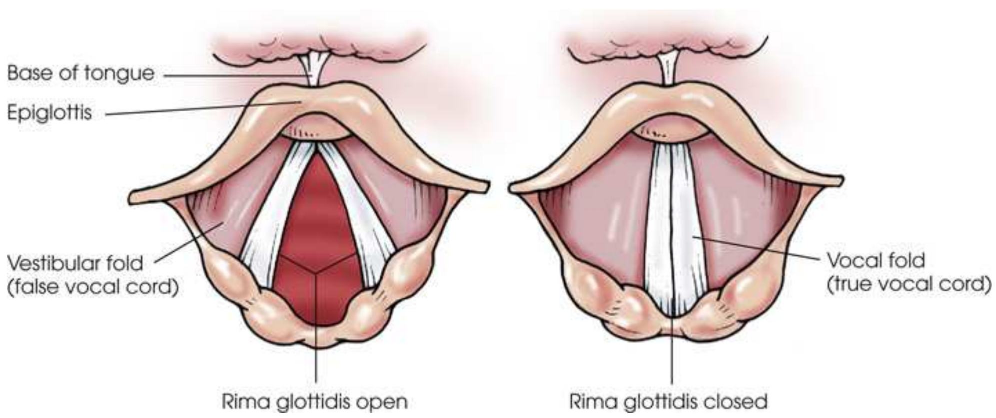


FIG. 3.10 Superior aspect of larynx (open and closed true vocal folds).

Diagram on the left shows the open vocal fold. It is triangle-shaped. The parts labeled in the diagram are as follows: base of tongue, epiglottis, vestibular fold, (false vocal cord) rima glottidis open. Diagram on the right shows the closed vocal folds. The parts labeled in the diagram are as follows: vocal fold (true vocal cord), rima glottidis closed.

Mediastinum

The *mediastinum* is the area of the thorax bounded by the sternum anteriorly, the spine posteriorly, and the lungs laterally (Fig. 3.11). The structures associated with the mediastinum are as follows:

- Heart
- Great vessels
- Trachea
- Esophagus
- Thymus
- Lymphatics
- Nerves
- Fibrous tissue
- Fat

The *esophagus* is the part of the digestive canal that connects the pharynx with the stomach. It is a narrow, musculomembranous tube approximately 9 inches (23 cm) in length. Following the curves of the vertebral column, the esophagus descends through the posterior part of the mediastinum and then runs anteriorly to pass through the esophageal hiatus of the diaphragm.

The esophagus lies just in front of the vertebral column, with its anterior surface in close relation to the trachea, aortic arch, and heart. This makes the esophagus valuable in certain heart examinations. When the esophagus is filled with barium sulfate, the posterior border of the heart and the aorta are outlined well in lateral and oblique projections (Fig. 3.12). Frontal, oblique, and lateral images are often used in examinations of the esophagus. Radiography of the esophagus is discussed in Chapter 15.

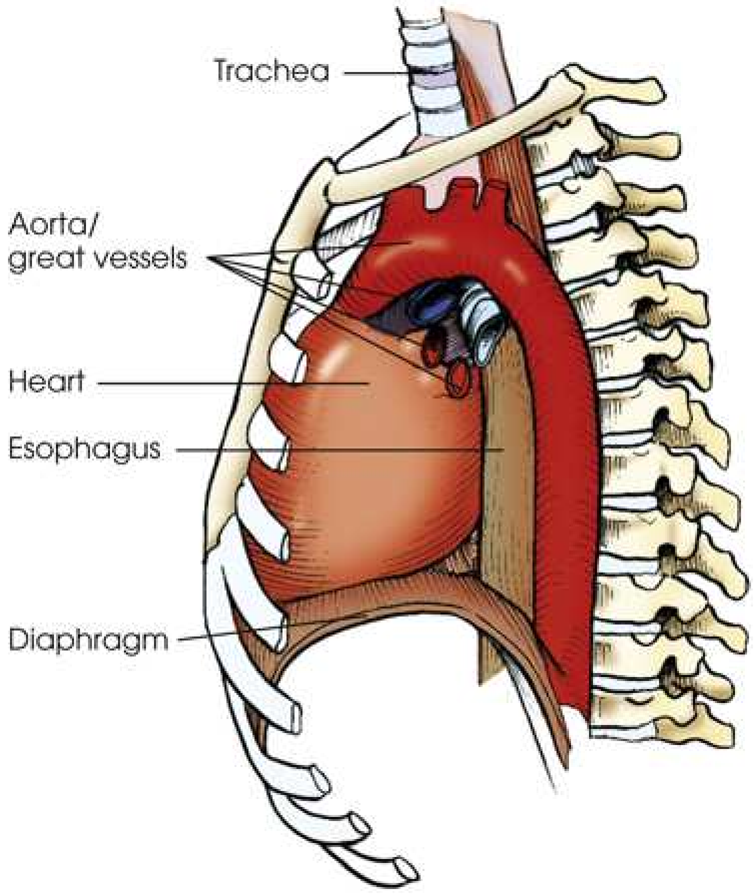


FIG. 3.11 Lateral view of mediastinum, identifying main structures.

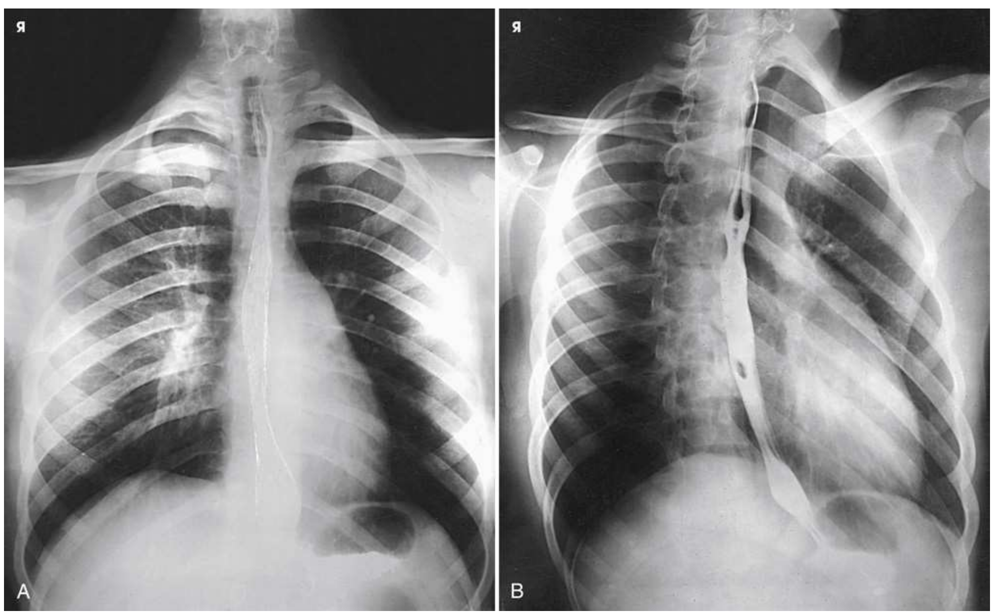


FIG. 3.12 (A) PA projection of esophagus with barium sulfate coating its walls. (B) PA oblique projection with barium-filled esophagus (RAO position).

(A) An x-ray view of the chest shows the posterior border of the heart and the aorta outlined. The lungs appear radiolucent. (B) An x-ray view of the chest shows the long and slender esophagus and it appears radiopaque.

The *thymus gland* is the primary control organ of the lymphatic system. It is responsible for producing the hormone *thymosin*, which plays a crucial role in the development and maturation of the immune system. The thymus consists of two pyramid-shaped lobes that lie in the lower neck and superior mediastinum, anterior to the trachea and great vessels of the heart, and posterior to the manubrium. The thymus reaches its maximum size at puberty and then gradually undergoes atrophy until it almost disappears (Fig. 3.13).

In older individuals, lymphatic tissue is replaced by fat. At its maximum development, the thymus rests on the pericardium and reaches as high as the thyroid gland. When the thymus is enlarged in infants and young children, it can press on the retrothymic organs, displacing them posteriorly and causing respiratory disturbances. A radiographic examination may be made in the AP and lateral projections. For optimal image contrast, exposures should be made at the end of full inspiration.

Summary of Anatomy

Body habitus

- Sthenic
- Asthenic
- Hyposthenic
- Hypersthenic

Thoracic cavity

- Superior thoracic aperture
- Inferior thoracic aperture
- Diaphragm
- Thoracic viscera
  - Lungs
  - Heart
  - Respiratory system
  - Cardiac system
  - Lymphatic system
  - Inferior esophagus
  - Thymus gland
  - Pericardial cavity
  - Pleural cavities
  - Serous membranes
  - Mediastinum

Respiratory system

- Pharynx
- Nasopharynx
- Soft palate
- Hard palate
- Uvula
- Pharyngeal tonsil
- Oropharynx
- Hyoid bone
- Laryngeal pharynx
- Larynx
  - Epiglottis
  - Thyroid cartilage
  - Piriform recess
  - Laryngeal cavity
  - Vestibular folds (false vocal cords)
  - Laryngeal vestibule
  - Rima glottides
- Vocal folds (true vocal cords)
- Glottis
- Trachea
  - Carina
- Primary bronchi
  - Right primary bronchus
  - Left primary bronchus
  - Secondary bronchi
  - Tertiary bronchi
  - Bronchioles
  - Terminal bronchioles
- Bronchial tree

Alveoli

- Alveolar duct

Alveolar sac
Alveoli

Lungs

Parenchyma
Apex
Base
Costophrenic angles
Hilum
Cardiac notch
Pleura
- Visceral pleura
- Parietal pleura
- Serous fluid
- Pleural cavity

Lobes
- Superior lobes
- Inferior lobes
- Right middle lobe

Interlobar fissures
- Oblique fissures (2)
- Horizontal fissure

Lingula
Bronchopulmonary segments
Primary lobules

Mediastinum

Heart
Great vessels
Trachea
Esophagus
Thymus
Lymphatics
Nerves
Fibrous tissue
Fat

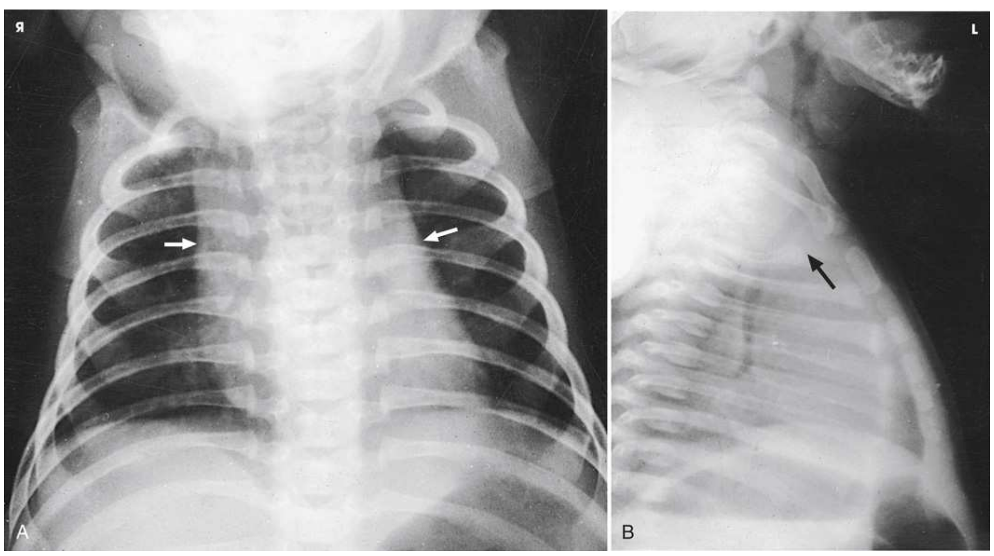


FIG. 3.13 (A) PA chest radiograph showing mediastinal enlargement caused by hypertrophy of thymus *(arrows)*. (B) Lateral chest radiograph showing enlarged thymus *(arrow)*.

(A) An x-ray view of the chest has a white area around the mediastinum. It is indicated by two white arrows on either side of the mediastinum. (B) (A) An x-ray view of the lateral chest shows a radiopaque region on top. It is indicated by a black arrow.

Computed Tomography

Currently, computed tomography (CT) is used almost exclusively to image the anatomic areas of the thorax, including the thymus gland. CT is excellent at showing all thoracic structures (Fig. 3.14).

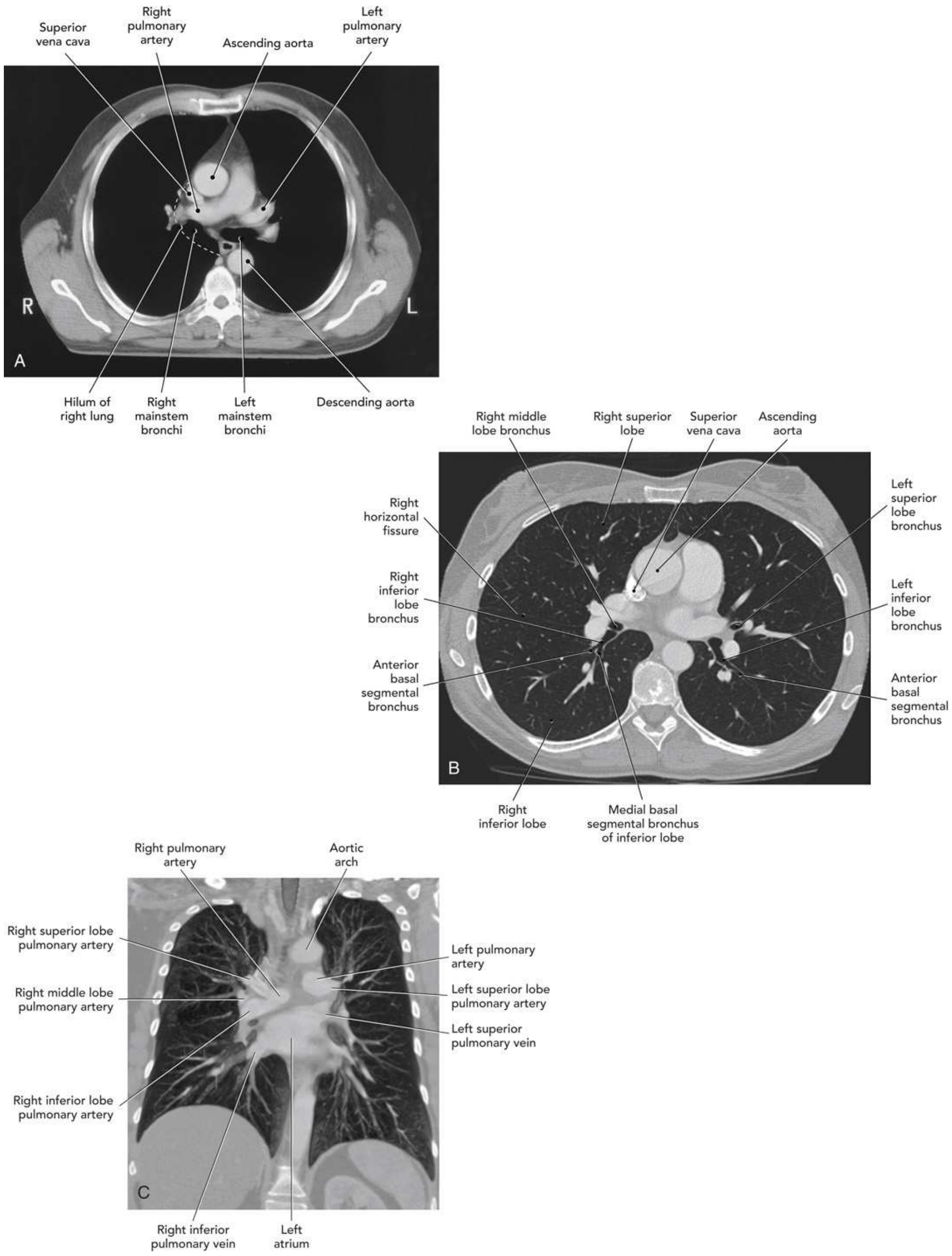


FIG. 3.14 CT images of the thorax. (A) Axial CT scan of midthorax showing mediastinal structures. (B) Axial CT scan of midthorax showing mediastinal structures along with lung and bronchial structures. (C) Coronal CT reformat image showing pulmonary vessels.

(A) A C T image shows the mediastinal structures. The parts labeled on top are as follows: superior vena cava, right pulmonary, artery, ascending aorta, left pulmonary artery. At the bottom: hilum of right lung, right mainstem bronchi, left mainstem bronchi, descending aorta. The ascending and descending aorta is round. (B) A C T image shows the mediastinal structures, lung, and bronchial structures. The parts labeled are as follows: right horizontal fissure, right inferior lobe bronchus, anterior basal segmental bronchus, right inferior lobe, medial basal segmental bronchus of inferior lobe, right middle lobe bronchus, right superior lobe, superior vena cava, ascending aorta, left superior lobe bronchus, left inferior lobe bronchus, anterior basal segmental bronchus. (C) A C T image shows the pulmonary vessels. The parts labeled are as follows: right superior lobe pulmonary artery, left superior lobe pulmonary artery, left superior pulmonary vein, right middle lobe pulmonary artery, right pulmonary artery, left pulmonary artery, aortic arch, left atrium, right inferior pulmonary vein, right inferior lobe pulmonary artery.

Summary of Pathology

Condition	Definition
Aspiration/foreign body	Inspiration of a foreign material into the airway
Atelectasis	Collapse of all or part of the lung
Bronchiectasis	Chronic dilation of the bronchi and bronchioles associated with secondary infection
Bronchitis	Inflammation of the bronchi
Chronic obstructive pulmonary disease	Chronic condition of persistent obstruction of bronchial airflow
Cystic fibrosis	Disorder associated with widespread dysfunction of the exocrine glands, abnormal secretion of sweat and saliva, and accumulation of thick mucus in the lungs
Emphysema	Destructive and obstructive airway changes leading to an increased volume of air in the lungs
Epiglottitis	Inflammation of the epiglottis
Fungal disease	Inflammation of the lung caused by a fungal organism
Histoplasmosis	Infection caused by the yeast-like organism *Histoplasma capsulatum*
Granulomatous disease	Condition of the lung marked by formation of granulomas
Sarcoidosis	Condition of unknown origin often associated with pulmonary fibrosis
Tuberculosis	Chronic infection of the lung caused by the tubercle bacillus
Hyaline membrane disease or respiratory distress syndrome	Under-aeration of the lungs caused by lack of surfactant
Metastasis	Transfer of a cancerous lesion from one area to another
Pleural effusion	Collection of fluid in the pleural cavity
Pneumoconiosis	Lung diseases resulting from inhalation of industrial substances
Anthracosis or coal miner lung or black lung	Inflammation caused by inhalation of coal dust (anthracite)
Asbestosis	Inflammation caused by inhalation of asbestos
Silicosis	Inflammation caused by inhalation of silicon dioxide
Pneumonia	Acute infection in the lung parenchyma
Aspiration	Pneumonia caused by aspiration of foreign particles
Interstitial or viral or pneumonitis	Pneumonia caused by a virus and involving the alveolar walls and interstitial structures
Lobar or bacterial	Pneumonia involving the alveoli of an entire lobe without involving the bronchi
Lobular or bronchopneumonia	Pneumonia involving the bronchi and scattered throughout the lung
Pneumothorax	Accumulation of air in the pleural cavity resulting in collapse of the lung
Pulmonary edema	Replacement of air with fluid in the lung interstitium and alveoli
Tumor	New tissue growth where cell proliferation is uncontrolled

Eponymous (named) pathologies are listed in nonpossessive form to conform to the *AMA manual of style: a guide for authors and editors*, ed 10, Oxford, 2009, Oxford University Press.

These techniques were accurate for the equipment used to produce each exposure. However, use caution when applying them in your department because "there is considerable variability in image receptor response owing to varying scatter sensitivity, the use of grids with different grid ratios, collimation, beam filtration, the choice of kilovoltage, source-to-image distance, and image receptor size."[1]

This chart was created in collaboration with Dennis Bowman, AS, RT(R), Clinical Instructor, Community Hospital of the Monterey Peninsula, Monterey, CA. http://digitalradiographysolutions.com/.

Thoracic Viscera

Part	cm	kVp[a]	SID[b]	Collimation	CR[c]		DR[d]	
					mAs	Dose (mGy)[e]	mAs	Dose (mGy)[e]
Chest: Lungs and heart—*PA*[f]	22	120	72″	14″ × 16″ (35 × 40 cm)	2.8[g]	0.188	1.4[g]	0.089
Chest: Lungs and heart—*lateral*[f]	33	120	72″	14″ × 17″ (35 × 43 cm)	7.1[g]	0.550	3.6[g]	0.273
Chest: Lungs and heart—*PA oblique*[f]	25	120	72″	14″ × 17″ (35 × 43 cm)	3.6[g]	0.255	1.8[g]	0.124
Chest: Lungs and heart—*AP*[h]	22	90	40″	16″ × 14″ (40 × 35 cm)	4.0[g]	0.655		
Chest: Lungs and heart—*AP*[h]	22	105	40″	16″ × 14″ (40 × 35 cm)			1.6[g]	0.340
Chest: Lungs and heart—*AP*[f]	22	120	72″	14″ × 16″ (35 × 40 cm)	3.2[g]	0.217	1.6[g]	0.104
Pulmonary apices—*AP axial*[f]	23	120	72″	14″ × 11″ (35 × 28 cm)	4.0[g]	0.198	2.0[g]	0.097
Lungs and pleurae—*lateral decubitus*[f]	22	120	72″	17″ × 14″ (43 × 35 cm)	4.0[g]	0.271	2.0[g]	0.133
Lungs and pleurae—*dorsal/ventral decubitus*[f]	33	120	72″	17″ × 14″ (43 × 35 cm)	9.0[g]	0.697	4.5[g]	0.344

AP, Anteroposterior; *PA,* posteroanterior; *SID,* source-to-image receptor distance.

[1] ACR-AAPM-SIMM Practice Parameter for Digital Radiography, revised 2017.

[a] kVp values are for a high-frequency generator.

[b] 40 inches minimum; 44 to 48 inches recommended to improve spatial resolution (mAs increase needed, but no increase in patient dose will result).

[c] AGFA CR MD 4.0 General IP, CR 75.0 reader, 400 speed class, with 6:1 (178LPI) grid when needed.

[d] GE Definium 8000, with 13:1 grid when needed.

[e] All doses are skin entrance for average adult (160 to 200 pounds male, 150 to 190 pounds female) at part thickness indicated.

[f] Bucky/Grid.

[g] Large focal spot.

[h] Nongrid.

Radiography

Soft Tissue Neck

Radiography of the neck can be used to evaluate the cervical spine or the soft tissues of the anterior neck. Soft tissue neck radiographs can demonstrate foreign bodies, swelling (especially epiglottitis), masses (intrinsic and extrinsic to airway), and fractures of the larynx and hyoid bone. The patient can be positioned either upright or recumbent, depending on physical condition. Radiographs are most commonly made of the upper airway, from the superior oropharynx to the proximal trachea.

Ap Projection

Image receptor + grid: Positioned by manufacturer or department protocol for proper anatomy display orientation; central ray (CR) plate: 10 × 12 inches (24 × 30 cm) lengthwise.

Position of patient

- Performed in either the supine or the upright position, depending on patient condition
- Position of part
- Center the midsagittal plane of the body to the midline of the grid.
- Adjust the patient's shoulders to lie in the same transverse plane.
- Extend the patient's neck slightly and adjust it so that the midsagittal plane is perpendicular to the plane of the IR (Figs. 3.15 and 3.16).
- Center the IR at the level of the laryngeal prominence (for upper airway) or manubrium (for larynx and superior mediastinum).
- *Shield gonads.*
- *Respiration*: Exposure is made during slow inspiration to ensure that the trachea is filled with air.

Central ray

- Perpendicular through the midsagittal plane at the level of the laryngeal prominence (upper airway) or manubrium (larynx and superior mediastinum)

Collimation

- Adjust radiation field to 12 inches (30 cm) lengthwise and 1 inch (2.5 cm) beyond the skin line on the sides but not more than 10 inches (24 cm). Place a side marker in the collimated exposure field.

FIG. 3.15 AP soft tissue neck: pharynx and larynx.

A patient is in a supine position. The neck is extended and the midsagittal plane is perpendicular to the plane of the I R. The patient's shoulders lie in the same transverse plane. The central ray is perpendicular through the midsagittal plane at the level of the laryngeal prominence.

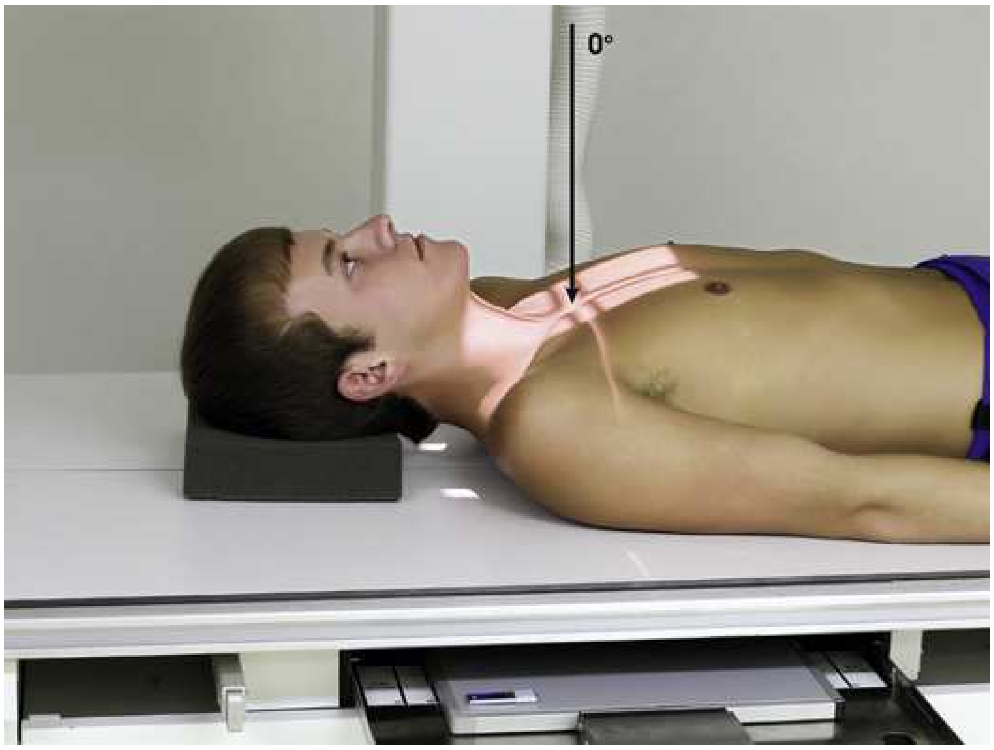


FIG. 3.16 AP soft tissue neck: trachea and superior mediastinum.

A patient is in a supine position. The patient's shoulders lie in the same transverse plane. The head is elevated by placing support under it. The central ray is perpendicular to the midsagittal plane at the level of the laryngeal prominence.

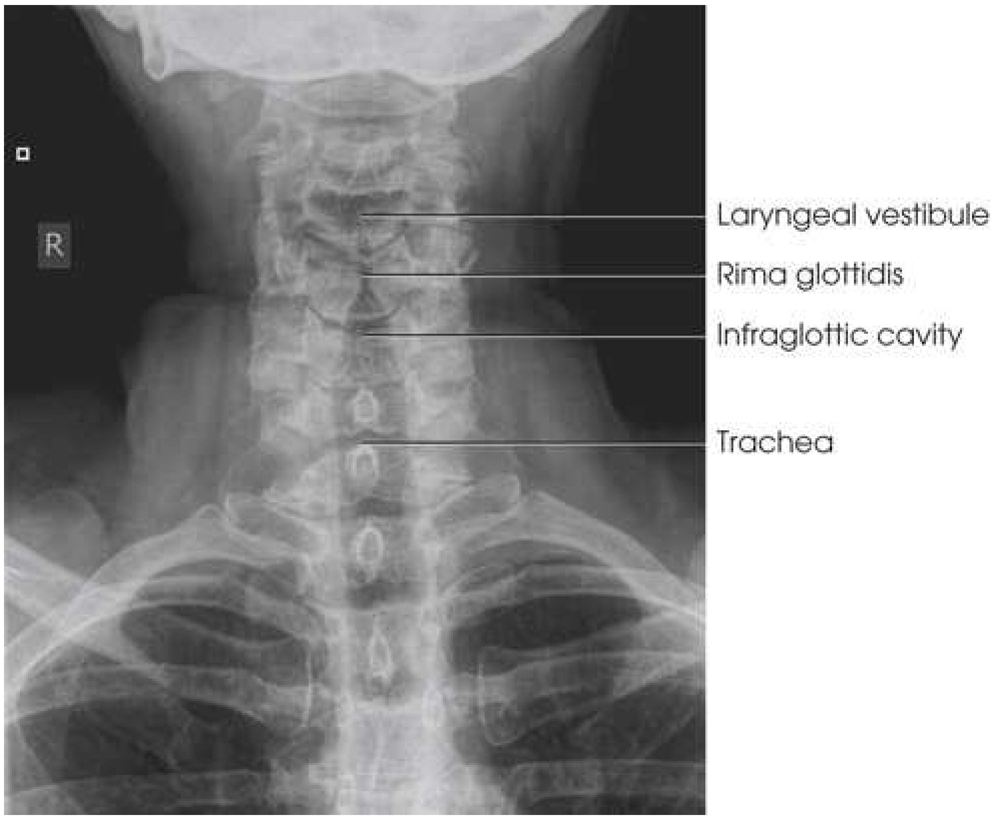


FIG. 3.17 AP soft tissue neck: pharynx and larynx during quiet breathing.

An x-ray shows the air-filled upper airway from the pharynx to the proximal trachea. Small teardrop-shaped outlines are on the mediastinum. The parts labeled are marked from top to bottom as follows: laryngeal vestibule, rima glottidis, infraglottic cavity, and trachea.

FIG. 3.18 AP soft tissue neck: trachea *(arrows)* and superior mediastinum during quiet breathing.

An x-ray shows the air-filled airway, from the midcervical to the midthoracic region. Small teardrop-shaped outlines are on the trachea. The airway is superimposed on the shadow of the cervical vertebrae. The trachea is marked by three black arrows.

Structures shown

The resulting image shows the air-filled upper airway or the trachea and superior mediastinum. Under normal conditions, the airway is superimposed on the shadow of the cervical vertebrae (Figs. 3.17 and 3.18).

Evaluation Criteria

The following should be clearly seen:

- Evidence of proper collimation and presence of a side marker placed clear of anatomy of interest
- Air-filled upper airway, from the pharynx to the proximal trachea (for upper airway)
- Air-filled airway, from the midcervical to the midthoracic region (for trachea and superior mediastinum)
- No rotation, with spinous processes equidistant to the pedicles and aligned with the midline of the cervical bodies
- Bony trabecular detail and surrounding soft tissues

Lateral Projection

R or L position

Image receptor + grid: Positioned by manufacturer or department protocol for proper anatomy display orientation; CR plate: 10 × 12 inches (24 × 30 cm) lengthwise.

Position of patient

- Place the patient in a lateral position, either seated or standing, before a vertical grid device. If the standing position is used, the weight of the patient's body must be equally distributed on the feet.

Position of part

- Instruct the patient to clasp the hands behind the body and rotate the shoulders posteriorly as far as possible (see Figs. 3.19 and 3.20). This position keeps the superimposed shadows of the arms from obscuring the structures of the superior mediastinum.
- Adjust the patient's position to center the airway to the midline of the IR. The trachea lies in the coronal plane that passes approximately midway between the jugular notch and the midcoronal plane.
- Center the IR at the level of the laryngeal prominence (for upper airway) or manubrium (for larynx and superior mediastinum).
- Readjust the position of the body, being careful to have the midsagittal plane vertical and parallel with the plane of the IR.
- Extend the neck slightly.
- *Shield gonads.*
- *Respiration:* Exposure is made during slow inspiration to ensure that the trachea is filled with air.

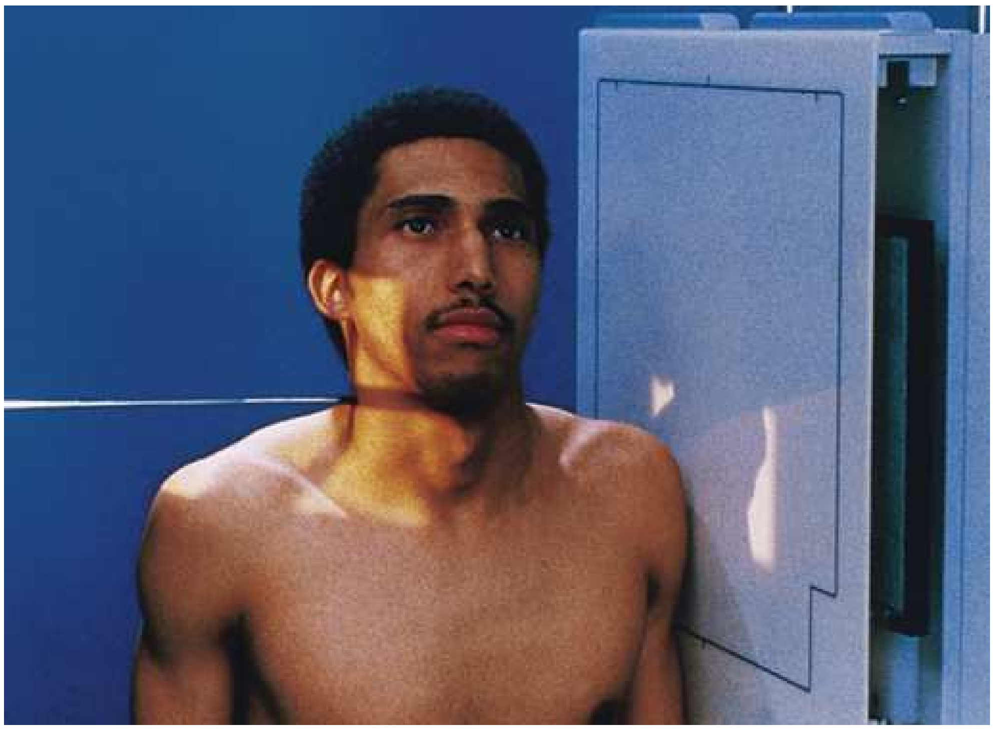


FIG. 3.19 Lateral soft tissue neck: pharynx and larynx.

A patient is in an upright position and his lateral side is placed against the vertical grid. The shoulders are rotated posteriorly. The central ray is horizontal through the midcoronal plane at the level of the laryngeal prominence.

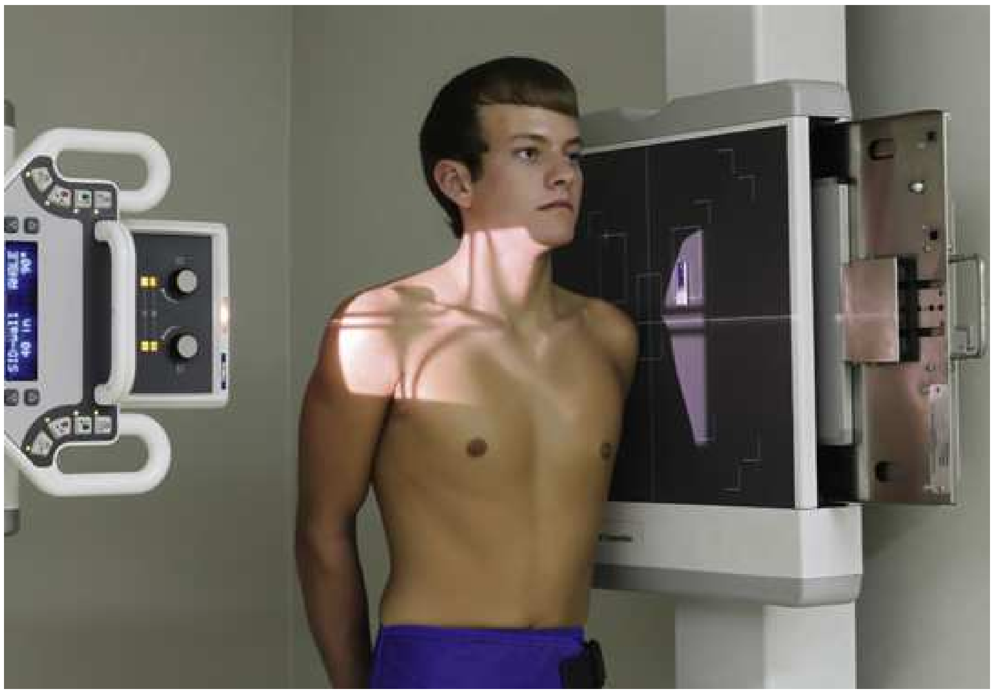


FIG. 3.20 Lateral soft tissue neck: trachea and superior mediastinum.

A patient is in an upright position and his lateral side is placed against the vertical grid. The hands are clasped behind the body and the shoulders are rotated posteriorly. The central ray is at the level of the jugular notch through a point midway between the jugular notch and the midcoronal plane.

Central ray

- Horizontal through the midcoronal plane at the level of the laryngeal prominence (for upper airway [Fig. 3.21]) or at the level of the jugular notch through a point midway between the jugular notch and the midcoronal plane (for trachea and superior mediastinum [Fig. 3.22])

Collimation

- Adjust radiation field to 12 inches (30 cm) lengthwise and 1 inch (2.5 cm) beyond the skin line of the anterior and posterior surfaces but not greater than 10 inches (24 cm). Place a side marker in the collimated exposure field.

Structures shown

The resulting image shows the air-filled upper airway or the trachea and superior mediastinum. The projection for the trachea and superior mediastinum, first described by Eiselberg and Sgalitzer, [1] is used to show retrosternal extensions of the thyroid gland, thymic enlargement in infants (in the recumbent position), the opacified pharynx and upper esophagus, and an outline of the trachea and bronchi. It is also used to locate foreign bodies.

Evaluation Criteria

The following should be clearly seen:

- Evidence of proper collimation and presence of a side marker placed clear of anatomy of interest
- Air-filled upper airway, from the pharynx to the proximal trachea (for upper airway)
- Air-filled airway, from the midcervical to the midthoracic region (for trachea and superior mediastinum)
- No rotation or tilt of the cervical spine
  - Superimposed zygapophyseal joints and open intervertebral joints
  - Superimposed or nearly superimposed mandibular rami
- Bony trabecular detail and surrounding soft tissues

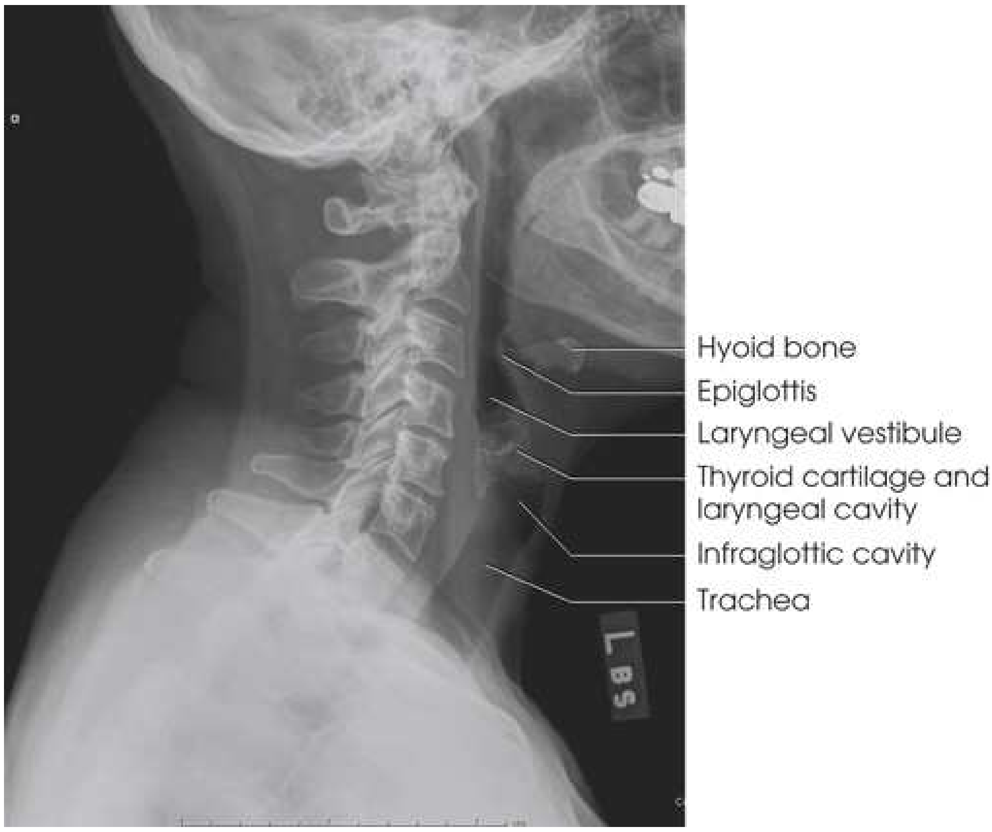


FIG. 3.21 Lateral soft tissue neck: pharynx and larynx during quiet breathing.

An x-ray shows the pharynx and larynx. It appears radiopaque. The parts labeled are as follows: hyoid bone, epiglottis, laryngeal vestibule, thyroid cartilage and laryngeal cavity, infraglottic cavity, and trachea.

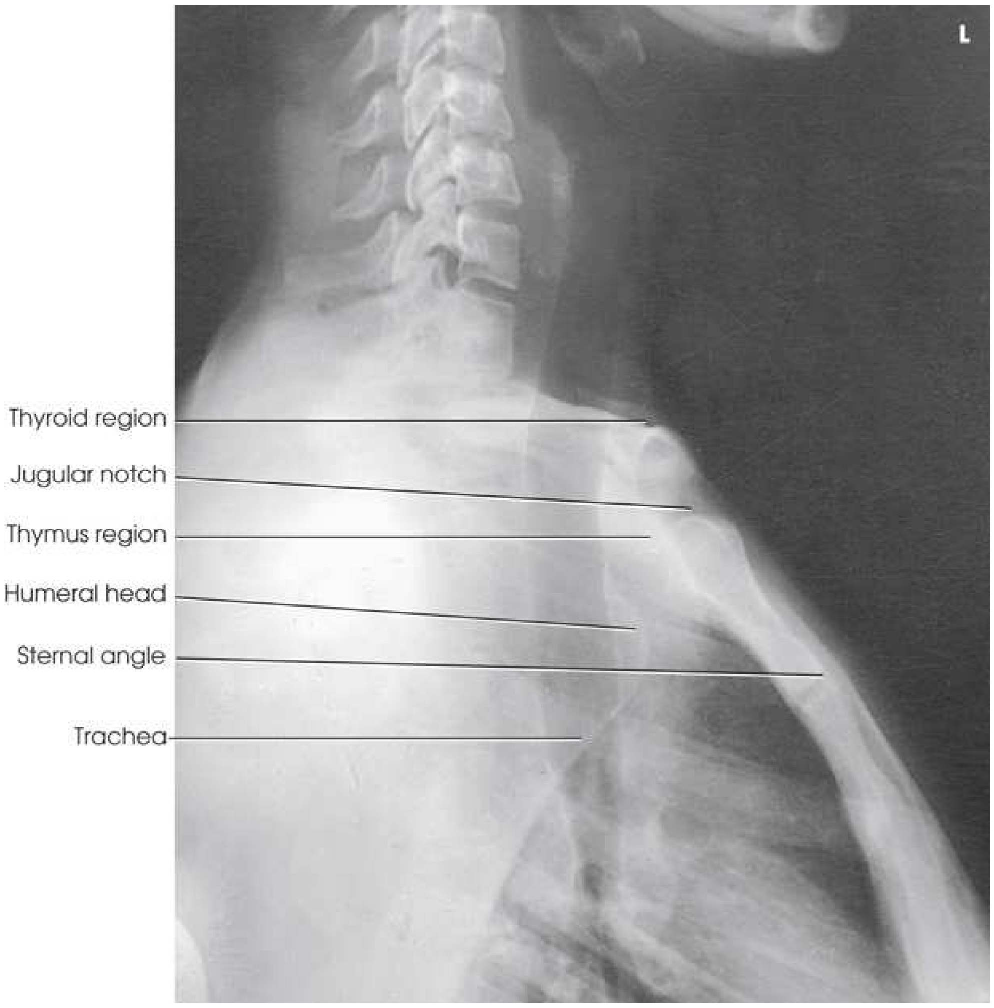


FIG. 3.22 Lateral soft tissue neck: trachea and superior mediastinum during quiet breathing.

An x-ray shows the air-filled upper airway or the trachea and superior mediastinum. The parts labeled are as follows: thyroid region, jugular notch, thymus region, humeral head, sternal angle, trachea.

General Positioning Considerations for the Chest

For radiography of the chest, the patient is placed in an *upright position* whenever possible to prevent engorgement of the pulmonary vessels and to allow gravity to depress the diaphragm. Of equal importance, the upright position shows air and fluid levels. In the recumbent position, gravitational force causes the abdominal viscera and diaphragm to move superiorly; it compresses the thoracic viscera, which prevents full expansion of the lungs. Although the difference in diaphragm movement is not great in hyposthenic individuals, it is marked in hypersthenic individuals. Figs. 3.23 and 3.24 illustrate the effects of body position in the same patient. The left lateral chest position (Fig. 3.25) is most commonly used because it places the heart closer to the IR, resulting in a less magnified heart image. Left and right lateral chest images are compared in Figs. 3.25 and 3.26.

A *slight amount of rotation* from the PA or lateral projection causes considerable distortion of the heart shadow. To prevent this distortion, the body must be carefully positioned and immobilized.

PA Criteria

For PA projections, procedures are as follows:

- Instruct the patient to sit or stand upright. If the standing position is used, the weight of the body must be equally distributed on the feet.
- Position the patient's head upright, facing directly forward.
- Have the patient depress the shoulders and hold them in contact with the grid device to carry the clavicles below the lung apices. Except in the presence of an upper thoracic scoliosis, a faulty body position can be detected by the asymmetric appearance of the sternoclavicular joints. Compare the clavicular margins in Figs. 3.27 and 3.28.

Lateral Criteria

For lateral projections, procedures are as follows:

- Place the side of interest against the IR holder.
- Have the patient stand so that the weight is equally distributed on the feet. The patient should *not* lean toward or away from the IR holder.
- Raise the patient's arms to prevent the soft tissue of the arms from superimposing the lung fields.
- Instruct the patient to face straight ahead and raise the chin.

- To determine rotation, examine the posterior aspects of the ribs. Radiographs without rotation show superimposed posterior ribs (see Figs. 3.25 and 3.26).

Oblique Criteria

In oblique projections, the patient rotates the hips with the thorax and points the feet directly forward. The shoulders should lie in the same transverse plane on all radiographs.

FIG. 3.23 Upright chest radiograph.

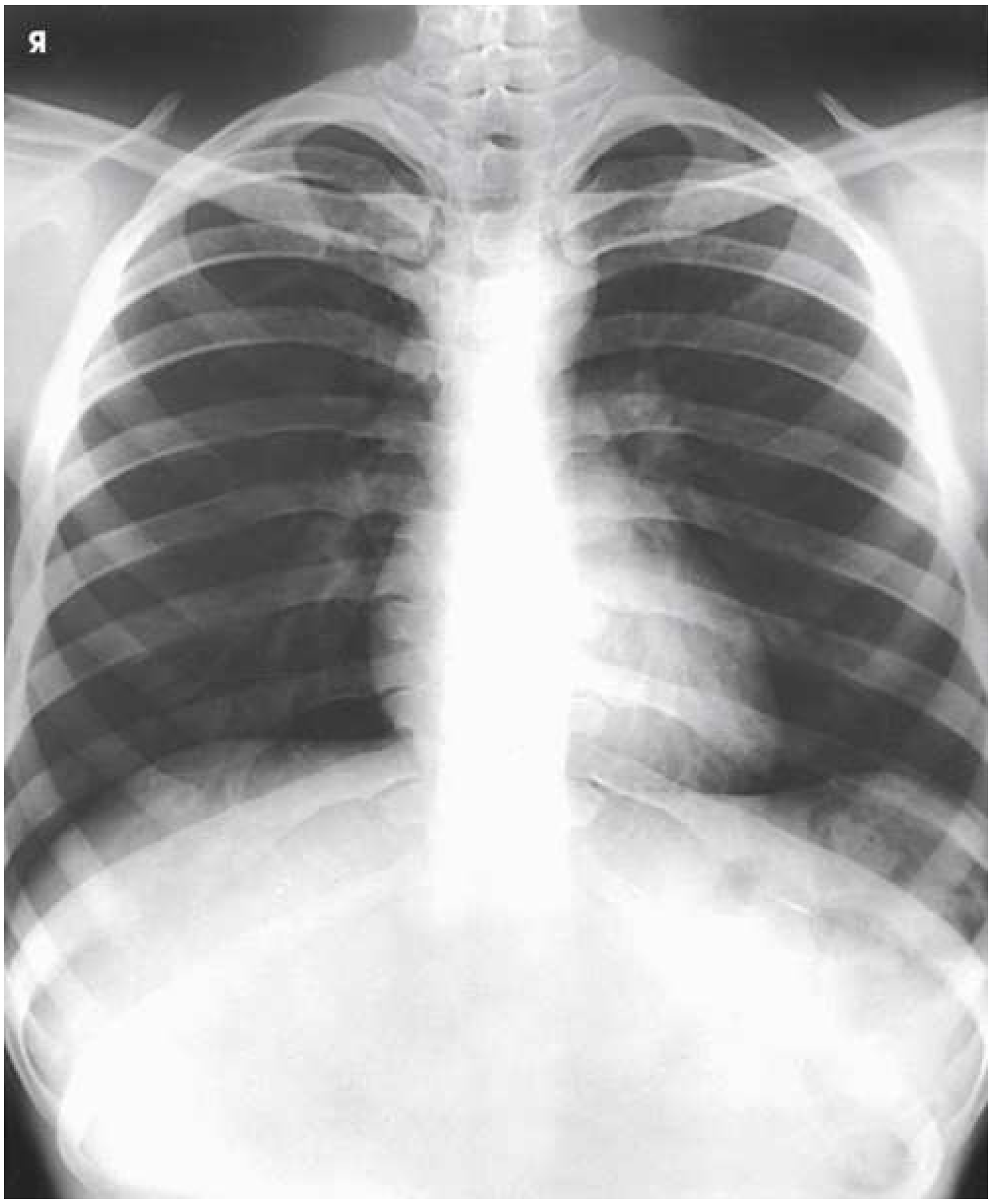


FIG. 3.24 Prone chest radiograph. Diaphragm is superior when compared to Fig. 3.23.

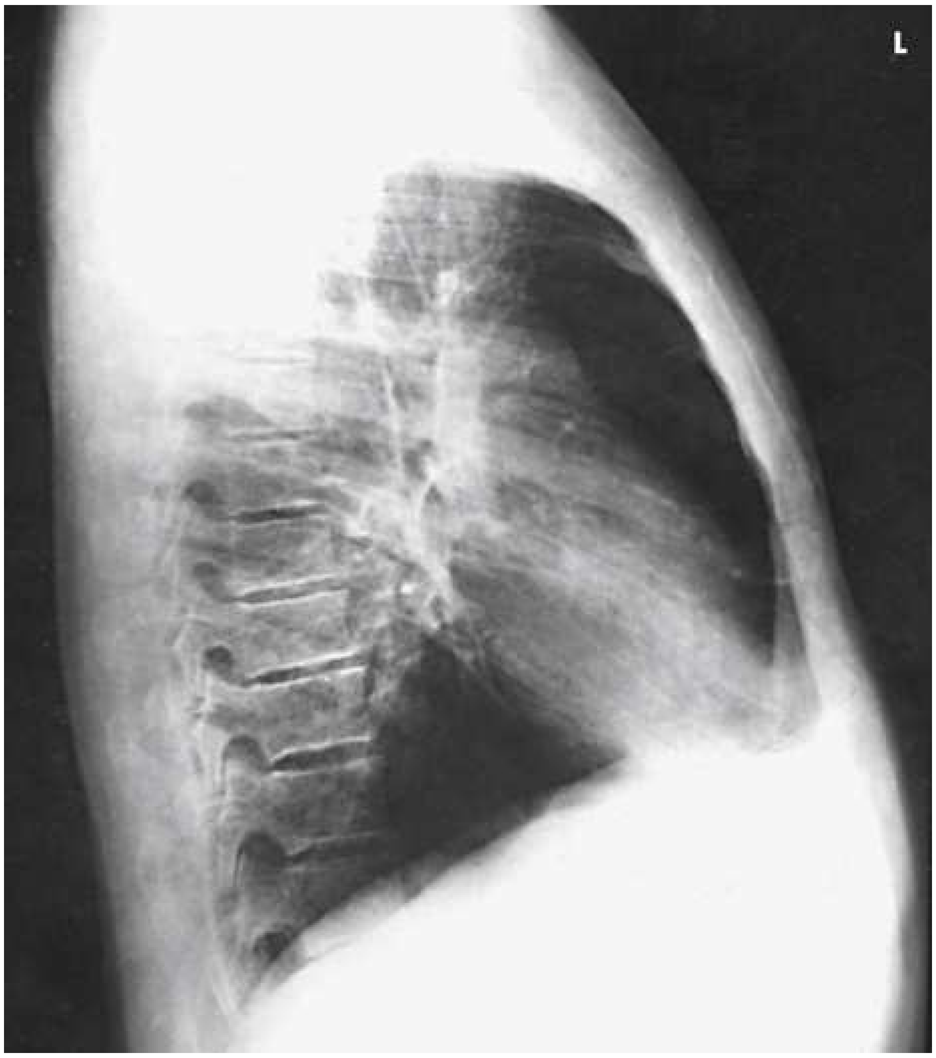


FIG. 3.25 Left lateral chest.

FIG. 3.26 Right lateral chest.

FIG. 3.27 PA chest without rotation. Sternoclavicular joints equidistant from midsagittal plane.

FIG. 3.28 PA chest with rotation. Left sternoclavicular joint *(arrow)* fully visible in pulmonary apex.

Breathing Instructions

During *normal inspiration*, the costal muscles pull the anterior ribs superiorly and, laterally, the shoulders rise, and the thorax expands from front to back and from side to side. These changes in the height and AP dimension of the thorax must be considered when the patient is positioned.

Deep inspiration causes the diaphragm to move inferiorly, resulting in elongation of the heart. Radiographs of the heart should be obtained at the end of normal inspiration to prevent distortion. More air is inhaled during the second breath (and without strain) than during the first breath.

When *pneumothorax* (gas or air in the pleural cavity) is suspected, one exposure is often made at the end of full inspiration and another at the end of full expiration, to show small amounts of free air in the pleural cavity that might be obscured on the inspiration exposure (Figs. 3.29 and 3.30). Inspiration and expiration radiographs are also used to show the movement of the diaphragm, the occasional presence of a foreign body, and atelectasis (absence of air).

Technical Procedure

The projections required to show the thoracic viscera adequately are usually requested by the attending physician and are determined by the clinical history of the patient. The PA projection of the chest is the most common projection and is used in all lung and heart examinations. The lateral projection is usually ordered in conjunction with the PA. Right and left oblique projections may be used as required to supplement the PA projection. Improvised variations of the basic positions are often necessary to project a localized area free of superimposed structures.

The exposure factors and accessories used in examining the thoracic viscera depend on the radiographic characteristics of the individual patient's pathologic condition. Normally chest radiography uses a high kilovoltage peak (kVp) to penetrate and show all thoracic anatomy on the radiograph. The kVp can be lowered if exposures are made without a grid. An appropriate kVp will penetrate the mediastinum to show a faint image of the spine, as well as demonstrate the pulmonary vascular markings of the lung periphery.

Whenever possible, a minimum source-to-image receptor distance (SID) of 72 inches (183 cm) should be used to minimize magnification of the heart and to obtain greater spatial resolution of the delicate lung structures (Fig. 3.31).

Use of a grid is recommended for opaque areas within the lung fields and to show the lung structure through thickened pleural membranes (Figs. 3.32 and 3.33). This technique allows penetration of these opaque areas while maintaining appropriate contrast resolution.

Radiation Protection

Protection of the patient from unnecessary radiation is the professional responsibility of the radiographer (see Chapter 1 for specific guidelines). In this chapter, the *Shield gonads* statement indicates that the patient is to be protected from unnecessary radiation by restricting the radiation beam using proper collimation. The placement of lead shielding between the gonads and the radiation source may be when necessary to decrease patient or caregiver anxiety about radiation exposure and when the clinical objectives of the examination are not compromised. An example of a properly placed lead shield is shown in Fig. 3.34.

FIG. 3.29 PA chest during inspiration.

An x-ray view of the chest shows small amounts of free air in the pleural cavity. It shows the descended abdominal structures. The heart and other soft tissues appear radiopaque. The air-filled fully expanded lungs appear radiolucent.

FIG. 3.30 PA chest during expiration. Diaphragm is superior and fewer posterior ribs are visible when compared with Fig. 3.29.

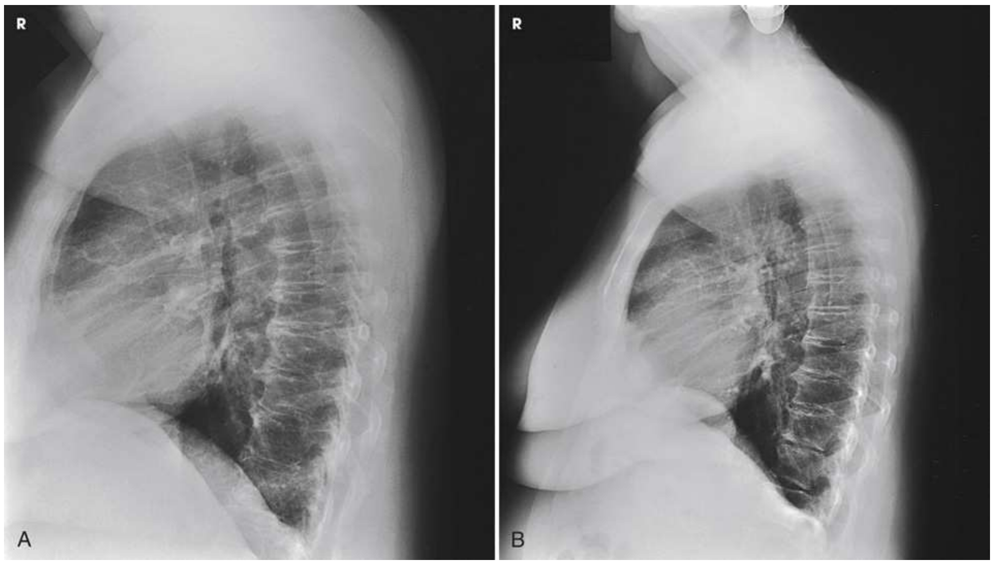


FIG. 3.31 (A) Lateral chest radiograph performed at 44-inch (112-cm) SID. (B) Radiograph in the same patient performed at 72-inch (183-cm) SID. Note decreased magnification and greater spatial resolution of lung structures.

(A) An x-ray view of the lateral chest shows the heart and the other structures. The air-filled lungs appear radiolucent and the surrounding structures appear radiopaque. (B) An x-ray view of the lateral chest shows greater spinal resolution and the heart appears smaller than (A).

FIG. 3.32 Nongrid radiograph showing fluid-type pathologic condition in same patient as in Fig. 3.33. The left lung is opaque, obscuring lung detail.

FIG. 3.33 Grid radiograph of the same patient as in Fig. 3.32. Details in the left lung are visible.

Chest

PA Projection

Image receptor + grid: Positioned by a manufacturer or department protocol for proper anatomy display orientation; CR plate: 14 × 17 inches (35 × 43 cm) lengthwise, or crosswise for hypersthenic patients.

SID:

Minimum SID of 72 inches (183 cm) is recommended to decrease magnification of the heart and increase spatial resolution of the thoracic structures.

Position of patient

- If possible, always examine patients in the upright position, either standing or seated, so that the diaphragm is at its lowest position, and air or fluid levels are seen. Engorgement of the pulmonary vessels is also avoided. Patients on a stretcher can be radiographed sitting with the legs dangling over the side of the stretcher, if conditions allow.

Position of part

- Place the patient, with arms hanging at sides, before a vertical grid device.
- Adjust the height of the IR so that its upper border is 1.5 to 2 inches (3.8 to 5 cm) above the relaxed shoulders.
- Center the midsagittal plane of the patient's body to the midline of the IR.
- Have the patient stand straight, with the weight of the body equally distributed on the feet.
- Extend the patient's chin upward or over the top of the grid device, then adjust the head so that the midsagittal plane is vertical.
- Ask the patient to flex the elbows and to rest the *backs of the hands* low on the hips, below the level of the costophrenic angles. Depress the shoulders and adjust to lie in the same transverse plane. These movements will position the clavicles below the apices of the lungs.

- Rotate the shoulders forward so that both touch the vertical grid device. This movement will rotate the scapulae outward and laterally to reduce superimposition of the scapulae with the lungs (Fig. 3.34).
- If a female patient's breasts are large enough to be superimposed over the lower part of the lung fields, especially the costophrenic angles, ask the patient to pull the breasts upward and laterally. This is especially important when ruling out the presence of fluid. Have the patient hold the breasts in place by leaning against the IR holder (Figs. 3.35 and 3.36).
- *Shield gonads.*

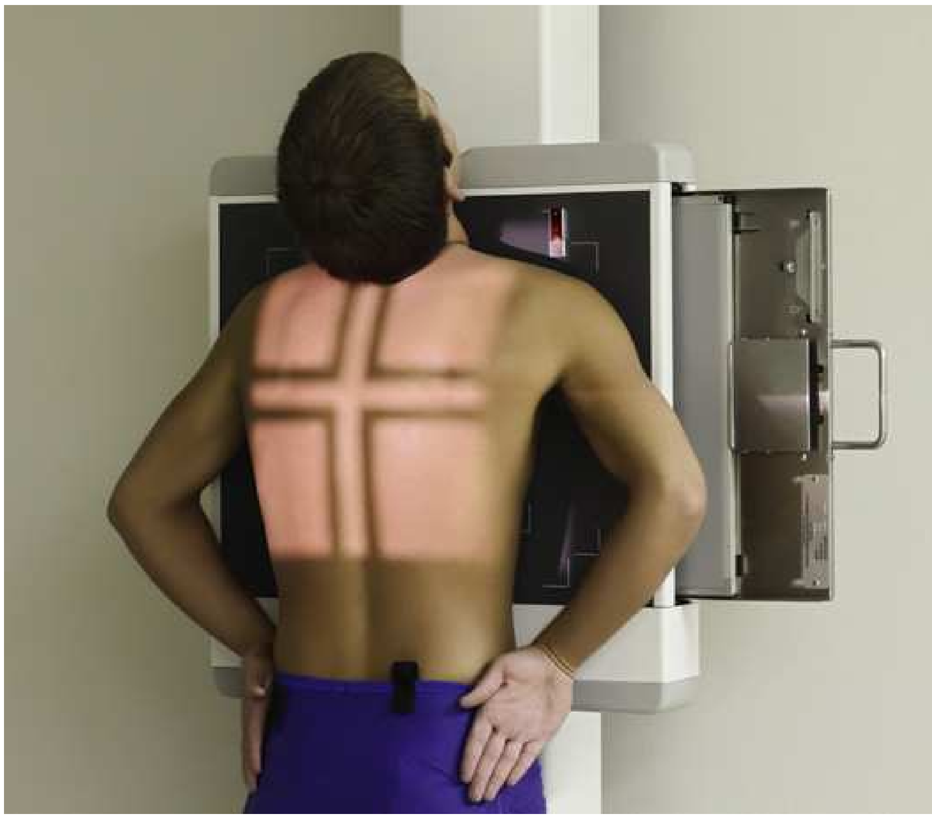


FIG. 3.34 Patient positioned for PA chest.

A patient is standing before a vertical grid device with elbows flexed and is resting the backs of the hands low on the hips below the level of the costophrenic angles. The shoulders are rotated forward. The chin is upward over the top of the grid device. The central ray is perpendicular to the center of the I R.

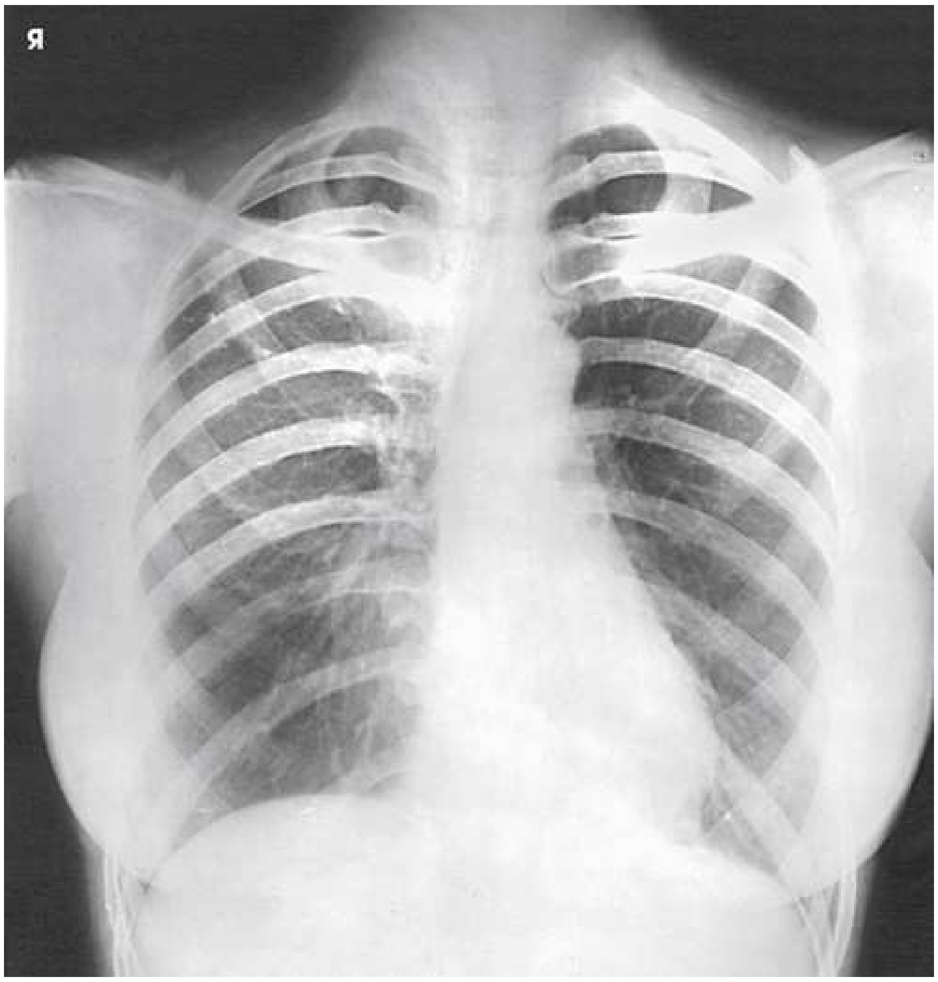


FIG. 3.35 Breasts superimposed over lower lungs.

- *Respiration*: Full inspiration. The exposure is made after the *second* full inspiration to ensure the maximum expansion of the lungs. The lungs expand transversely, anteroposteriorly, and vertically, with vertical being the greatest dimension.
- For certain conditions, such as pneumothorax and the presence of a foreign body, radiographs are sometimes made at the end of full inspiration and expiration (Figs. 3.37 through 3.39). Pneumothorax is shown more clearly on expiration, because collapse of the lung is accentuated.

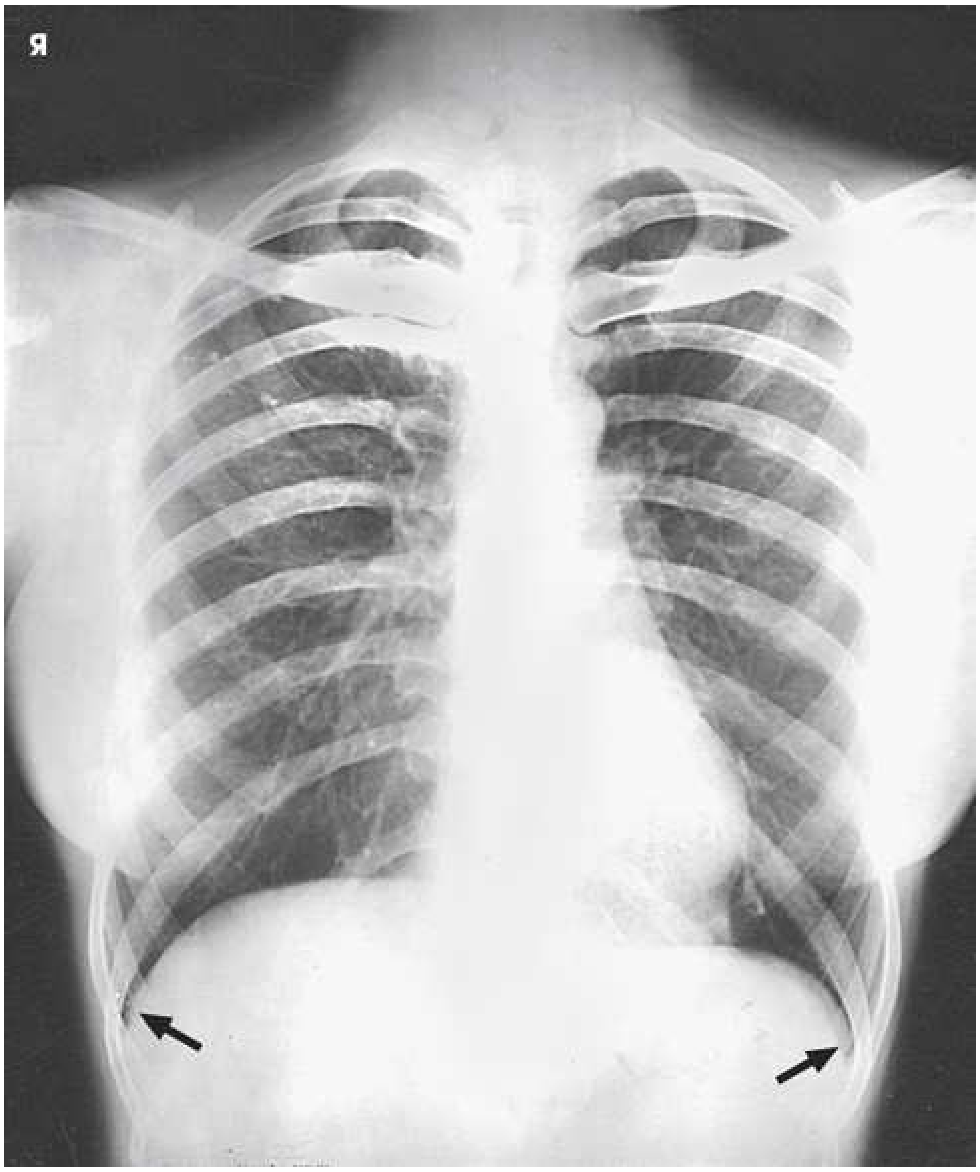


FIG. 3.36 Correct placement of breasts. Costophrenic angles are clearly seen *(arrows)*.

FIG. 3.37 Inspiration (10 posterior ribs visible).

FIG. 3.38 Expiration in the same patient as in Fig. 3.38 (8 posterior ribs visible).

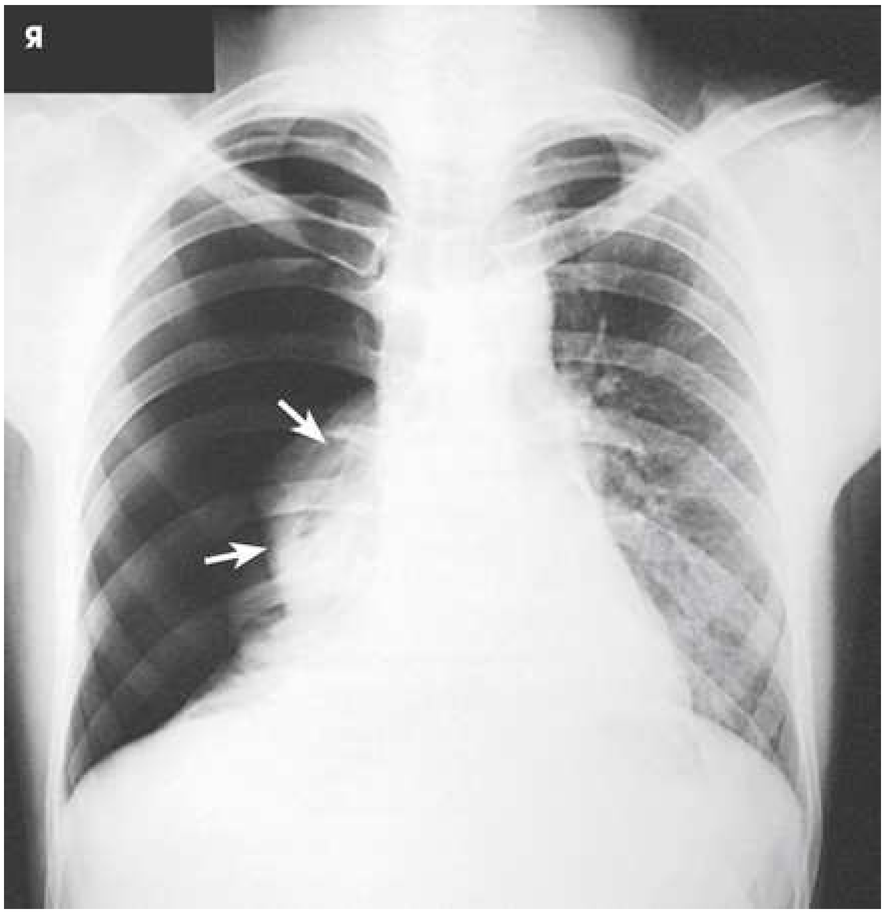


FIG. 3.39 PA chest during expiration. The patient had blunt trauma to the right chest. Left side is normal. Pneumothorax is seen on entire right side, and totally collapsed lung is seen near hilum *(arrows)*.

Central ray

- Perpendicular to the center of the IR. The CR should enter at the level of T7 (inferior angle of the scapula).

Collimation

- Adjust the radiation field to 17 inches (43 cm) lengthwise and 1 inch (2.5 cm) beyond the lateral shadows but no more than 14 inches (35 cm). The opposite dimensions are used for a crosswise IR. Vertical dimension may be less for smaller patients. Place a side marker in the collimated exposure field.

Structures shown

PA projection of the thoracic viscera shows the air-filled trachea, the lungs, the diaphragmatic domes, the heart and aortic arch, and, if enlarged laterally, the thyroid or thymus gland (Fig. 3.40). The vascular markings are much more prominent on the projection made at the end of expiration. The bronchial tree is shown from an oblique angle. The esophagus is well shown when it is filled with a barium sulfate suspension.

Evaluation Criteria

The following should be clearly seen:

- Evidence of proper collimation and presence of a side marker placed clear of anatomy of interest
- Entire lungs from the apices to the costophrenic angles
- No rotation
  - Sternal ends of the clavicles equidistant from the vertebral column
  - Trachea visible in the midline
  - Equal distance from the vertebral column to the lateral border of the ribs on each side
- Proper anterior shoulder rotation demonstrated by scapulae projected outside the lung fields
- Proper inspiration demonstrated by 10 posterior ribs visible above the diaphragm; at least one less rib visible on expiration
- Sharp outlines of heart and diaphragm
- Faint shadows of the ribs and superior thoracic vertebrae visible through the heart shadow
- Pulmonary vascular markings from the hilar regions to the periphery of the lungs

NOTE: Inferior lobes of both lungs should be carefully checked for adequate penetration in women with large, pendulous breasts.

Cardiac studies with barium

PA chest radiographs may be obtained with the patient swallowing a bolus of barium sulfate to outline the posterior heart and aorta. The barium used in cardiac examinations should be thicker than the barium used for the stomach, so that the contrast medium descends more slowly and adheres to the esophageal walls. The patient should hold the barium in the mouth until just before the exposure is made. Then the patient should take a deep breath and swallow the bolus of barium; the exposure is made at this time (see Fig. 3.12).

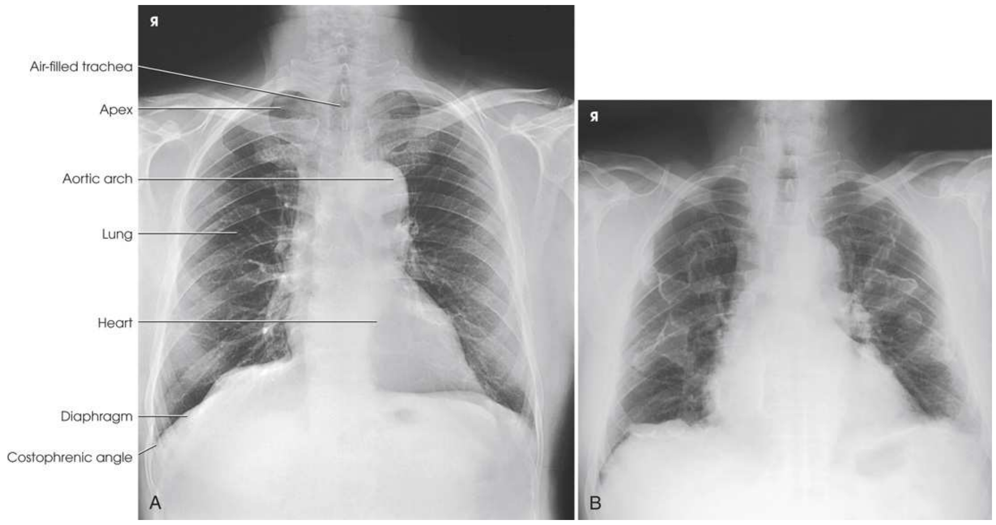


FIG. 3.40 (A) PA chest in a man. (B) PA chest showing pneumoconiosis in both lungs (multiple, irregularly shaped white areas show built-up coal dust).

(A) An x-ray view of the chest shows the air-filled trachea, the lungs, the diaphragmatic domes, the heart and aortic arch, and, if enlarged laterally, the thyroid or thymus gland. The parts labeled are as follows: air-filled trachea, apex, aortic arch, lung, heart, diaphragm, and costophrenic angle. (B) An x-ray view of the chest shows multiple, irregularly shaped white areas that show built-up coal dust.

Lateral Projection

R or L position

Image receptor + grid: Positioned by manufacturer or department protocol for proper anatomy display orientation; CR plate: 14 × 17 inches (35 × 43 cm) lengthwise.

SID:

Minimum SID of 72 inches (183 cm) is recommended to decrease magnification of the heart and increase spatial resolution of the thoracic structures.

Position of patient

- If possible, always examine the patient in the upright position, either standing or seated, so that the diaphragm is at its lowest position, and air and fluid levels can be seen. Engorgement of the pulmonary vessels is also avoided.
- Turn the patient to a true lateral position, with arms by the sides.
- To show the heart and left lung, use the left lateral position with the patient's left side against the IR.
- Use the right lateral position to best show the right lung.

Position of part

- Adjust the position of the patient so that the midsagittal plane of the body is parallel with the IR and the adjacent shoulder is touching the grid device.
- Center the thorax to the grid; the midcoronal plane should be perpendicular and centered to the midline of the grid.
- Have the patient extend the arms directly upward, flex the elbows, and with the forearms resting on the head, hold the arms in position (Fig. 3.41).
- Place an intravenous catheter stand in front of an unsteady patient. Have the patient extend the arms and grasp the stand as high as possible for support.
- Adjust the height of the IR so that the upper border is 1.5 to 2 inches (3.8 to 5 cm) above the shoulders.
- Recheck the position of the body; the midsagittal plane must be vertical. Depending on the width of the shoulders, the lower part of the thorax and hips may be a greater distance from the IR, but this body position is necessary for a true lateral projection. Having the patient *lean* against the grid device (foreshortening) results in distortion of all thoracic structures (Fig. 3.42). *Forward bending* also results in distorted structural outlines (Fig. 3.43).

• *Shield gonads.*
• *Respiration*: Full inspiration. The exposure is made after the *second* full inspiration to ensure the maximum expansion of the lungs.

Central ray

• Perpendicular to the center of the IR. The CR enters the patient on the midcoronal plane at the level of T7 or at the inferior aspect of the scapula.

Collimation

• Adjust radiation field to 17 inches (43 cm) lengthwise and 1 inch (2.5 cm) beyond the anterior and posterior shadows but no more than 14 inches (35 cm). Vertical dimension may be less for smaller patients. Place a side marker in the collimated exposure field.

Structures shown

The preliminary left lateral chest position is used to show the heart, the aorta, and left-sided pulmonary lesions (Figs. 3.44 and 3.45). The right lateral chest position is used to show right-sided pulmonary lesions (Fig. 3.46). These lateral projections are used extensively to show the interlobar fissures, to differentiate the lobes, and to localize pulmonary lesions.

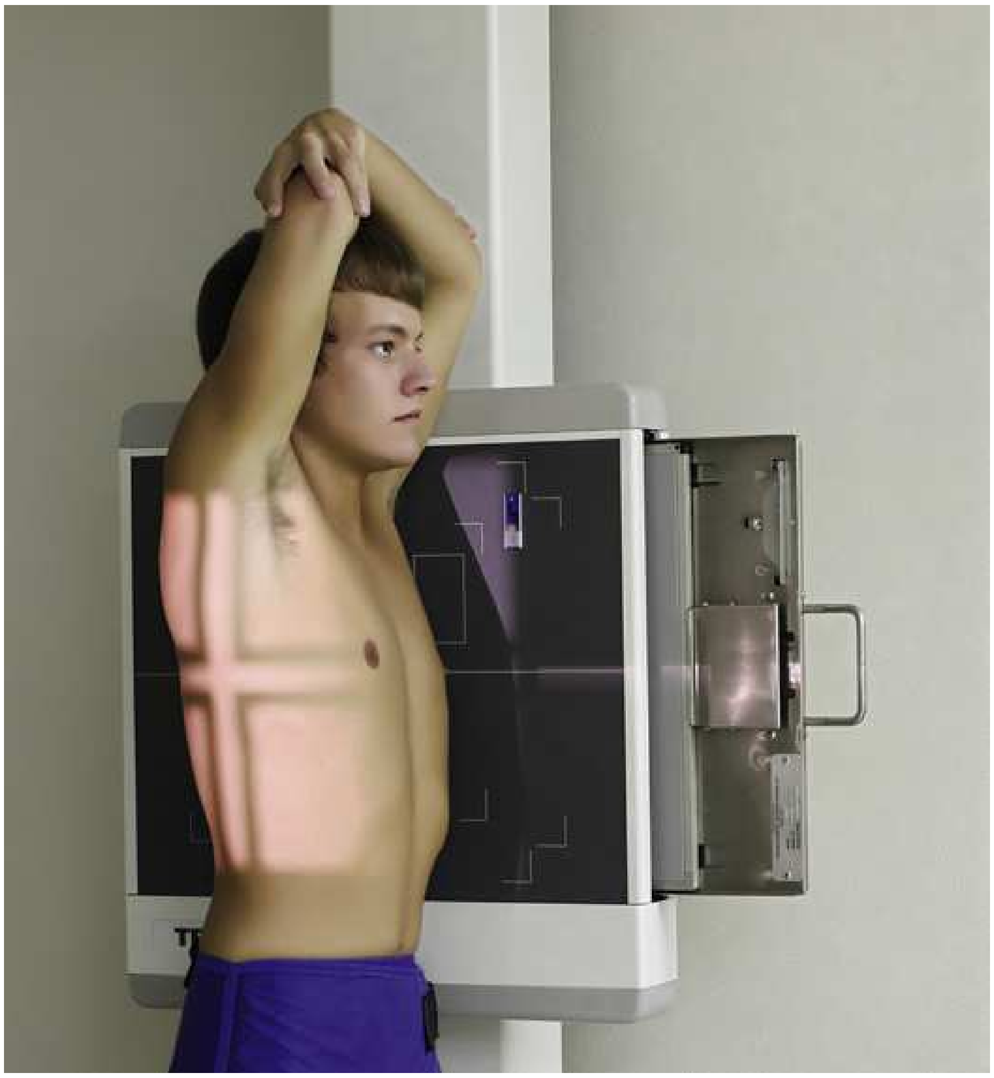


FIG. 3.41 Lateral chest.

A patient is standing upright with adjacent shoulder touching the grid device. Both his arms extended directly upward. The elbows are flexed and the forearm is resting on the head. The central ray is perpendicular to the center of the I R.

Evaluation Criteria

The following should be clearly seen:

- Evidence of proper collimation and presence of a side marker placed clear of anatomy of interest
- Arm or its soft tissues not overlapping the superior lung field

- Costophrenic angles and the portions of the pulmonary apices not obscured by the arms and shoulders
- No rotation
  - Hila in the approximate center of the radiograph
  - Superimposition of the ribs posterior to the vertebral column
  - Sternum in profile
  - Trachea visible in the midline
- Long axis of the lung fields shown in vertical position, without forward or backward leaning
- Open thoracic intervertebral joint spaces and intervertebral foramina, except in patients with scoliosis
- Sharp outlines of heart and diaphragm
- Pulmonary vascular markings from the hilar regions to the periphery of the lungs

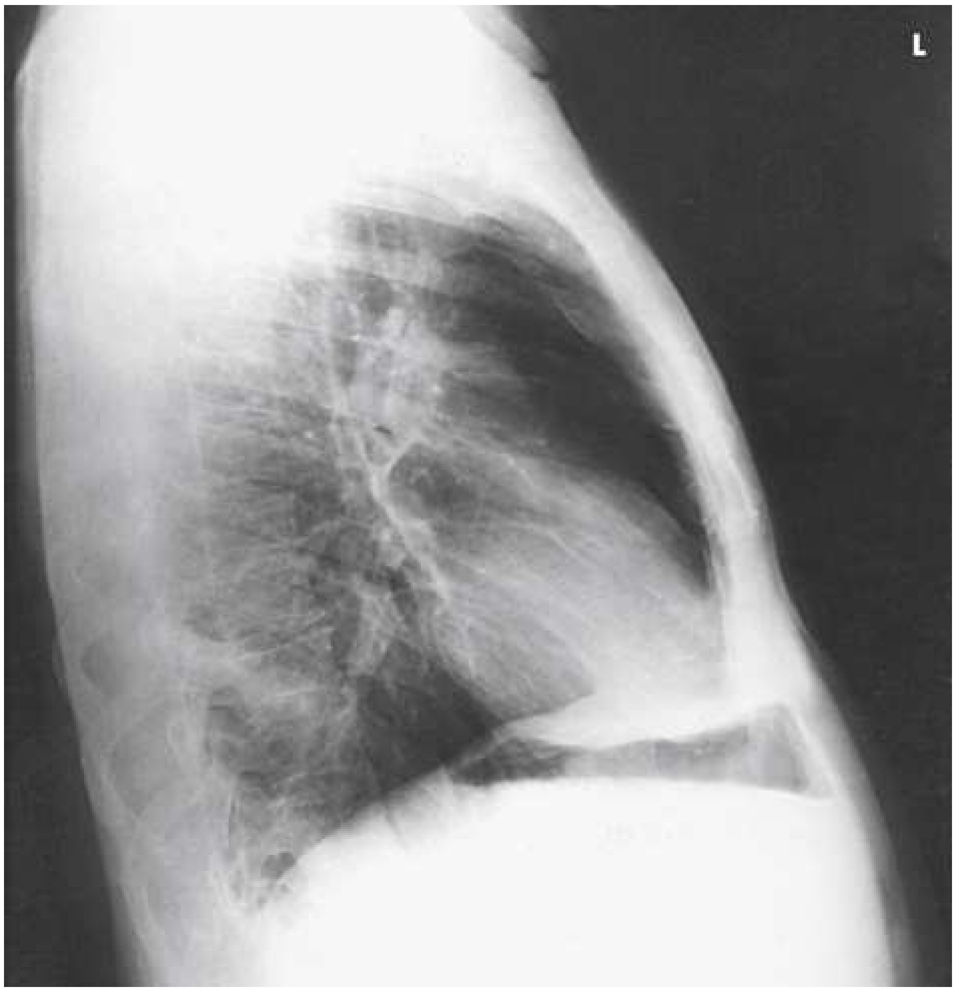


FIG. 3.42 Foreshortening.

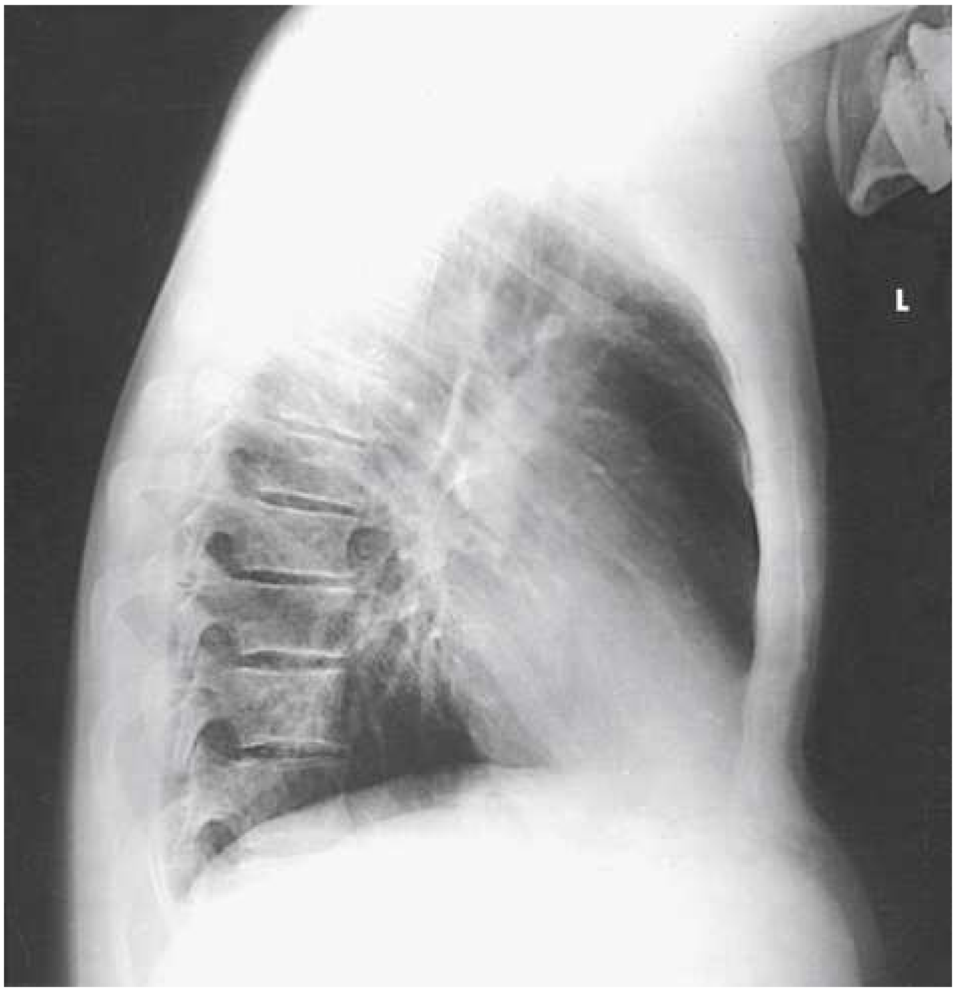


FIG. 3.43 Forward bending.

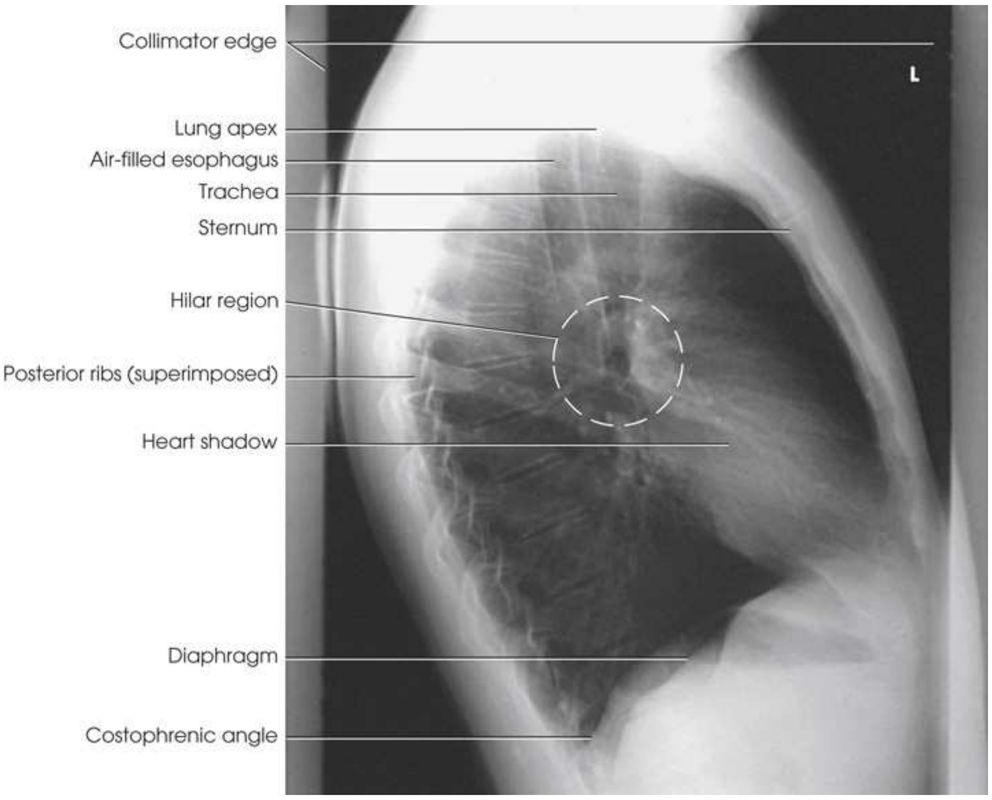


FIG. 3.44 Left lateral chest.

An x-ray view of the lateral chest shows a dark region hila in the approximate center of the radiograph. The parts labeled are as follows: collimator edge, lung apex, air-filled esophagus, trachea, sternum, hilar region, posterior ribs (superimposed), heart shadow, diaphragm, and costophrenic angle.

Cardiac studies with barium

The left lateral position is traditionally used during cardiac studies with barium. The procedure is the same as described for the PA chest projection (see p. 109).

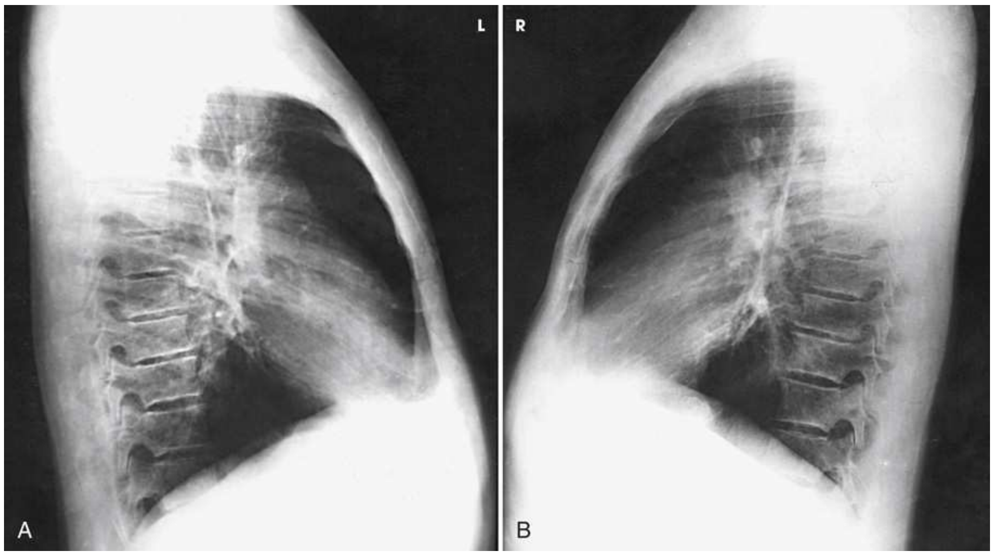


FIG. 3.45 (A) Left lateral chest. (B) Right lateral chest on same patient as in (A). Note the size of the heart shadows.

(A) An x-ray view of the left lateral chest shows the shadow of the heart that appears hazy. (B) An x-ray view of the right lateral chest shows the shadow of the heart that appears hazy. The upper and lower region in the radiograph appears radiopaque.

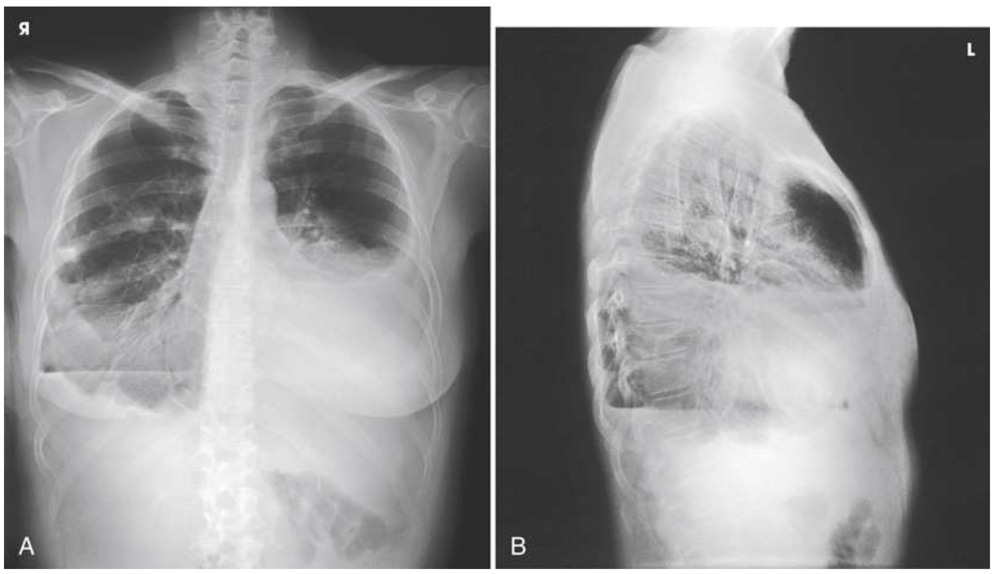


FIG. 3.46 (A) PA chest. (B) Lateral chest on same patient as in (A). The importance of two projections is seen on this patient with multiple chest pathologies, including fluid, air-fluid level, pneumothorax, and enlarged heart.

(A) An x-ray view of the chest shows fluid, multiple air-fluids level, pneumothorax, and enlarged heart. It appears radiopaque. (B) An x-ray view of the left lateral chest shows a radiopaque appearance of the entire chest except for a small area on the anterior surface.

PA Oblique Projection

RAO and LAO positions

Image receptor + grid: Positioned by manufacturer or department protocol for proper anatomy display orientation; CR plate: 14 × 17 inches (35 × 43 cm) lengthwise.

SID:

Minimum SID of 72 inches (183 cm) is recommended to decrease magnification of the heart and to increase spatial resolution of the thoracic structures.

Position of patient

- Maintain the patient in the position (standing or seated upright) used for the PA projection.
- Instruct the patient to let the arms hang free.
- Have the patient turn 45 degrees toward the left side for left anterior oblique (LAO) position and 45 degrees toward the right side for right anterior oblique (RAO) position.
- Ask the patient to stand or sit straight. If the standing position is used, the weight of the patient's body must be equally distributed on the feet to prevent unwanted rotation.
- For PA oblique projections, the side of interest is generally the side *farther* from the IR; however, the lung closer to the IR is also imaged.
- The top of the IR should be placed about 1.5 to 2 inches (3.8 to 5 cm) above the vertebral prominens because the top of the shoulders may not be on the same plane.

Position of part

LAO position

- Rotate the patient 45 degrees to place the left shoulder in contact with the grid device.
- Center the thorax to the IR. Ensure that the right and left sides of the body are positioned to the IR.
- Instruct the patient to place the left hand on the hip with the palm outward.
- Have the patient raise the right arm to shoulder level and grasp the top of the vertical grid device for support.
- Adjust the patient's shoulders to lie in the same horizontal plane.
- Instruct the patient not to rotate the head (see Fig. 3.47).
- Use a 55- to 60-degree oblique position when the examination is performed for a *cardiac series.* This projection is usually performed with barium contrast medium. The patient swallows the barium just before the exposure.
- *Shield gonads.*
- *Respiration*: Full inspiration. The exposure is made after the *second* full inspiration to ensure the maximum expansion of the lungs.

RAO position

- Reverse the previously described position, placing the patient's right shoulder in contact with the grid device, the right hand on the hip, and the left hand on the top of the vertical grid device (Fig. 3.48).
- *Shield gonads.*
- *Respiration*: Full inspiration. The exposure is made after the second full inspiration to ensure the maximum expansion of the lungs.

Central ray

- Perpendicular to the center of the IR. The CR should be at the level of T7.

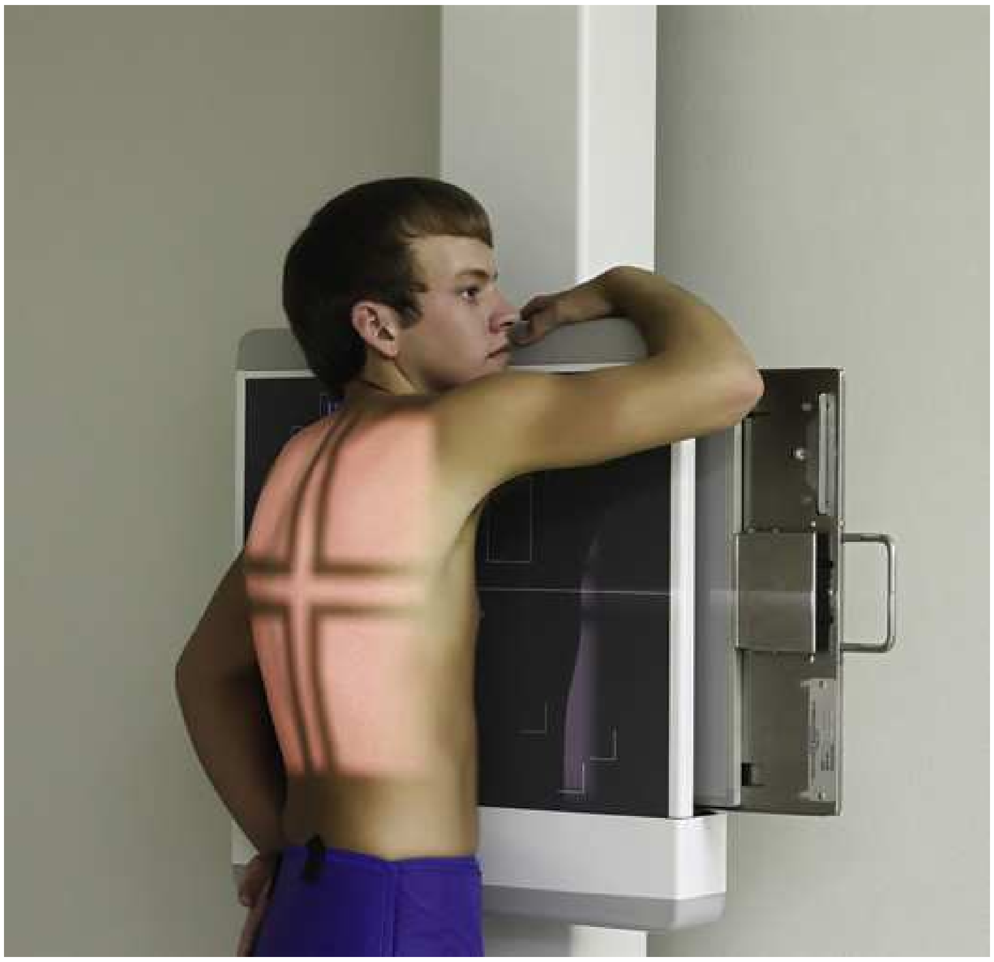


FIG. 3.47 PA oblique chest, LAO position.

A patient is standing before the vertical grid device with his left hand on the hip with his palm outward. The right arm is raised to shoulder level and is grasping the top of the vertical grid device for support. The central ray is perpendicular to the center of the I R.

FIG. 3.48 PA oblique chest, RAO position.

A patient is standing before the vertical grid device with his right hand on the hip with his palm outward. The left arm is raised to shoulder level and is grasping the top of the vertical grid device for support. The central ray is perpendicular to the center of the I R.

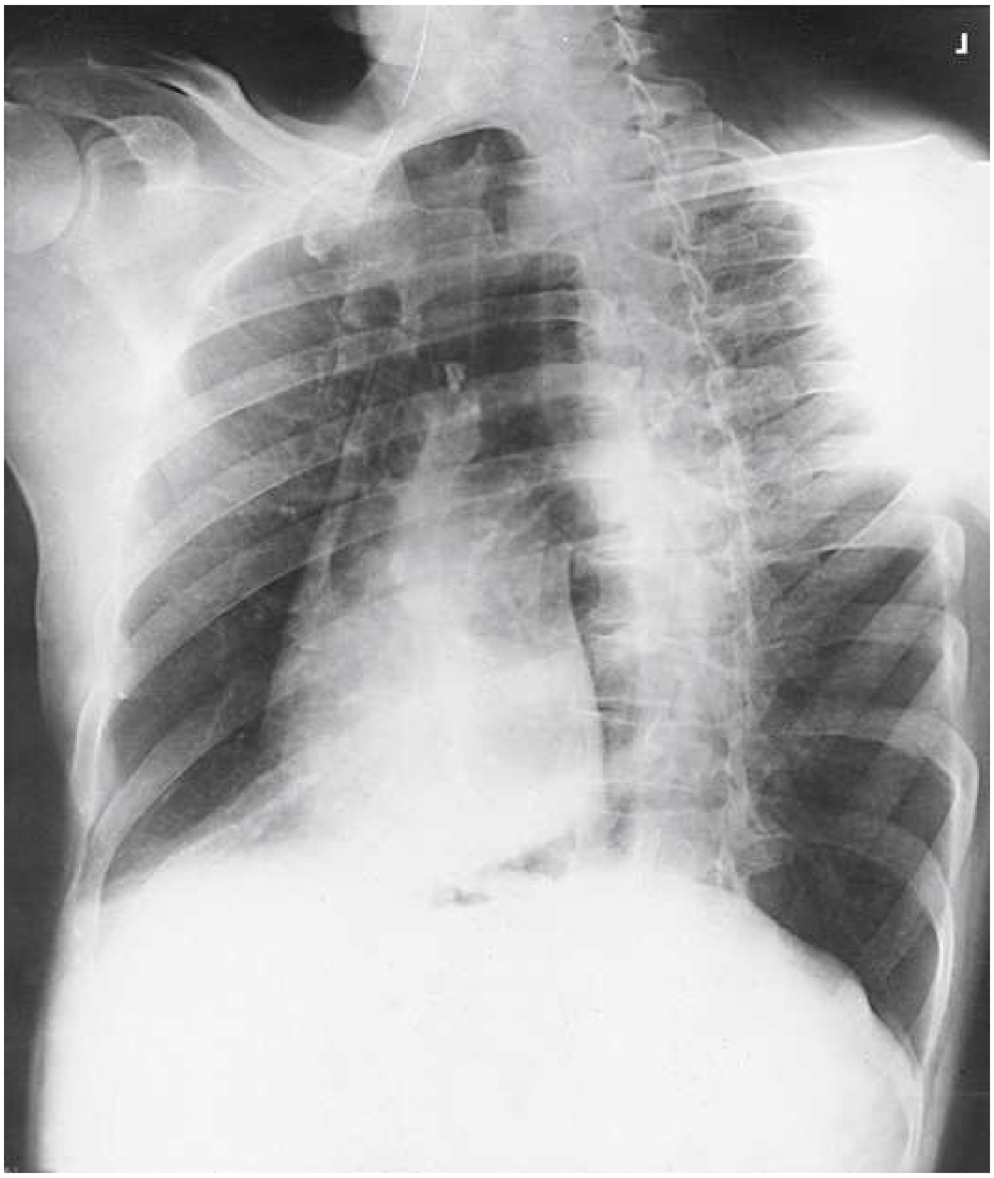


FIG. 3.49 PA oblique chest, LAO position at 45 degrees.

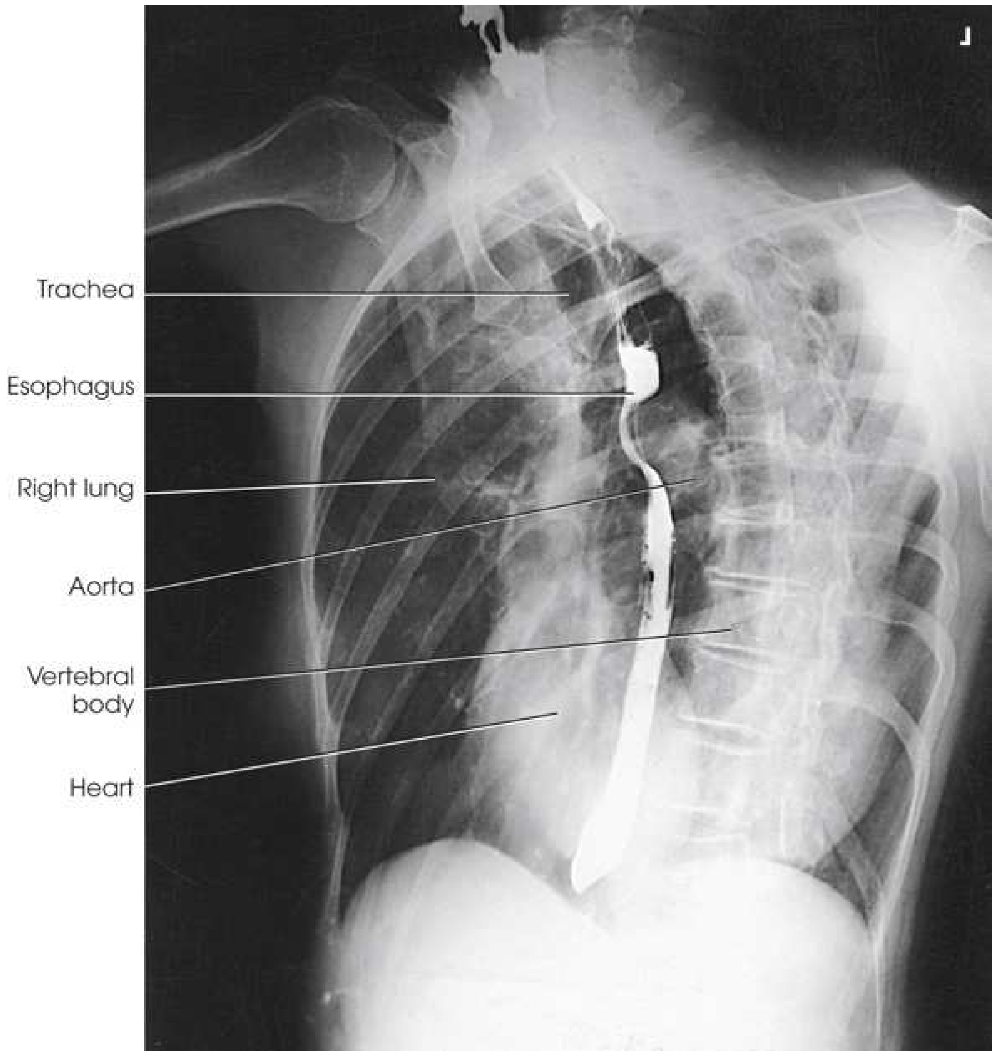


FIG. 3.50 PA oblique chest. LAO position is 60 degrees with barium-filled esophagus.

An x-ray view of the chest shows the spine bent to the right. The anterior portion of the left lung is superimposed by the spine. The esophagus appears long and narrow. It is radiopaque. The parts labeled are as follows: trachea, esophagus, right lung, aorta, vertebral, body, and heart.

Collimation

- Adjust radiation field to 17 inches (43 cm) lengthwise and 1 inch (2.5 cm) beyond the shadows on both sides but no more than 14 inches (35 cm). Vertical dimension may be less for smaller patients. Place a side marker in the collimated exposure field.

Structures shown

LAO position

The maximum area of the right lung field (side farther from the IR) is shown along with the thoracic viscera. The anterior portion of the left lung is superimposed by the spine (Figs. 3.49 and 3.50). Also shown are the trachea and its bifurcation (the carina), and the entire right branch of the bronchial tree. The heart, the descending aorta (lying just in front of the spine), and the arch of the aorta are also presented.

RAO position

The maximum area of the left lung field (side farther from the IR) is shown along with the thoracic viscera. The anterior portion of the right lung is superimposed by the spine (Figs. 3.51 and 3.52). Also shown are the trachea and the entire left branch of the bronchial tree. This position gives the best image of the left atrium, the anterior portion of the apex of the left ventricle, and the right retrocardiac space. When filled with barium, the esophagus is shown clearly in the RAO and LAO positions (see Fig. 3.52).

NOTE: The radiographs in this section, similar to the radiographs throughout this text, are printed as though the reader is looking at the patient's anterior body surface (see Chapter 1).

Evaluation Criteria

The following should be clearly seen:

- Evidence of proper collimation and presence of a side marker placed clear of anatomy of interest
- Both lungs included from apices to costophrenic angles
- Trachea filled with air

- Heart and mediastinal structures within the lung field of the elevated side in oblique images of 45 degrees
- Right lung best demonstrated on LAO
- Left lung best demonstrated on RAO
- Pulmonary vascular markings from the hilar regions to the periphery of the lung

Barium studies

RAO and LAO positions are routinely used during cardiac studies with barium. Follow the same procedures described in the PA chest section (see p. 109).

NOTE: A slightly oblique position has been found to be of particular value in the study of pulmonary diseases. The patient is turned only slightly (10 to 20 degrees) from the RAO or LAO body position. This slight degree of obliquity rotates the superior segment of the respective lower lobe from behind the hilum and displays the medial part of the right middle lobe or the lingula of the left upper lobe free from the hilum. These areas are not clearly shown in the standard "cardiac oblique" of 45- to 60-degree rotation, largely because of superimposition of the spine.

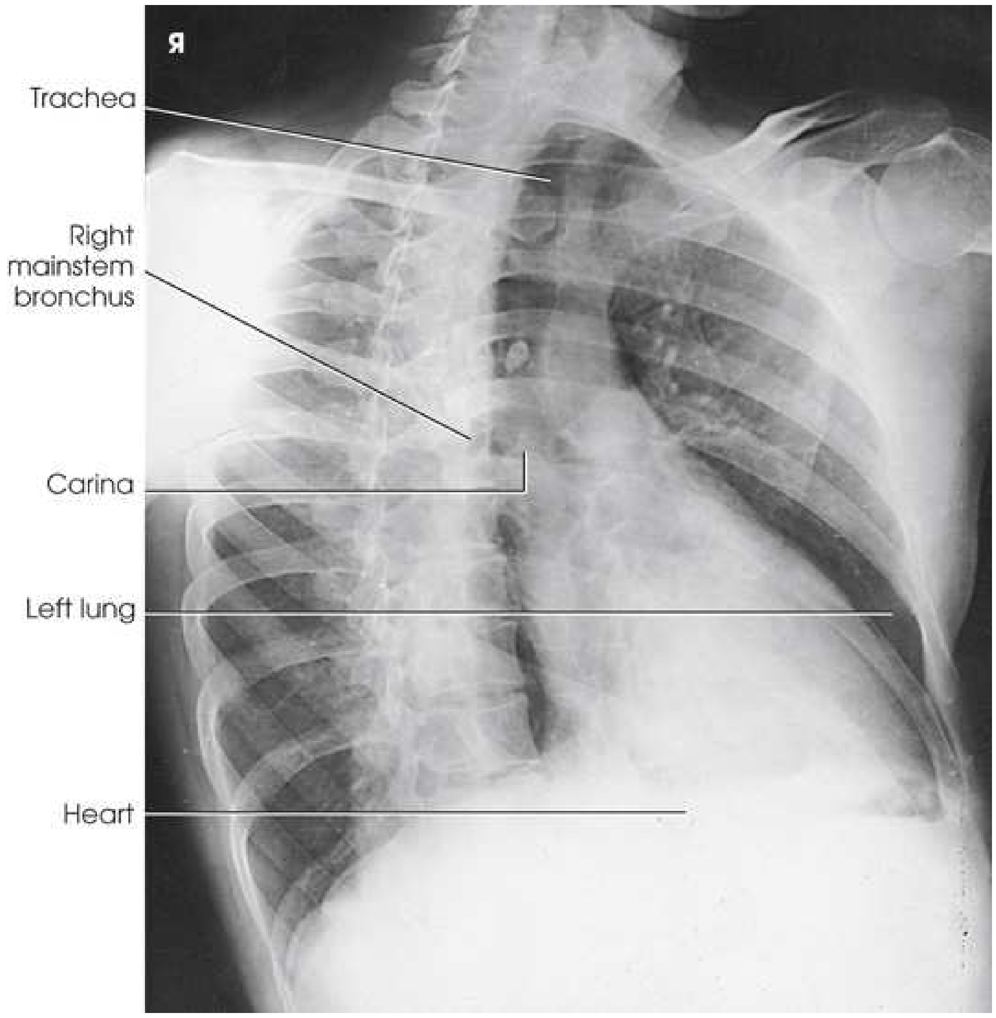


FIG. 3.51 PA oblique chest, RAO position at 45 degrees.

An x-ray view of the chest shows the anterior portion of the right lung is superimposed by the spine. The trachea is filled with air. The parts labeled are as follows: trachea, right mainstem, bronchus, carina, left lung, and heart.

FIG. 3.52 PA oblique chest, RAO position at 60 degrees. Note barium in esophagus.

An x-ray view of the chest shows the spine bent towards the left. The radiopaque esophagus is long and narrow. The anterior portion of the right lung is superimposed by the spine The trachea is filled with air.

AP Oblique Projection

RPO and LPO positions

RPO and LPO positions are used when the patient is too ill to be turned to the prone position and sometimes as supplementary positions in the investigation of specific lesions. These positions are also used with the recumbent patient in contrast studies of the heart and great vessels.

For AP oblique projections, the side of interest is generally the side closest to the IR. The resulting image shows the greatest area of the lung closest to the IR. The lung farthest from the IR is also imaged, and diagnostic information is often obtained for that side.

Image receptor + grid: Positioned by manufacturer or department protocol for proper anatomy display orientation; CR plate: 14 × 17 inches (35 × 43 cm) lengthwise.

SID:

Minimum SID of 72 inches (183 cm) is recommended to decrease magnification of the heart and increase spatial resolution of the thoracic structures.

Position of patient

- With the patient supine or facing the x-ray tube, either upright or recumbent, adjust the IR so that the upper border of the IR is approximately 1.5 to 2 inches (3.8 to 5 cm) above the vertebral prominens or approximately 5 inches (12.7 cm) above the jugular notch.

Position of part

- Rotate the patient toward the correct side, adjust the body at a 45-degree angle, and center the thorax to the grid.
- If the patient is recumbent, support the elevated hip and arm. Ensure that both sides of the chest are positioned to the IR.
- Flex the patient's elbows and place the hands on the hips with the palms facing outward or pronate the hands beside the hips. The arm closer to the IR may be raised if the shoulder is rotated anteriorly.
- Adjust the shoulders to lie in the same transverse plane in a position of forward rotation (Figs. 3.53 and 3.54).

- *Shield gonads.*
- *Respiration*: Full inspiration. The exposure is made after the *second* full inspiration to ensure the maximum expansion of the lungs.

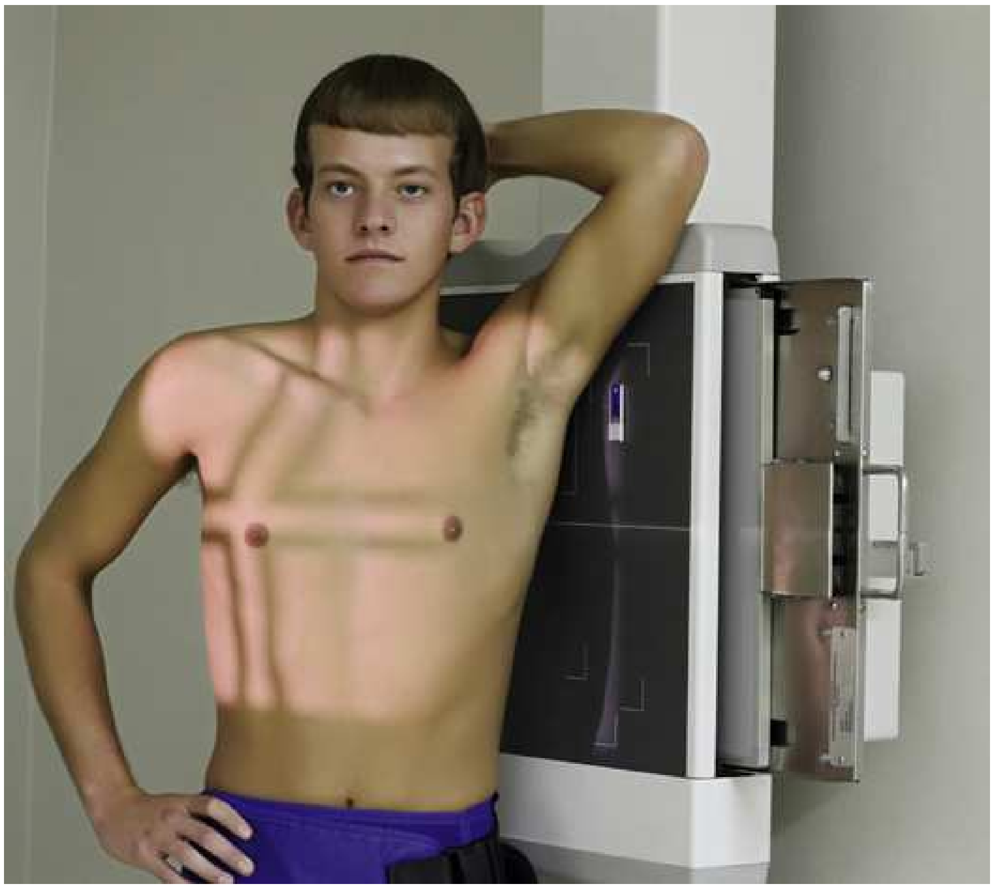


FIG. 3.53 Upright AP oblique chest, LPO position.

A patient is standing upright with the body rotated 45 degrees and the thorax is centered to the grid. The elbows are flexed. One hand is placed on the hips. The other shoulder is raised and the arm is placed behind the head. The side marker is in the collimated exposure field. The central ray is perpendicular to the center of the I R.

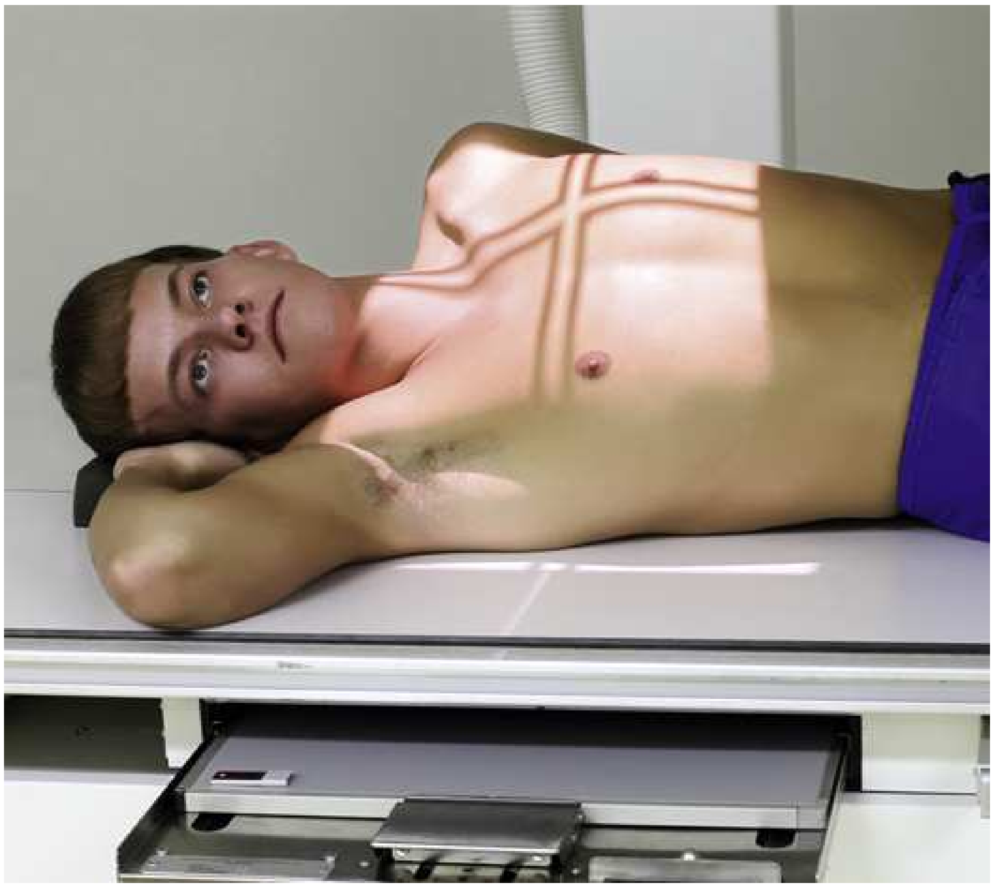


FIG. 3.54 Recumbent AP oblique chest, RPO position.

A patient is supine on the radiographic table with one of his hands under the head. The other hand is behind the back. The shoulders to lie in the same transverse plane in a position of forward rotation. The central ray is perpendicular to the center of the I R.

Central ray

- Perpendicular to the center of the IR at a level 3 inches (7.6 cm) below the jugular notch (CR exits at T7).

Collimation

- Adjust radiation field to 17 inches (43 cm) lengthwise and 1 inch (2.5 cm) beyond the shadows on both sides but no more than 14 inches (35 cm). Vertical dimension may be less for smaller patients. Place a side marker in the collimated exposure field.

Structures shown

This radiograph presents an AP oblique projection of the thoracic viscera similar to the corresponding PA oblique projection (Fig. 3.55). The RPO position is comparable with the LAO position. However, the lung field of the elevated side usually appears shorter because of magnification of the diaphragm. The heart and great vessels also cast magnified shadows as a result of being farther from the IR.

Evaluation Criteria

The following should be clearly seen:

- Evidence of proper collimation and presence of a side marker placed clear of anatomy of interest
- Both lungs included from apices to costophrenic angles
- Trachea filled with air
- Left lung best demonstrated on LPO
- Right lung best demonstrated on RPO
- Pulmonary vascular markings from the hilar regions to the periphery of the lung

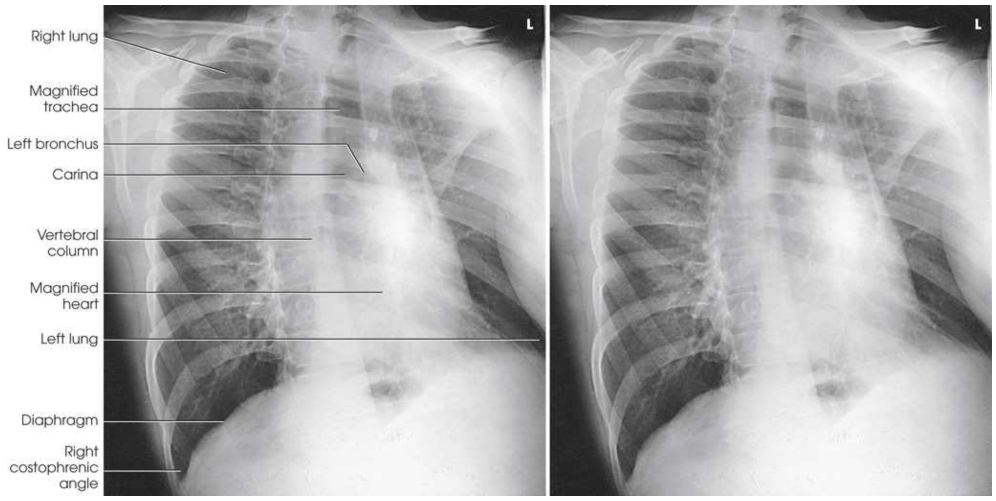


FIG. 3.55 AP oblique chest, LPO position.

Two x-ray shows both lungs included from apices to costophrenic angle. The heart and great vessels cast magnified white shadows. The parts labeled are as follows: right lung, magnified trachea, left bronchus, carina, vertebral column, magnified heart, left lung diaphragm, and right costophrenic angle.

AP Projection [a]

Supine or upright

NOTE: The supine position is used when the patient is too ill to sit or stand. The upright position is used for patients in a wheelchair who cannot stand and must remain in a wheelchair for the radiograph. In addition, patients on a stretcher can be radiographed sitting up with their legs dangling over the side of the stretcher and their back against the upright IR.

Image receptor + grid: Positioned by manufacturer or department protocol for proper anatomy display orientation; CR plate: 14 × 17 inches (35 × 43 cm) lengthwise or crosswise for hypersthenic patients.

SID:

SID of 72 inches (183 cm) is recommended. A shorter SID may be required depending on the equipment and space available.

Position of patient

- Place the patient in the supine or upright position with the back against the grid.

Position of part

- Center the midsagittal plane of the chest to the IR.
- Adjust the IR so that the upper border is 1.5 to 2 inches (3.8 to 5 cm) above the relaxed shoulders.
- If patient condition allows, flex the patient's elbows, pronate the hands, and place the hands on the hips to draw the scapulae laterally.
- Adjust the shoulders to lie in the same transverse plane (Fig. 3.56).
- *Shield gonads.*
- *Respiration*: Full inspiration. The exposure is made after the *second* full inspiration to ensure the maximum expansion of the lungs.

Central ray

- Perpendicular to the long axis of the sternum and the center of the IR. The CR should enter approximately 3 inches (7.6 cm) below the jugular notch.

Collimation

- Adjust radiation field to 17 inches (43 cm) lengthwise and 1 inch (2.5 cm) beyond the shadows on both sides but no more than 14 inches (35 cm). The opposite dimensions are used for a crosswise IR. Vertical dimension may be less for smaller patients. Place a side marker in the collimated exposure field.

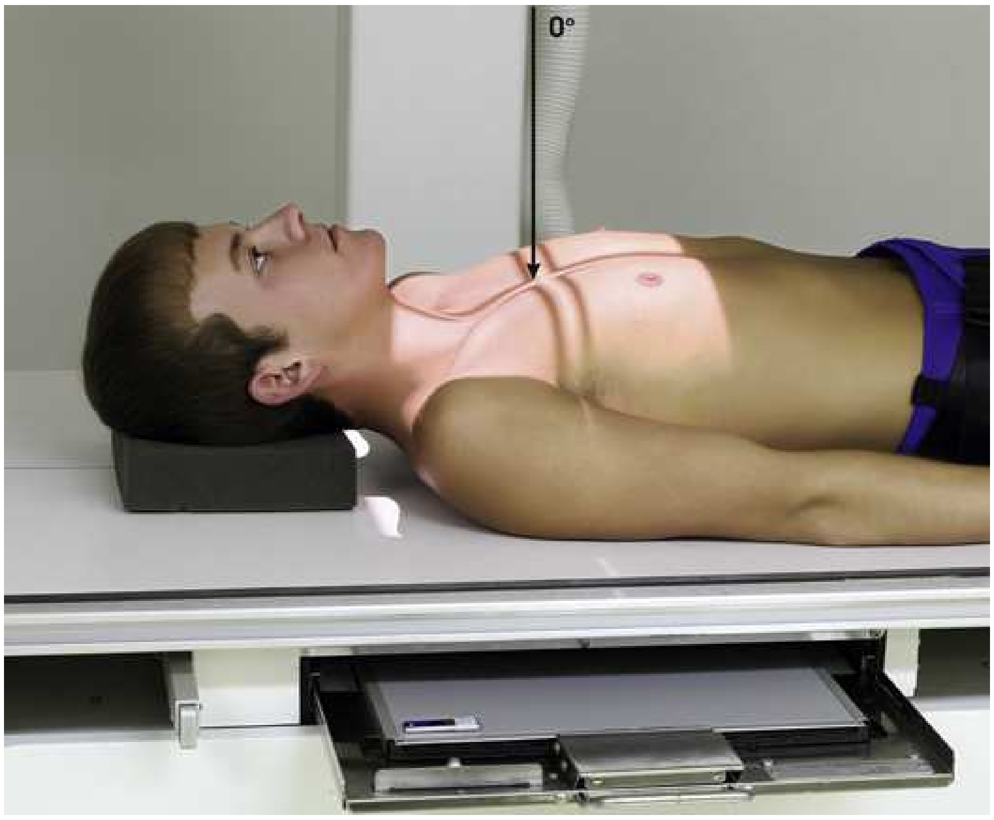


FIG. 3.56 AP chest.

A patient is in a supine position. The patient's shoulders lie in the same transverse plane. The head is elevated by placing support under it. The central ray is perpendicular to the long axis of the sternum and the center of the IR.

Structures shown

An AP projection of the thoracic viscera (Fig. 3.57) shows an image similar to the PA projection (Fig. 3.58). Being farther from the IR, the heart and great vessels are magnified and engorged, and the lung fields appear shorter because abdominal compression moves the diaphragm to a higher level. The clavicles are projected higher, and the ribs assume a more horizontal appearance.

Evaluation Criteria

The following should be clearly seen:

- Evidence of proper collimation and presence of a side marker placed clear of anatomy of interest
- Entire lungs, from the apices to the costophrenic angles
- No rotation
  - Sternal ends of the clavicles equidistant from the vertebral column
  - Trachea visible in the midline
  - Equal distance from the vertebral column to the lateral border of the ribs on each side
- Clavicles appear more horizontal than in the PA projection.
- Approximately 1 inch of the pulmonary apices should be seen superior to the clavicles.
- Pulmonary vascular markings from the hilar regions to the periphery of the lungs

NOTE: Resnick [2] recommended an angled AP projection to free the basal portions of the lung fields from superimposition by the anterior diaphragmatic, abdominal, and cardiac structures. He reported that this projection also differentiates middle lobe and lingular processes from lower lobe disease. For this projection, the patient may be either upright or supine, and the CR is directed to the midsternal region at an angle of 30 degrees caudad. Resnick stated that a more suitable angulation may be chosen based on the preliminary images.

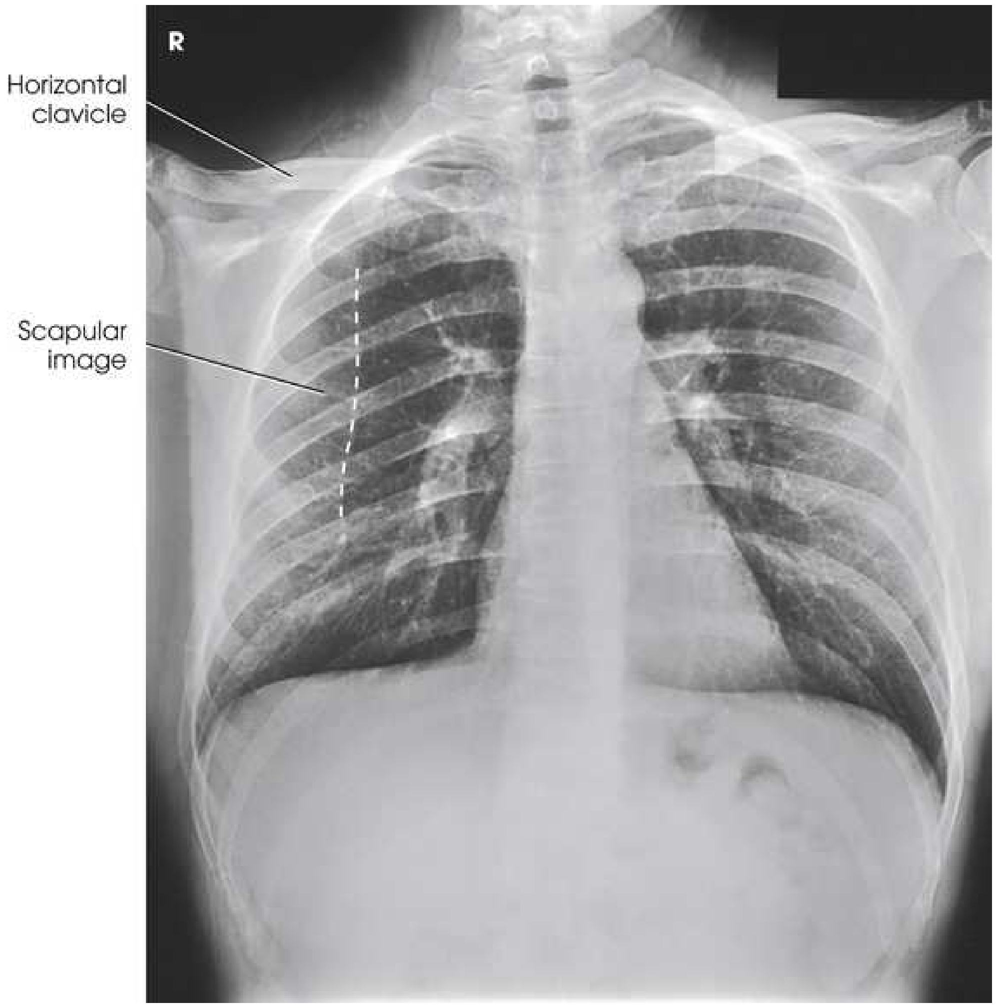


FIG. 3.57 AP chest.

An x-ray view of the chest shows the thoracic viscera. The heart and great vessels are magnified and engorged, and the lung fields appear shorter. The trachea is visible in the midline. The parts labeled are the horizontal clavicle and the scapular image.

FIG. 3.58 PA chest.

An x-ray view of the chest shows the thoracic viscera. The heart and great vessels are magnified and engorged, and the lung fields appear shorter. The trachea is visible in the midline. It appears hazy.

Pulmonary Apices

AP Axial Projection

Lindblom Method [3]

Lordotic position

Image receptor + grid: Positioned by manufacturer or department protocol for proper anatomy display orientation; CR plate: 14 × 17 inches (35 × 43 cm) lengthwise.

SID:

Minimum SID of 72 inches (183 cm) is recommended to decrease magnification of the heart and to increase spatial resolution of the thoracic structures.

Position of patient

- Place the patient in the upright position, facing the x-ray tube and standing approximately 1 foot (30.5 cm) in front of the vertical grid device.

Position of part

- Adjust the height of the IR so that the upper margin is approximately 3 inches (7.6 cm) above the upper border of the shoulders when the patient is adjusted in the lordotic position.

Lordotic position

- Adjust the patient for the AP axial projection, with the coronal plane of the thorax 15 to 20 degrees from the vertical and midsagittal plane centered to the midline of the grid (Fig. 3.59).

Oblique lordotic positions—LPO or RPO

- Rotate the patient's body approximately 30 degrees away from the position used for the AP projection, with the affected side toward and centered to the grid (Fig. 3.60).
- With either of the preceding positions, have the patient flex the elbows and place the hands, palms out, on the hips.
- Have the patient lean backward in a position of extreme lordosis and rest the shoulders against the vertical grid device.
- *Shield gonads.*
- *Respiration*: Full inspiration. The exposure is made after the *second* full inspiration to ensure the maximum expansion of the lungs.

Central ray

- Perpendicular to the center of the IR at the level of the midsternum (3 to 4 inches [7.5 to 10 cm] below jugular notch).

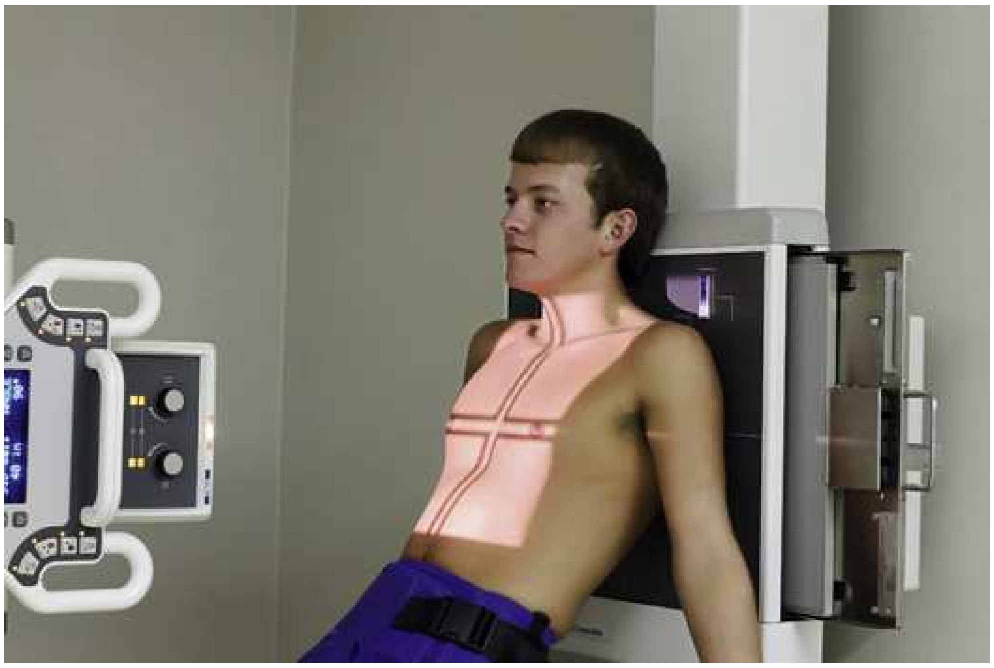


FIG. 3.59 AP axial pulmonary apices, lordotic position.

A patient is standing leaning backward facing the x-ray tube and standing in front of the vertical grid device. The shoulders are resting the vertical grid device. The hands are placed on the table. The central ray is perpendicular to the center of the I R at the level of the mid sternum.

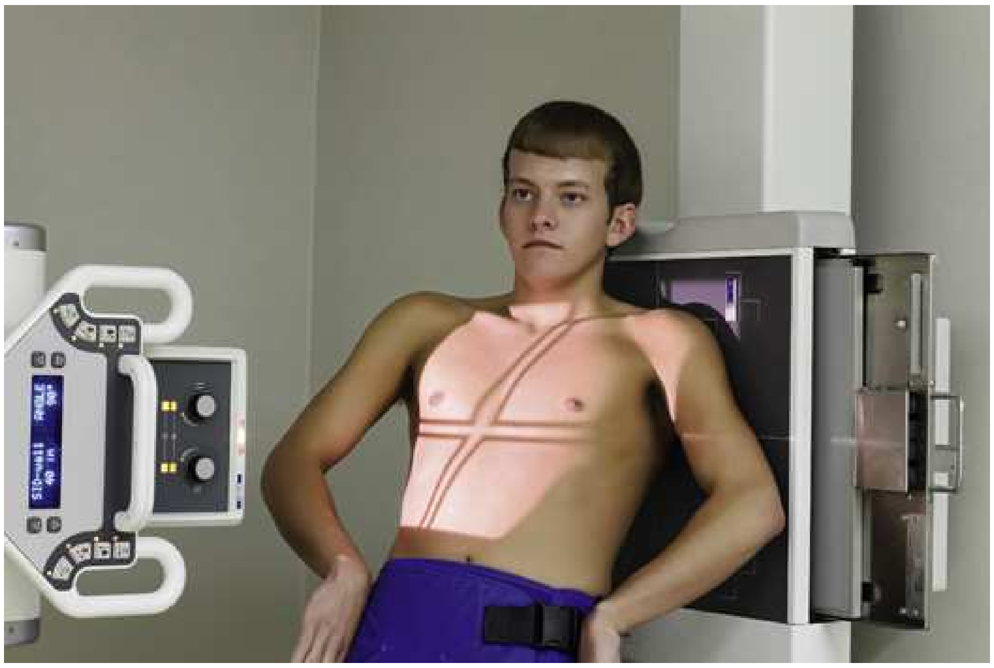


FIG. 3.60 AP axial oblique pulmonary apices, LPO lordotic position.

A patient is standing leaning backward at the vertical grid device. His body is rotated 30 degrees. His shoulders are resting on the vertical grid device. The hands are placed with palms out on the hips. The central ray is perpendicular to the center of the I R at the level of the mid sternum.

Collimation

- Adjust radiation field to 17 inches (43 cm) lengthwise and 1 inch (2.5 cm) beyond the shadows on both sides but no more than 14 inches (35 cm). Exposure field may be smaller, depending on department protocol. Place a side marker in the collimated exposure field.

Structures shown

AP axial (Fig. 3.61) and AP axial oblique (Fig. 3.62) images of the lungs show the apices and conditions such as interlobar effusions.

Evaluation Criteria

The following should be clearly seen:

- Evidence of proper collimation and presence of a side marker placed clear of anatomy of interest
- Pulmonary vascular markings of the apices

Lordotic position

- Entire apices and appropriate portion of lungs
- Clavicles located superior to the apices
- Sternal ends of the clavicles equidistant from the vertebral column
- Clavicles lying horizontally with their sternal ends overlapping only the first or second ribs
- Ribs distorted with their anterior and posterior portions superimposed

Oblique lordotic position

- Dependent apex and lung of the affected side in its entirety

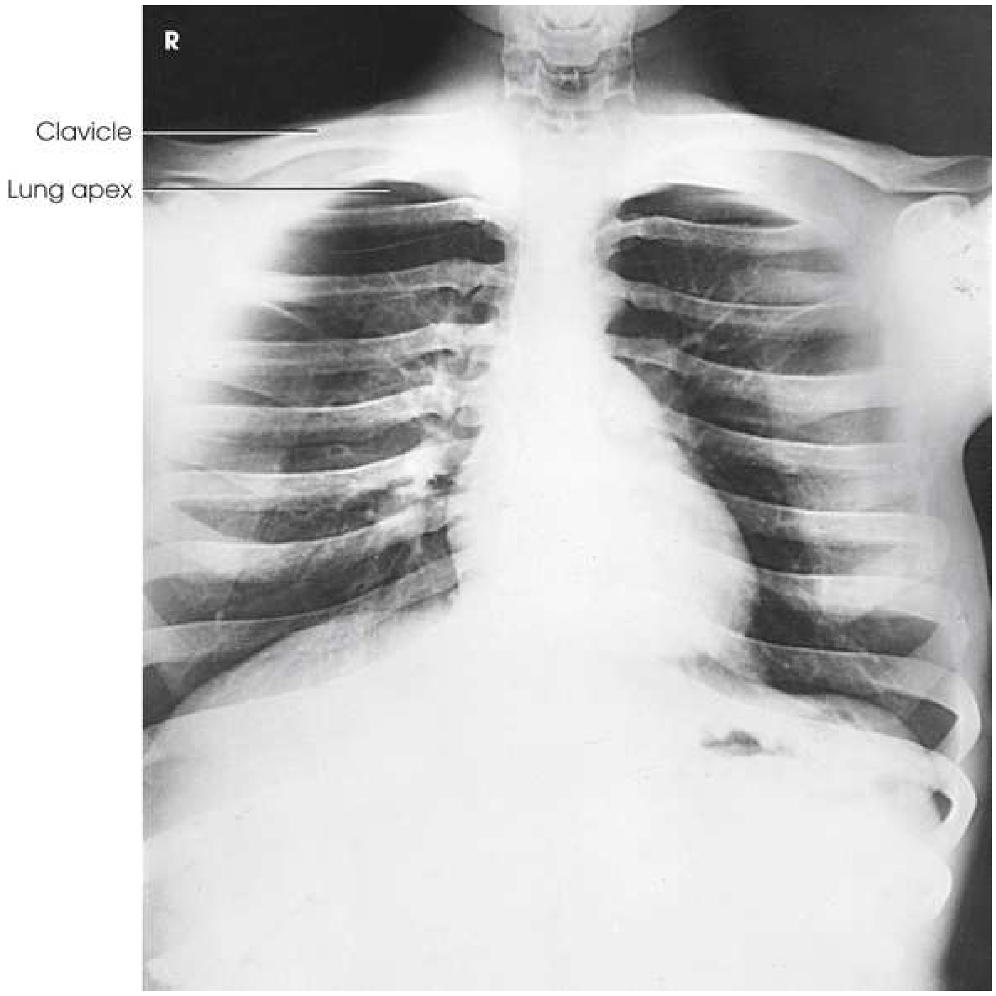


FIG. 3.61 AP axial pulmonary apices, lordotic position.

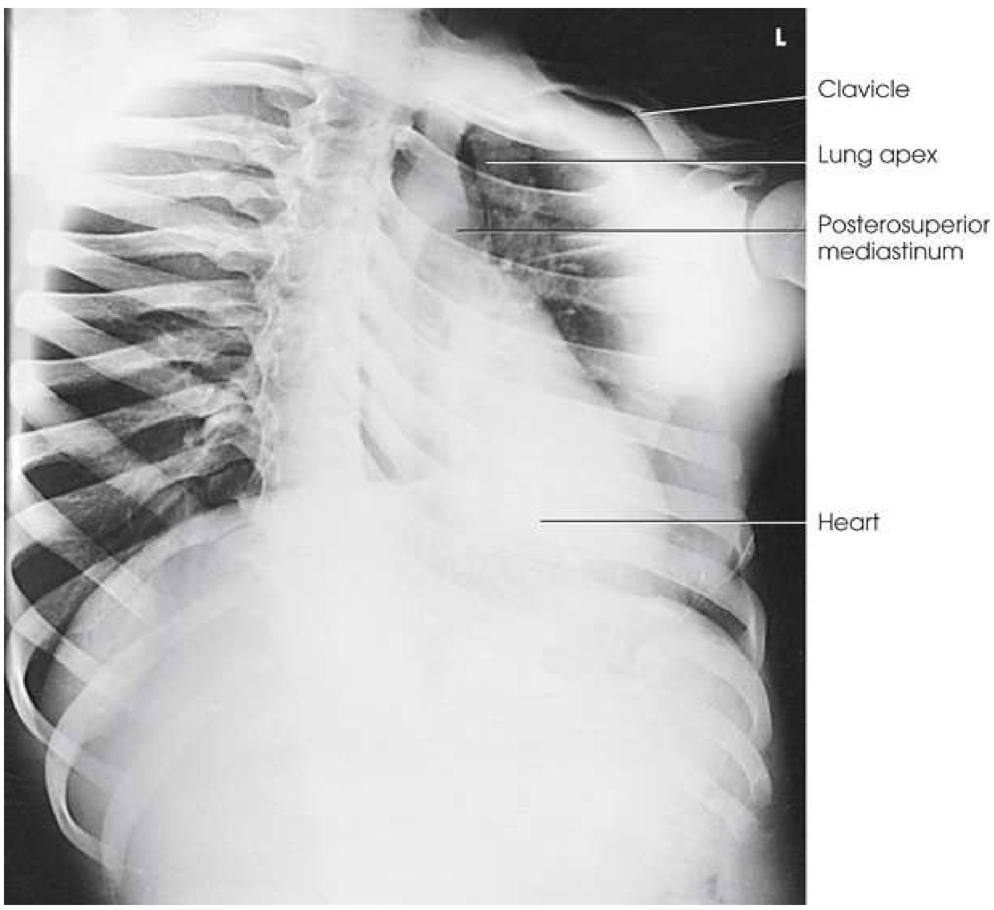


FIG. 3.62 AP axial oblique pulmonary apices, LPO lordotic position.

AP Axial Projection

Image receptor + grid: Positioned by manufacturer or department protocol for proper anatomy display orientation; CR plate: 10 × 12 inches (24 × 30 cm) crosswise or 14 × 17 inches (35 × 43 cm)

NOTE: This projection is recommended when the patient cannot be placed in the lordotic position.

SID:

Minimum SID of 72 inches (183 cm) is recommended to decrease magnification of the heart and to increase spatial resolution of the thoracic structures.

Position of patient

- Examine the patient in the upright or supine position.

Position of part

- Center the IR to the midsagittal plane at the level of T2.
- Adjust the patient's body so that it is not rotated, ensuring MSP is perpendicular to the IR plane.
- Flex the patient's elbows and place the hands on the hips with the palms out or pronate the hands beside the hips.
- Place the shoulders back against the grid and adjust them to lie in the same transverse plane (Fig. 3.63).
- *Shield gonads.*
- *Respiration*: Expose at the end of *full inspiration.*

Central ray

- Directed at an angle of 15 or 20 degrees cephalad to the center of the IR and entering the manubrium

Collimation

- Adjust radiation field to 10 × 12 inches (24 × 30 cm). Approximately 1 inch (2.5 cm) of field light should be seen above shadow of the shoulders. Place a side marker in the collimated exposure field.

Structures shown

AP axial projection shows the apices lying below the clavicles (Fig. 3.64).

Evaluation Criteria

The following should be clearly seen:

- Evidence of proper collimation and presence of a side marker placed clear of anatomy of interest
- Apices in their entirety
- Superior lung region adjacent to the apices
- Clavicles located superior to the apices and oriented horizontally with the sternal ends overlapping the first or second rib
- Sternal ends of the clavicles equidistant from the vertebral column
- Ribs distorted, with their anterior and posterior portions superimposed
- Pulmonary vascular markings of the apices

NOTE: The AP axial projection is used in preference to the PA axial projection in hypersthenic patients and patients whose clavicles occupy a high position. The AP axial projection makes it possible to separate the apical and clavicular shadows without undue distortion of the apices.

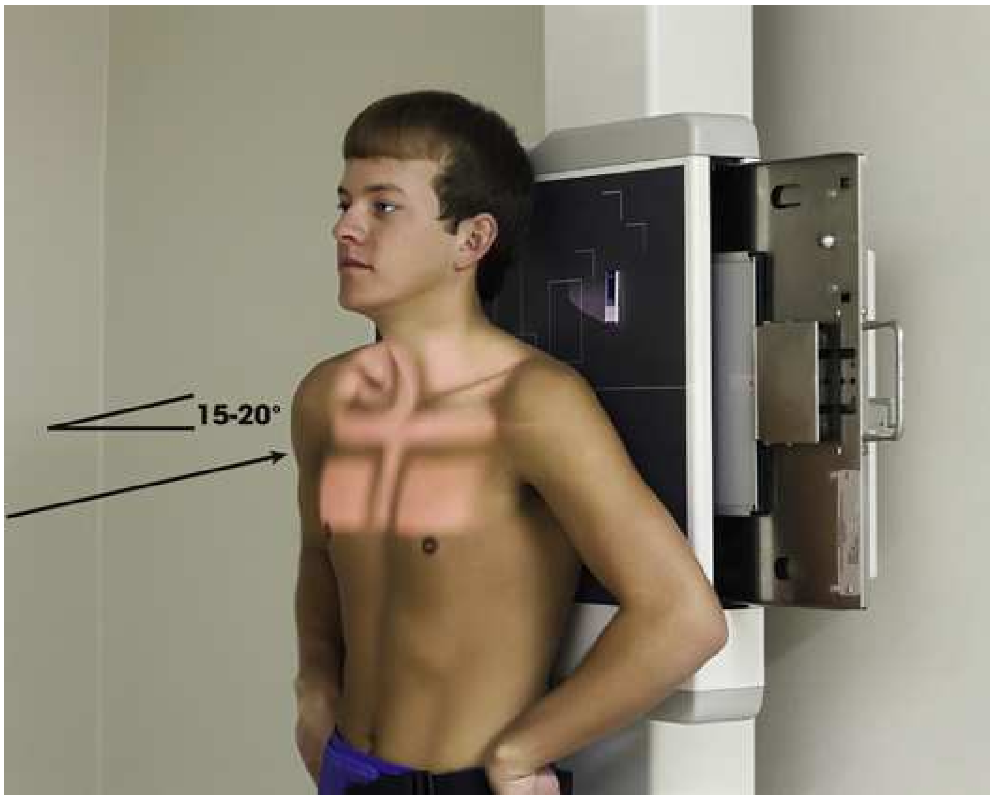


FIG. 3.63 AP axial pulmonary apices.

A patient is standing in front of the vertical grid. The elbows are flexed and the hands are placed on the hips with the palms out. The shoulders back are placed against the grid. The central ray is directed at an angle of 15 or 20 degrees cephalad to the center of the I R and entering the manubrium.

FIG. 3.64 AP axial pulmonary apices.

An x-ray view of the chest shows the apices lying below the clavicles. The clavicles are located superior to the apices and oriented horizontally with the sternal ends overlapping the first or second rib. The parts labeled are clavicle and apex. The clavicle appears grey.

PA Axial Projection

Image receptor + grid: Positioned by manufacturer or department protocol for proper anatomy display orientation; CR plate: 10 × 12 inches (24 × 30 cm) crosswise

SID:

Minimum SID of 72 inches (183 cm) is recommended to decrease magnification of the heart and to increase spatial resolution of the thoracic structures.

Position of patient

- Position the patient seated or standing before a vertical grid device. If the patient is standing, the weight of the body must be equally distributed on the feet.

Position of part

- Adjust the height of the IR so that it is centered at the level of the jugular notch.
- Center the MSP of the patient's body to the midline of the IR and rest the chin against the grid device.
- Adjust the patient's head so that the midsagittal plane is vertical, and then flex the elbows and place the hands, palms out, on the hips.
- Depress the patient's shoulders, rotate them forward, and adjust them to lie in the same transverse plane.
- Instruct the patient to keep the shoulders in contact with the grid device to move the scapulae from the lung fields (Fig. 3.65).
- *Shield gonads.*
- *Respiration*: Make the exposure at the end of *full inspiration* or, as an option, at *full expiration.* The clavicles are elevated by inspiration and depressed by expiration; the apices move little, if at all, during either phase of respiration.

Central ray

Inspiration

- Directed 10 to 15 degrees cephalad through T3 to the center of the IR

Expiration (optional)

- Directed perpendicular to the plane of the IR and centered at the level of T3

Collimation

- Adjust radiation field to 10 × 12 inches (24 × 30 cm). Place a side marker in the collimated exposure field.

Structures shown

The apices are projected above the shadows of the clavicles in the PA axial and PA projections (Fig. 3.66).

Evaluation Criteria

The following should be clearly seen:

- Evidence of proper collimation and presence of a side marker placed clear of anatomy of interest
- Entire apices and appropriate portion of lungs
- Clavicles located below the apices
- Sternal ends of the clavicles equidistant from the vertebral column
- Pulmonary vascular markings of the apices

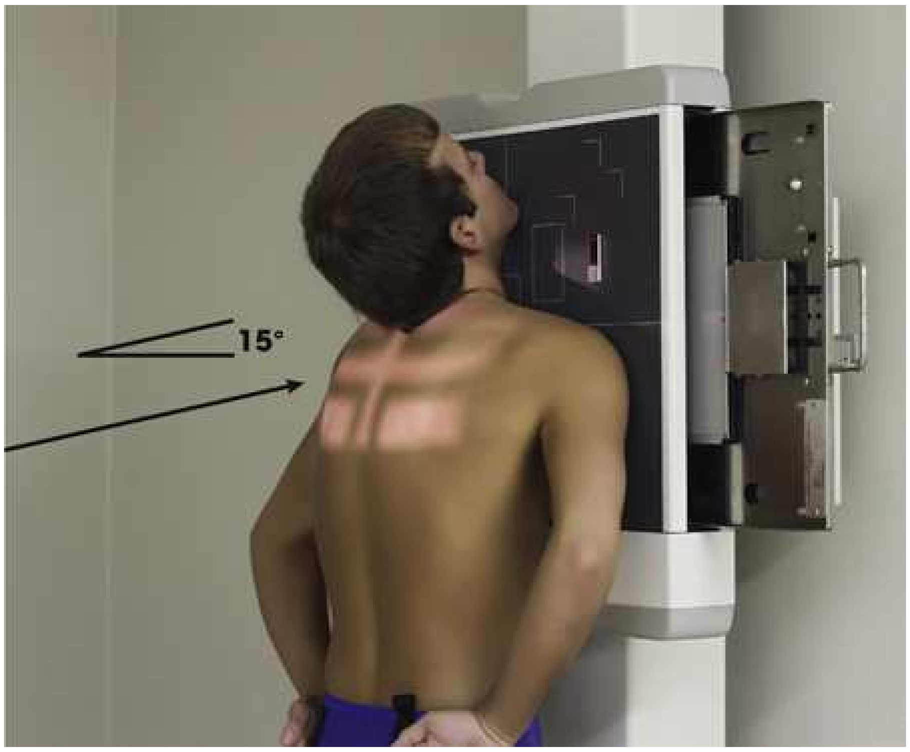


FIG. 3.65 PA axial pulmonary apices (inspiration).

A patient is standing close to the vertical grid the chin resting against it. The elbows are flexed and the hands are placed on the hips with the palms out. The shoulders are placed against the grid. The central ray is directed 10 to 15 degrees cephalad through T 3 to the center of the I R.

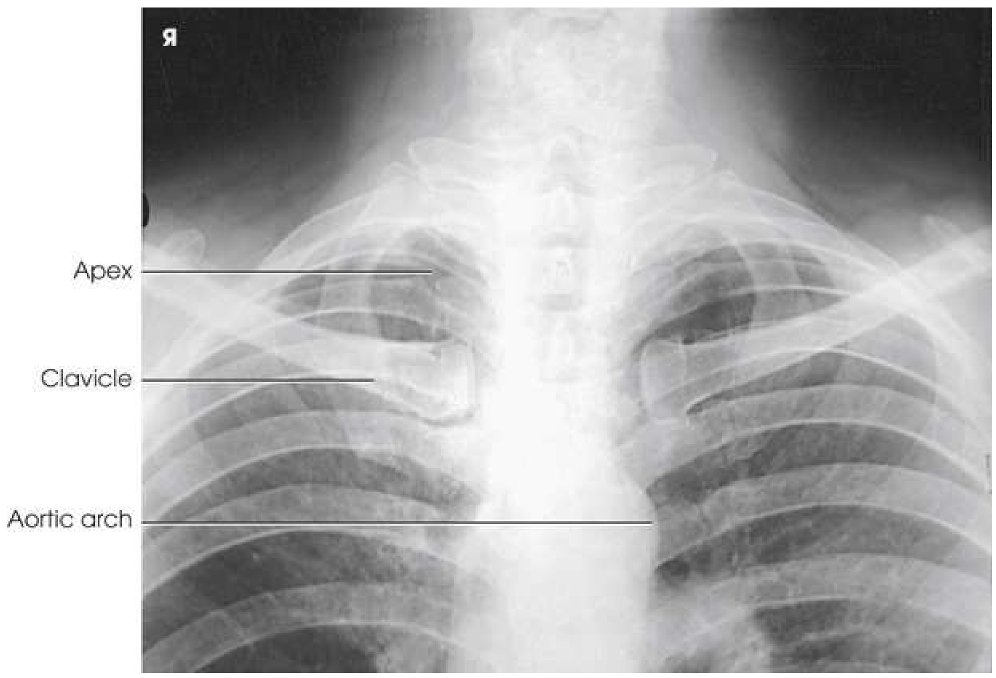


FIG. 3.66 PA axial pulmonary apices, inspiration with central ray angled.

Chest

AP or PA Projection [a]

R or L lateral decubitus positions

Image receptor + grid: Positioned by manufacturer or department protocol for proper anatomy display orientation; CR plate: 14 × 17 inches (35 × 43 cm) lengthwise.

Position of patient

- Place the patient in a lateral decubitus position, lying on either the affected or the unaffected side, as indicated by the existing condition. A small amount of fluid in the pleural cavity, a *pleural effusion*, is usually best shown with the patient lying on the *affected* side. With this positioning, the mediastinal shadows and the fluid do not overlap. A small amount of free air in the pleural cavity, a pneumothorax, is generally best shown with the patient lying on the *unaffected* side.
- *Exercise care* to ensure that the patient does not fall off the cart. If a cart is used, *lock all wheels* securely in position.
- Achieve the best visualization by allowing the patient to remain in the position for 5 *minutes before the exposure.* This allows fluid to settle and air to rise.

Position of part

- If the patient is lying on the affected side to demonstrate presence of a pleural effusion, elevate the body 2 to 3 inches (5 to 7.6 cm) on a suitable platform or a firm pad.
- Extend the arms well above the head and adjust the thorax in a true lateral position (Fig. 3.67).
- Place the anterior or posterior surface of the chest against a vertical grid device.
- Adjust the IR to place the cephalic edge it 1.5 to 2 inches (3.8 to 5 cm) above the shoulders.
- *Shield gonads.*
- *Respiration*: Full inspiration. The exposure is made after the *second* full inspiration to ensure the maximum expansion of the lungs.

Central ray

- *Horizontal* and perpendicular to the center of the IR at a level 3 inches (7.6 cm) below the jugular notch for AP and T7 for PA.

Collimation

- Adjust radiation field to 14 × 17 inches (35 × 43 cm) on the collimator. Place a side marker and decubitus marker in the collimated exposure field.

Structures shown

AP or PA projection obtained using the lateral decubitus position shows the change in fluid position and reveals any previously obscured pulmonary areas or, in the case of suspected pneumothorax, the presence of any free air (Figs. 3.68 through 3.70).

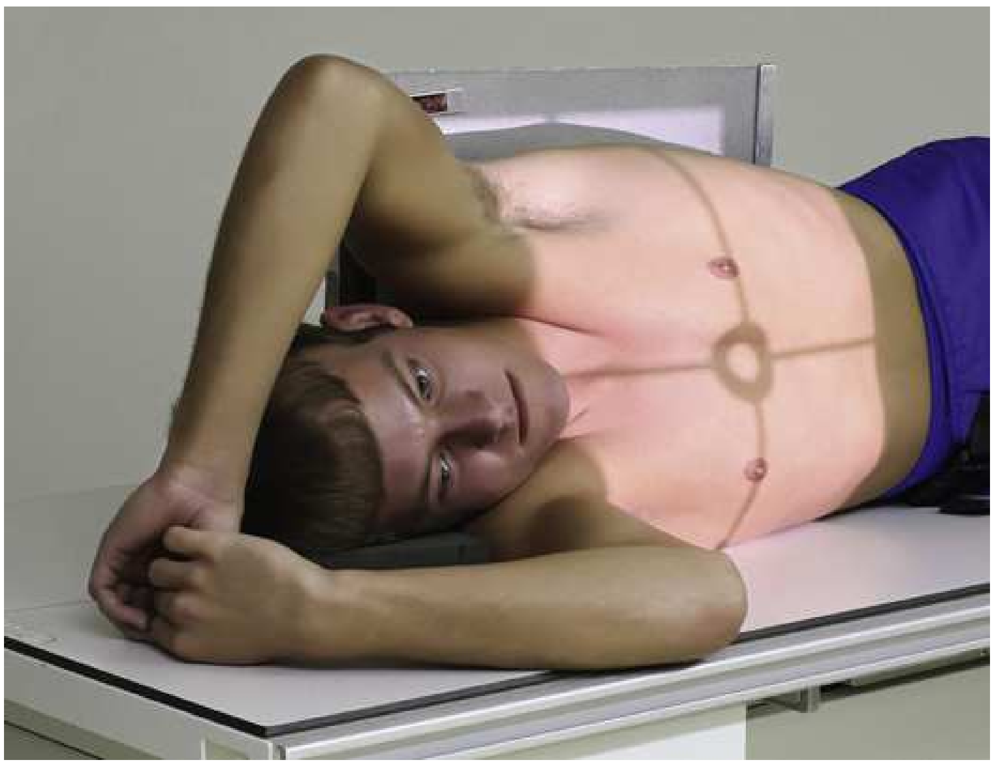


FIG. 3.67 AP projection, right lateral decubitus position. Side up is the affected side, so no table pad was used. This projection would demonstrate free air rising up to the left side.

A patient is in a right lateral decubitus position. The arms are extended above the head. The posterior surface of the chest is against a vertical grid device. The central ray is horizontal and perpendicular to the center of the I R.

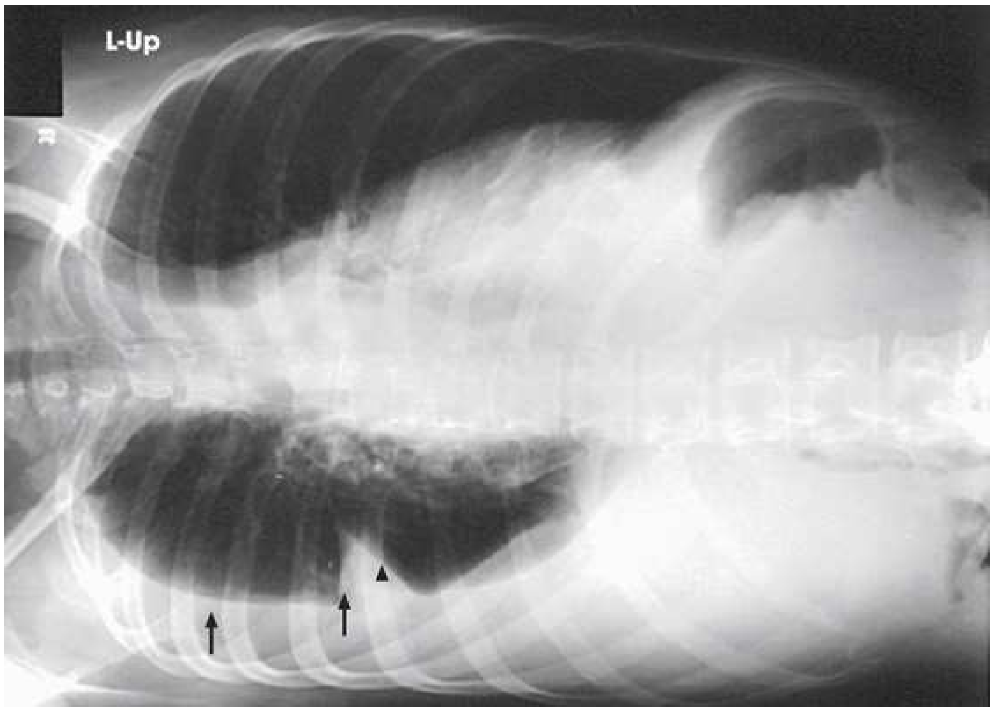


FIG. 3.68 AP projection, right lateral decubitus position, showing a fluid level *(arrows)* on the side that is down. Note the fluid in the lung fissure *(arrowhead)*. Note correct marker placement, with the upper side of the patient indicated.

Evaluation Criteria

The following should be clearly seen:

- Evidence of proper collimation and presence of a side marker and decubitus marker placed clear of anatomy of interest
- Affected side in its entirety, from apex to costophrenic angles
- No rotation of the patient, as demonstrated by the sternal ends of the clavicles equidistant from the spine
- Patient's arms not visible in the field of interest
- Faintly visible spine and pulmonary vascular markings from the hilar regions to the periphery of the lungs

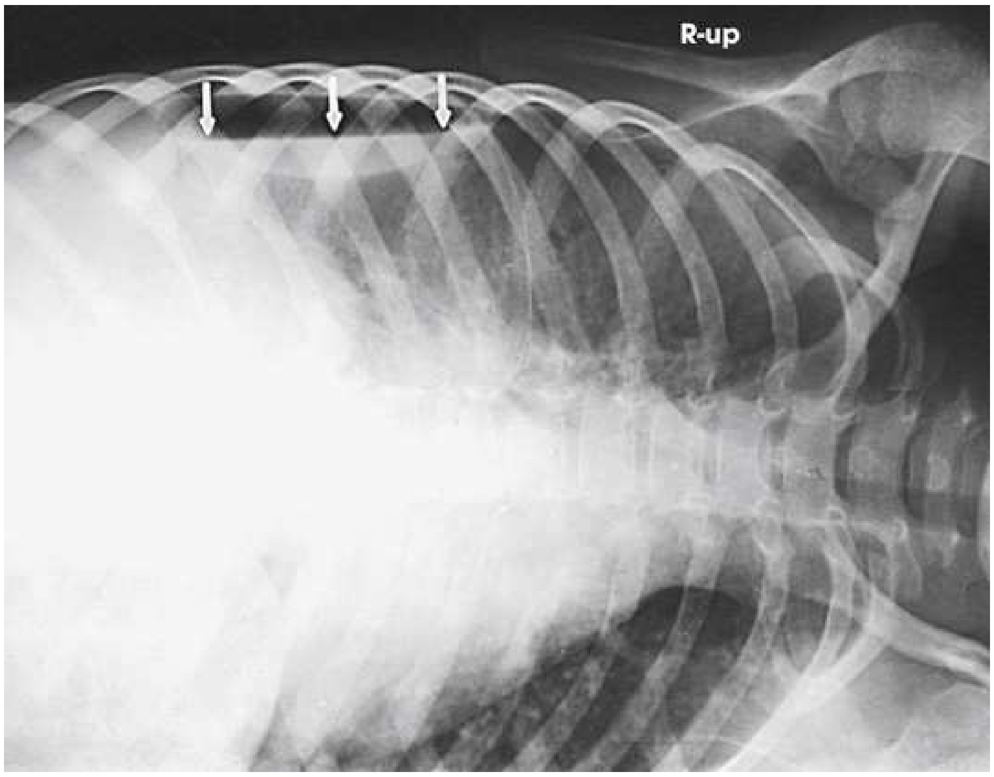


FIG. 3.69 AP projection, left lateral decubitus position, in same patient as in Fig. 3.73. *Arrows* indicate air-fluid level (air on the side up). Note correct marker placement, with upper side of the patient indicated.

FIG. 3.70 Upright PA chest. *Arrow* indicates air-fluid level.

Lateral Projection

R or L position

Ventral or dorsal decubitus position

Image receptor + grid: Positioned by manufacturer or department protocol for proper anatomy display orientation; CR plate: 14 × 17 inches (35 × 43 cm) lengthwise.

Position of patient

- With the patient in a prone or supine position, elevate the thorax 2 to 3 inches (5 to 7.6 cm) on folded sheets or a firm pad, centering the thorax to the grid.
- Achieve the best visualization by allowing the patient to remain in the position for *5 minutes before the exposure.* This allows fluid to settle and air to rise.

Position of part

- Adjust the body in a true prone or a supine position and extend the arms well above the head.
- Place the affected side against a vertical grid device, then place the cephalic edge of the IR at the level of the thyroid cartilage (Fig. 3.71).
- *Shield gonads.*
- *Respiration*: Full inspiration. The exposure is made after the *second* full inspiration to ensure the maximum expansion of the lungs.

Central ray

- *Horizontal* and centered to the IR. The CR enters at the level of the midcoronal plane and 3 to 4 inches (7.6 to 10.2 cm) below the jugular notch for the dorsal decubitus and at T7 for the ventral decubitus.

Collimation

- Adjust radiation field to 14 × 17 inches (35 × 43 cm) on the collimator. Place a side marker in the collimated exposure field.

Structures shown

A lateral projection in the decubitus position shows a change in the position of fluid and reveals pulmonary areas that are obscured by the fluid in standard projections (Figs. 3.72 and 3.73).

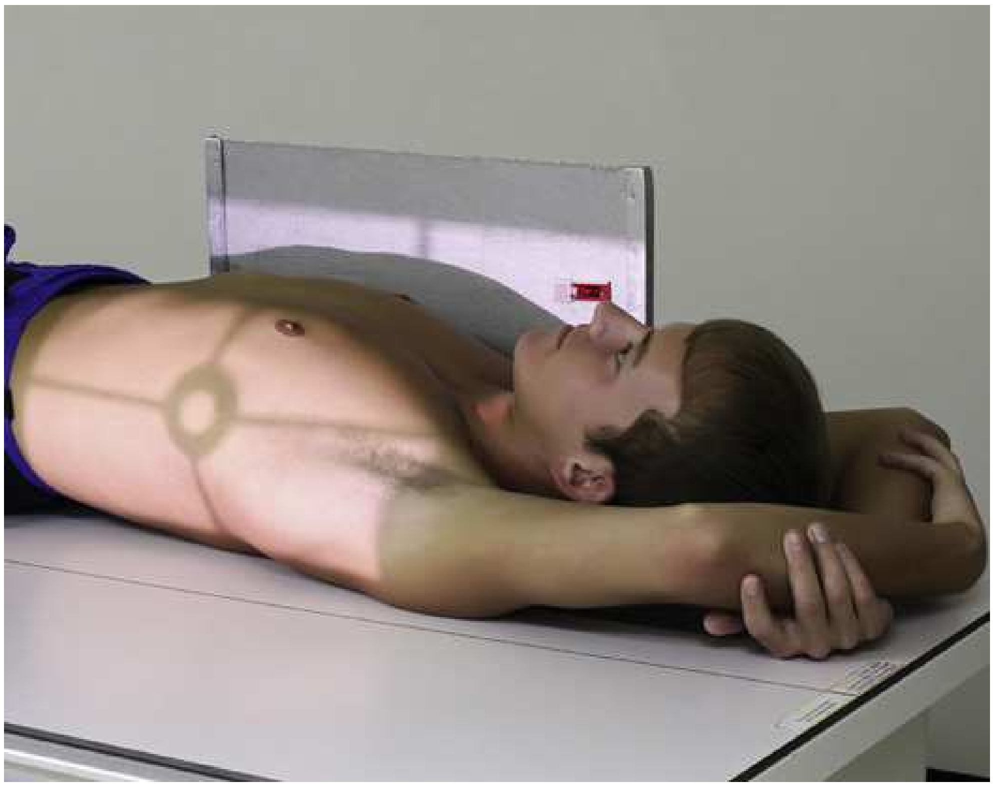


FIG. 3.71 Right lateral projection, dorsal decubitus position. Side up is the affected side, so no table pad was used. This projection would demonstrate free air rising up to the anterior chest.

A patient is in a supine position on the radiographic table with the affected side of the vertical grid device. The arms are extended above the head. The central ray is horizontal and centered to the I R.

FIG. 3.72 Right lateral projection, dorsal decubitus position. *Arrows* indicate air-fluid level. Note correct marker placement, with upper side of the patient indicated.

Evaluation Criteria

The following should be clearly seen:

- Evidence of proper collimation and presence of side and decubitus markers placed clear of anatomy of interest
- Entire lung fields, including the anterior and posterior surfaces
- Upper lung field not obscured by the arms
- No rotation of the thorax from a true lateral position
- T7 in the center of the IR
- Pulmonary vascular markings from the hilar regions to the periphery of the lungs

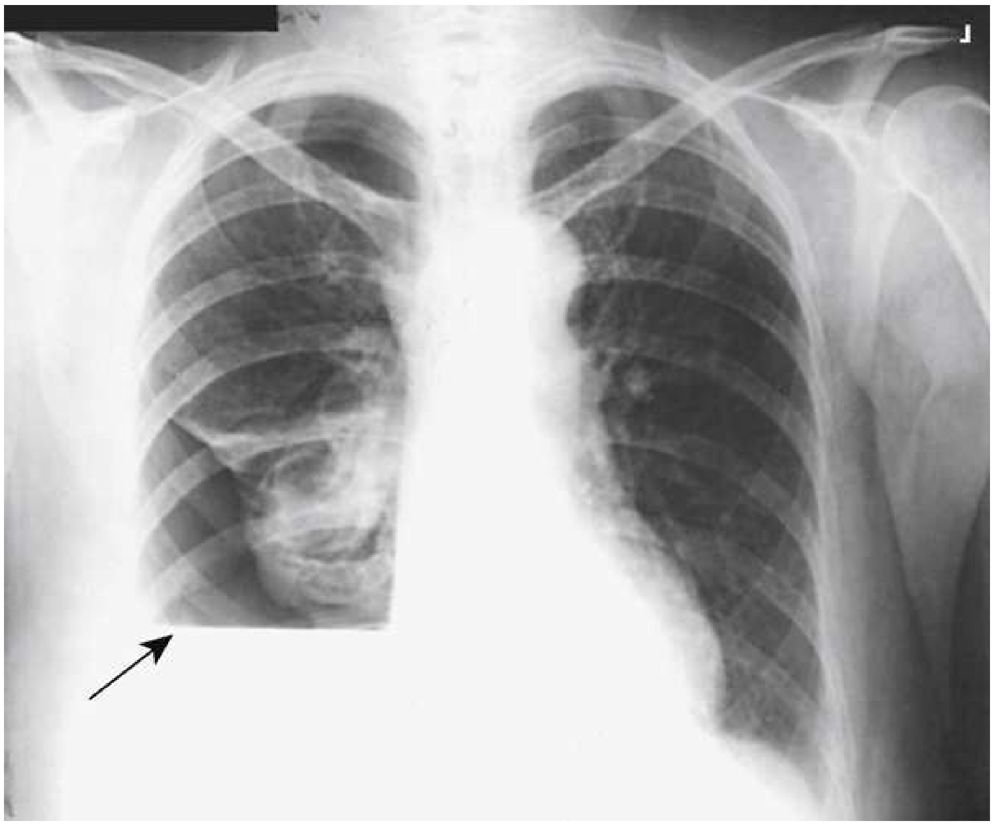


FIG. 3.73 Upright PA chest in same patient as in Fig. 3.72. Note right lung fluid level *(arrow)*.

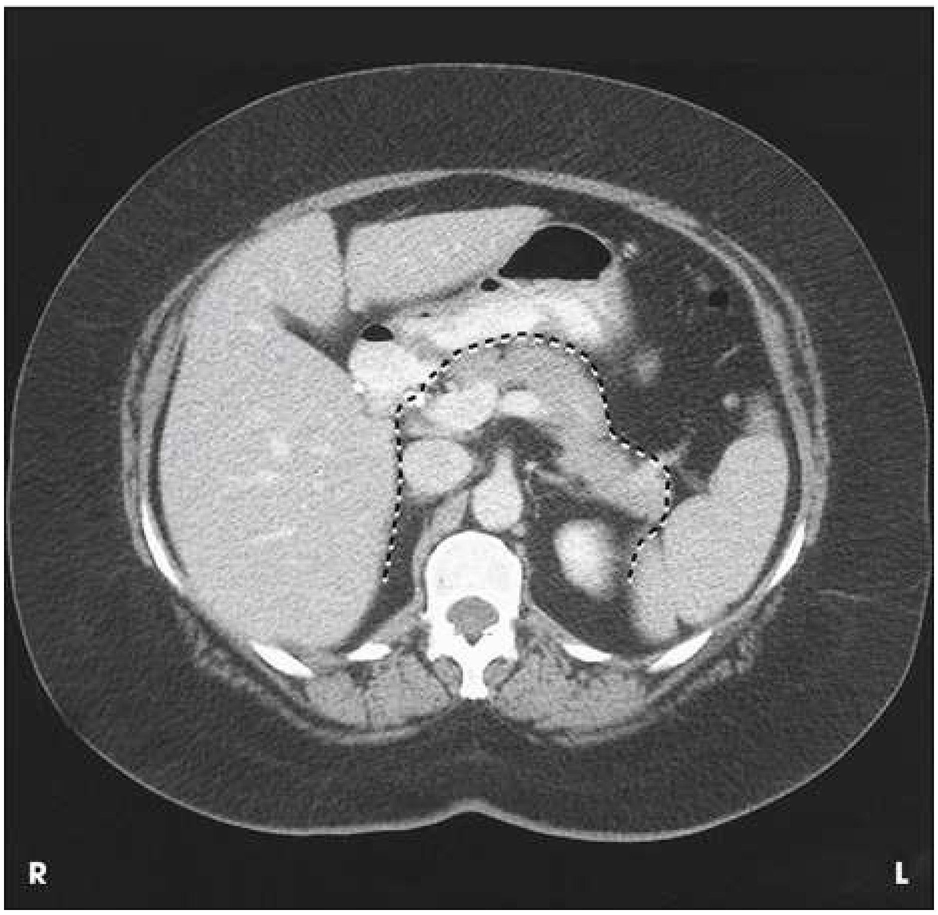
References

1. Eiselberg A, Sgalitzer D.M. X-ray examination of the trachea and the bronchi. *Surg Gynecol Obstet* . 1928;47:53.
2. Resnick D. The angulated basal view: a new method for evaluation of lower lobe pulmonary disease. *Radiology* . 1970;96:204.
3. Lindblom K. Half-axial projection in accentuated lordosis for Roentgen studies of the lungs. *Acta Radiol* . 1940;21:119.

[a] See Chapter 20, Volume 3, for a full description of mobile AP.

[a] See Chapter 20, Volume 3, for a full description of mobile AP.

4: Abdomen



OUTLINE

Summary of Projections

Projections, Positions, and Methods					
Page	Essential	Anatomy	Projection	Position	Method
138		Abdomen	AP	Supine; upright	
140		Abdomen	PA	Upright	
140		Abdomen	AP	L lateral decubitus	
142		Abdomen	Lateral	R or L	
143		Abdomen	Lateral	R or L dorsal decubitus	

AP, Anteroposterior; *L,* left; *PA,* posteroanterior; *R,* right.

Icons in the Essential column indicate projections frequently performed in the United States and Canada. Students should be competent in these projections.

Anatomy

Abdominopelvic Cavity

The *abdominopelvic* cavity consists of two parts: (1) a large superior portion, the abdominal cavity; and (2) a smaller inferior part, the pelvic cavity. The *abdominal cavity* extends from the diaphragm to the superior aspect of the bony pelvis (Fig. 4.1). The abdominal cavity contains the stomach, small and large intestines, liver, gallbladder, spleen, pancreas, and kidneys. The *pelvic cavity* lies within the margins of the bony pelvis and contains the rectum and sigmoid of the large intestine, the urinary bladder, and the reproductive organs. Anatomists define the "true pelvis" as that portion of the abdominopelvic cavity inferior to a plane passing through the sacral promontory posteriorly and the superior surface of the pubic bones anteriorly.

The abdominopelvic cavity is enclosed in a double-walled seromembranous sac called the *peritoneum*. The outer portion of this sac, termed the *parietal peritoneum*, is in close contact with the abdominal wall, the greater (false) pelvic wall, and most of the undersurface of the diaphragm. The inner portion of the sac, known as the *visceral peritoneum*, is positioned over or around the contained organs. The peritoneum forms folds called the *mesentery* and *omenta*, which serve to support the viscera in position. The space between the two layers of the peritoneum is called the *peritoneal cavity* and contains serous fluid (Fig. 4.2). Because there are no mesenteric attachments of the intestines in the pelvic cavity, pelvic surgery can be performed without entry into the peritoneal cavity.

The *retroperitoneum* is the cavity behind the peritoneum. Organs such as the kidneys and pancreas lie in the retroperitoneum (Fig. 4.3).

Recall from Chapter 2, the abdomen is divided in two ways: four quadrants or nine regions (Fig. 4.4). The four quadrants are:

- Right upper quadrant (RUQ)
- Left upper quadrant (LUQ)
- Right lower quadrant (RLQ)
- Left lower quadrant (LLQ)

The nine regions are:

Superior

- Right hypochondrium
- Epigastrium
- Left hypochondrium

Middle

- Right lateral
- Umbilical
- Left lateral

Inferior

- Right inguinal

• Hypogastrium
• Left inguinal

Radiographers must know the location of the abdominal organs using both divisions to record an accurate clinical history on patients with abdominal complaints.

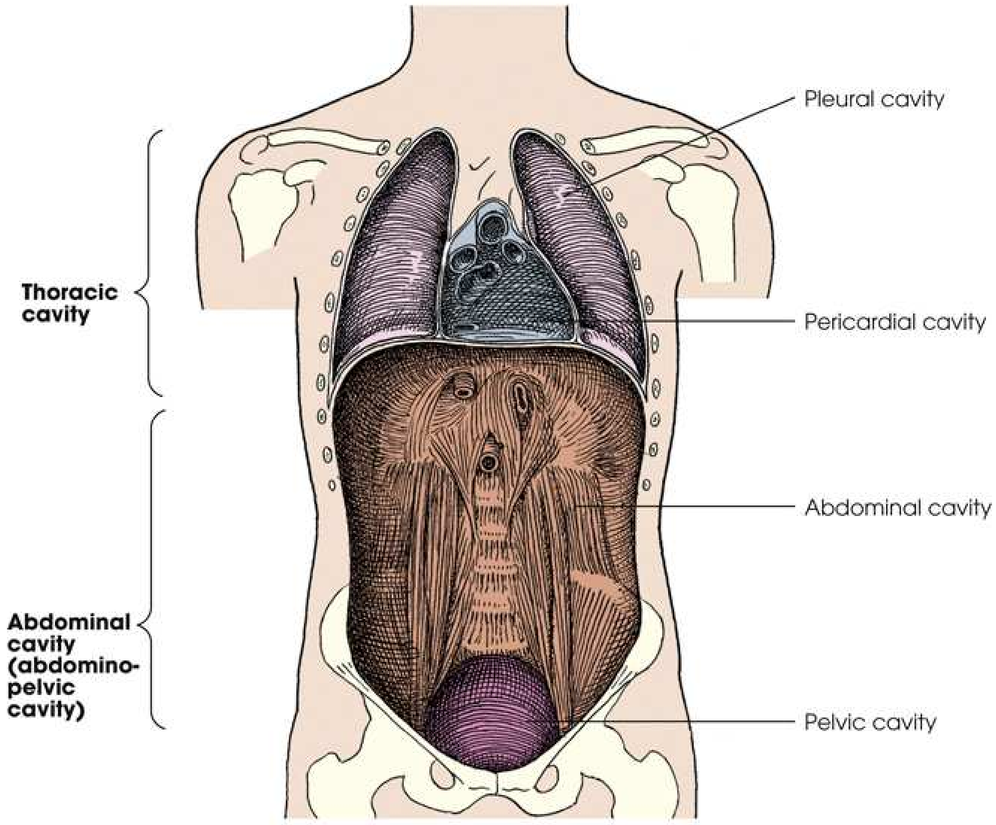


FIG. 4.1 Anterior view of torso showing two great cavities: thoracic and abdominopelvic.

Diagram of the anterior view of torso shows the following parts labeled in the thoracic cavity: pleural cavity and pericardial cavity. The parts labeled in the abdominal cavity (abdominopelvic cavity) are abdominal cavity and pelvic cavity.

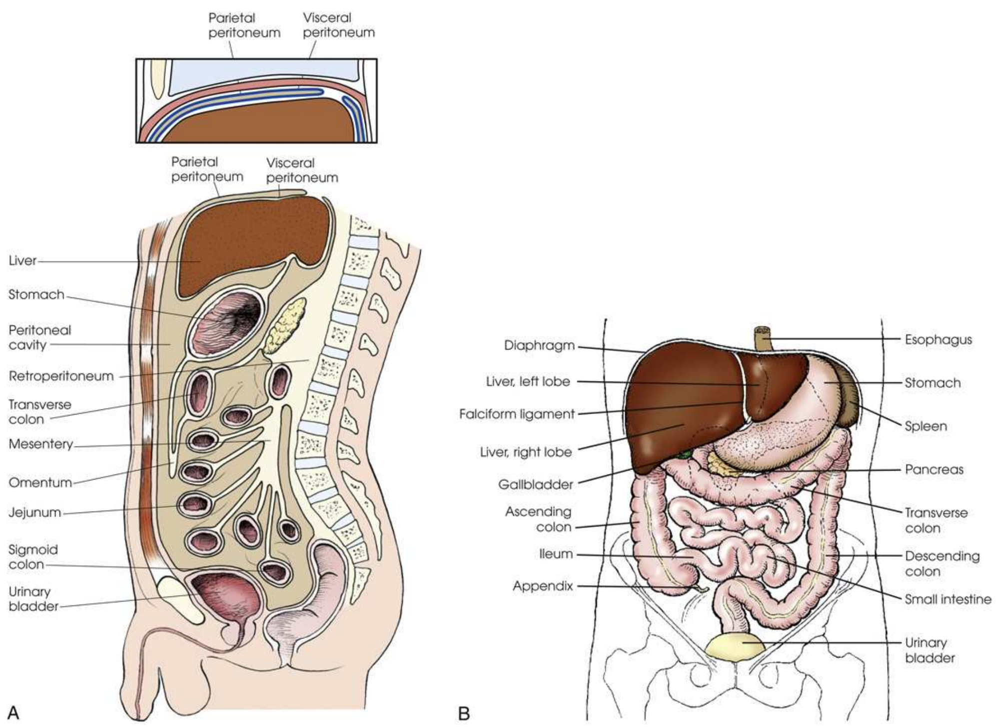


FIG. 4.2 (A) Lateral aspect of abdomen showing peritoneal sac and its components. (B) Anterior aspect of abdominal viscera in relation to surrounding structures.

Diagram (A) shows the lateral aspect of abdomen. The parts labeled in the diagram are as follows: parietal peritoneum, visceral peritoneum, liver, stomach, peritoneal cavity, retroperitoneum, transverse colon, mesentery, omentum, jejunum, sigmoid, colon, and urinary bladder. An enlarged diagram of the parietal peritoneum and visceral peritoneum is on top. Diagram (B) shows the anterior aspect of abdominal viscera. The parts labeled in the diagram on the left are as follows: diaphragm, liver left lobe, falciform ligament, liver right lobe, gallbladder, ascending colon, ileum, and appendix. The parts labeled in the diagram on the right are as follows: esophagus, stomach, spleen, pancreas, descending colon, transverse colon, small intestine, and urinary bladder.

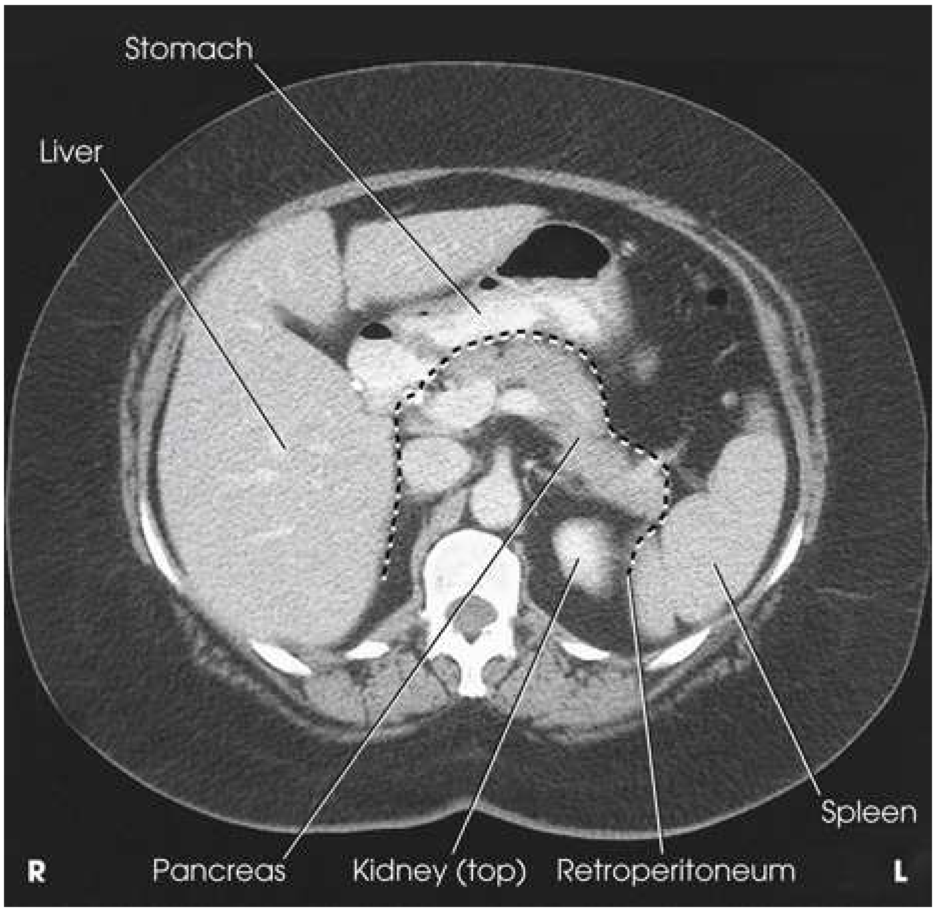


FIG. 4.3 Axial CT image of abdomen showing organs of upper abdomen. Retroperitoneum is posterior and medial to *dashed line*. From Kelley LL, Petersen CM. *Sectional Anatomy for Imaging Professionals*. 2nd ed. St. Louis: Mosby; 2007.

An axial C T image of abdomen shows the organs of upper abdomen. The organs appear radiopaque and the tissues around it appear radiolucent. The organs labeled are liver, stomach, spleen, retroperitoneum, kidney (top), and pancreas. Retroperitoneum is posterior and medial to dashed line.

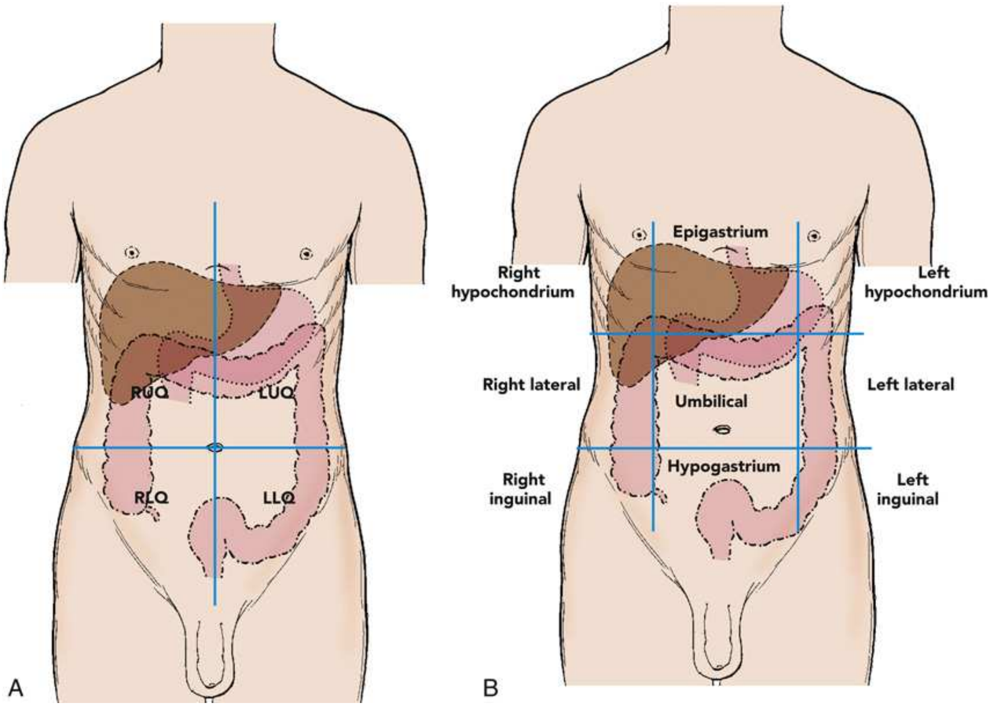


FIG. 4.4 (A) Four quadrants of the abdomen. (B) Nine regions of the abdomen.

Diagram (A) shows the anterior view of the human body showing the four quadrants of the abdomen. The four quadrants are right upper quadrant (R U Q), left upper quadrant (L U Q), right lower quadrant (R L Q), and left lower quadrant (L L Q). Diagram (B) shows the anterior view of the human body showing the nine regions of the abdomen. The nine regions are as follows. The superior regions are right hypochondrium, epigastrium, left hypochondrium. The middle regions are right lateral, umbilical, left lateral. The inferior regions are right inguinal, hypogastrium, left inguinal.

Summary of Anatomy

Abdomen
Abdominopelvic cavity
Abdominal cavity
Pelvic cavity
Peritoneum
Parietal peritoneum
Mesentery
Omenta
Peritoneal cavity
Retroperitoneum
Visceral peritoneum

Summary of Pathology

Condition	Definition
Abdominal aortic aneurysm (AAA)	Localized dilation of abdominal aorta
Ascites	Fluid accumulation in the peritoneal cavity
Bowel obstruction	Blockage of bowel lumen
Ileus	Failure of bowel peristalsis
Metastasis	Transfer of a cancerous lesion from one area to another
Pneumoperitoneum	Presence of air in peritoneal cavity
Tumor	New tissue growth where cell proliferation is uncontrolled

These techniques were accurate for the equipment used to produce each exposure. However, use caution when applying them in your department because "there is considerable variability in image receptor response owing to varying scatter sensitivity, the use of grids with different grid ratios, collimation, beam filtration, the choice of kilovoltage, source-to-image distance, and image receptor size."[1]

This chart was created in collaboration with Dennis Bowman, AS, RT(R), Clinical Instructor, Community Hospital of the Monterey Peninsula, Monterey, CA. http://digitalradiographysolutions.com/.

Abdomen								
Part	**cm**	**kVp**[a]	**SID**[b]	**Collimation**	**CR**[c]		**DR**[d]	
					mAs	**Dose (mGy)**[e]	**mAs**	**Dose (mGy)**[e]
AP[f]	21	85	40″	14″ × 17″ (35 × 43 cm)	25[g]	3.700	10[g]	1.474
PA[f]	21	85	40″	14″ × 17″ (35 × 43 cm)	22[g]	3.250	9[g]	1.321
AP/lateral decubitus[f]	24	85	40″	17″ × 14″ (43 × 35 cm)	28[g]	4.480	11[g]	1.753
Lateral[f]	30	90	40″	14″ × 17″ (35 × 43 cm)	50[g]	10.48	20[g]	4.170
Lateral/dorsal decubitus[f]	30	90	40″	17″ × 14″ (43 × 35 cm)	65[g]	13.64	25[g]	5.230

AP, Anteroposterior; *CR,* central ray; *PA,* posteroanterior; *SID,* source-to-image receptor distance.

[1] ACR-AAPM-SIMM Practice Parameter for Digital Radiography, revised 2017.

[a] kVp values are for a high-frequency generator.

[b] 40 inches minimum; 44 to 48 inches recommended to improve spatial resolution (mAs increase needed, but no increase in patient dose will result).

[c] AGFA CR MD 4.0 General IP, CR 75.0 reader, 400 speed class, with 6:1 (178LPI) grid when needed.

[d] GE Definium 8000, with 13:1 grid when needed.

[e] All doses are skin entrance for average adult (160 to 200 pounds male, 150 to 190 pounds female) at part thickness indicated.

[f] Bucky/Grid.

[g] Large focal spot.

Abbreviations used In Chapter 4

AAA	Abdominal aortic aneurysm
ERCP	Endoscopic retrograde cholangiopancreatography
NPO	Nil per os (nothing by mouth)
PTC	Percutaneous transhepatic cholangiography
RUQ	Right upper quadrant

See Addendum A for a summary of all abbreviations used in Volume 1.

Radiography

Abdominal Radiographic Procedures

Exposure Technique

In examinations without a contrast medium, it is imperative to obtain maximal soft tissue differentiation throughout the different regions of the abdomen. Because of the wide range in the thickness of the abdomen and the delicate differences in physical density between the contained viscera, a proper balance of exposure factors is critical to show both solid organs, as well as adjacent structures, while delivering the lowest possible radiation dose (Fig. 4.5A).

The best criterion for assessing the quality of an abdominal radiographic image is the ability to visualize each of the following (Fig. 4.5B):

- Sharply defined outlines of the psoas muscles
- Lower border of the liver
- Kidneys
- Ribs and transverse processes of the lumbar vertebrae

Immobilization

A prime requisite in abdominal examinations is to prevent voluntary and involuntary movement. The following steps are observed:

- To prevent muscle contraction caused by tension, adjust the patient in a comfortable position so that he or she can relax.
- Explain the breathing procedure and ensure that the patient understands exactly what is expected.
- Do not start the exposure for 1 to 2 seconds after suspension of respiration to allow the patient to come to rest and involuntary movement of the viscera to subside.

Voluntary motion produces a blurred outline of the structures that do not have involuntary movement, such as the liver, psoas muscles, and spine. Patient breathing during exposure results in blurring of bowel gas outlines in the upper abdomen as the diaphragm moves (Fig. 4.6). Involuntary motion caused by peristalsis may produce localized or generalized haziness of the image. Involuntary contraction of the abdominal wall or the muscles around the spine may cause movement of the entire abdominal area and may produce generalized image haziness.

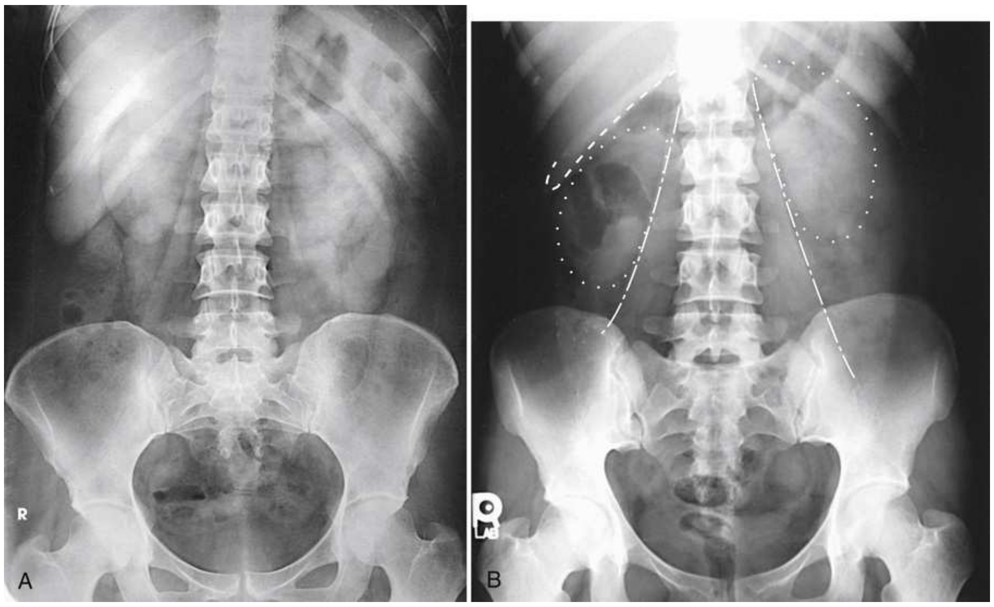


FIG. 4.5 (A) AP abdomen showing proper positioning and collimation. (B) AP abdomen showing kidney shadows *(dotted line)*, margin of liver *(dashed line)*, and psoas muscles *(dot-dash lines)*.

(A) An x-ray view of the abdomen shows the solid organs and the adjacent structures. The outlines of the organs are not sharp. (B) An x-ray view of the abdomen shows kidney shadows which are represented by a dotted line, margin of liver which are represented by a dashed line, and psoas muscles which are represented by dot dash lines, and the ribs and transverse processes of the lumbar vertebrae.

Abdomen

Radiographic Projections

Radiographic examination of the abdomen may include one or more projections. The most commonly performed is the supine AP projection, often called a *KUB* because it includes the *kidneys*, *ureters*, and *bladder*. Projections used to complement the supine AP projection include an upright AP abdomen or an AP or PA projection in the lateral decubitus position (the left lateral decubitus is most often preferred), or both. The AP upright and AP/PA lateral decubitus are useful in assessing the abdomen in patients with free air (pneumoperitoneum) and in determining the presence and location of air-fluid levels. Other abdominal projections include a lateral projection or a lateral projection in the supine (dorsal decubitus) body position. Many institutions also obtain a PA chest image to include the upper abdomen and diaphragm. The upright PA chest is indicated because any air escaping from the gastrointestinal tract into the peritoneal space rises to the highest level, usually just beneath the diaphragm.

Positioning Protocols

The required projections obtained to evaluate the patient's abdomen vary considerably depending on the institution and the physician. Some physicians consider the preliminary evaluation image (often termed a *scout* or *survey*) to consist of only the AP (supine) projection. Others obtain two projections: a supine and an upright AP abdomen (often called a *flat* and an *upright*). A three-way or acute abdomen series may be requested to rule out free air, bowel obstruction, and infection. The three projections usually include (1) AP with the patient supine, (2) AP with the patient upright, and (3) upright PA chest. If the patient cannot stand for the upright AP abdomen projection, the projection is performed using the left lateral decubitus position. The upright PA chest projection can be used to demonstrate free air that may accumulate under the diaphragm.

Positioning for radiographic examination of the abdomen is described in the following pages. (For a description of positioning for the upright PA chest, see Chapter 3.)

Recommended Sequence for Abdominal Radiography

To show small amounts of intraperitoneal gas in acute abdominal cases, Miller [1, 2] recommended that the patient be kept in the left lateral position on a stretcher for 10 to 20 minutes before abdominal images are obtained. This position allows gas to rise into the flank area adjacent to the right hemidiaphragm, where the potential pathology would not be superimposed by the gastric air bubble (Fig. 4.7). If larger amounts of free air are present, many radiology departments suggest that the patient lie on the side for a minimum of 5 minutes before the exposure is made.

Projections are taken for a three-way or acute abdomen series as follows:

- Perform an AP or PA projection of the abdomen with the patient in the left lateral decubitus position.

- Maintain the patient in the left lateral decubitus position while the patient is being moved onto a horizontally placed table. Move the patient to the upright position.
- Turn the patient to obtain upright AP or PA projections of the chest (Fig. 4.8) and abdomen (Fig. 4.9).
- Return the patient to the horizontal position for a supine AP projection of the abdomen (Fig. 4.10).

FIG. 4.6 AP abdomen showing blurred bowel gas in right upper quadrant (RUQ), caused by patient breathing during exposure.

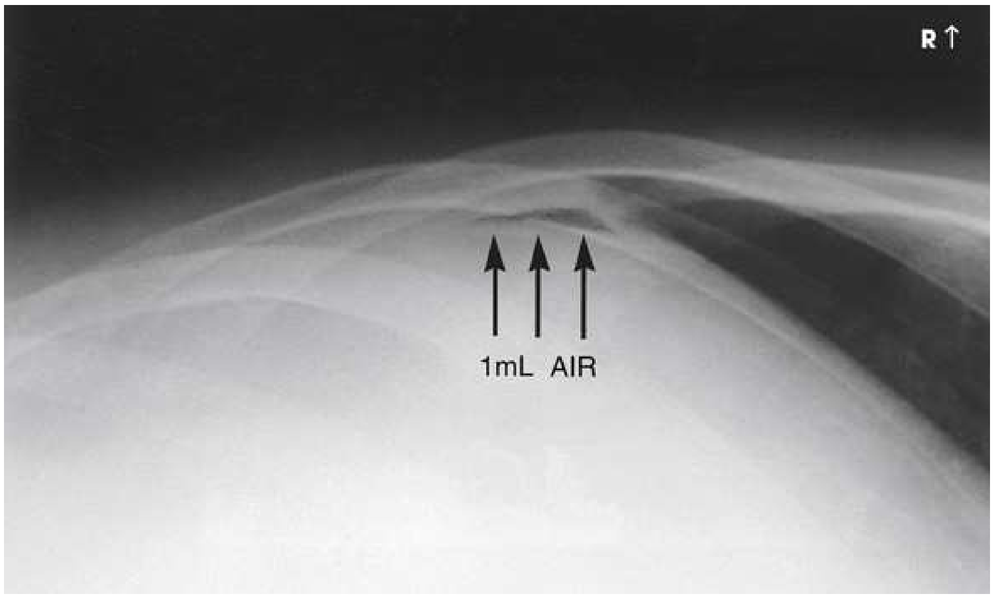


FIG. 4.7 Enlarged portion of AP abdomen, left lateral decubitus position in a patient injected with 1 mL of air into abdominal cavity.

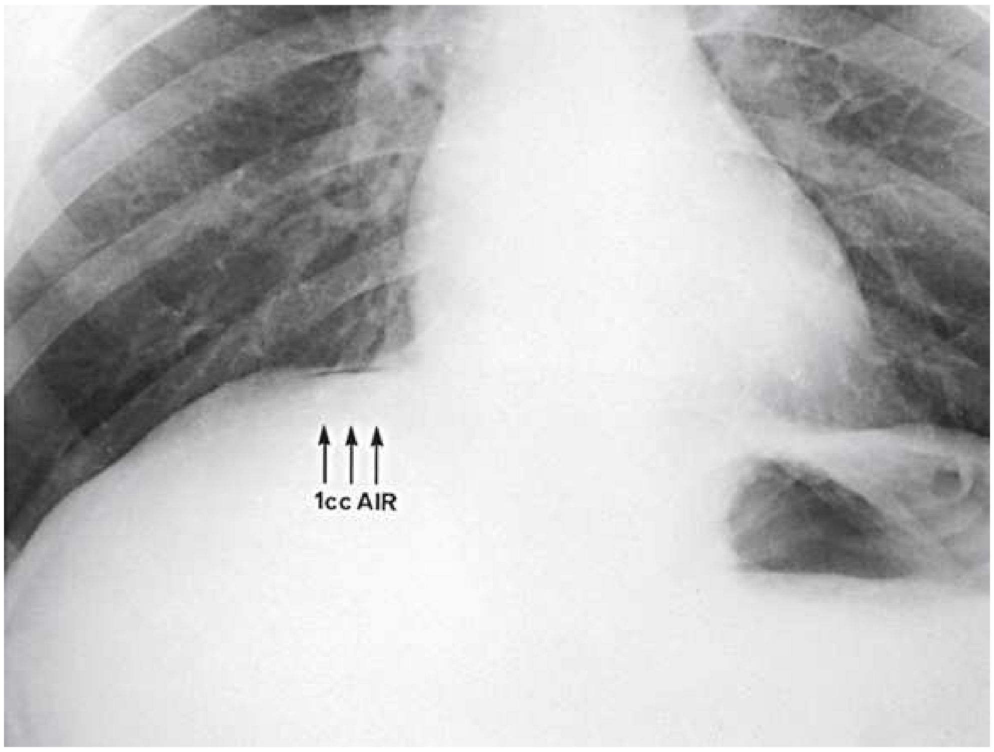


FIG. 4.8 Enlarged portion of upright AP chest showing free air in same patient as in Fig. 4.7.

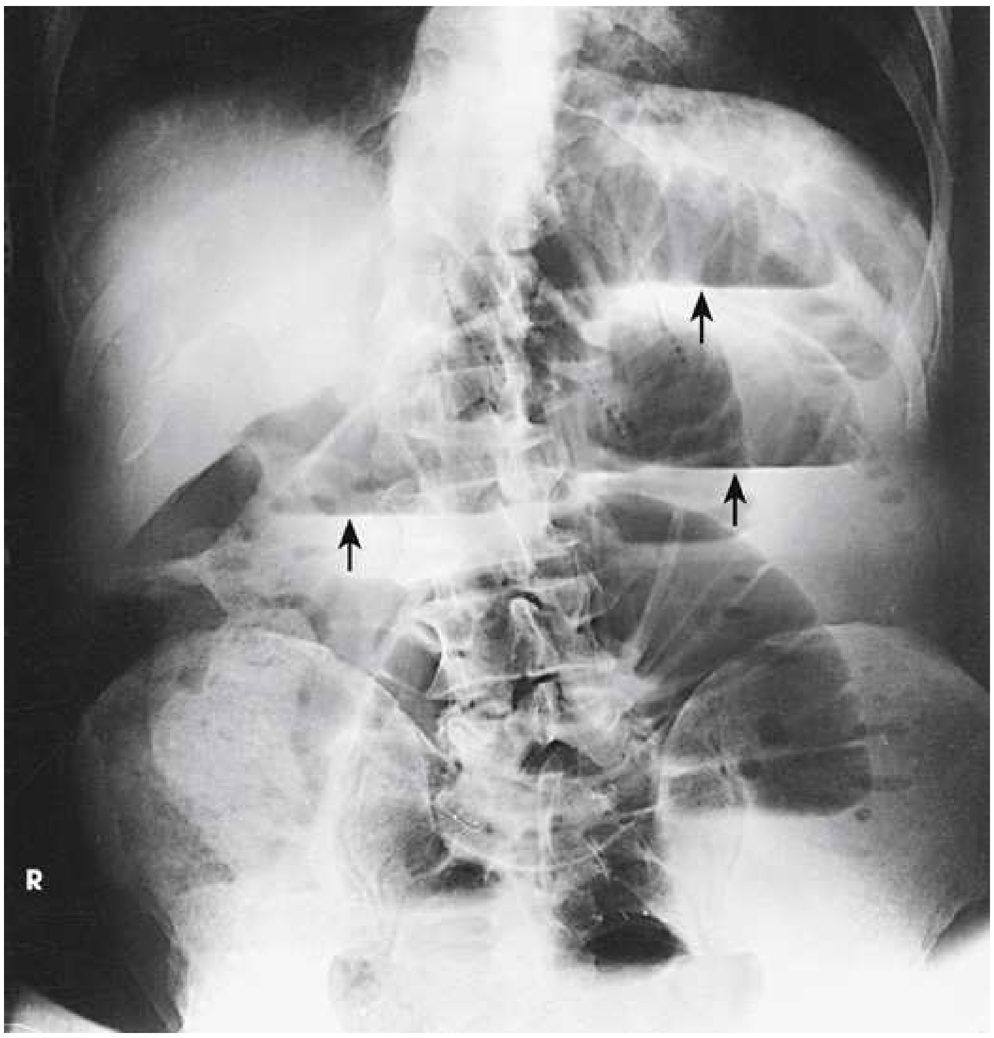


FIG. 4.9 AP abdomen, upright position, showing air-fluid levels *(arrows)* in intestine (same patient as in Fig. 4.10).

An x-ray view of the abdomen shows the air fluid levels are represented by three upward arrows in the intestine. One arrow is on the left and the other two arrows are on the right one above the other, above the liver.

FIG. 4.10 AP abdomen. Supine study showing intestinal obstruction in same patient as in Fig. 4.9.

AP Projection

Supine; upright

Image receptor + grid:

Positioned by manufacturer or department protocol for proper anatomy display orientation; CR plate: 14 × 17 inches (35 × 43 cm) lengthwise.

Position of patient

- For the AP abdomen, or KUB, projection, place the patient in either the supine or the upright position. The supine position is preferred for most initial examinations of the abdomen.

Position of part

- Center the midsagittal plane of the body to the midline of the grid device.
- If the patient is upright, distribute the weight of the body equally on the feet.
- Place the patient's arms where they do not cast shadows on the image.
- With the patient supine, place a support under the knees to relieve strain.
- For the *supine position*, center the IR/collimated field at the level of the iliac crests, and ensure that the pubic symphysis is included (Fig. 4.11).
- For the *upright position*, center the IR/collimated field 2 inches (5 cm) above the level of the iliac crests or high enough to include the diaphragm (Fig. 4.12).
- If the bladder is to be included on the upright image, center the IR/collimated field at the level of the iliac crests.
- If a patient is too tall to include the entire pelvic area, obtain a second image to include the bladder, if necessary. A 10 × 12 inches (24 × 30 cm) IR or collimated field is oriented crosswise and is centered 2 to 3 inches (5 to 7.6 cm) above the upper border of the pubic symphysis.
- *Respiration:* Suspend at the end of expiration so that the abdominal organs are not compressed.

Central ray

- Perpendicular to the IR at the level of the iliac crests for the supine position.
- Horizontal and 2 inches (5 cm) above the level of the iliac crests to include the diaphragm for the upright position.

Collimation

- Adjust radiation field to 14 × 17 inches (35 × 43 cm) on the collimator. For smaller patients, collimate to within 1 inch (2.5 cm) of shadow of the abdomen flanks. Place side marker in the collimated exposure field.

FIG. 4.11 AP abdomen, supine.

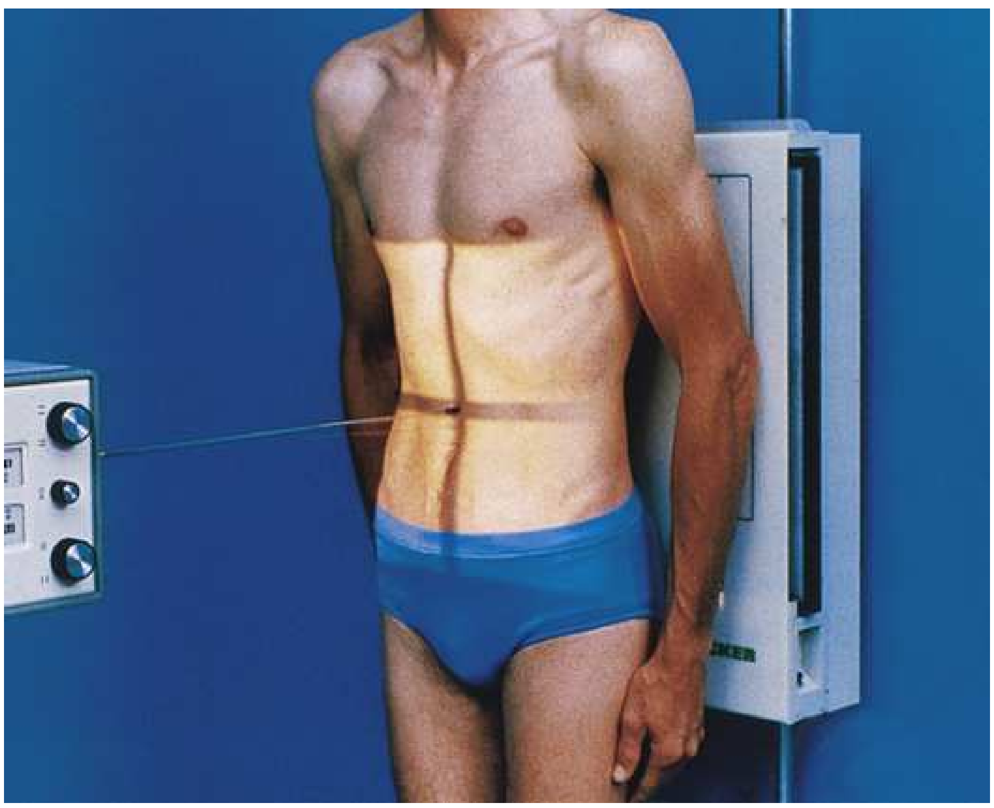


FIG. 4.12 AP abdomen, upright.

Structures shown

AP projection of the abdomen shows the size and shape of the liver, the spleen, and the kidneys and intra-abdominal calcifications or evidence of tumor masses (Fig. 4.13). Additional examples of supine and upright abdomen projections are shown in Figs. 4.9 and 4.10.

Evaluation Criteria

The following should be clearly seen:

- Evidence of proper collimation and presence of side marker and upright marker, if appropriate, placed clear of anatomy of interest
- Area from the pubic symphysis to the upper abdomen (two images may be necessary if the patient is tall or wide)
- Proper patient alignment to IR
  - Centered vertebral column
  - Ribs, pelvis, and hips equidistant to the edge of the image or collimated borders on both sides
- No rotation
  - Spinous processes in the center of the lumbar vertebrae
  - Ischial spines of the pelvis symmetric, if visible
  - Alae or wings of the ilia symmetric
- Exposure factors sufficient to demonstrate the following:
  - Lateral abdominal wall and properitoneal fat layer (flank stripe)
  - Psoas muscles, lower border of the liver, and kidneys
  - Inferior ribs
  - Transverse processes of the lumbar vertebrae
- Diaphragm without motion on upright radiograph (crosswise IR placement/collimated field is appropriate if the patient is large)

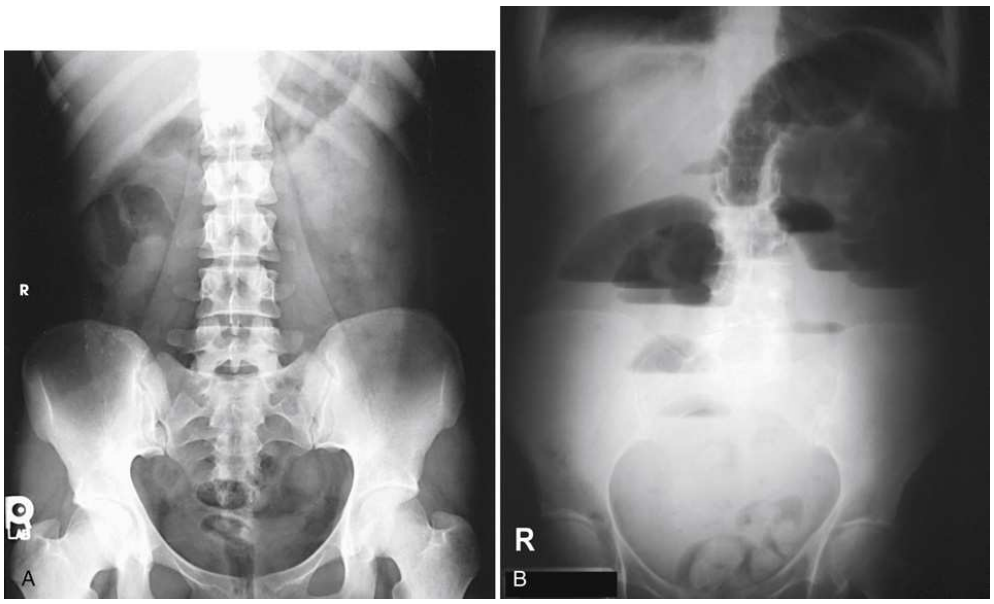


FIG. 4.13 (A) AP abdomen, supine position. (B) AP abdomen, upright position.

PA Projection

Upright

NOTE: When the kidneys are not of primary interest, the upright PA projection should be considered. Compared with the AP projection, the PA projection of the abdomen greatly reduces patient gonadal dose.

Image receptor + grid:

Positioned by manufacturer or department protocol for proper anatomy display orientation; CR plate: 14 × 17 inches (35 × 43 cm) lengthwise.

Position of patient

- With the patient in the upright position, place the anterior abdominal surface in contact with the vertical grid device.
- Center the abdominal midline to the midline of the IR.
- Center the IR/collimated field 2 inches (5 cm) above the level of the iliac crests (Fig. 4.14), as previously described for the upright AP projection. The central ray, structures shown, and evaluation criteria are the same as for the upright AP projection.

AP Projection

Left lateral decubitus position

Image receptor + grid:

Positioned by manufacturer or department protocol for proper anatomy display orientation; CR plate: 14 × 17 inches (35 × 43 cm) lengthwise.

Position of patient

- If the patient is too ill to stand, place him or her in a lateral recumbent position lying on a radiolucent pad on a transportation cart. Use a left lateral decubitus position in most situations.
- The radiolucent pad is particularly important to ensure inclusion of the entire dependent side when fluid demonstration is of primary concern.
- When free intraperitoneal air is suspected, have the patient lie on the side for 5 minutes before the exposure to allow air to rise to its highest level within the abdomen.
- Place the patient's arms above the level of the diaphragm so that they are not projected over any abdominal contents.
- Flex the patient's knees slightly to provide stabilization.
- *Exercise care* to ensure that the patient does not fall off the cart; if a cart is used, *lock all wheels* securely in position.

Position of part

- Adjust the height of the vertical grid device so that the long axis of the IR is centered to the midsagittal plane.
- If the abdomen is too wide to include both flanks on one image, adjust patient and IR height to include side down when intraperitoneal fluid is suspected and to include side up when pneumoperitoneum is suspected.
- Position the patient so that the level of the iliac crests is centered to the IR. A slightly higher centering point, 2 inches (5 cm) above the iliac crests, may be necessary to ensure that the diaphragm is included in the image (Fig. 4.15).
- Adjust the patient to ensure that a true lateral position is attained.
- *Respiration:* Suspend at the end of expiration.

Compensating Filter

For patients with a large abdomen, a compensating filter improves image quality by preventing overexposure of the upper-side abdominal area.

Central ray

- Directed *horizontal* and perpendicular to the midpoint of the IR.

Collimation

- Adjust radiation field to 14 × 17 inches (35 × 43 cm) on the collimator. For smaller patients, collimate to within 1 inch (2.5 cm) of shadow of the abdomen flanks. Place side marker and decubitus marker in the collimated exposure field.

NOTE: A right lateral decubitus position is often requested or may be required when the patient cannot lie on the left side.

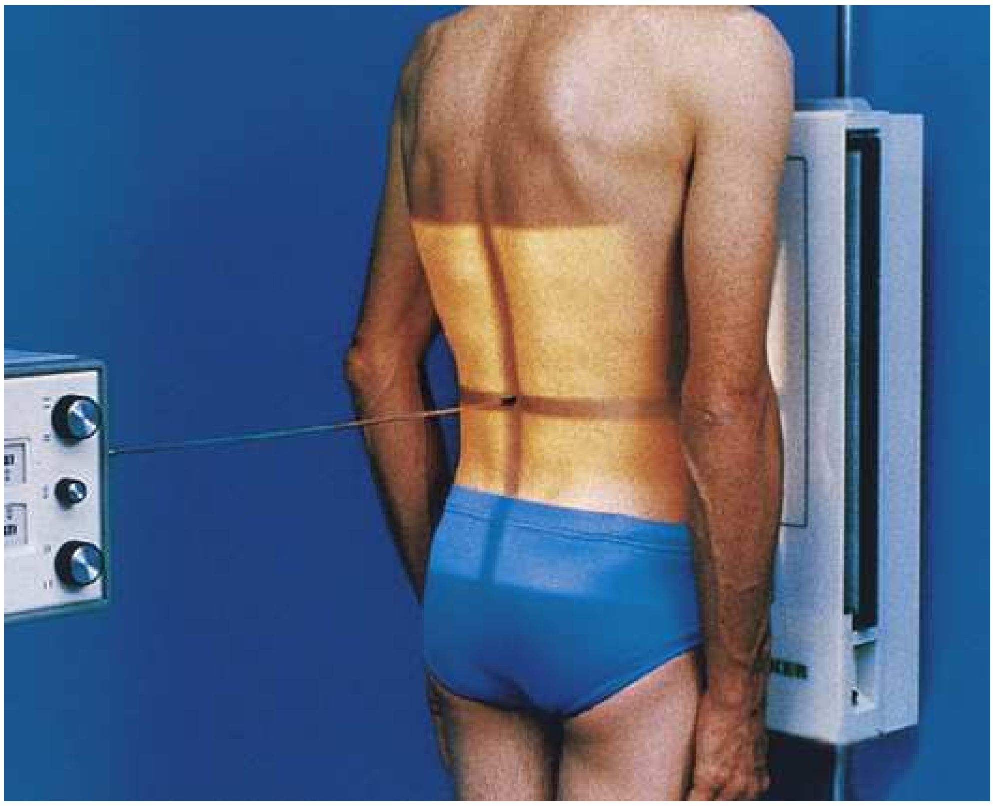


FIG. 4.14 PA abdomen, upright position. This projection is suggested for survey examination of the abdomen when the kidneys are not of primary interest.

FIG. 4.15 AP abdomen, left lateral decubitus position.

Structures shown

In addition to showing the size and shape of the liver, spleen, and kidneys, the AP abdomen with the patient in the left decubitus position is most valuable for showing free air and air-fluid levels when an upright abdomen projection cannot be obtained (Fig. 4.16).

Evaluation Criteria

The following should be clearly seen:

- Evidence of proper collimation and presence of side marker and decubitus marker placed clear of anatomy of interest

- Diaphragm without motion
- Both sides of the abdomen. If abdomen is too wide:
    - Side down when fluid is suspected (ensure entire dependent side is included in the collimated field)
    - Side up when free air is suspected
- Abdominal wall, flank structures, and diaphragm
- No rotation
    - Spinous processes in the center of the lumbar vertebrae
    - Ischial spines of the pelvis symmetric, if visible
    - Alae or wings of the ilia symmetric
- Abdominal contents visible without contrast media

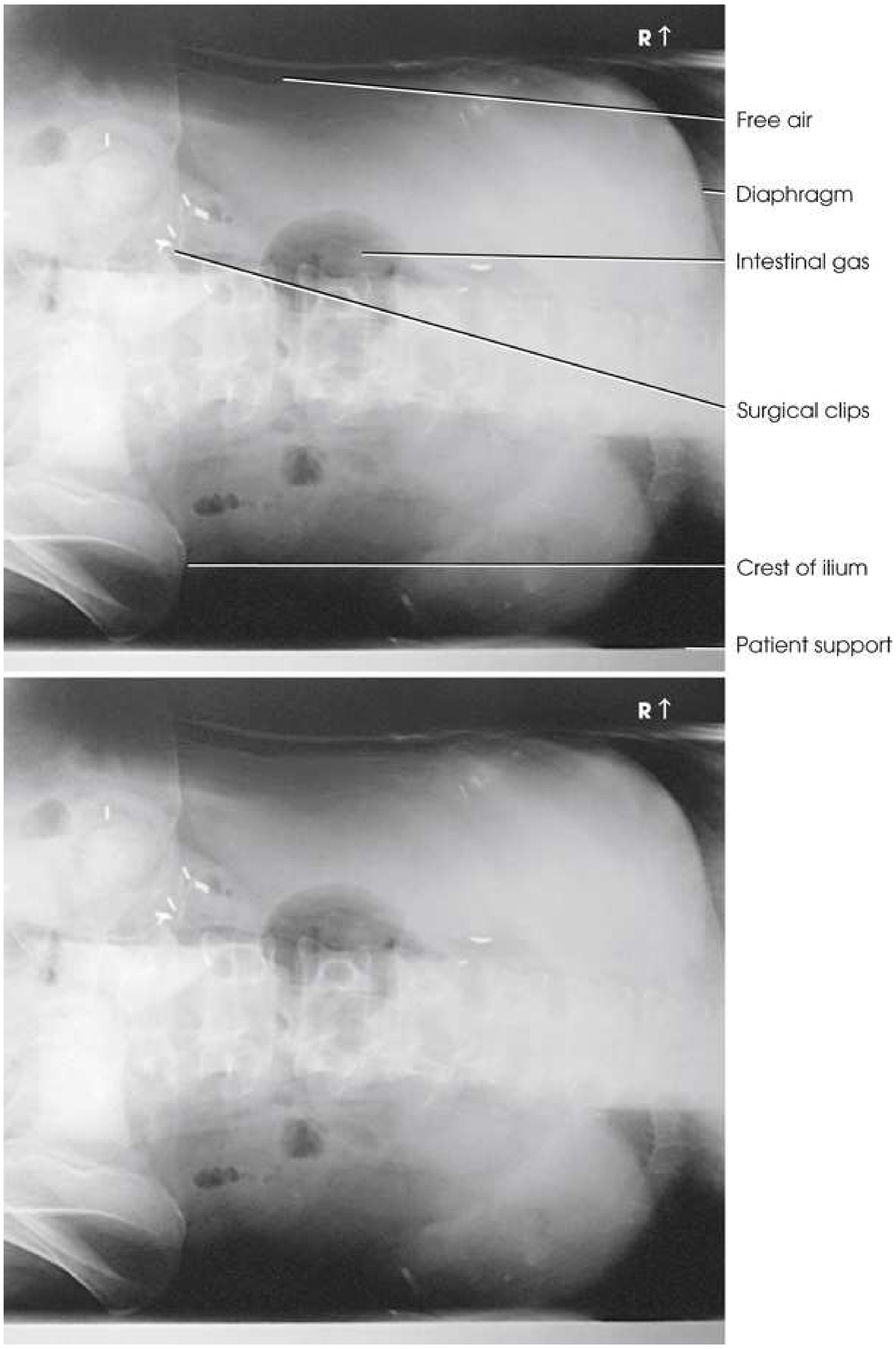


FIG. 4.16 AP abdomen, left lateral decubitus position, showing free air collection along right flank. Note correct marker placement.

An x-ray view of the abdomen on top shows the following parts labeled on it: free air, diaphragm, intestinal gas, surgical clips, crest of ilium, and patient support. An x-ray view of the abdomen at the bottom shows the abdominal wall, flank structures, and diaphragm.

Lateral Projection

R or L position

Image receptor + grid:

Positioned by manufacturer or department protocol for proper anatomy display orientation; CR plate: 14 × 17 inches (35 × 43 cm) lengthwise.

Position of patient

- Turn the patient to a lateral recumbent position on the right or the left side.

Position of part

- Flex the patient's knees to a comfortable position and adjust the body so that the midcoronal plane is centered to the midline of the grid.
- Place supports between the knees and the ankles.
- Flex the elbows and place the hands under the patient's head (Fig. 4.17).
- Center the IR at the level of the iliac crests or 2 inches (5 cm) above the crests to include the diaphragm.
- *Respiration:* Suspend at the end of expiration.

Central ray

- Perpendicular to the IR and entering the midcoronal plane at the level of the iliac crest or 2 inches (5 cm) above the iliac crest if the diaphragm is included.

Collimation

- Adjust radiation field to 14 × 17 inches (35 × 43 cm) on the collimator. For smaller patients, collimate to within 1 inch (2.5 cm) of the anterior and posterior shadows of the abdomen. Place side marker in the collimated exposure field.

Structures shown

A lateral projection of the abdomen shows the prevertebral space occupied by the abdominal aorta and any intra-abdominal calcifications or tumor masses. The lateral abdomen is also used to show proper placement of AAA grafts and other vascular interventional devices (Fig. 4.18).

Evaluation Criteria

The following should be clearly seen:

- Evidence of proper collimation and presence of side marker placed clear of anatomy of interest
- No rotation
  - Superimposed ilia
  - Superimposed lumbar vertebrae pedicles and open intervertebral foramina
- As much of the remaining abdomen as possible when the diaphragm is included
- Abdominal contents visible without contrast media

FIG. 4.17 Right lateral abdomen.

FIG. 4.18 Right lateral abdomen showing AAA graft with extensions into both common iliac arteries.
Courtesy NEA Baptist Memorial Hospital, Jonesboro, AR.

An x-ray view of the right lateral abdomen shows the prevertebral space occupied by the abdominal aorta and the placement of A A A graft on the anterior surface of the body. The radiation field is marked as 250 millimeter.

Lateral Projection

Right or left dorsal decubitus position

Image receptor + grid:

Positioned by manufacturer or department protocol for proper anatomy display orientation; CR plate: 14 × 17 inches (35 × 43 cm) lengthwise.

Position of patient

- When the patient cannot stand or lie on the side, place the patient in the supine position on a transportation cart or other suitable support with the right or left side in contact with the vertical grid device.
- Place the patient's arms across the upper chest to ensure that they are not projected over any abdominal contents or place them behind the patient's head.
- Flex the patient's knees slightly to relieve strain on the back.
- *Exercise care* to ensure that the patient does not fall from the cart or table; if a cart is used, *lock all wheels* securely in position.

Position of part

- Adjust the height of the vertical grid device so that the long axis of the IR is centered to the midcoronal plane.
- Position the patient so that a point approximately 2 inches (5 cm) above the level of the iliac crests is centered to the IR (Fig. 4.19).
- Adjust the patient to ensure that no rotation from the supine position occurs.

• *Respiration:* Suspend at the end of expiration.

Central ray

• Directed *horizontal* and perpendicular to the center of the IR, entering the midcoronal plane 2 inches (5 cm) above the level of the iliac crests.

Collimation

• Adjust radiation field to 14 × 17 inches (35 × 43 cm) on the collimator. For smaller patients, collimate to within 1 inch (2.5 cm) of the anterior and posterior shadows of the abdomen. Place side marker in the collimated exposure field.

Structures shown

The lateral projection of the abdomen is valuable in showing the prevertebral space and is useful in determining air-fluid levels in the abdomen (Fig. 4.20).

Evaluation Criteria

The following should be clearly seen:

- Evidence of proper collimation and presence of side marker and decubitus marker placed clear of anatomy of interest
- No rotation
    - Superimposed ilia
    - Superimposed lumbar vertebrae pedicles and open intervertebral foramina
  - Open intervertebral foramina
- As much of the remaining abdomen as possible when the diaphragm is included
- Abdominal contents visible without contrast media

FIG. 4.19 Lateral abdomen, left dorsal decubitus position.

A patient is lying in a left dorsal decubitus position near the vertical grid with both his hands resting under his head. The image receptor is above the level of the iliac crests dividing it into four quadrants.

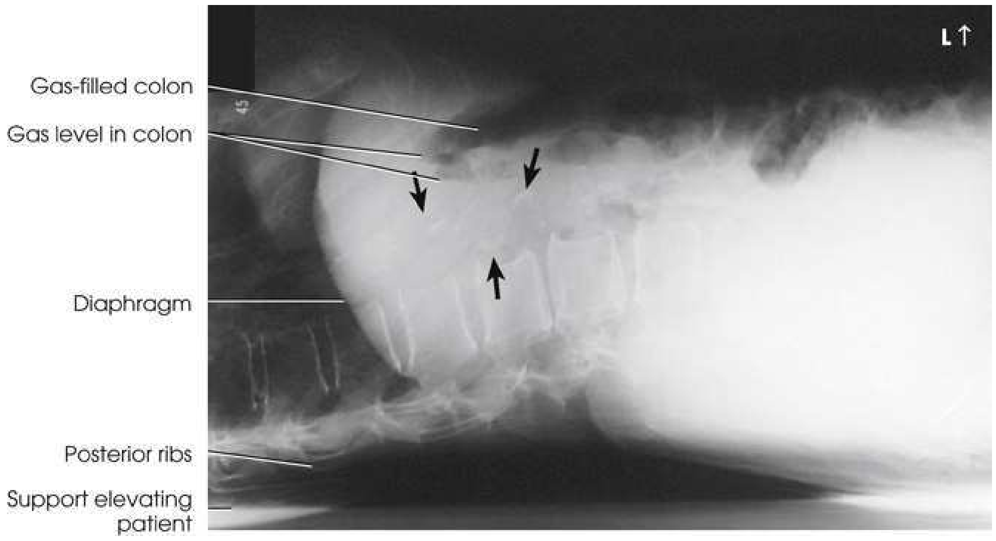


FIG. 4.20 Lateral abdomen, left dorsal decubitus position, showing calcified aorta *(arrows)*. Note correct marker placement.

An x-ray view of the lateral abdomen shows the calcified aorta that is represented with arrows. The parts labeled are gas filled colon, gas level in colon, diaphragm, posterior ribs, and support elevating patient.

References

1. Miller R.E, Nelson S.W. The roentgenologic demonstration of tiny amounts of free intraperitoneal gas: experimental and clinical studies. *AJR Am J Roentgenol* . 1971;112:574.
2. Miller R.E. The technical approach to the acute abdomen. *Semin Roentgenol* . 1973;8:267.

5: Upper Extremity

OUTLINE

Summary of Projections

Projections, Positions, and Methods					
Page	**Essential**	**Anatomy**	**Projection**	**Position**	**Method**
156		Digits (second through fifth)	PA		
158		Digits (second through fifth)	Lateral	Lateromedial, mediolateral	
160		Digits (second through fifth)	PA oblique	Lateral rotation	
162		First digit (thumb)	AP		
162		First digit (thumb)	PA		
162		First digit (thumb)	Lateral		
163		First digit (thumb)	PA oblique		
164		First digit (thumb): *First carpometacarpal joint*	AP		ROBERT
166		First digit (thumb): *First carpometacarpal joint*	AP		BURMAN
168		First digit (thumb): *First metacarpophalangeal joint*	PA		FOLIO
170		Hand	PA		
172		Hand	PA oblique	Lateral rotation	
174		Hand	Lateral	Extension and fan lateral	
176		Hand	Lateral	Flexion	
176		Hand	AP oblique	Medial rotation	NORGAARD
178		Wrist	PA		
179		Wrist	AP		
180		Wrist	Lateral		
182		Wrist	PA oblique	Lateral rotation	
183		Wrist	AP oblique	Medial rotation	
184		Wrist	PA	Ulnar deviation	
185		Wrist	PA	Radial deviation	
186		Wrist: *Scaphoid*	PA axial		STECHER
188		Wrist: *Scaphoid series*	PA, PA axial	Ulnar deviation	RAFERT-LONG
190		Wrist: *Trapezium*	PA axial oblique		CLEMENTS-NAKAYAMA
191		Carpal bridge	Tangential		
192		Carpal canal	Tangential		GAYNOR-HART
194		Forearm	AP		
196		Forearm	Lateral		
197		Elbow	AP		
198		Elbow	Lateral		
200		Elbow	AP oblique	Medial rotation	
201		Elbow	AP oblique	Lateral rotation	
202		Elbow: *Distal humerus*	AP	Partial flexion	
203		Elbow: *Proximal forearm*	AP	Partial flexion	
204		Elbow: *Distal humerus*	AP	Acute flexion	
205		Elbow: *Proximal forearm*	PA	Acute flexion	
206		Elbow: *Radial head*	Lateral		
208		Elbow: *Radial head, coronoid process*	Axiolateral	Lateral	COYLE
211		Distal humerus	PA axial		
212		Olecranon process	PA axial		
213		Humerus	AP	Upright	
214		Humerus	Lateral	Upright	
215		Humerus	AP	Recumbent	
216		Humerus	Lateral	Recumbent	
217		Humerus	Lateral	Recumbent, lateral recumbent	

The icons in the Essential column indicate projections frequently performed in the United States and Canada. Students should demonstrate competence in these projections.

AP, Anteroposterior; *PA,* posteroanterior.

Anatomy

Anatomists divide the bones of the upper extremities into the following main groups:

- Hand
- Forearm
- Arm
- Shoulder girdle

The proximal arm and shoulder girdle are discussed in Chapter 6.

Hand

The *hand* consists of 27 bones, which are subdivided into the following groups (Fig. 5.1):

- Phalanges: Bones of the digits (fingers and thumb)
- Metacarpals: Bones of the palm
- Carpals: Bones of the wrist

Digits

The five *digits* are described by numbers and names; however, description by number is the more correct practice. Beginning at the lateral, or thumb, side of the hand, the numbers and names are as follows:

- First digit (thumb)
- Second digit (index finger)
- Third digit (middle finger)
- Fourth digit (ring finger)
- Fifth digit (small finger)

The digits contain 14 *phalanges* (*phalanx,* singular), which are long bones that consist of a cylindrical body and articular ends. Nine phalanges have two articular ends. The first digit has two phalanges—*proximal* and *distal*. The other digits have three phalanges—*proximal, middle,* and *distal* (Fig. 5.1C). The proximal phalanges are the closest to the palm, and the distal phalanges are the farthest from the palm. The distal phalanges are small and flattened, with a roughened rim around their distal anterior end; this gives them a spatula-like appearance. Each phalanx has a *head, body,* and *base* (Fig. 5.1B).

Metacarpals

Five *metacarpals,* which are cylindric in shape and slightly concave anteriorly, form the palm of the hand (see Fig. 5.1). They are long bones consisting of a *body* and two articular ends—the *head* distally and the *base* proximally. The area below the head is the *neck,* where fractures often occur. The first metacarpal contains two small *sesamoid* bones on its palmar aspect below the neck (see Fig. 5.1). A single sesamoid is often seen at this same level on the second metacarpal. The metacarpal heads, commonly known as the *knuckles,* are visible on the dorsal hand in flexion. The metacarpals are also numbered 1 to 5, beginning from the lateral side of the hand.

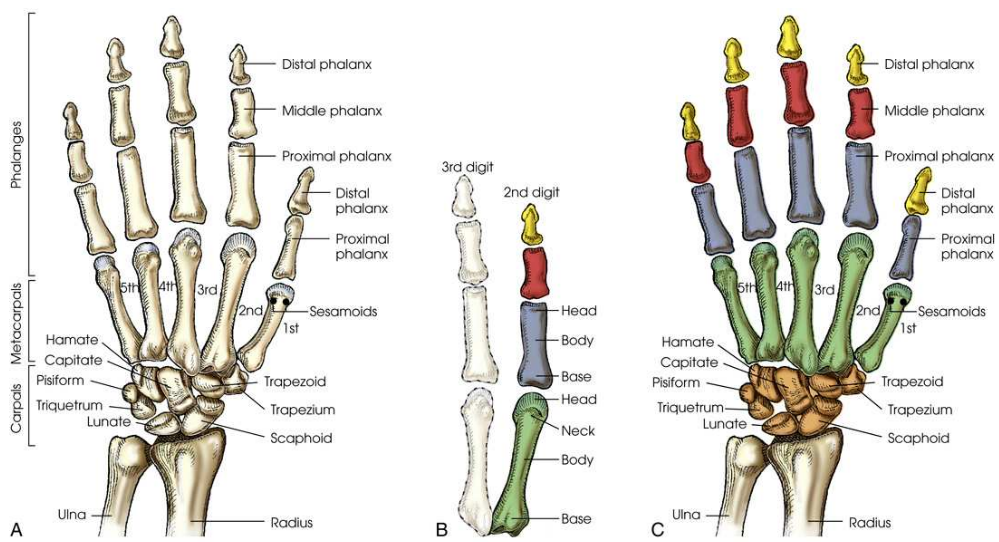


FIG. 5.1 (A) Anterior aspect of right hand and wrist. (B) Second metacarpal *(green)* and phalanges (distal—*yellow;* middle—*red;* proximal—*blue*) showing head, neck, body, and base on second digit. (C) Color-coded anterior aspect of right hand and wrist. *Blue*, Proximal phalanges; *green*, metacarpals; *orange*, carpals; *red*, middle phalanges; *yellow*, distal phalanges.

Diagram (A) shows the Anterior aspect of right hand and wrist. The parts labeled in the diagram are as follows: The Phalanges are distal phalanx, middle phalanx, proximal phalanx. There are five metacarpals. The carpals are distal phalanx, proximal phalanx, sesamoids, trapezoid, trapezium, scaphoid, radius, hamate, capitate, pisiform, lunate, triquetrum, ulna, radius. Diagram (B) shows second metacarpals and phalanges. The parts labeled are head, body, base, head, neck, body, base. Diagram (C) shows color-coded anterior aspect of right hand and wrist. The parts labeled in yellow are distal phalanx. The parts labeled on red are middle phalanx. The parts labeled in blue are proximal phalanx. The parts labeled in green are the metacarpals. The parts labeled in orange are the carpals.

Wrist

The *wrist* has eight *carpal* bones, which are fitted closely together and arranged in two horizontal rows (Figs. 5.1 and 5.2). The carpals are classified as short bones and are composed largely of cancellous tissue with an outer layer of compact bony tissue. The proximal row of carpals, which is nearest the forearm, contains the scaphoid, lunate, triquetrum, and pisiform. The distal row includes the trapezium, trapezoid, capitate, and hamate.

Each carpal contains identifying characteristics. Beginning at the proximal row of carpals on the lateral side, the *scaphoid,* the largest bone in the proximal carpal row, has a tubercle on the anterior and lateral aspect for muscle attachment and is palpable near the base of the thumb. The *lunate* articulates with the radius proximally and is easy to recognize because of its crescent shape. The *triquetrum* is approximately pyramidal and articulates anteriorly with the hamate. The *pisiform* is a pea-shaped bone situated anterior to the triquetrum and is easily palpated.

Beginning at the distal row of carpals on the lateral side, the *trapezium* has a tubercle and groove on the anterior surface. The tubercles of the trapezium and scaphoid constitute the lateral margin of the carpal groove. The *trapezoid* has a smaller surface anteriorly than posteriorly. The *capitate* articulates with the base of the third metacarpal and is the largest and most centrally located carpal. The wedge-shaped *hamate* exhibits the prominent *hook of hamate,* which is located on the anterior surface. The hamate and the pisiform form the medial margin of the carpal groove.

A triangular depression is located on the posterior surface of the wrist and is visible when the thumb is abducted and extended. This depression, known as the *anatomic snuff-box,* is formed by the tendons of the two major muscles of the thumb. The anatomic snuff-box overlies the scaphoid bone and the radial artery, which carries blood to the dorsum of the hand. Tenderness in the snuff-box area is a clinical sign suggesting fracture of the scaphoid, which is the most commonly fractured carpal bone.

Carpal Sulcus

The anterior or palmar surface of the wrist is concave from side to side and forms the *carpal sulcus* (Fig. 5.3). The *flexor retinaculum,* a strong fibrous band, attaches medially to the pisiform and the hook of hamate and laterally to the tubercles of the scaphoid and trapezium. The *carpal canal* or *carpal tunnel* is the passageway created between the carpal sulcus and the flexor retinaculum. The *median nerve* and the *flexor tendons* pass through the carpal canal. Carpal tunnel syndrome results from compression of the median nerve inside the carpal tunnel.

Forearm

The *forearm* contains two bones that lie parallel to each other—the *radius* and the *ulna*. Like other long bones, they have a body and two articular extremities. The radius is located on the lateral side of the forearm, and the ulna is located on the medial side (Figs. 5.4 and 5.5).

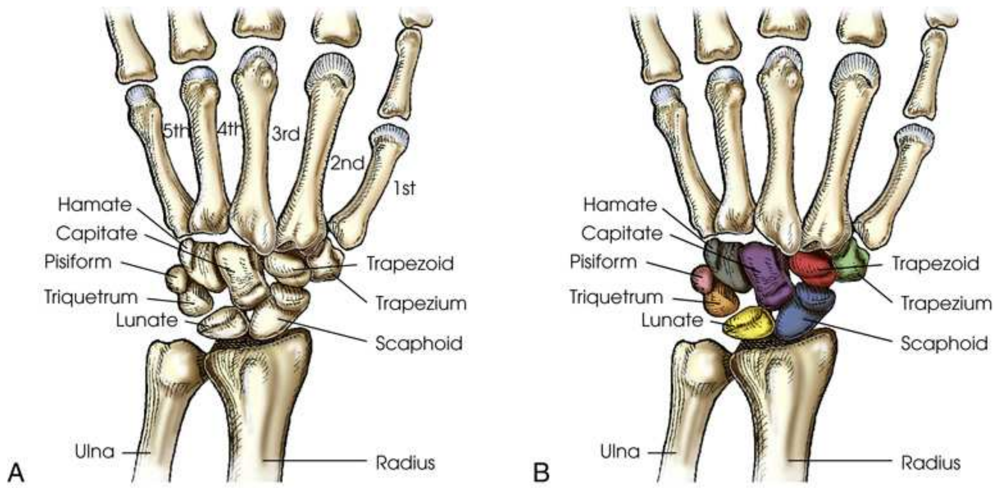


FIG. 5.2 (A) Anterior aspect of right carpals. (B) Color-coded anterior aspect of right carpals. *Blue*, Scaphoid; *gray*, hamate; *green*, trapezium; *orange*, triquetrum; *pink*, pisiform; *purple*, capitate; *red*, trapezoid; *yellow*, lunate.

Diagram (A) shows the anterior aspect of right carpals. The parts labeled in the diagram are the first, second, third, fourth, and fifth metacarpals, trapezoid, trapezium, scaphoid, radius, hamate, capitate, pisiform, triquetrum, lunate, and ulna. Diagram (B) shows the Color coded anterior aspect of right carpals. Blue is the scaphoid, gray is the hamate, green is the trapezium, orange is the triquetrum, pink is the pisiform, purple is the capitate, red is the trapezoid and yellow is the lunate.

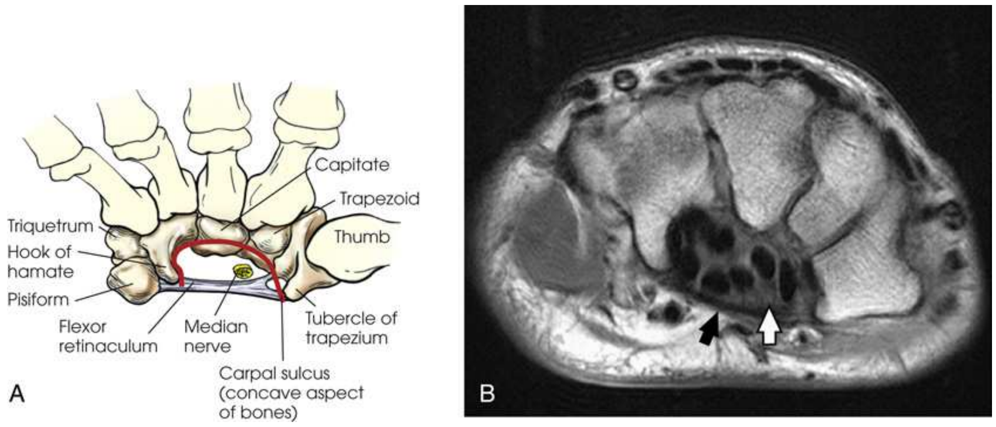


FIG. 5.3 (A) Carpal sulcus. (B) Axial MRI of wrist. Bones in same position as in Fig. 5.3A. Note arched position of carpal bones and carpal sulcus protecting tendons of fingers (*black circles* within sulcus) and median nerve *(white arrow)*. Flexor retinaculum *(black arrow)* is also seen.

Diagram (A) shows Carpal sulcus. The parts labeled in the diagram are capitate, trapezoid, thumb, tubercle of trapezium, carpal sulcus (concave aspect of bones), median nerve, flexor retinaculum, pisiform, hook of hamate, and triquetrum. (B) shows an x-ray view of the axial M R I of the wrist. The carpal bones and carpal sulcus protecting tendons of fingers are represented in black circles within sulcus, the median nerve is represented with a white arrow and flexor retinaculum is represented with a black arrow.

Ulna

The *body* of the ulna is long and slender and tapers inferiorly. The upper portion of the ulna is large and presents two beaklike processes and concave depressions (Fig. 5.6). The proximal process, or *olecranon process,* concaves anteriorly and slightly inferiorly and forms the proximal portion of the *trochlear notch*. The more distal *coronoid process* projects anteriorly from the anterior surface of the body and curves slightly superiorly. The process is triangular and forms the lower portion of the trochlear notch. A depression called the *radial notch* is located on the lateral aspect of the coronoid process.

The distal end of the ulna includes a rounded process on its lateral side called the *head* and a narrower conic projection on the posteromedial side called the *ulnar styloid process*. An articular disk separates the head of the ulna from the wrist joint.

Radius

The proximal end of the radius is small and presents a flat disk-like *head* above a constricted area called the *neck*. Just inferior to the neck on the medial side of the *body* of the radius is a roughened process called the *radial tuberosity*. The distal end of the radius is broad and flattened and has a conic projection on its lateral surface called the *radial styloid process*.

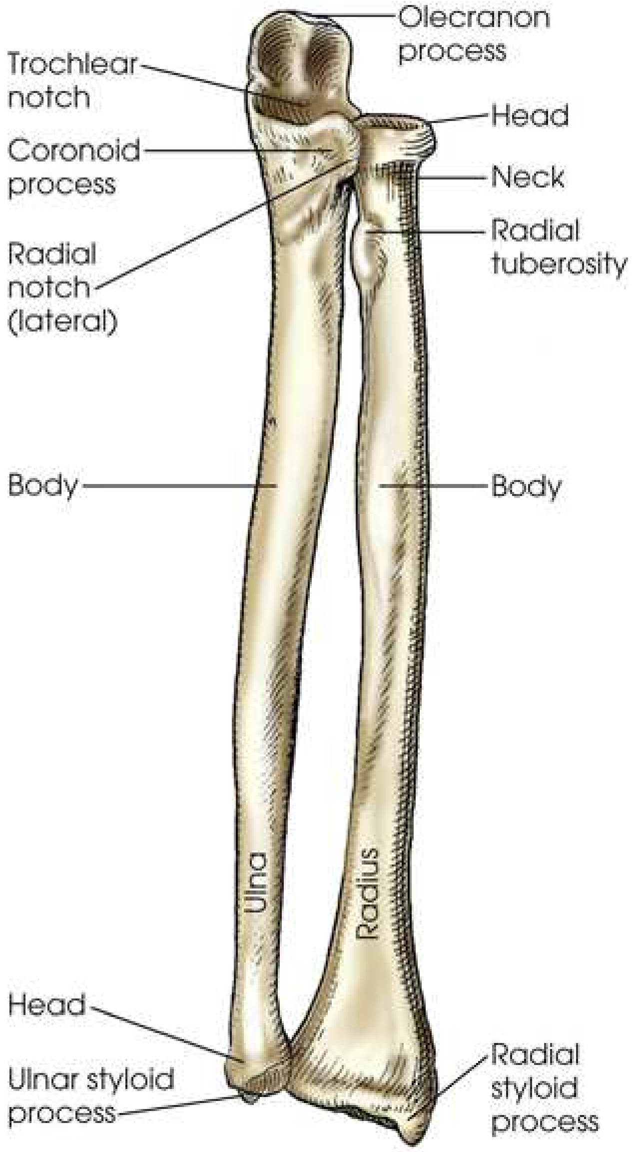


FIG. 5.4 Anterior aspect of left radius and ulna.

Diagram shows the anterior aspect of the left radius and ulna. The parts labeled in the diagram are olecranon process, head, neck, radial tuberosity, body, radial styloid process, trochlear notch, radial notch (lateral), coronoid process, body, head, and ulnar styloid process.

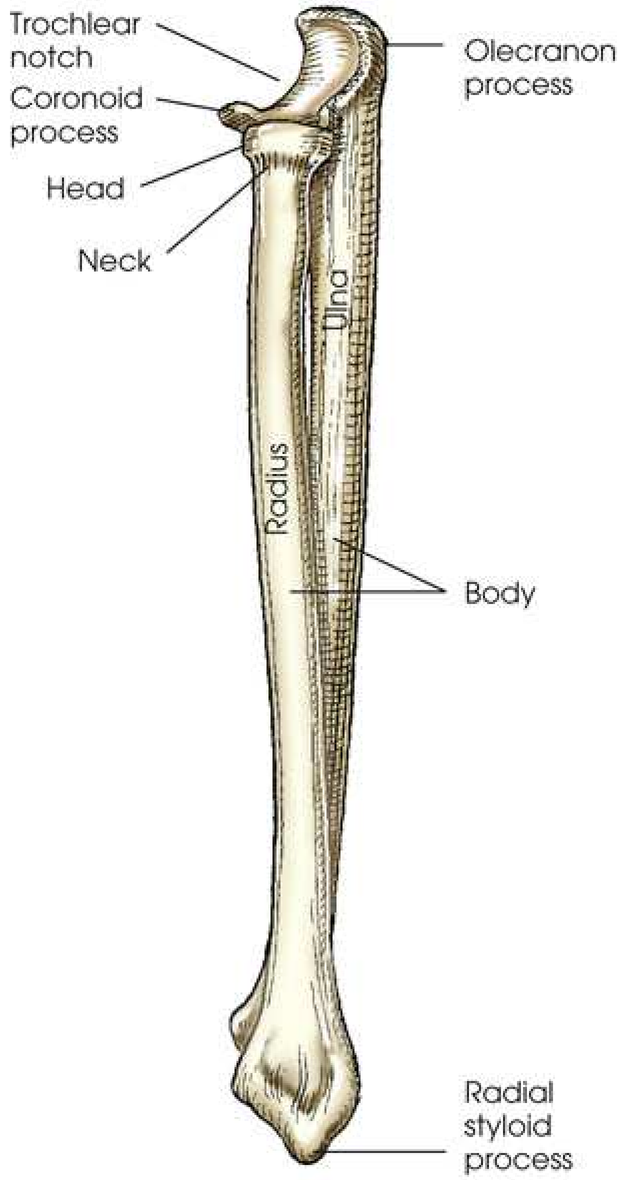


FIG. 5.5 Lateral aspect of left radius and ulna.

Diagram shows the lateral aspect of the left radius and ulna. The parts labeled in the diagram are as follows: trochlear notch, coronoid process, head, neck, olecranon process, body, and radial styloid process.

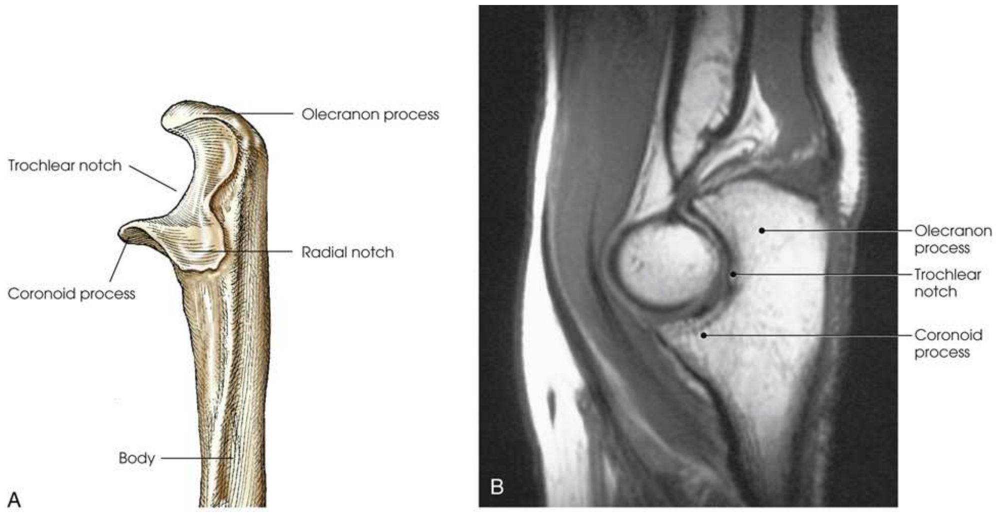


FIG. 5.6 (A) Radial aspect of left proximal ulna. (B) Sagittal MRI of elbow joint showing trochlear notch surrounding trochlea of humerus. B, Modified from Kelley LL, Petersen CM. *Sectional anatomy for imaging professionals*. 2nd ed. St Louis: Mosby; 2007.

Diagram (A) shows the radial aspect of left proximal ulna. The parts labeled in the diagram are as follows: olecranon process, trochlear notch, radial notch, coronoid process, and body. (B) shows the sagittal M R I of elbow joint. It presents two beak like processes and concave depressions. The parts labeled are as follows: olecranon process, trochlear notch, and coronoid process.

Arm

The arm has one bone called the *humerus,* which consists of a *body* and two articular ends (Fig. 5.7A and B). The proximal part of the humerus articulates with the shoulder girdle and is described further in Chapter 6. The distal humerus is broad and flattened and presents numerous processes and depressions.

The entire distal end of the humerus is called the *humeral condyle* and includes two smooth elevations for articulation with the bones of the forearm—the *trochlea* on the medial side and the *capitulum* on the lateral side. The *medial* and *lateral epicondyles* are superior to the condyle and are easily palpated. On the anterior surface superior to the trochlea, a shallow depression called the *coronoid fossa* receives the coronoid process when the elbow is flexed. The relatively small *radial fossa,* which receives the radial head when the elbow is flexed, is located lateral to the coronoid fossa and proximal to the capitulum. The *olecranon fossa* is a deep depression found immediately behind the coronoid fossa on the posterior surface and accommodates the olecranon process when the elbow is extended (see Fig. 5.7C).

The proximal end of the humerus contains the *head,* which is large, smooth, and rounded and lies in an oblique plane on the superomedial side. Just below the head, lying in the same oblique plane, is the narrow, constricted *anatomic neck*. The constriction of the body just below the tubercles is called the *surgical neck,* which is the site of many fractures.

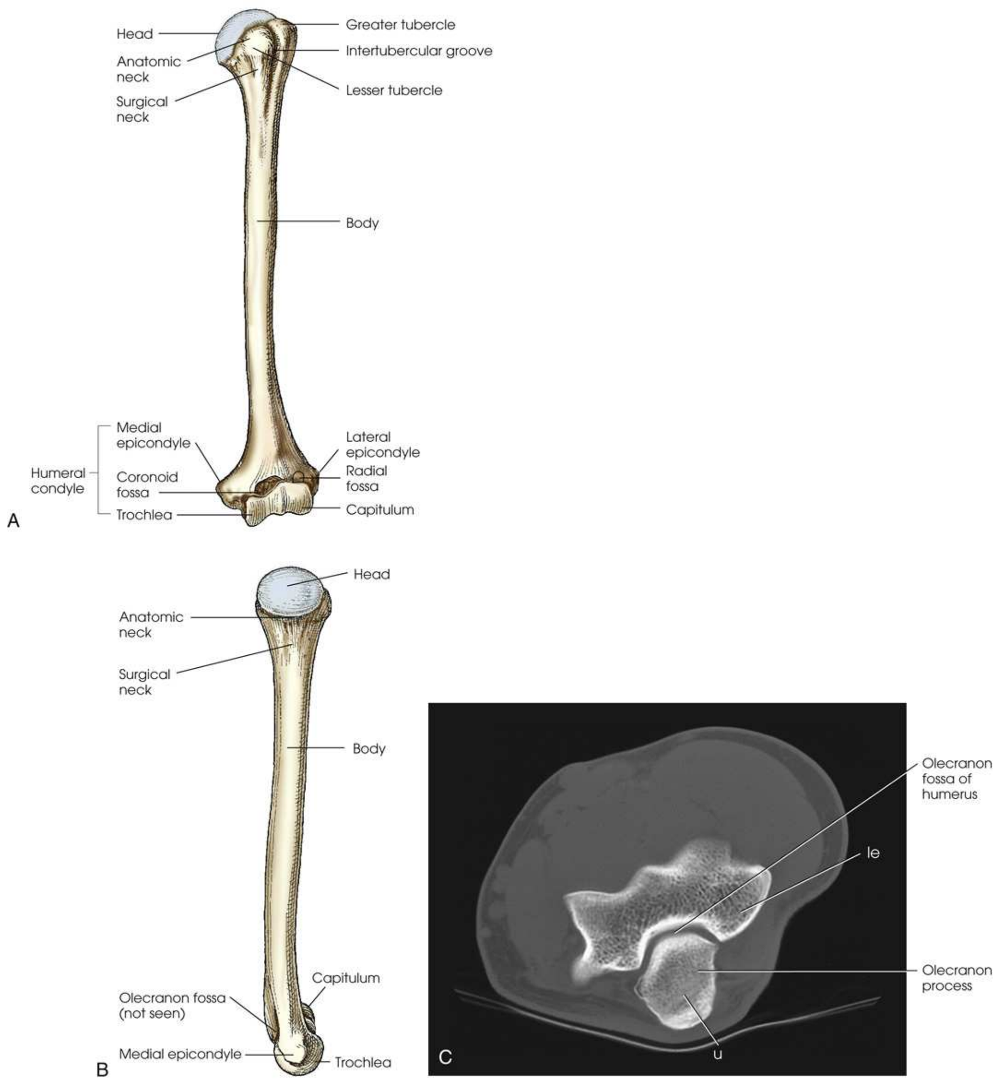


FIG. 5.7 (A) Anterior aspect of left humerus. (B) Medial aspect of left humerus. (C) Axial CT scan of elbow. *le,* Lateral epicondyle; *u,* ulna.

Diagram (A) shows the anterior aspect of left humerus. The parts labeled in the diagram are as follows: greater tubercle, intertubercular groove, lesser tubercle, body, head, anatomic neck, surgical neck, lateral epicondyle, radial fossa, capitulum, the humeral condyle such as medial epicondyle, coronoid fossa, and trochlea. Diagram (B) shows the medial aspect of left humerus. The parts labeled in the diagram are as follows: head, body, anatomic neck, surgical neck, olecranon fossa (not seen), medial epicondyle. (C) shows the axial C T scan of elbow. The parts labeled are as follows: olecranon fossa of humerus and olecranon process. Olecranon process is below the olecranon fossa of the humerus.

The *lesser tubercle* is situated on the anterior surface of the bone immediately below the anatomic neck. The tendon of the subscapularis muscle inserts at the lesser tubercle. The *greater tubercle* is located on the lateral surface of the bone just below the anatomic neck and is separated from the lesser tubercle by a deep depression called the *intertubercular groove*.

Upper Extremity Articulations

Table 5.1 contains a summary of the joints of the upper extremity. A detailed description of the upper extremity articulations follows.

The *interphalangeal* (IP) articulations between the phalanges are *synovial hinge* type and allow only flexion and extension (Fig. 5.8). The IP joints are named by location and are differentiated as either *proximal interphalangeal* (PIP) or *distal interphalangeal* (DIP), by the digit number, and by right or left hand (e.g., the PIP articulation of the fourth digit of the left hand) (Fig. 5.9A). Because the first digit has only two phalanges, the joint between the two phalanges is simply called the IP joint.

The metacarpals articulate with the phalanges at their distal ends and the carpals at their proximal ends. The *metacarpophalangeal* (MCP) articulations are *synovial ellipsoidal* joints and have the movements of flexion, extension, abduction, adduction, and circumduction. Because of the less convex and wider surface of the MCP joint of the thumb, only limited abduction and adduction are possible.

TABLE 5.1

Structural classification			
Joint	**Tissue**	**Type**	**Movement**
Interphalangeal	Synovial	Hinge	Freely movable
Metacarpophalangeal	Synovial	Ellipsoidal	Freely movable
Carpometacarpal			
First digit	Synovial	Saddle	Freely movable
Second to fifth digits	Synovial	Gliding	Freely movable
Intercarpal	Synovial	Gliding	Freely movable
Radiocarpal	Synovial	Ellipsoidal	Freely movable
Radioulnar			
Proximal	Synovial	Pivot	Freely movable
Distal	Synovial	Pivot	Freely movable
Humeroulnar	Synovial	Hinge	Freely movable
Humeroradial	Synovial	Hinge	Freely movable

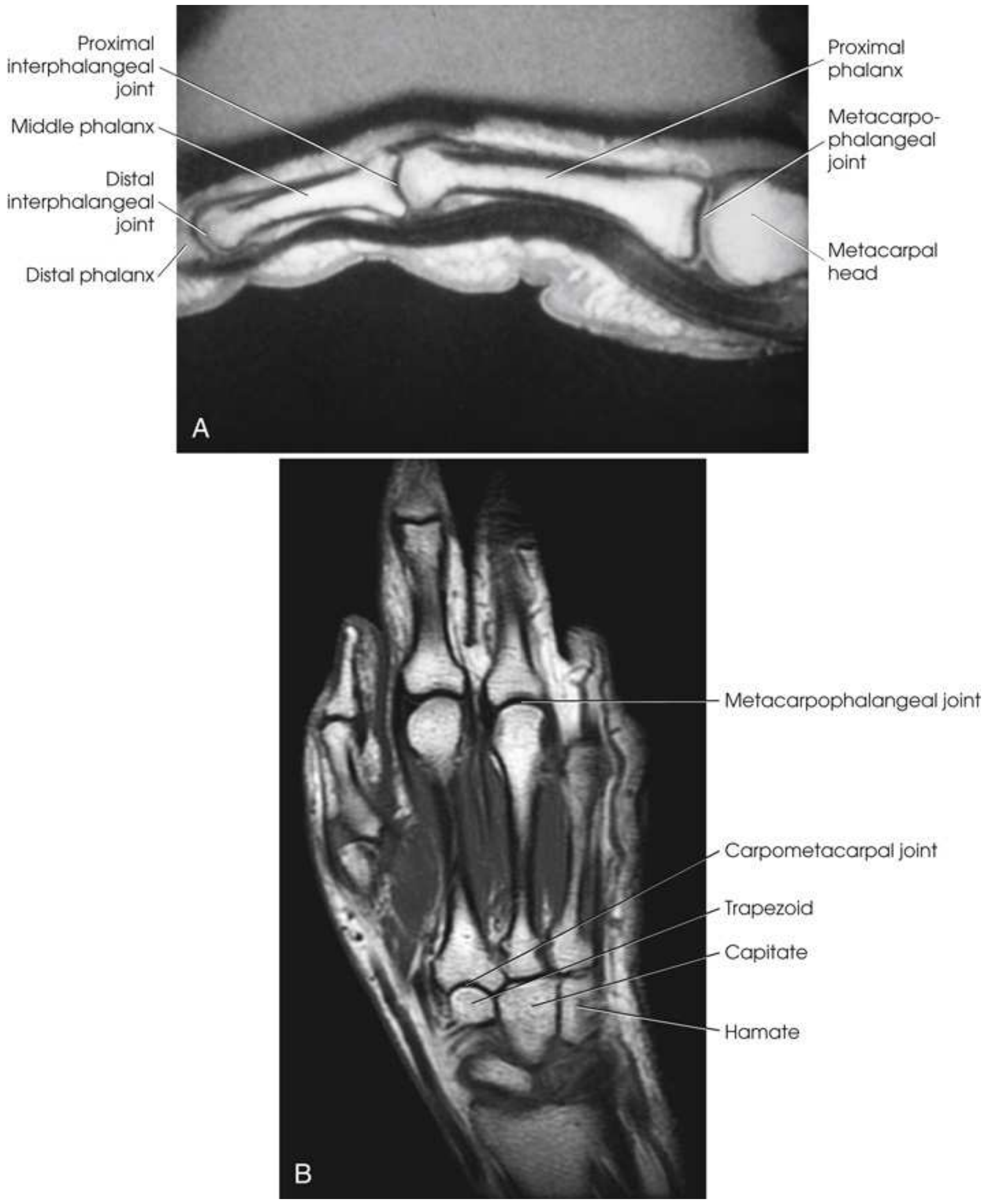


FIG. 5.8 (A) Sagittal MRI of finger showing IP and MCP joints. (B) Coronal MRI of hand and wrist showing same joints.

(A) shows the sagittal M R I of finger. The I P and M C P joints appear radiopaque. The parts labeled are proximal phalanx, metacarpal head, metacarpophalangeal joint, proximal interphalangeal joint, middle phalanx, distal interphalangeal joint, and distal phalanx. (B) shows the coronal M R I of hand and wrist. The parts labeled are hamate, capitate, trapezoid, carpometacarpal joint, and metacarpophalangeal joint.

The carpals articulate with each other, the metacarpals, and the radius of the forearm. In the *carpometacarpal* (CMC) articulations, the first metacarpal and trapezium form a *synovial saddle* joint, which permits the thumb to oppose the fingers (touch the fingertips). The articulations between the second, third, fourth, and fifth metacarpals and the trapezoid, capitate, and hamate form *synovial gliding* joints. The *intercarpal* articulations are also *synovial gliding* joints. The articulations between the lunate and scaphoid form a gliding joint. The *radiocarpal* articulation is a *synovial ellipsoidal* type. This joint is formed by the articulation of the scaphoid, lunate, and triquetrum, with the radius and the articular disk just distal to the ulna (see Fig. 5.9B and C).

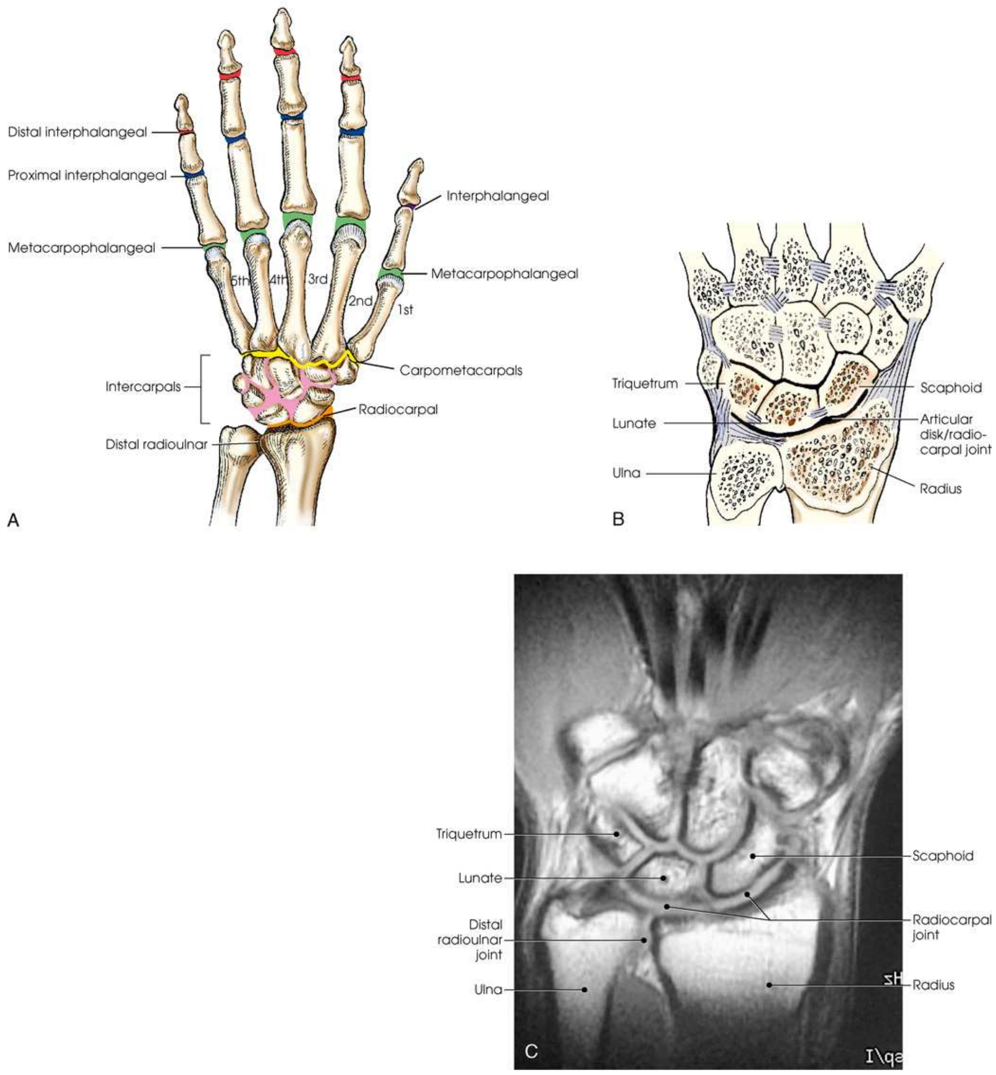


FIG. 5.9 (A) Color-coded articulations of hand and wrist. *Blue*, Proximal IP joints; *green*, MCP joints; *orange*, radiocarpal joint; *pink*, intercarpal joints; *purple*, IP joint of first digit; *red*, Distal IP joints; *yellow*, CMC joints. (B) Radiocarpal articulation formed by scaphoid, lunate, and triquetrum with radius. (C) Coronal MRI of wrist showing bones and joints of wrist.

Diagram (A) shows the color coded articulations of hand and wrist. The parts labeled in the diagram are as follows: blue is the proximal interphalangeal I P joints, green is the metacarpophalangeal M C P joints, orange is the radiocarpal joint, pink is the intercarpal joints; purple is the interphalangeal I P joint of first digit, red is the Distal I P joints and yellow is the carpometacarpals C M C joints. Diagram (B) shows the radiocarpal articulation. The parts labeled in the diagram are scaphoid, articular disk or radiocarpal joint, radius, ulna, lunate, and triquetrum. (C) shows the coronal M R I of wrist showing the bones and joints of wrist. The parts labeled are triquetrum, lunate, distal radioulnar joint, ulna, scaphoid, radiocarpal joint, and radius.

The *distal* and *proximal radioulnar* articulations are synovial pivot joints. The distal ulna articulates with the ulnar notch of the distal radius. The proximal head of the radius articulates with the radial notch of the ulna at the medial side. The movements of supination and pronation of the forearm and hand largely result from the combined rotary action of these two joints. In pronation, the radius turns medially and crosses over the ulna at its upper third, and the ulna makes a slight counterrotation that rotates the humerus medially.

The elbow joint proper includes the proximal radioulnar articulation and the articulations between the humerus and the radius and ulna. The three joints are enclosed in a common capsule. The trochlea of the humerus articulates with the ulna at the trochlear notch. The capitulum of the humerus articulates with the flattened head of the radius. The *humeroulnar* and *humeroradial* articulations form a *synovial hinge* joint and allow only flexion and extension movement (Figs. 5.10 and 5.11A). The proximal humerus and its articulations are described with the shoulder girdle in Chapter 6.

Fat Pads

The three areas of fat [1,2] associated with the elbow joint can be visualized only in the lateral projection (see Fig. 5.11B and C). The *posterior fat pad* covers the largest area and lies within the olecranon fossa of the posterior humerus. The superimposed coronoid and radial fat pads, which lie in the coronoid and radial fossae of the anterior humerus, form the *anterior fat pad*. The *supinator fat pad* is positioned anterior to and parallel with the anterior aspect of the proximal radius.

When the elbow is flexed 90 degrees for the lateral projection, only the anterior and supinator fat pads are visible, and the posterior fat pad is depressed within the olecranon fossa. The anterior fat pad resembles a teardrop, and the supinator fat pad appears as shown in Fig. 5.11B. The fat pads become significant radiographically when an elbow injury causes effusion and displaces the fat pads or alters their shape. Visualization of the posterior fat pad is a reliable indicator of elbow pathology. Exposure factors designed to show soft tissues are extremely important on lateral elbow radiographs because visualization of the fat pads may be the only evidence of injury.

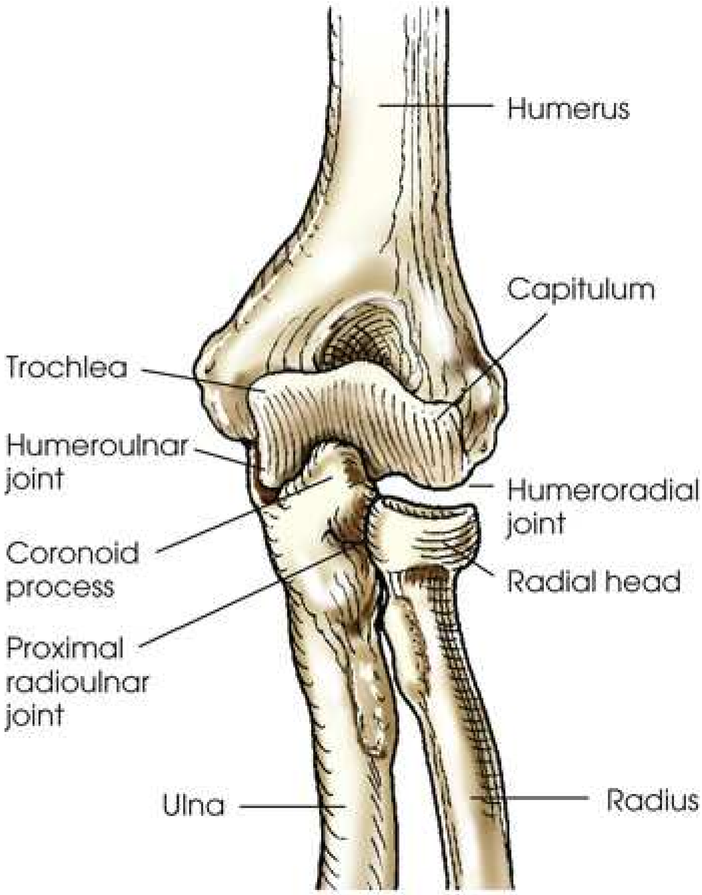


FIG. 5.10 Anterior aspect of left elbow joint.

Diagram shows the anterior aspect of left elbow joint. The parts labeled in the diagram are as follows: humerus, capitulum, trochlea, humeroulnar joint, coronoid process, humeroradial joint, radial head, proximal radioulnar joint, ulna, and radius.

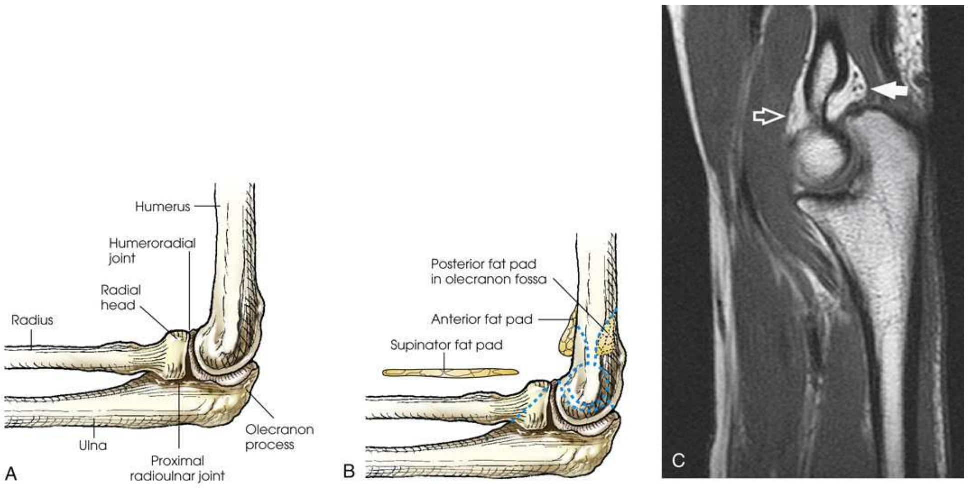


FIG. 5.11 (A) Lateral aspect of elbow. (B) Fat pads of elbow joint. (C) Sagittal MRI of elbow joint showing posterior fat pad *(solid arrow)* and anterior fat pad *(open arrow)*.

Diagram (A) shows the lateral aspect of elbow. The parts labeled in the diagram are as follows: humerus, humeroulnar joint, radial head, radius, ulna, proximal radioulnar joint, and olecranon process. Diagram (B) shows the fat pads of elbow joint. The anterior fat pad resembles a teardrop. The parts labeled in the diagram are as follows: posterior fat pad in olecranon fossa, anterior fat pad, and supinator fat pad. (C) shows the sagittal M R I of elbow joint. The posterior fat pad on the left is represented by a solid arrow and the anterior fat pad on the right is represented by an open arrow.

Summary of Anatomy

Hand

- Phalanges (bones of digits)
- Digits
  - Head
  - Body
  - Base
- Metacarpals
- Carpals

Metacarpals

- First to fifth metacarpals
  - Head
  - Neck
  - Body
  - Base
- Sesamoids

Wrist

- Scaphoid
- Lunate
- Triquetrum
- Pisiform
- Trapezium
- Trapezoid
- Capitate
- Hamate
- Hook of hamate
- Anatomic snuff-box

Carpal sulcus

- Carpal tunnel
- Flexor retinaculum

- Median nerve
- Flexor tendons

Forearm

- Ulna
- Radius

Ulna

- Olecranon process
- Trochlear notch
- Coronoid process
- Radial notch
- Body
- Head
- Ulnar styloid process

Radius

- Head
- Neck
- Radial tuberosity
- Body
- Radial styloid process

Arm

- Humerus

Humerus

- Humeral condyle
- Trochlea
- Capitulum
- Medial epicondyle
- Lateral epicondyle
- Coronoid fossa
- Radial fossa
- Olecranon fossa
- Body
- Surgical neck
- Lesser tubercle
- Greater tubercle
- Intertubercular groove
- Anatomic neck
- Head

Articulations

- Interphalangeal
- Metacarpophalangeal
- Carpometacarpal
- Intercarpal
- Radiocarpal
- Radioulnar
- Humeroulnar
- Humeroradial

Fat pads

- Anterior fat pads
- Posterior fat pad
- Supinator fat pad

These techniques were accurate for the equipment used to produce each exposure. However, use caution when applying them in your department because "there is considerable variability in image receptor response owing to varying scatter sensitivity, the use of grids with different grid ratios, collimation, beam filtration, the choice of kilovoltage, source-to-image distance, and image receptor size."[a]								
This chart was created in collaboration with Dennis Bowman, AS, RT(R), Clinical Instructor, Community Hospital of the Monterey Peninsula, Monterey, CA. http://digitalradiographysolutions.com/.								
Upper Extremity								
Part	cm	kVp[b]	SID[c]	Collimation	CR[d]		DR[e]	
					mAs	Dose (mGy)[f]	mAs	Dose (mGy)[f]
Digits[g]	1.5	63	40″	2″ × 6″ (5 × 15 cm)	1.6[h]	0.042	0.6[h]	0.017
Hand—*PA*[g]	3	66	40″	7″ × 8″ (18 × 20 cm)	1.6[h]	0.085	0.71[h]	0.035
Hand—*Oblique*[g]	5	66	40″	7″ × 8″ (18 × 20 cm)	2.0[h]	0.111	0.8[h]	0.044
Hand—*Lateral*[g]	7	70	40″	6″ × 8″ (15 × 20 cm)	2.5[h]	0.166	1.25[h]	0.082
Wrist—*PA/AP, Oblique*[g]	4	66	40″	4″ × 8″ (10 × 20 cm)	2.0[h]	0.102	0.9[h]	0.044
Wrist—*Lateral*[g]	6	70	40″	3″ × 8″ (8 × 20 cm)	2.5[h]	0.125	1.1[h]	0.054
Carpal canal[g]	6	70	40″	4″ × 4″ (10 × 10 cm)	2.5[h]	0.134	1.25[h]	0.066
Forearm—*AP, lateral*[g]	7	70	40″	5″ × 15″ (13 × 38 cm)	2.2[h]	0.151	1.25[h]	0.084
Elbow—*AP, lateral*[g]	8	70	40″	5″ × 9″ (13 × 23 cm)	2.5[h]	0.171	1.4[h]	0.094
Elbow—*Distal humerus*[g]	9	70	40″	5″ × 9″ (13 × 23 cm)	3.2[h]	0.224	1.8[h]	0.125
Elbow—*Proximal forearm*[g]	9	70	40″	5″ × 9″ (13 × 23 cm)	2.0[h]	0.138	1.25[h]	0.086
Humerus—*AP, lateral*[g]	12	70	40″	7″ × 17″ (18 × 43 cm)	4.0[h]	0.314	2.0[h]	0.158
Humerus—*AP, lateral*[i]	12	75	40″	7″ × 17″ (18 × 43 cm)	5.6[h]	0.443	2.8[h]	0.222
Cast—*Fiberglass*[j]	Increase mAs 25% *or* 4 kVp							
Cast—*Plaster medium*[j]	Increase mAs 50% *or* 7 kVp							
Cast—*Plaster large*[j]	Increase mAs 100% *or* 10 kVp							

[a] ACR-AAPM-SIMM Practice Parameter for Digital Radiography, revised 2017.

[b] kVp values are for a high-frequency generator.

[c] 40-inch minimum; 44 to 48 inches recommended to improve spatial resolution (mAs increase needed, but no increase in patient dose will result).

[d] AGFA CR MD 4.0 General IP, CR 75.0 reader, 400 speed class, with 6:1 (178LPI) grid when needed.

[e] GE Definium 8000, with 13:1 grid when needed.

[f] All doses are skin entrance for average adult (160- to 200-pound male, 150- to 190-pound female) at part thickness indicated.

[g] Tabletop, nongrid.

[h] Small focal spot.

[i] Bucky/Grid.

[j] Gratale P, Turner GW, Burns CB. Using the same exposure factors for wet and dry casts. *Radiol Technol*. 1986;57:328.

Summary of Pathology

Condition	Definition
Bone cyst	Fluid-filled cyst with wall of fibrous tissue
Bursitis	Inflammation of bursa
Dislocation	Displacement of bone from joint space
Fracture	Disruption in continuity of bone
Bennett	Fracture at base of first metacarpal
Boxer	Fracture of metacarpal neck
Colles	Fracture of distal radius with posterior (dorsal) displacement
Smith	Fracture of distal radius with anterior (palmar) displacement
Torus or buckle	Impacted fracture with bulging of periosteum
Gout	Hereditary form of arthritis in which uric acid is deposited in joints
Joint effusion	Accumulation of fluid in joint associated with underlying condition
Metastases	Transfer of cancerous lesion from one area to another
Osteoarthritis or degenerative joint disease	Form of arthritis marked by progressive cartilage deterioration in synovial joints and vertebrae
Osteomyelitis	Inflammation of bone owing to pyogenic infection
Osteopetrosis	Increased density of atypically soft bone
Osteoporosis	Loss of bone density
Rheumatoid arthritis	Chronic, systemic, inflammatory collagen disease
Tumor	New tissue growth where cell proliferation is uncontrolled
Chondrosarcoma	Malignant tumor arising from cartilage cells
Enchondroma	Benign tumor consisting of cartilage
Ewing sarcoma	Malignant tumor of bone arising in medullary tissue
Osteosarcoma	Malignant, primary tumor of bone with bone or cartilage formation

Eponymous (named) pathologies are listed in nonpossessive form to conform to the *AMA manual of style: a guide for authors and editors*, ed 10, Oxford, 2009, Oxford University Press.

Abbreviations Used in Chapter 5

CMC	Carpometacarpal
DIP	Distal interphalangeal
IP [a]	Interphalangeal
MC	Metacarpal
MCP	Metacarpophalangeal
PIP	Proximal interphalangeal

See Addendum A for a summary of all abbreviations used in Volume 1.

[a] Note that IP has two different meanings; it is used in Chapter 1 to mean "image plate."

Radiography

Digits (Second Through Fifth)

General Procedures

When the upper extremity is radiographed, the following steps should be initiated:

- Remove rings, watches, and other radiopaque objects, and place them in secure storage during the procedure.
- Seat the patient at the side or end of the table to avoid a strained or uncomfortable position.
- Place the image receptor (IR) at a location and angle that allows the patient to be in the most comfortable position. Because the degree of immobilization (particularly of the hand and digits) is limited, the patient must be comfortable to promote relaxation and cooperation in maintaining the desired position.
- Unless otherwise specified, direct the central ray (CR) at a right angle to the midpoint of the IR. Because the joint spaces of the extremities are narrow, accurate centering is essential to avoid obscuring the joint spaces.
- Radiograph each side separately when performing a bilateral examination of the hands or wrists; this prevents distortion, particularly of the joint spaces.
- *Shield gonads* if needed to reduce patient or caregiver anxiety (see Fig. 5.12).
- Use close collimation. This technique is recommended for all upper extremity radiographs.
- Use right or left markers and any other identification markers, when appropriate.

Digits (Second Through Fifth)

PA Projection

Image receptor:

Positioned by manufacturer or department protocol for proper anatomy display orientation; CR plate: 10 × 12 inches (24 × 30 cm) lengthwise.

Position of patient

- Seat the patient at the end of the radiographic table.

Position of part

When radiographing individual digits (except the first), take the following steps:

- Place the extended digit with the palmar surface down on the IR.
- Separate the digits slightly, and center the digit under examination to the center of the IR.
- Center the PIP joint to the IR (Figs. 5.13 through 5.15).
- *Shield gonads.*

FIG. 5.12 Patient seated at end of table.

A patient is shielded with a lead apron placed over the patient's pelvis area as she is sitting at the end of the radiographic table with her arm resting on a support on the radiographic table. The side marker is in the collimated exposure field.

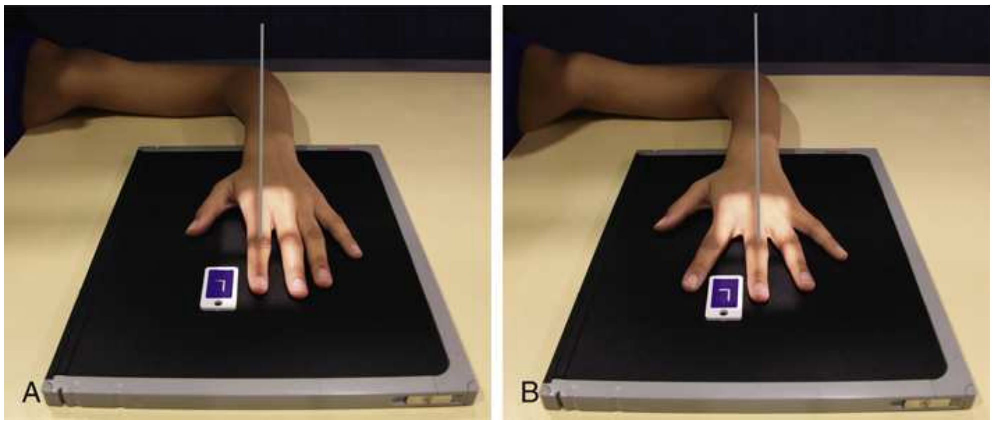


FIG. 5.13 (A) PA second digit. (B) PA third digit.

(A) shows the patient's extended digit with the palmar placed surface down on the image receptor. The digits are separated. The side marker is in the collimated exposure field. The central ray is centered on the second digit. (B) shows the patient's extended digit with the palmar placed surface down on the image receptor. The side marker is in the collimated exposure field. The central ray is centered on the third digit.

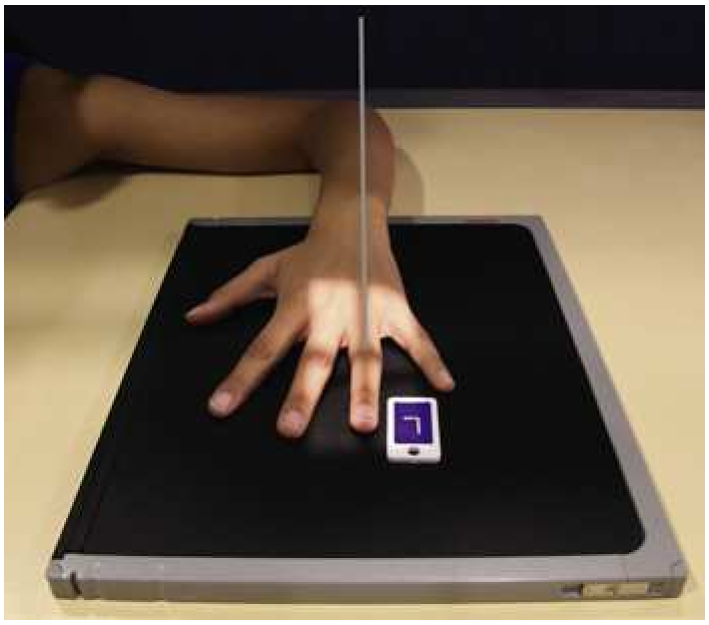


FIG. 5.14 PA fourth digit.

The patient's extended digit with the palmar is placed surface down on the image receptor and the digits are separated. The side marker is in the collimated exposure field. The central ray is centered on the fourth digit.

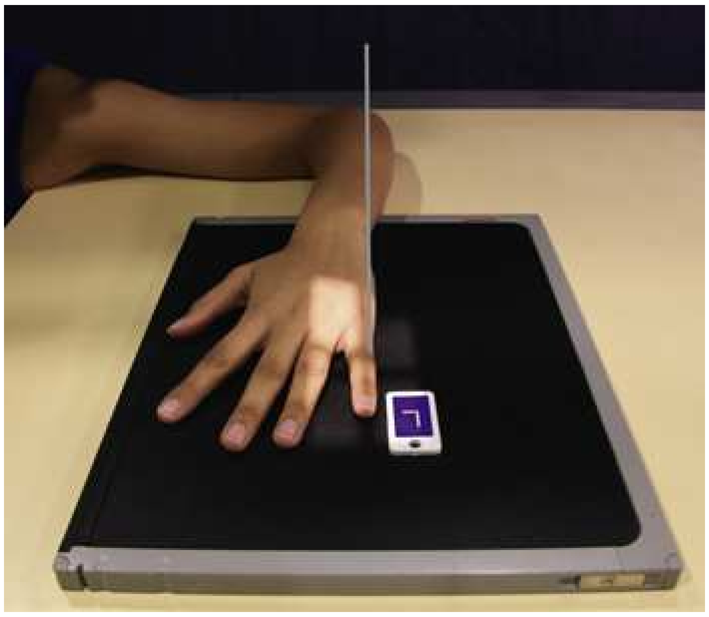


FIG. 5.15 PA fifth digit.

The patient's extended digit with the palmar is placed surface down on the image receptor and the digits are separated. The side marker is in the collimated exposure field. The central ray is centered on the fifth digit.

Central ray

- Perpendicular to the PIP joint of the affected digit

Collimation

- Adjust radiation field to 1 inch (2.5 cm) on all sides of the digit, including 1 inch (2.5 cm) proximal to the MCP joint. Place side marker in the collimated exposure field.

Computed Radiography

For all projections, the digit must be centered to the plate or plate section with four collimator margins. Two or more images can be projected on one crosswise IP; however, there should be four collimator margins for each projection. A lead blocker must cover the unexposed side when multiple images are made on one IP.

Structures shown

A PA projection of the appropriate digit and adjoining distal metacarpal (Figs. 5.16 through 5.19).

Evaluation Criteria

The following should be clearly seen:

- Evidence of proper collimation and presence of side marker placed clear of anatomy of interest
- Entire digit from fingertip to distal portion of the adjoining metacarpal
- No soft tissue overlap from adjacent digits
- No rotation:
  - Equal concavity on both sides of the phalangeal bodies
  - Equal amount of soft tissue on both sides of the phalanges
- Fingernail, if seen, centered over the distal phalanx
- Open IP and MCP joint spaces
- Bony trabecular detail and surrounding soft tissues

NOTE: Digits that cannot be extended can be examined in small sections. When joint injury is suspected, an AP projection instead of a PA projection is recommended.

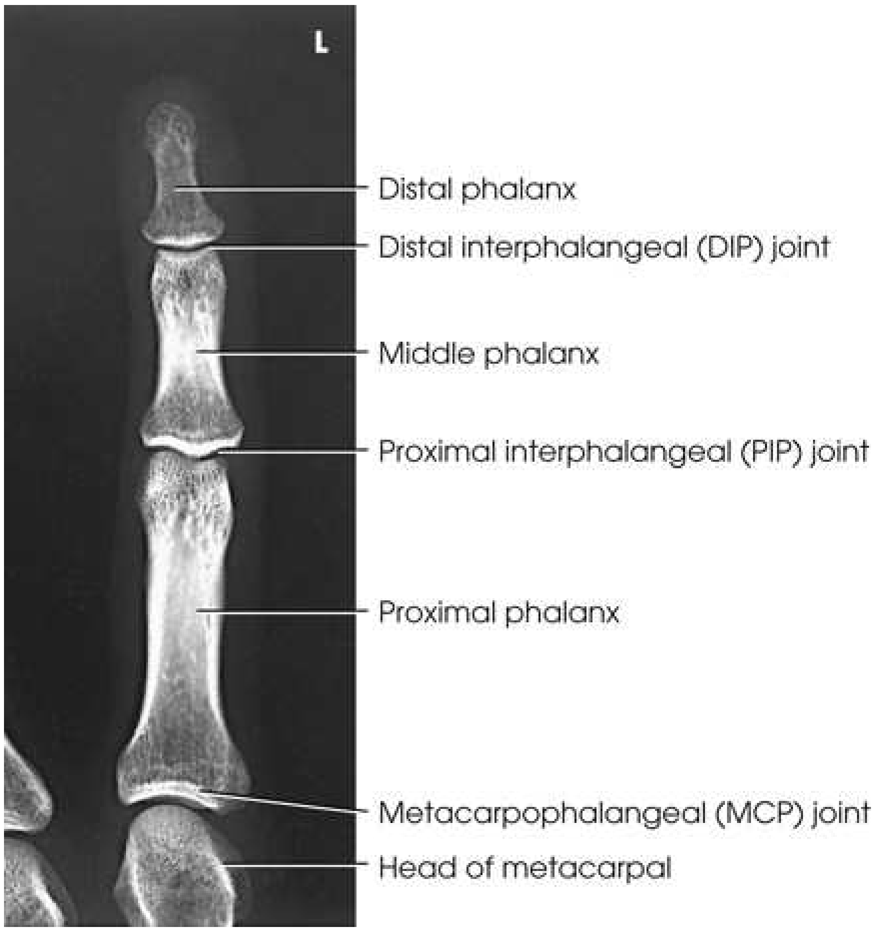


FIG. 5.16 PA second digit.

An x-ray shows the second digit. The parts labeled in the x-ray are as follows: distal phalanx, distal interphalangeal (D I P) joint, middle phalanx, proximal interphalangeal (P I P) joint, proximal phalanx, metacarpophalangeal (M C P) joint, and head of metacarpal.

FIG. 5.17 PA third digit.

An x-ray view of the third digit. There is open I P and M C P joint spaces. There is equal concavity on both sides of the phalangeal bodies. There is equal amount of soft tissue on both sides of the phalanges.

FIG. 5.18 PA fourth digit.

An x-ray view of the fourth digit. There is open I P and M C P joint spaces. There is equal concavity on both sides of the phalangeal bodies. There is equal amount of soft tissue on both sides of the phalanges.

FIG. 5.19 Fractured fifth digit *(arrow)*.

Lateral Projection

Lateromedial or mediolateral

Image receptor:

Positioned by manufacturer or department protocol for proper anatomy display orientation; CR plate: 10 × 12 inches (24 × 30 cm) lengthwise.

Position of patient

- Seat the patient at the end of the radiographic table.

Position of part

- Because lateral digit positions are difficult to hold, tell the patient how the digit is adjusted on the IR and demonstrate with your own finger. Allow the patient to assume the most comfortable arm position.
- Ask the patient to extend the digit to be examined. Close the rest of the digits into a fist, and hold them in complete flexion with the thumb.
- Support the elbow on sandbags or provide other suitable support when the elbow must be elevated to bring the digit into position.
- With the digit under examination extended and other digits folded into a fist, have the patient's hand rest on the lateral, or radial, surface for the second or third digit (Figs. 5.20 and 5.21) or on the medial, or ulnar, surface for the fourth or fifth digit (Figs. 5.22 and 5.23).
- Before making the final adjustment of the digit position, place the IR so that the midline is parallel with the long axis of the digit. Center the IR to the PIP joint.
- Rest the second and fifth digits directly on the IR, but for an accurate image of the bones and joints, elevate the third and fourth digits and place their long axes parallel with the plane of the IR. A radiolucent sponge may be used to support the digits.
- Immobilize the extended digit by placing a strip of adhesive tape, a tongue depressor, or other support against its palmar surface. The patient can hold the support with the opposite hand.
- Adjust the anterior or posterior rotation of the hand to obtain a true lateral position of the digit.
- *Shield gonads.*

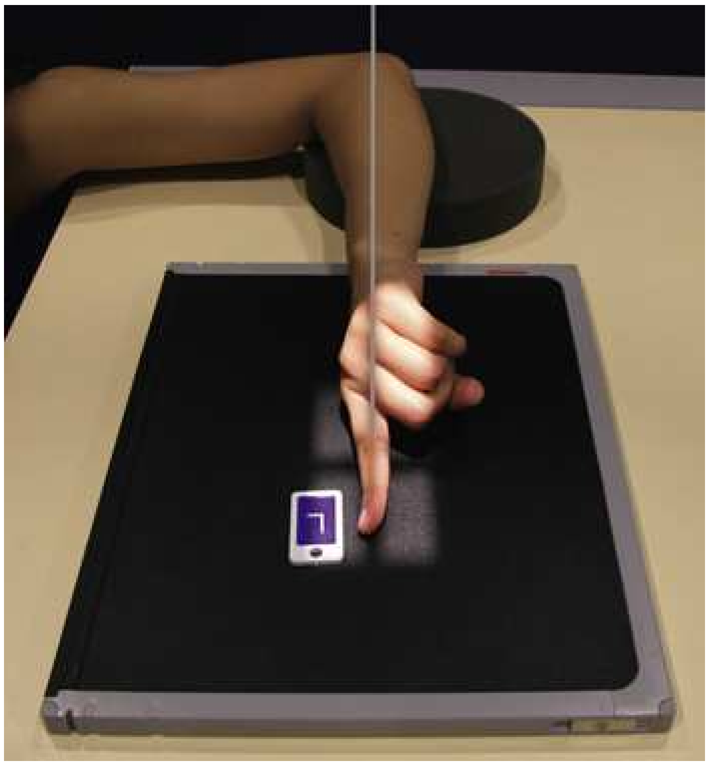


FIG. 5.20 Lateral second digit.

The patient's second digit is extended on the image receptor and the rest of the digits are closed into a fist and are in a complete flexion with the thumb. The elbow is supported using a sandbag. The side marker is in the collimated exposure field. The C R is perpendicular to the second digit.

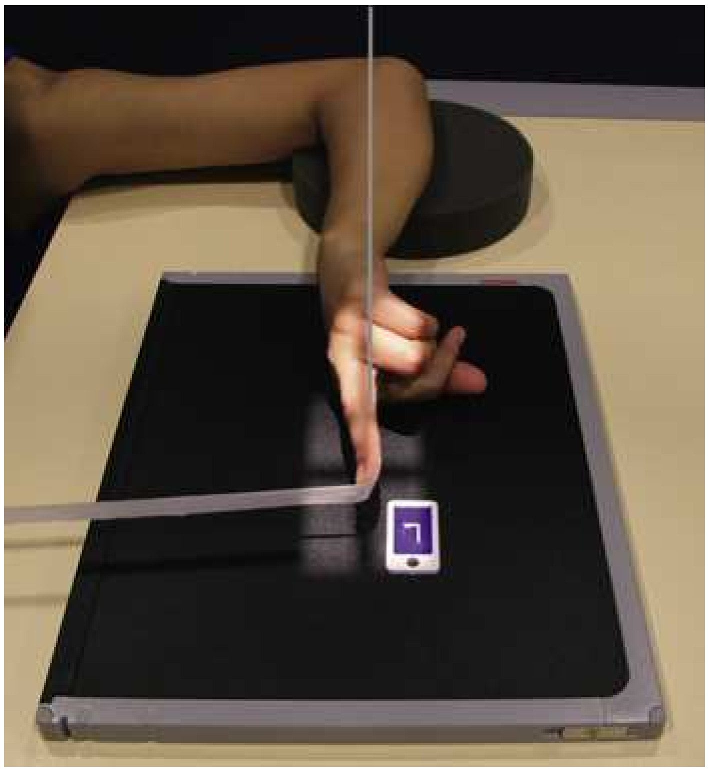


FIG. 5.21 Lateral third digit (adhesive tape).

The patient's third digit is immobilized using an adhesive tape. The third digit is extended and the rest of the digits are closed into a fist and are in a complete flexion with the thumb. The side marker is in the collimated exposure field. The C R is perpendicular to the third digit.

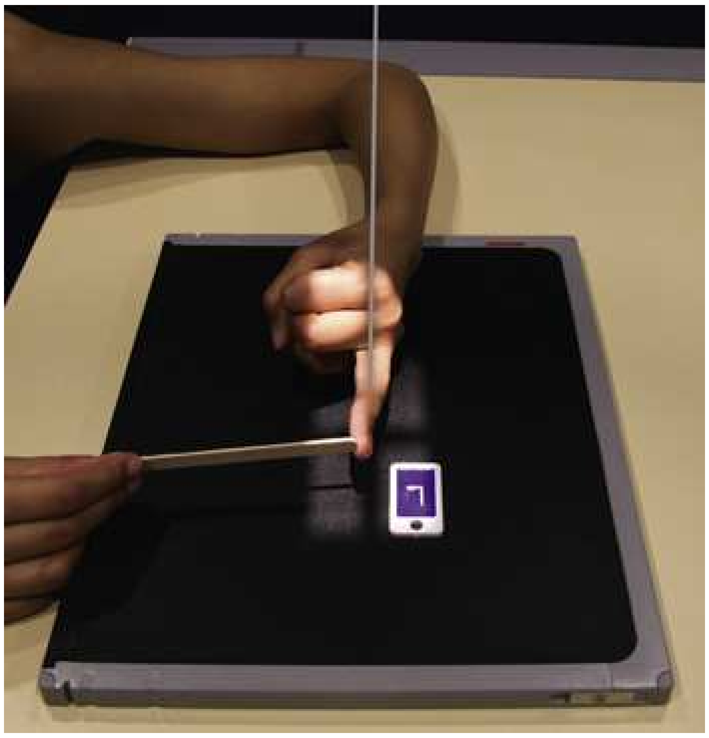


FIG. 5.22 Lateral fourth digit (tongue blade).

The patient's fourth digit is immobilized using a tongue blade. The fourth digit is extended and the rest of the digits are closed into a fist and are in a complete flexion with the thumb. The side marker is in the collimated exposure field. The C R is perpendicular to the fourth digit.

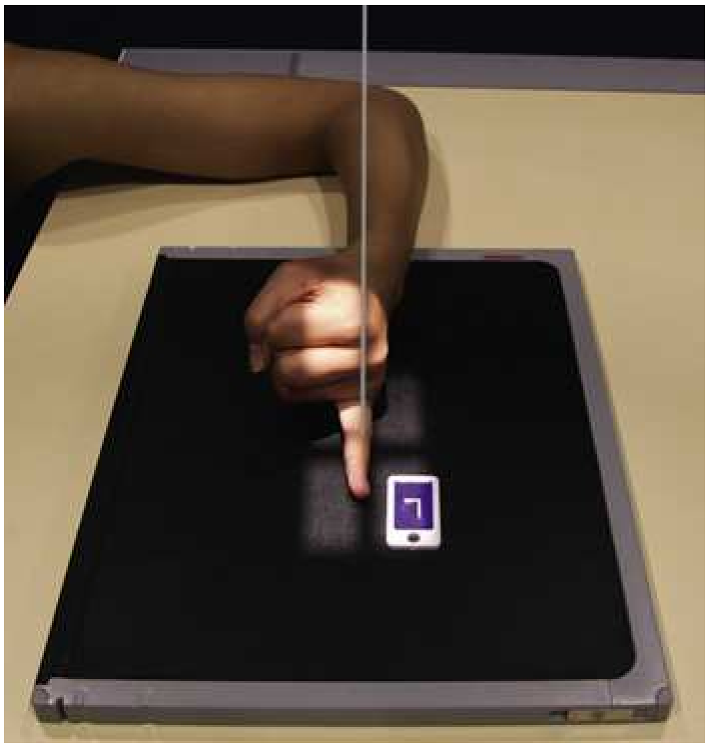


FIG. 5.23 Lateral fifth digit.

The patient's fifth digit is extended on the image receptor and the rest of the digits are closed into a fist and are in a complete flexion with the thumb. The side marker is in the collimated exposure field .The C R is perpendicular to the fifth digit.

Central ray

- Perpendicular to the PIP joint of the affected digit

Collimation

- Adjust radiation field to 1 inch (2.5 cm) on all sides of the digit, including 1 inch (2.5 cm) proximal to the MCP joint. Place side marker in the collimated exposure field.

Structures shown

A lateral projection of the affected digit and adjoining distal metacarpal (Figs. 5.24 through 5.27).

Evaluation Criteria

The following should be clearly seen:

- Evidence of proper collimation and presence of side marker placed clear of anatomy of interest
- Entire digit from fingertip to distal portion of the adjoining metacarpal
- No rotation:
  - Fingernail in profile, if visualized and normal
  - Concave, anterior surfaces of the phalanges
- No superimposition of the proximal phalanx or MCP joint by adjacent digits
- Open IP joint spaces
- Bony trabecular detail and surrounding soft tissues

OPTION: Some radiographers rotate the second digit medially from the pronated position (Fig. 5.36). The advantage of medially rotating the digit is that the part is closer to the IR for improved resolution and increased visibility of certain fractures. [3]

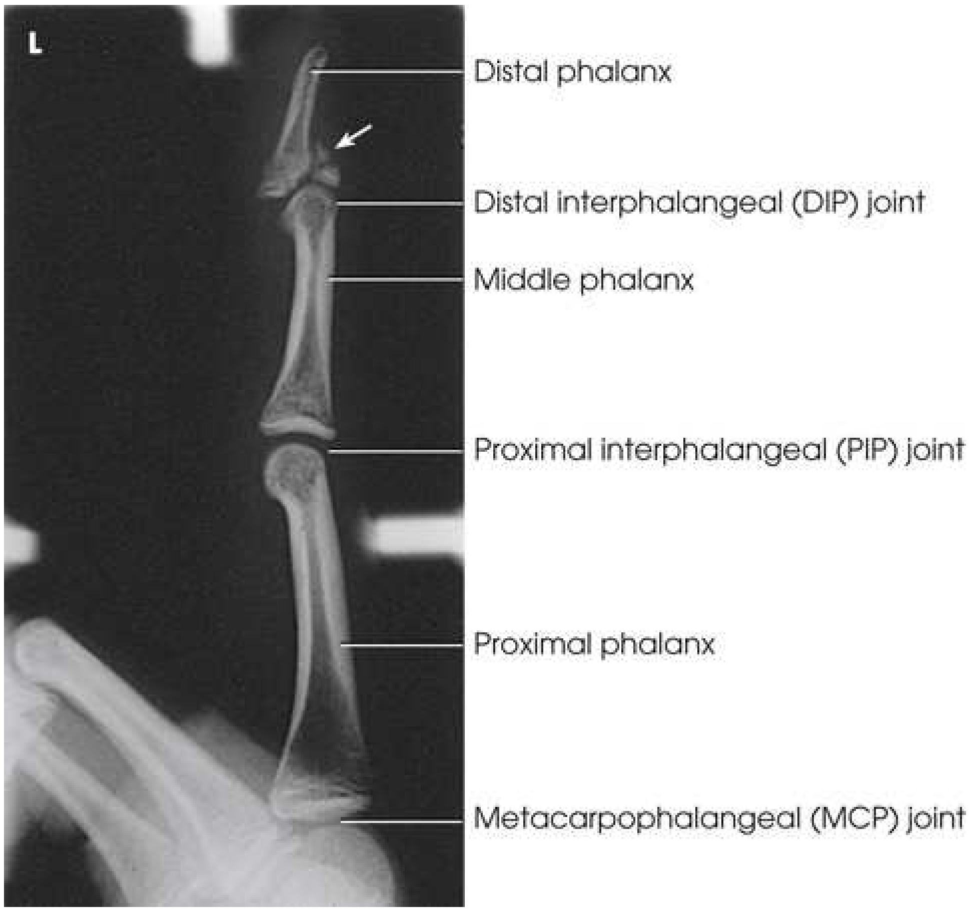


FIG. 5.24 Lateral digit showing chip fracture and dislocation involving DIP joint of second digit *(arrow).*

An x-ray view of the lateral digit shows a dislocation of the second digit involving the D I P joint. It is represented by an arrow. The parts labeled in the x-ray are as follows: distal phalanx, distal interphalangeal (D I P) joint, middle phalanx, proximal interphalangeal (P I P) joint, proximal phalanx, and metacarpophalangeal (M C P) joint.

FIG. 5.25 Lateral third digit.

FIG. 5.26 Lateral fourth digit.

FIG. 5.27 Lateral fifth digit.

PA Oblique Projection

Lateral rotation

Image receptor:

Positioned by manufacturer or department protocol for proper anatomy display orientation; CR plate: 10 × 12 inches (24 × 30 cm) lengthwise.

Position of patient

- Seat the patient at the end of the radiographic table.

Position of part

- Place the patient's forearm on the table, with the hand pronated and the palm resting on the IR.
- Center the IR at the level of the PIP joint.
- Rotate the hand laterally until the digits are separated and supported on a 45-degree foam wedge. The wedge supports the digits in a position parallel with the IR plane (Figs. 5.28 through 5.31) so that the IP joint spaces are open.
- *Shield gonads.*

Central ray

- Perpendicular to the PIP joint of the affected digit

Collimation

- Adjust radiation field to 1 inch (2.5 cm) on all sides of the digit, including 1 inch (2.5 cm) proximal to the MCP joint. Place side marker in the collimated exposure field.

Structures shown

A PA oblique projection of the affected digit and adjoining distal metacarpal (Figs. 5.32 through 5.35).

Evaluation Criteria

The following should be clearly seen:

- Evidence of proper collimation and presence of side marker placed clear of anatomy of interest
- Entire digit, including the distal portion of the adjoining metacarpal
- Digit rotated at 45 degrees, demonstrated by concavity of the elevated side of the phalangeal bodies
- No superimposition of the proximal phalanx or MCP joint by adjacent digits
- Open IP and MCP joint spaces
- Bony trabecular detail and surrounding soft tissues

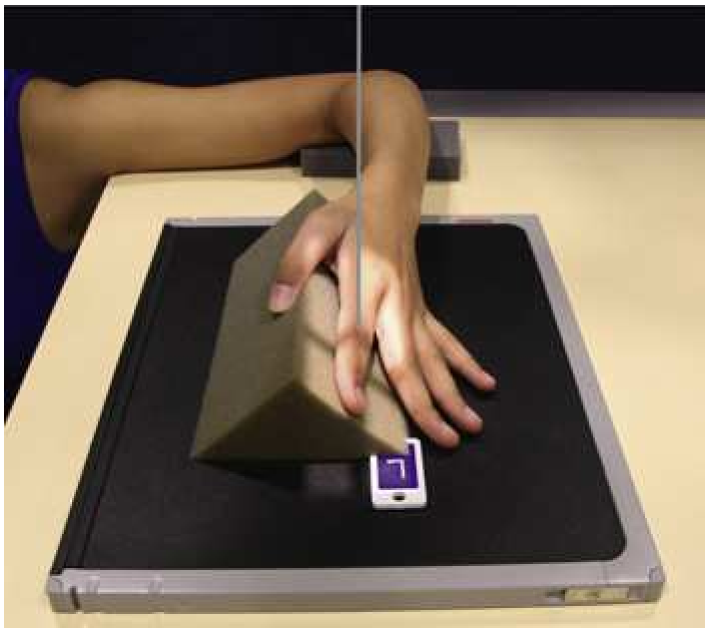


FIG. 5.28 PA oblique second digit.

The patient's hand is rotated laterally and the digits are separated and supported on a 45 degree foam wedge. The side marker is in the collimated exposure field. The C R is perpendicular to the second digit.

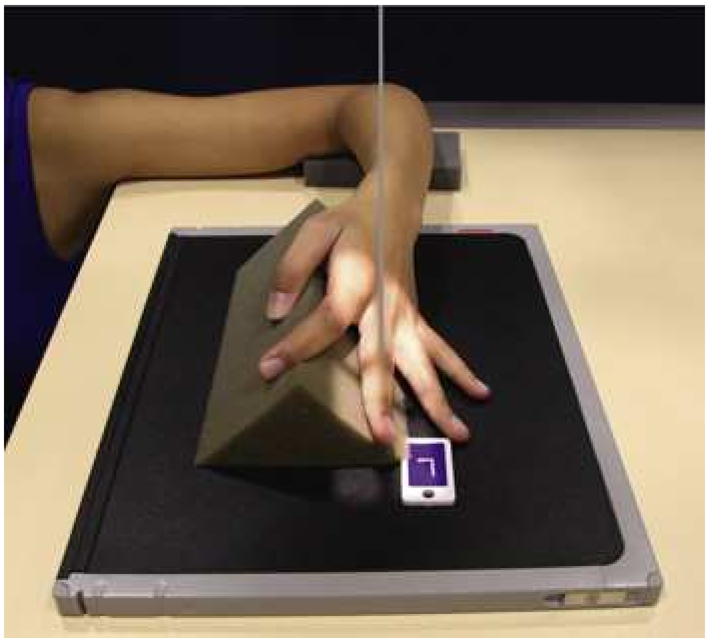


FIG. 5.29 PA oblique third digit.

The patient's hand is rotated laterally and the digits are separated and supported on a 45 degree foam wedge. The side marker is in the collimated exposure field. The C R is perpendicular to the third digit.

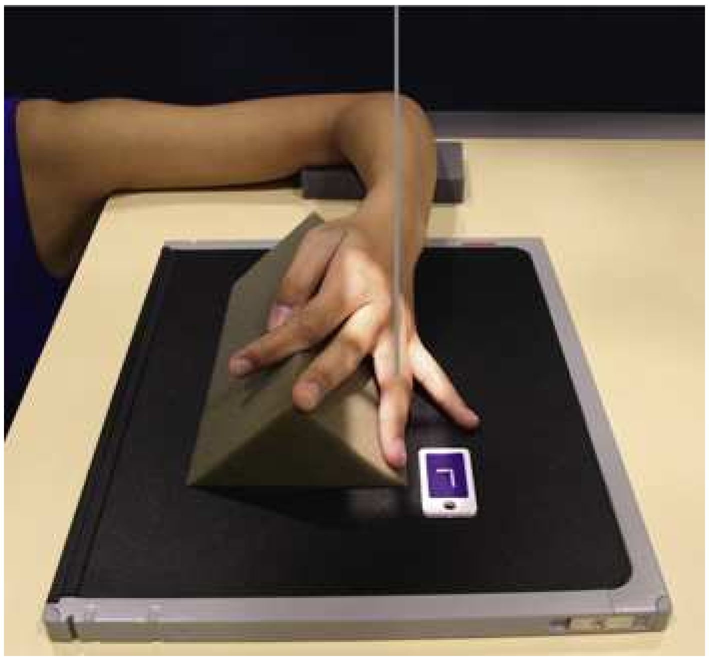


FIG. 5.30 PA oblique fourth digit.

The patient's hand is rotated laterally and the digits are separated and supported on a 45 degree foam wedge. The side marker is in the collimated exposure field. The C R is perpendicular to the fourth digit.

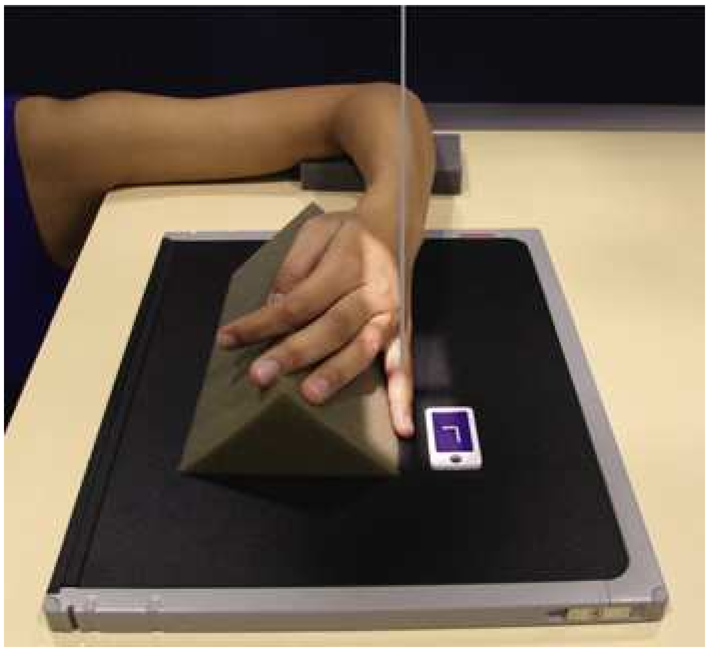


FIG. 5.31 PA oblique fifth digit.

The patient's hand is rotated laterally and the digits are separated and supported on a 45 degree foam wedge. The side marker is in the collimated exposure field. The C R is perpendicular to the fifth digit.

FIG. 5.32 PA oblique second digit.

FIG. 5.33 PA oblique third digit.

An x-ray view of the oblique third digit shows the entire digit, including the distal portion of the adjoining metacarpal. There is open I P and M C P spaces. The second and the fourth digits are marked.

FIG. 5.34 PA oblique fourth digit.

An x-ray view of the oblique fourth digit shows the entire digit, including the distal portion of the adjoining metacarpal. There is open I P and M C P spaces. The fifth and the third digits are marked.

FIG. 5.35 PA oblique fifth digit.

An x-ray view of the oblique fifth digit shows the entire digit, including the distal portion of the adjoining metacarpal. There is open I P and M C P spaces. The third and the fourth digits are marked.

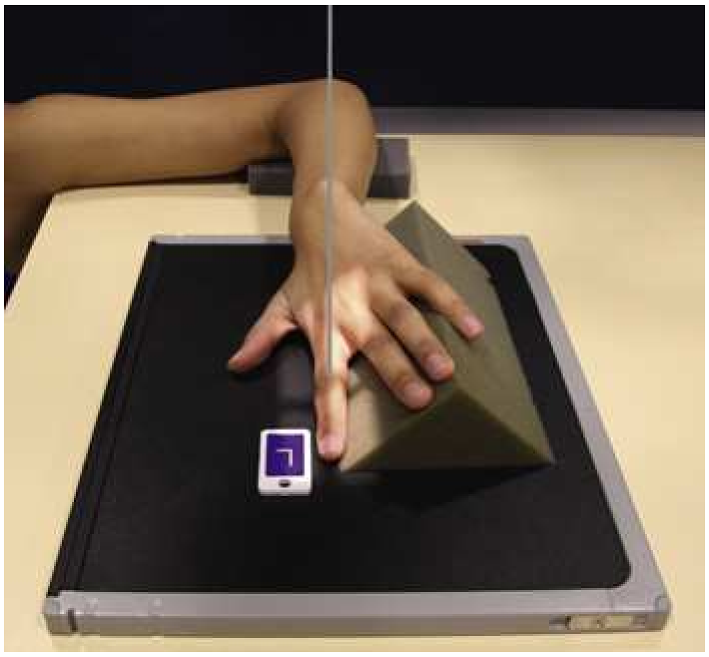


FIG. 5.36 PA oblique second digit (alternative method, medial rotation).

The patient's hand is rotated medially and the digits are separated and supported on a 45 degree foam wedge. The side marker is in the collimated exposure field. The C R is perpendicular to the second digit.

First Digit (Thumb)

AP, PA, Lateral, and PA Oblique Projections

Image receptor:

Positioned by manufacturer or department protocol for proper anatomy display orientation; CR plate: 10 × 12 inches (24 × 30 cm) lengthwise.

AP Projection

Position of patient

- Seat the patient at the end of the radiographic table with the arm internally rotated.

Position of part

- Demonstrate how to avoid motion or rotation with the hand. By adjusting the body position on the chair, the patient can place the hand in the correct position with the least amount of strain on the arm.
- Put the patient's hand in a position of extreme medial rotation. Have the patient hold the extended digits back with tape or the opposite hand. Rest the thumb on the IR. If the elbow is elevated, place a support under it and have the patient rest the opposite forearm against the table for support (Fig. 5.37).
- Center the long axis of the thumb parallel with the long axis of the IR. Adjust the position of the hand to ensure a true AP projection of the thumb. Place the fifth metacarpal back far enough to avoid superimposition.
- Lewis [4] suggested directing the CR 10 to 15 degrees along the long axis of the thumb, toward the wrist to show the first metacarpal free of the soft tissue of the palm.
- *Shield gonads.*

PA Projection

Position of patient

- Seat the patient at the end of the radiographic table with the hand resting on its medial surface.

Position of part

- If a PA projection of the first CMC joint and first digit is to be performed, place the hand in the lateral position. Rest the elevated and abducted thumb on a radiographic support or hold it up with a radiolucent stick. Adjust the hand to place the dorsal surface of the digit parallel with the IR. This position magnifies the part (Fig. 5.38).
- Center the MCP joint to the center of the IR.
- *Shield gonads.*

Lateral Projection

Position of patient

- Seat the patient at the end of the radiographic table, with the relaxed hand placed on the IR.

Position of part

- Place the hand in its natural arched position, with the palmar surface down and fingers flexed or resting on a sponge.
- Place the midline of the IR parallel with the long axis of the digit. Center the IR to the MCP joint.
- Adjust the arching of the hand until a true lateral position of the thumb is obtained (Fig. 5.39).

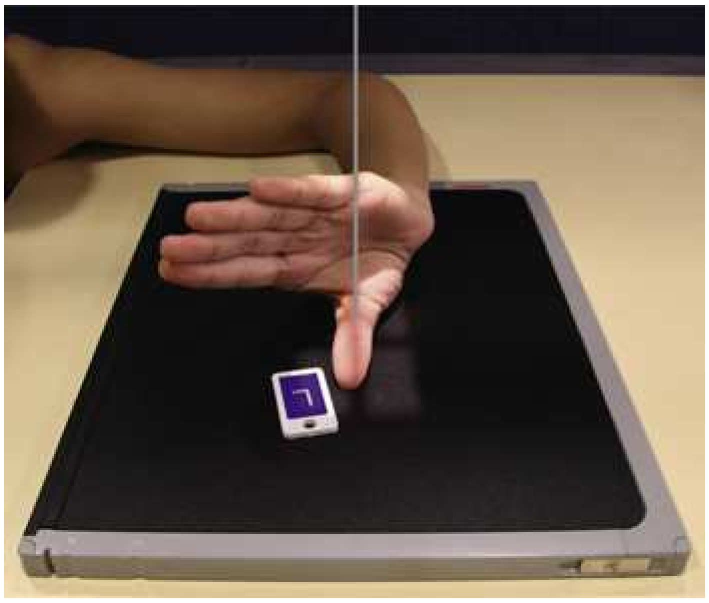


FIG. 5.37 AP first digit.

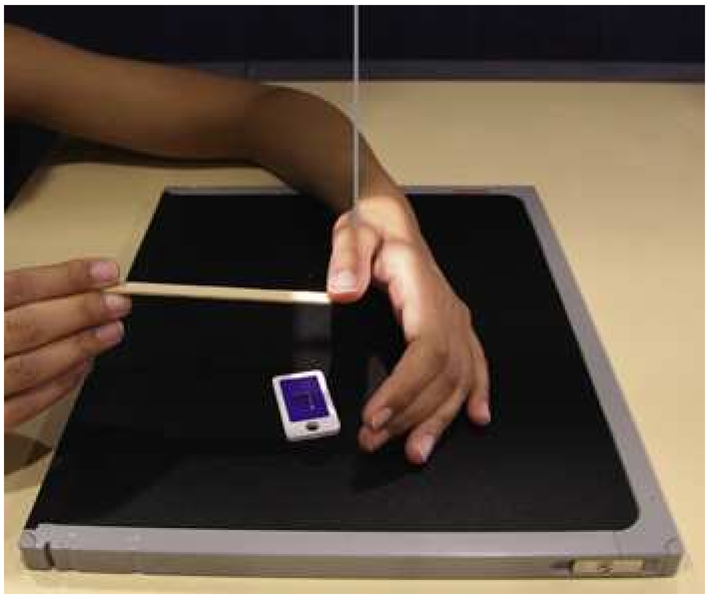


FIG. 5.38 PA first digit (tongue blade).

The patient's hand is placed in lateral position. The elevated and abducted thumb is supported using a tongue blade. The dorsal surface of the digit is placed parallel with the I R. The side marker is in the collimated exposure field. The C R is perpendicular to the thumb.

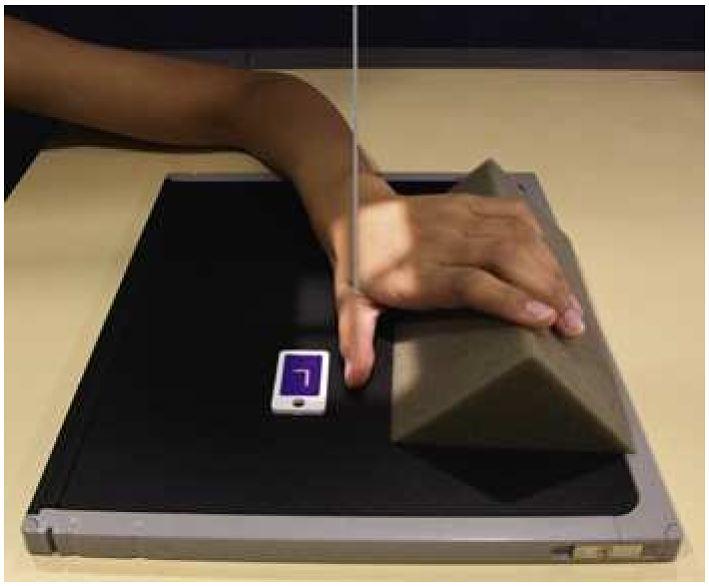


FIG. 5.39 Lateral first digit.

The patient's hand is placed in an arched position, with the palmar surface supported by a foam wedge and fingers flexed. The side marker is in the collimated exposure field. The C R is perpendicular to the thumb.

PA Oblique Projection

Position of patient

- Seat the patient at the end of the radiographic table, with the palm of the hand resting on the IR.

Position of part

- With the thumb abducted, place the palmar surface of the hand in contact with the IR. Ulnar deviate the hand slightly. This relatively normal placement positions the thumb in the oblique position.
- Align the longitudinal axis of the thumb with the long axis of the IR. Center the IR to the MCP joint (Fig. 5.40).
- *Shield gonads.*

Central ray

- Perpendicular to the MCP joint for AP, PA, lateral, and oblique projections

Collimation

- Adjust radiation field to 1 inch (2.5 cm) on all sides of the digit, including 1 inch (2.5 cm) proximal to the CMC joint. Place side marker in the collimated exposure field.

Structures shown

AP, PA, lateral, and PA oblique projections of the thumb and first metacarpal, including the trapezium (Figs. 5.41 through 5.44).

Evaluation Criteria

AP and PA Thumb

The following should be clearly seen:

- Evidence of proper collimation and presence of side marker placed clear of anatomy of interest
- Area from the distal tip of the thumb to the trapezium
- No rotation
  - Concavity of the phalangeal and metacarpal bodies
  - Equal amount of soft tissue on both sides of the phalanges
  - Thumbnail, if visualized, in the center of the distal thumb
- Overlap of soft tissue profile of the palm over the midshaft of the first metacarpal
- Open IP and MCP joint spaces without overlap of bones
- Bony trabecular detail and surrounding soft tissues

▪ PA thumb projection will be magnified compared with AP projection

Lateral thumb

The following should be clearly seen:

- Evidence of proper collimation and presence of side marker placed clear of anatomy of interest
- Area from the distal tip of the thumb to the trapezium
- No rotation
  - Concave anterior surface of the proximal phalanx and metacarpal
  - Thumbnail, if visualized and normal, in profile
- Open IP and MCP joint spaces
- Bony trabecular detail and surrounding soft tissues

Oblique thumb

The following should be clearly seen:

- Evidence of proper collimation and presence of side marker placed clear of anatomy of interest
- Area from the distal tip of the thumb to the trapezium
- Proper rotation, demonstrated by concave surface of elevated side of the proximal phalanx and metacarpal
- Open IP and MCP joint spaces
- Bony trabecular detail and surrounding soft tissues

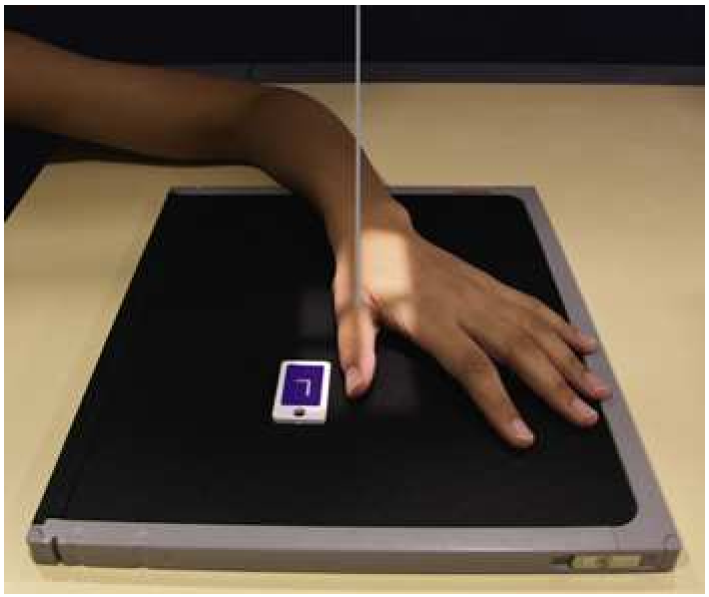


FIG. 5.40 PA oblique first digit.

The patient's thumb is abducted and the palmar surface of the hand is placed in contact with the image receptor. The side marker is in the collimated exposure field. The C R is centered perpendicular to the M C P joint of the thumb.

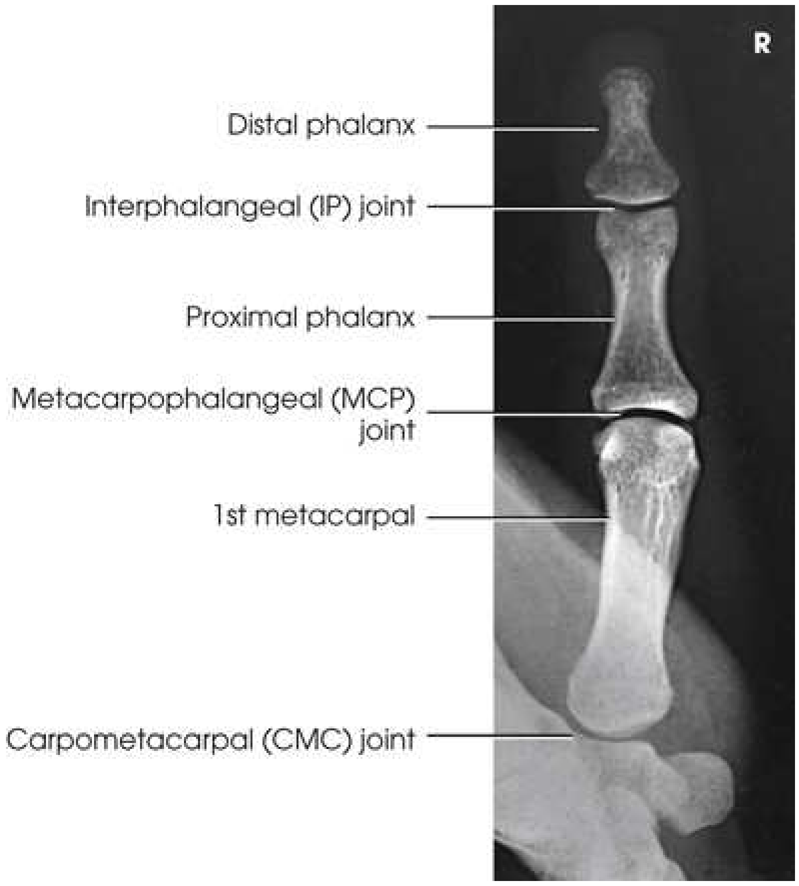


FIG. 5.41 AP first digit.

An x-ray view of the first digit shows the area from the distal tip of the thumb to the trapezium. The parts labeled in the diagram are as follows: distal phalanx, interphalangeal (I P) joint, proximal phalanx, metacarpophalangeal (M C P) joint, first metacarpal, and carpometacarpal (C M C) joint.

FIG. 5.42 PA first digit.

FIG. 5.43 Lateral first digit.

An x-ray view of the lateral first digit shows the area from the distal tip of the thumb to the trapezium. The I P and M C P joint spaces are open. There is concavity of the anterior surface of the proximal phalanx and metacarpal.

FIG. 5.44 PA oblique first digit.

An x-ray view of the oblique first digit shows the area from the distal tip of the thumb to the trapezium. The I P and M C P joint spaces are open. There is concavity of the phalangeal and metacarpal bodies.

First Carpometacarpal Joint

AP Projection

Robert Method

Robert [4] first described the radiographic projection of the first CMC joint in 1936. Lewis [5] modified the CR for this projection in 1988, and Long and Rafert [6] further modified the CR in 1995. This projection is commonly performed to show arthritic changes, fractures, displacement of the first CMC joint, and Bennett fracture. The Robert method does not replace the initial AP or PA thumb projection.

Image receptor:

Positioned by manufacturer or department protocol for proper anatomy display orientation; CR plate: 10 × 12 inches (24 × 30 cm) lengthwise.

Position of patient

- Seat the patient sideways at the end of the radiographic table. The patient should be positioned low enough to place the shoulder, elbow, and wrist on the same plane. The entire extremity *must* be on the same plane to prevent elevation of the carpal bones and closing of the first CMC joint (Fig. 5.45).

Position of part

- Extend the extremity straight out on the radiographic table.
- Rotate the arm internally to place the posterior aspect of the thumb on the IR with the thumbnail down (see Fig. 5.45).
- Place the thumb in the center of the IR.
- Hyperextend the hand so that the soft tissue over the ulnar aspect does not obscure the first CMC joint (Fig. 5.46). Ensure that the thumb is not oblique.
- Long and Rafert [6] stated that the patient may hold the fingers back with the other hand.
- Steady the hand on a sponge if necessary.
- *Shield gonads.*

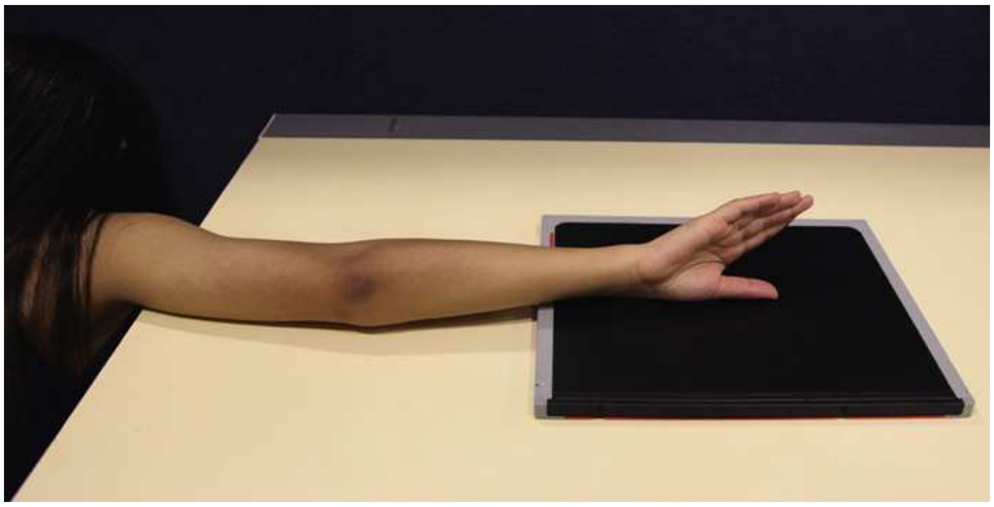


FIG. 5.45 Patient in position for AP thumb to show first CMC joint: Robert method. The patient leans forward to place entire arm on same plane and for ease of maximum internal arm rotation.

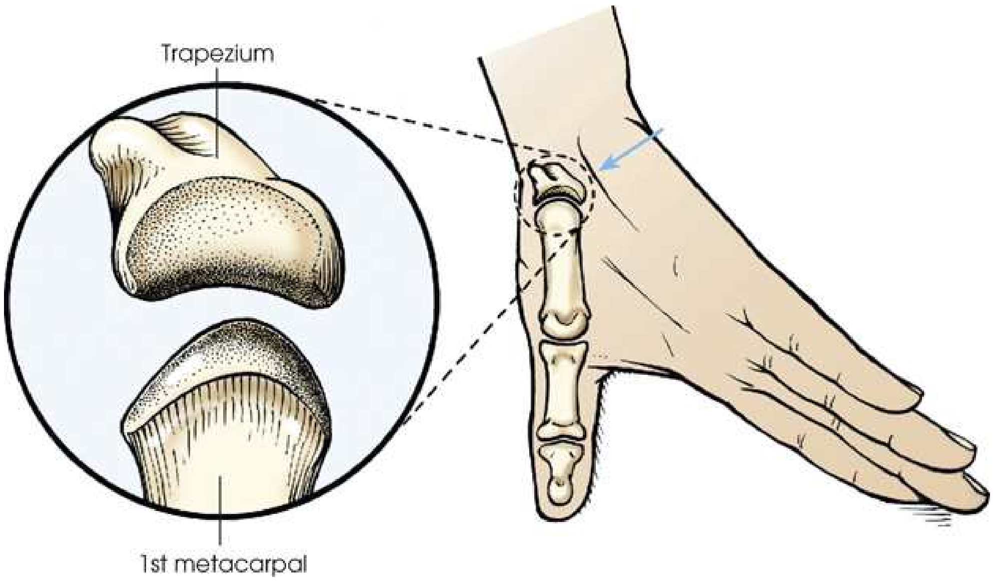


FIG. 5.46 Hyperextended hand and thumb position for AP projection of first CMC joint: Robert method. Soft tissue of palm *(arrow)* is positioned out of the way so that joint is clearly seen. *Inset:* First CMC joint is a saddle joint; articular surfaces are shown.

Diagram on the right shows a hyperextended hand and thumb with the saddle joint highlighted. The soft tissue of the palm are represented by an arrow. Diagram on the left shows an enlarged diagram of the saddle joint. The part labeled on it is the trapezium.

Central ray (Fig. 5.47)

Robert method

- Perpendicular entering at the first CMC joint

Long and Rafert modification

- Angled 15 degrees proximally along the long axis of the thumb and entering the first CMC joint

Lewis modification

- Angled 10 to 15 degrees proximally along the long axis of the thumb and entering the first MCP joint

NOTE: Angulation of the CR serves two purposes: (1) It may help to project the soft tissue of the hand away from the first CMC joint, and (2) it can help to open the joint space when the space is not shown with a perpendicular CR.

Collimation

- Adjust radiation field to 1 inch (2.5 cm) on all sides of the digit, including 1 inch (2.5 cm) proximal to the CMC joint. Place side marker in the collimated exposure field.

Structures shown

The first CMC joint free of superimposition of the soft tissues of the hand (Fig. 5.48).

Evaluation Criteria

The following should be clearly seen:

- Evidence of proper collimation and presence of side marker placed clear of anatomy of interest
- First CMC joint free of superimposition of the hand or other bony elements
- First metacarpal with the base in convex profile
- Trapezium
- Bony trabecular detail and surrounding soft tissues

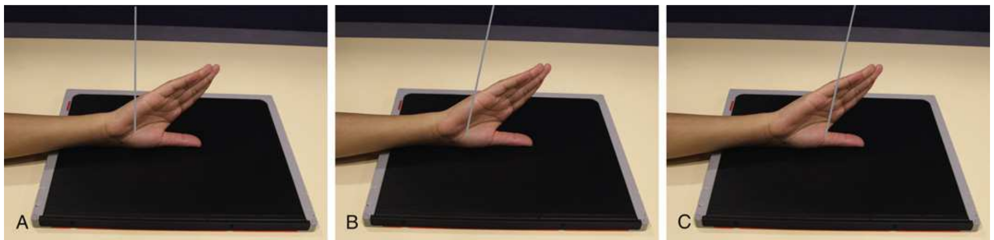


FIG. 5.47 Central ray angulation choices to show first CMC joint. (A) Robert method, 0 degrees to CMC joint. (B) Long-Rafert modification, 15 degrees proximal to CMC joint. (C) Lewis modification, 10 to 15 degrees proximal to MCP joint.

(A) shows the patient's posterior aspect of the thumb is placed on the I R with the thumbnail down. The central ray is perpendicular to the carpometacarpal joint. (B) the patient's posterior aspect of the thumb is placed on the I R with the thumbnail down. The central ray is angled 15 degrees proximally along the long axis of the thumb and entering the first C M C joint. (C) shows the patient's posterior aspect of the thumb is placed on the I R with the thumbnail down. The central ray is angled 10 to 15 degrees proximally along the long axis of the thumb and entering the first metacarpophalangeal joint.

FIG. 5.48 (A) Optimal radiograph of AP first CMC joint *(arrow)*: Robert method. (B) Example of typical repeat radiograph. Soft tissue of palm *(arrows)* obscured first CMC joint. Long-Rafert or Lewis modification of central ray would help to show the joint on this patient.

(A) shows an x-ray view of the first C M C joint. The C M C joints are represented with an arrow. (B) shows an x-ray view of the C M C joint. The soft tissue of the palm are represented with two arrows.

First Carpometacarpal Joint

AP Projection

Burman Method

When hyperextension of the wrist is not contraindicated, Burman [7] stated that this projection provides a clearer image of the first CMC joint than is seen on the standard AP projection.

Image receptor:

Positioned by manufacturer or department protocol for proper anatomy display orientation; CR plate: 10 × 12 inches (24 × 30 cm) lengthwise.

SID:

18 inches is recommended to produce a magnified image that creates a greater field of view of the concavoconvex aspect of this joint.

Position of patient

- Seat the patient at the end of the radiographic table so that the forearm can be adjusted to lie approximately parallel with the long axis of the IR.

Position of part

- Place the IR under the wrist, and center the first CMC joint to the center of the IR.
- Hyperextend the hand, and have the patient hold the position with the opposite hand or with a bandage looped around the digits.
- Rotate the hand internally and abduct the thumb so that it is flat on the IR (Fig. 5.49).
- *Shield gonads.*

Central ray

• Through the first CMC joint at a 45-degree angle toward the elbow

FIG. 5.49 Hyperextended hand and abducted thumb position for AP of first CMC joint: Burman method.

Structures shown

A magnified concavoconvex outline of the first CMC joint (Fig. 5.50).

Evaluation Criteria

The following should be clearly seen:

- Evidence of proper collimation and presence of side marker placed clear of anatomy of interest
- First metacarpal
- Trapezium in concave profile
- Base of the first metacarpal in convex profile
- First CMC joint, unobscured by adjacent carpals
- Bony trabecular detail and surrounding soft tissues

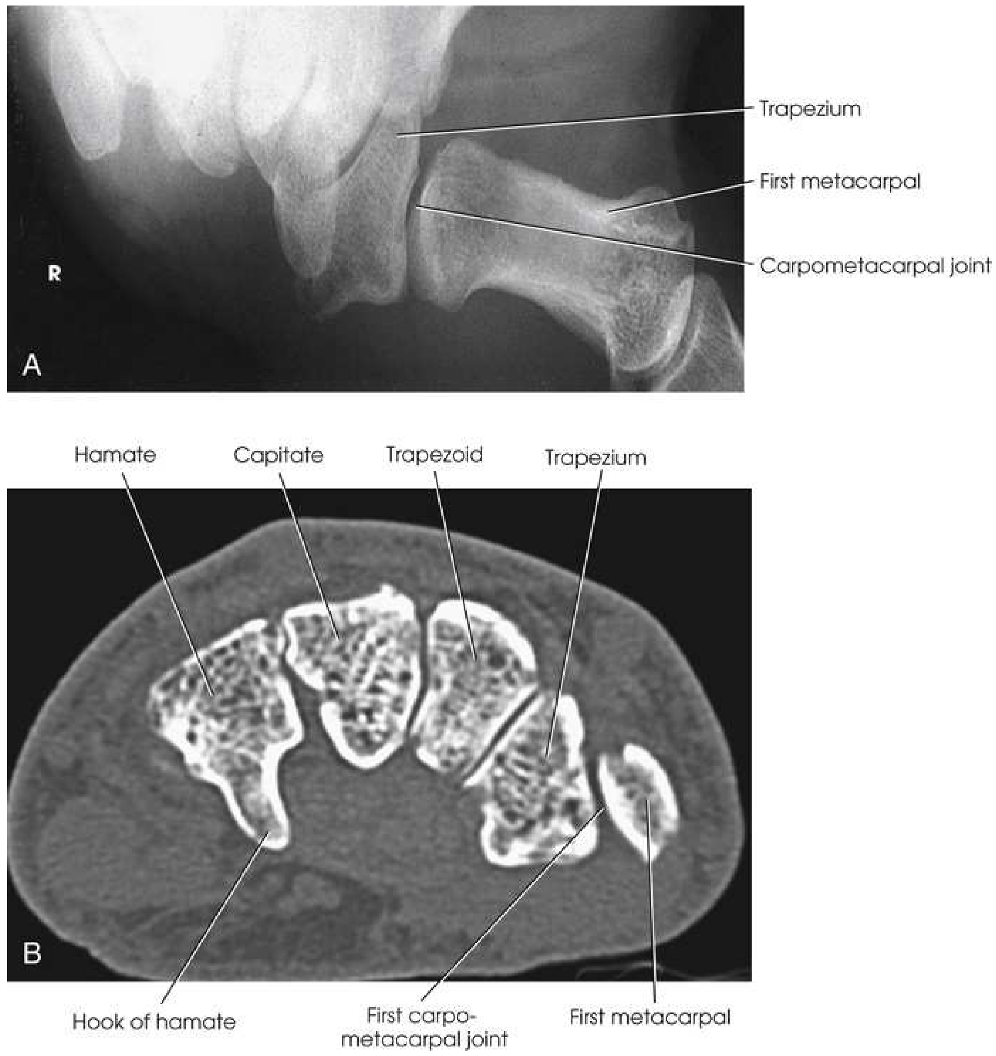


FIG. 5.50 (A) AP thumb to demonstrate the first CMC joint: Burman method. (B) Axial CT scan through distal carpals. Note that CMC joint is well visualized. A, Courtesy Michael Burman.

(A) shows an x-ray view of the thumb. The parts labeled in the x-ray are as follows: trapezium, carpometacarpal joint, and first metacarpal. (B) an axial C T scan shows an magnified concavo-convex outline of the first C M C joint. The parts labeled are as follows: hamate, capitate, trapezoid, trapezium, hook of hamate, first carpometacarpal joint, and first metacarpal.

First Metacarpophalangeal Joint

PA Projection

Folio Method

This projection is useful for the diagnosis of ulnar collateral ligament (UCL) rupture in the MCP joint of the thumb, also known as "skier's thumb." [8]

Image receptor:

Positioned by manufacturer or department protocol for proper anatomy display orientation; CR plate: 10 × 12 inches (24 × 30 cm) crosswise.

Position of patient

- Seat the patient at the end of the radiographic table.

Position of part

- Place the patient's hands on the IR, resting them on their medial aspects.
- Tightly wrap a rubber band around the distal portion of both thumbs and place a roll of medical tape between the bodies of the first metacarpals.
- Ensure the thumbs remain in the PA plane by keeping the thumbnails parallel to the IR (Fig. 5.51).
- Before exposure, instruct the patient to pull the thumbs apart and hold.
- *Shield gonads.*

Central ray

• Perpendicular to a point midway between both hands at the level of the MCP joints

NOTE: To avoid motion, have the correct technical factors set on the generator and be ready to make the exposure before instructing the patient to pull the thumbs apart.

Collimation

• Adjust radiation field to include the third metacarpals on the sides, the bases of the thumbs proximally and 1 inch (2.5 cm) distal to the thumbnails. Place side marker in the collimated exposure field.

Structures shown

The MCP joints and MCP angles bilaterally (Fig. 5.52).

Evaluation Criteria

The following should be clearly seen:

- Evidence of proper collimation and presence of side marker placed clear of anatomy of interest
- Thumbs in a PA projection with no rotation
- First metacarpals
- First MCP joint
- Rubber band and medical tape in correct position
- Thumbs centered to the center of the image
- Bony trabecular detail and surrounding soft tissues

FIG. 5.51 Hands and thumbs in position for PA first MCP joints: Folio method. Note roll of tape between thumbs.

The patient's both hands are on the image receptor. A rubber band is wrapped around the distal portion of both thumbs and a medical tape us placed between the bodies of the first metacarpals. The side marker is in the collimated exposure field.

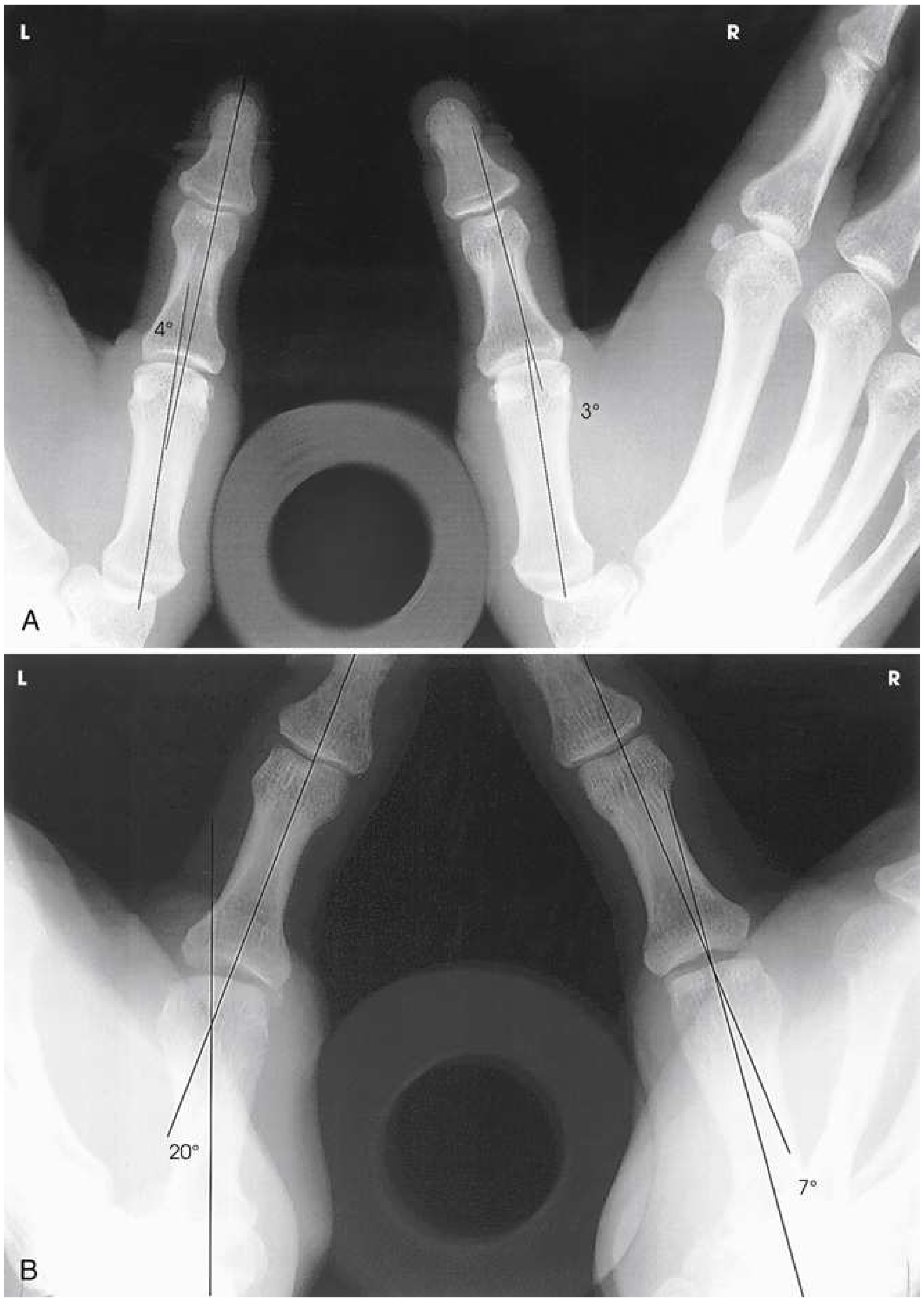


FIG. 5.52 First MCP joint, Folio method. (A) Normal thumbs with acceptable MCP joints bilaterally. Roll of tape between metacarpals and rubber band holding distal aspects of thumbs are visible. (B) Increased angulation of left MCP joint with 13-degree difference compared with right MCP joint. Partially torn left UCL measures 20 degrees between long axis of first metacarpal and proximal phalanx, whereas uninjured side measures 7 degrees.

(A) shows an x-ray view of the normal thumbs. A tape is rolled between the metacarpals and a rubber band is around the distal portion of both thumbs. It measures 4 degrees between long axis of first metacarpal and proximal phalanx and the right side measures 3 degrees. (B) shows an x-ray view of the thumb with angulation of left M C P joint. A tape is rolled between metacarpals . It measures 20 degrees between long axis of first metacarpal and proximal phalanx and the uninjured side on the right measures 7 degrees.

Hand

PA Projection

Image receptor:

Positioned by manufacturer or department protocol for proper anatomy display orientation; CR plate: 10 × 12 inches (24 × 30 cm) lengthwise.

Position of patient

- Seat the patient at the end of the radiographic table.
- Adjust the patient's height so that the forearm is resting on the table (Fig. 5.53A).

Position of part

- Rest the patient's forearm on the table, and place the hand with the palmar surface down on the IR.
- Center the IR to the MCP joints, then adjust the long axis of the IR parallel with the long axis of the hand and forearm.
- Spread the fingers slightly (see Fig. 5.53B).
- Ask the patient to relax the hand to avoid motion. Prevent involuntary movement with the use of adhesive tape or positioning sponges. A sandbag may be placed over the distal forearm.
- *Shield gonads.*

Central ray

- Perpendicular to the third MCP joint

Collimation

- Adjust radiation field to 1 inch (2.5 cm) on all sides of the hand, including 1 inch (2.5 cm) proximal to the ulnar styloid. Place side marker in the collimated exposure field.

Structures shown

PA projections of the carpals, metacarpals, phalanges (except the thumb), interarticulations of the hand, and distal radius and ulna are shown in Fig. 5.54. This image also shows a PA oblique projection of the first digit.

Evaluation Criteria

The following should be clearly seen:

- Evidence of proper collimation and presence of side marker placed clear of anatomy of interest
- Anatomy from fingertips to distal radius and ulna
- Slightly separate digits with no soft tissue overlap
- No rotation of the hand
    - Equal concavity of the metacarpal and phalangeal bodies on both sides
    - Equal amount of soft tissue on both sides of the phalanges
    - Fingernails, if visualized, in the center of each distal phalanx
    - Equal distance between the metacarpal heads
- Open MCP and IP joints, indicating that the hand is placed flat on the IR
- Bony trabecular detail and surrounding soft tissues

NOTE: When the MCP joints are under examination and the patient cannot extend the hand enough to place its palmar surface in contact with the IR, the position of the hand can be reversed for an AP projection. This position is also used for the metacarpals when the hand cannot be extended because of an injury, a pathologic condition, or the use of dressings.

SPECIAL TECHNIQUES: Clements and Nakayama [9] described a special exposure technique for imaging early rheumatoid arthritis. Lewis [10] described a positioning variation to place the second through fifth metacarpals parallel to the IR, resulting in a true PA projection.

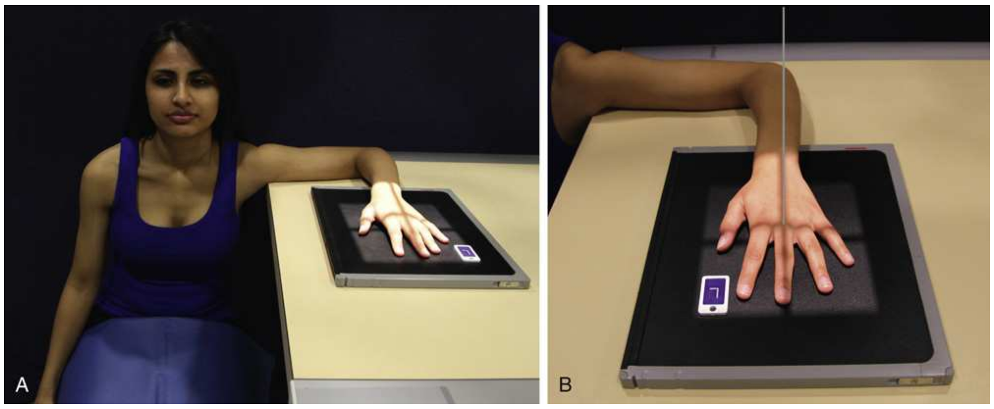


FIG. 5.53 (A) Patient seated at the end of the table for PA hand. (B) PA hand.

(A) shows a patient shielded with a lead apron placed over the her pelvis area as she is sitting at the end of the radiographic table with her hand on the image receptor. The side marker is in the collimated exposure field. (B) shows the fingers spread on the image receptor. The side marker is in the collimated exposure field.

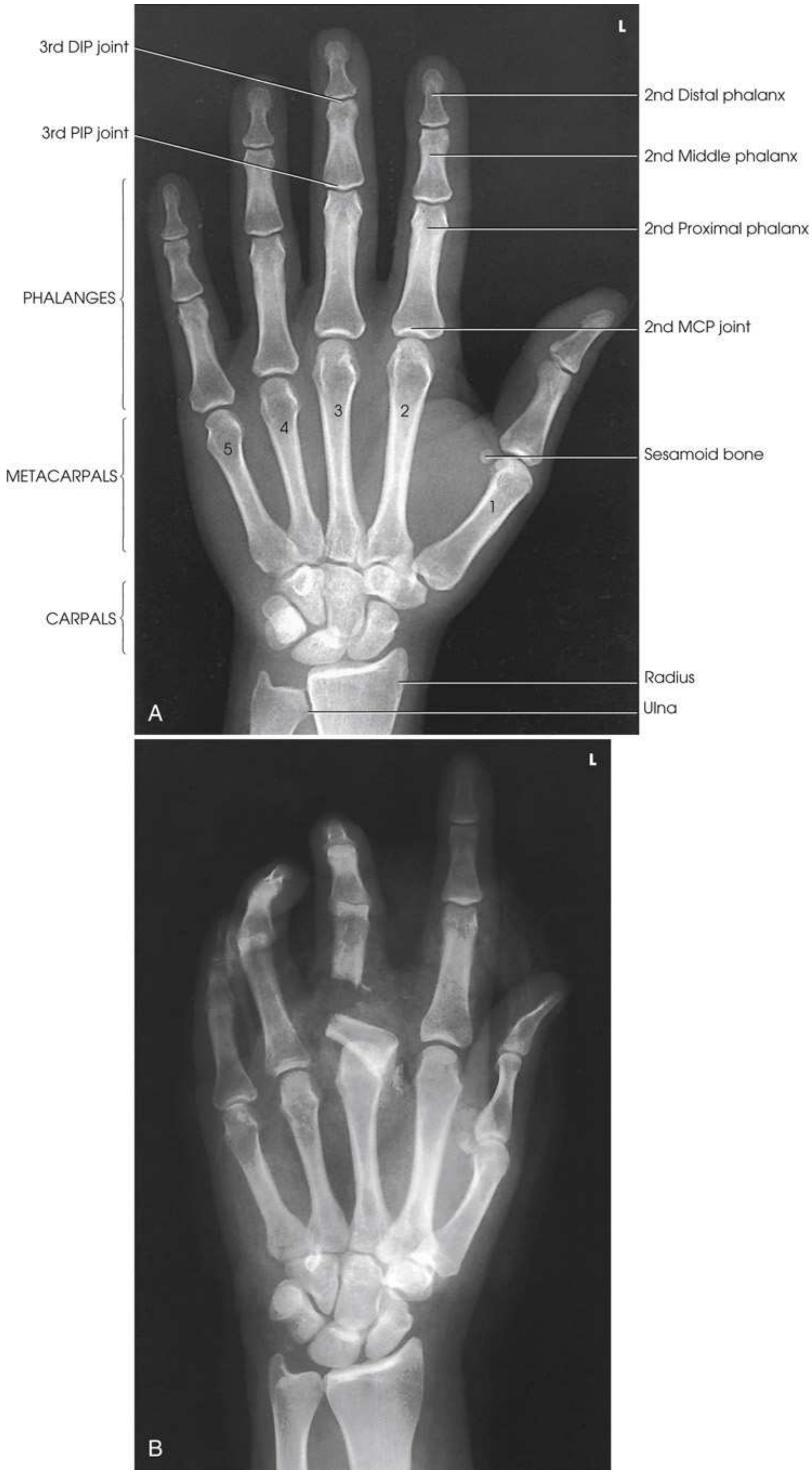


FIG. 5.54 (A) PA hand. (B) PA hand showing closed, displaced, transverse fracture of third proximal phalanx with dislocation of MCP joint. Overall hand was placed in correct position despite trauma. This gives physician accurate information about displacement of bone. *DIP*, Distal interphalangeal; *PIP*, proximal interphalangeal.

(A) An x-ray view of the hand shows the anatomy from fingertips to distal radius and ulna. The parts labeled are as follows: third D I P joint, third P I P joint, phalanges, metacarpals, carpals, second distal phalanx, third distal phalanx, second proximal phalanx, second M C P joint, sesamoid bone, radius, and ulna. (B) shows an x-ray view of the hand with fracture of the third proximal phalanx with dislocation of M C P joint.

PA Oblique Projection

Lateral rotation

Image receptor:

Positioned by manufacturer or department protocol for proper anatomy display orientation; CR plate: 10 × 12 inches (24 × 30 cm) lengthwise.

Position of patient

- Seat the patient at the end of the radiographic table.
- Adjust the patient's height to rest the forearm on the table.

Position of part

- Rest the patient's forearm on the table, with the hand pronated and the palm resting on the IR.
- Adjust the obliquity of the hand so that the MCP joints form an angle of approximately 45 degrees with the IR plane.
- Use a 45-degree foam wedge to support the fingers in the extended position to show the IP joints (see Figs. 5.55 and 5.56).
- When examining the metacarpals, obtain a PA oblique projection of the hand by rotating the patient's hand laterally (externally) from the pronated position until the fingertips touch the IR (Fig. 5.57).
- If it is impossible to obtain the correct position with all fingertips resting on the IR, elevate the index finger and thumb on a suitable radiolucent material (see Fig. 5.56). Elevation opens the joint spaces and reduces the degree of foreshortening of the phalanges.
- For either approach, center the IR to the MCP joints and adjust the midline to be parallel with the long axis of the hand and forearm.
- *Shield gonads.*

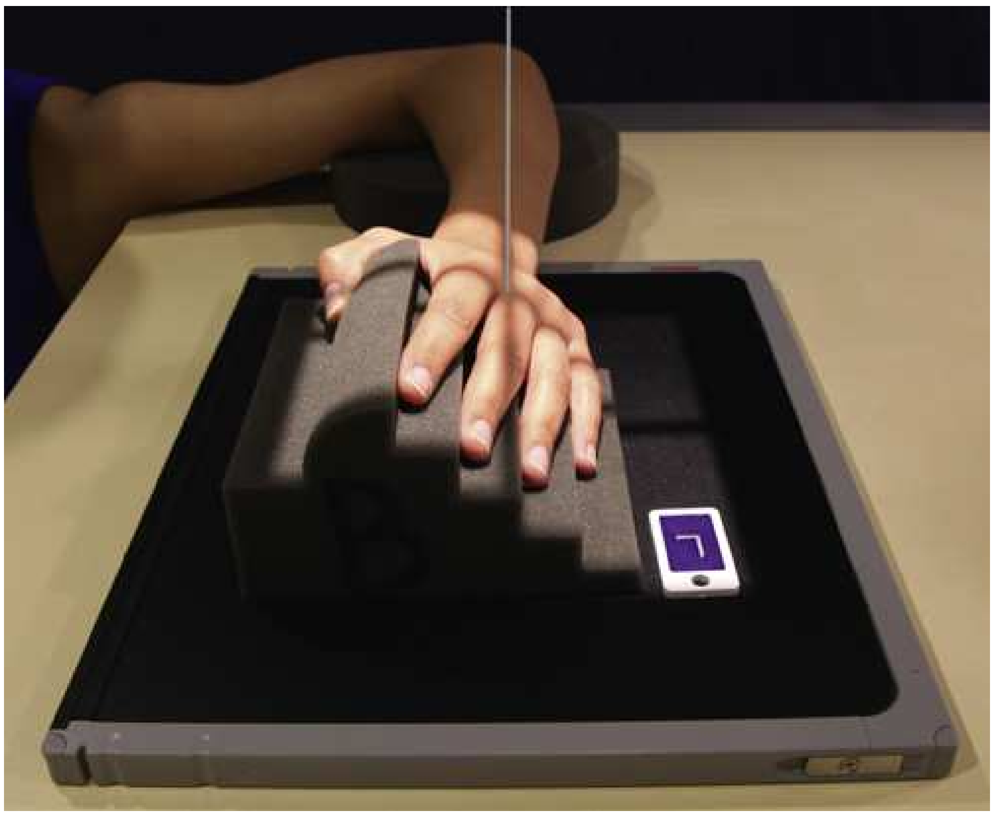


FIG. 5.55 PA oblique hand to show joint spaces.

A 45 degree foam wedge is used to support the fingers of the patient in the extended position on the image receptor. The side marker is in the collimated exposure field. The central ray is perpendicular to the third M C P joint.

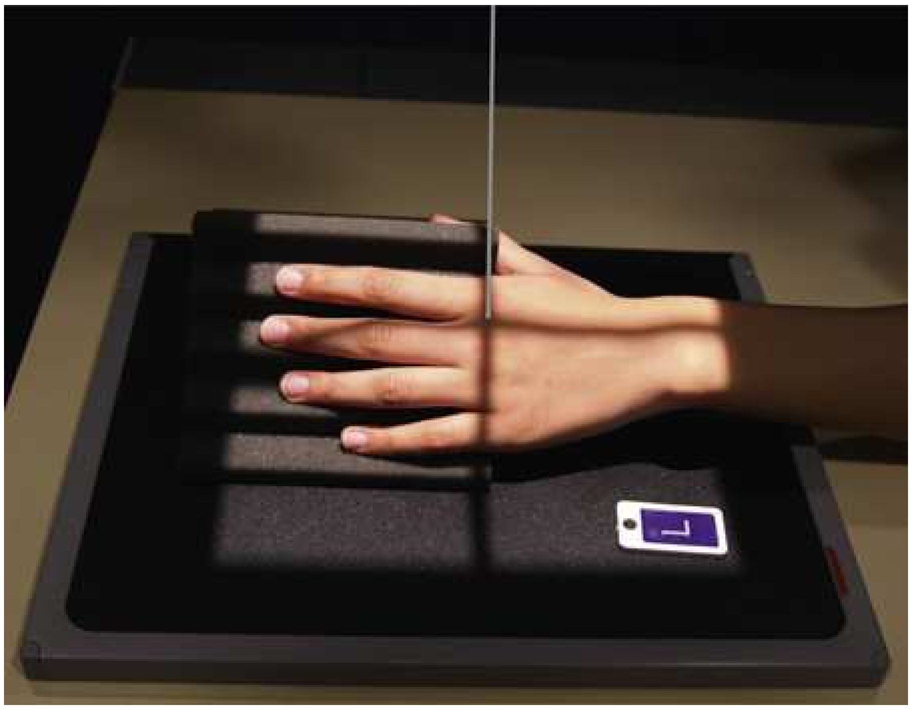


FIG. 5.56 PA oblique hand to show joint spaces.

A 45 degree foam wedge is used to support the index finger and thumb on a of the patient placed in the extended position on the image receptor. The side marker is in the collimated exposure field. The central ray is perpendicular to the third M C P joint.

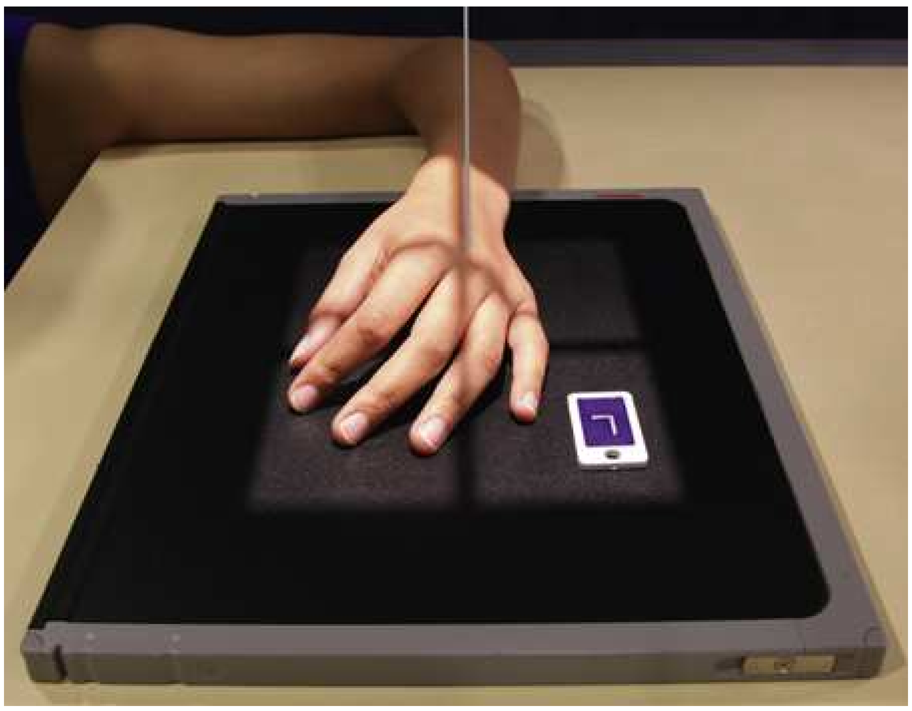


FIG. 5.57 PA oblique hand to show metacarpals.

The patient's hand is rotated laterally (externally) and the fingertips touch the image receptor. The side marker is in the collimated exposure field. The central ray is perpendicular to the third M C P joint.

Central ray

- Perpendicular to the third MCP joint

Collimation

- Adjust radiation field to 1 inch (2.5 cm) on all sides of the hand, including 1 inch (2.5 cm) proximal to the ulnar styloid. Place side marker in the collimated exposure field.

Structures shown

A PA oblique projection of the bones and soft tissues of the hand, including the distal radius and ulna (see Fig. 5.58). This supplemental position is used for investigating fractures and pathologic conditions.

Evaluation Criteria

The following should be clearly seen:

- Evidence of proper collimation and presence of side marker placed clear of anatomy of interest
- Anatomy from fingertips to distal radius and ulna
- Digits separated slightly with no overlap of their soft tissues
- 45 degrees of rotation of anatomy
  - Decreasing amounts of separation between metacarpal bodies two through five, with the second and third having the greatest separation.
  - Partial superimposition of the third, fourth, and fifth metacarpal bases and heads
- Open MCP joints
- Open IP joints, when digits are positioned parallel to IR
- Bony trabecular detail and surrounding soft tissues

NOTE: Lane et al. [11] recommended the inclusion of a reverse oblique projection to better show severe metacarpal deformities or fractures. This projection is accomplished by having the patient rotate the hand 45 degrees medially (internally) from the palm-down position.

Kallen [12] recommended using a tangential oblique projection to show metacarpal head fractures. From the PA hand position, the MCP joints are flexed 75 to 80 degrees with the dorsum of the digits resting on the IR. The hand is rotated 40 to 45 degrees toward the ulnar surface. Then the hand is rotated 40 to 45 degrees forward until the affected MCP joint is projected beyond its proximal phalanx. The perpendicular CR is directed tangentially to enter the MCP joint of interest. Variations of rotation are described to show the second metacarpal head free of superimposition.

FIG. 5.58 (A) PA oblique hand with digits on sponge to show open joints. (B) PA oblique hand without support sponge, showing fracture *(arrow)*. IP joints *(arrowheads)* are not entirely open, and phalanges are foreshortened.

(A) shows an x-ray view of the anatomy from fingertips to distal radius and ulna. (B) shows an x-ray view of the hand. The fracture is represented by an arrow. The I P joints are represented by arrowheads.

Lateral Projection

Mediolateral or lateromedial extension and fan lateral

Image receptor:

Positioned by manufacturer or department protocol for proper anatomy display orientation; CR plate: 10 × 12 inches (24 × 30 cm) lengthwise.

Position of patient

- Seat the patient at the end of the radiographic table, with the forearm in contact with the table and the hand in the lateral position with the ulnar aspect down (Fig. 5.59).
- Alternatively, place the radial side of the wrist against the IR (Fig. 5.60). This position is more difficult for the patient to assume.
- If the elbow is elevated, support it with sandbags.

Position of part

- Extend the patient's digits and adjust the first digit at a right angle to the palm.
- Place the palmar surface perpendicular to the IR.
- Center the IR to the MCP joints and adjust the midline to be parallel with the long axis of the hand and forearm. If the hand is resting on the ulnar surface, immobilization of the thumb may be necessary.
- The two extended digit positions result in superimposition of the phalanges. A modification of the lateral hand is the *fan lateral position,* which eliminates superimposition of all but the proximal phalanges. For the fan lateral position, place the digits on a sponge wedge. Abduct the thumb and place it on the radiolucent sponge for support (Fig. 5.61).
- *Shield gonads.*

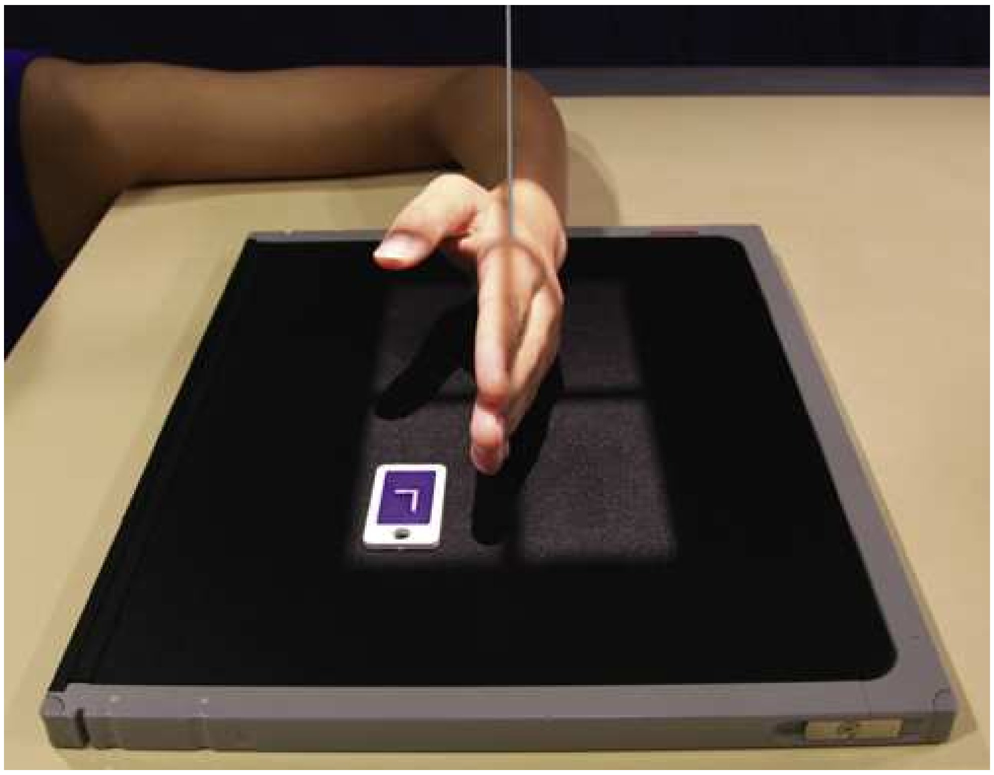


FIG. 5.59 Lateral hand with ulnar surface to IR: lateromedial.

The patient's forearm is in contact with the table and the hand in the lateral position with the ulnar aspect down on the image receptor. The side marker is in the collimated exposure field. The central ray is perpendicular to the second digit of the M C P joint.

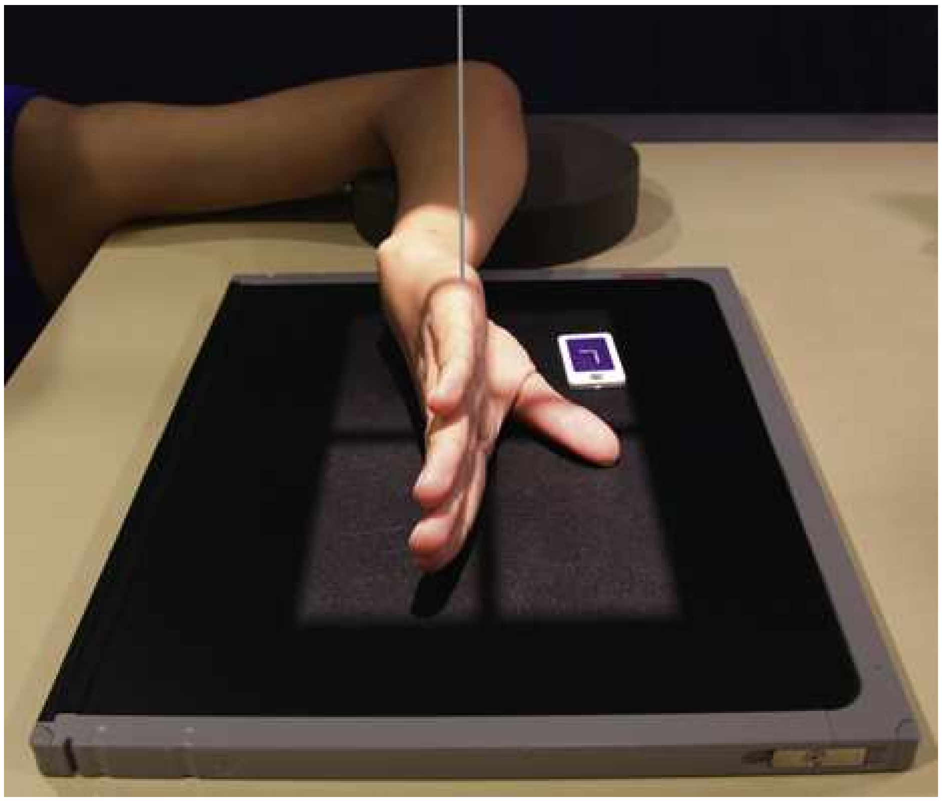


FIG. 5.60 Lateral hand with radial surface to IR: mediolateral.

The patient's forearm is in contact with the table and the hand in the lateral position with the radial aspect down on the image receptor. The elevated elbow is supported with sandbags. The side marker is in the collimated exposure field. The central ray is perpendicular to the second digit of the M C P joint.

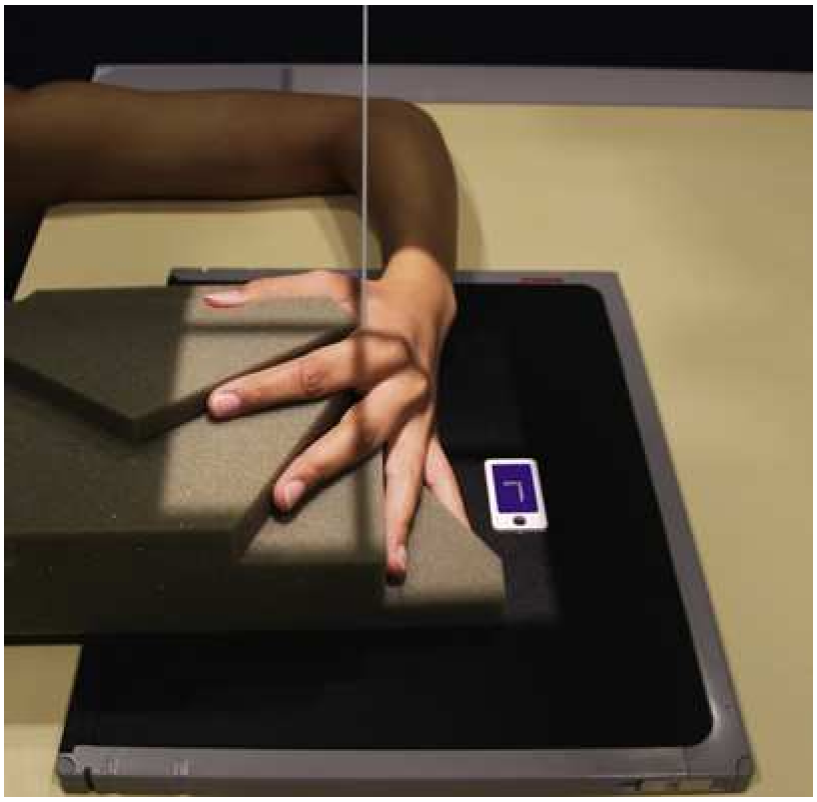


FIG. 5.61 Fan lateral hand.

The digits are placed on a sponge wedge. The thumb is abducted and is placed on the radiolucent sponge for support. The side marker is in the collimated exposure field. The central ray is perpendicular to the second digit of the M C P joint.

Central ray

- Perpendicular to the *second digit* MCP joint for mediolateral

• Perpendicular to *fifth digit* MCP for lateromedial

Collimation

• Adjust radiation field to 1 inch (2.5 cm) on all sides of the shadow of the hand and thumb, including 1 inch (2.5 cm) proximal to the ulnar styloid. Place side marker in the collimated exposure field.

Structures shown

This image, which shows a lateral projection of the hand in extension (Fig. 5.62), presents the customary position for localizing foreign bodies and metacarpal fracture displacement. The exposure technique depends on the foreign body.

The fan lateral superimposes the metacarpals but shows almost all of the individual phalanges. The most proximal portions of the proximal phalanges remain superimposed (Fig. 5.63).

Evaluation Criteria

The following should be clearly seen:

- Evidence of proper collimation and presence of side marker placed clear of anatomy of interest
- Anatomy from fingertips to distal radius and ulna
- Extended digits
- Hand in a true lateral position
  - Superimposed phalanges (individually seen on fan lateral)
  - Superimposed metacarpals
  - Superimposed distal radius and ulna
- Thumb free of motion and superimposition
- Bony trabecular detail and surrounding soft tissues

NOTE: To show fractures of the fifth metacarpal better, Lewis [4] recommended rotating the hand 5 degrees posteriorly from the true lateral position. This positioning removes the superimposition of the second through fourth metacarpals. The thumb is extended as much as possible, and the hand is allowed to become hollow by relaxation. The central ray is angled so that it passes parallel to the extended thumb and enters the midshaft of the fifth metacarpal.

FIG. 5.62 Lateral hand.

An x-ray view of the lateral projection of the hand in extension from fingertips to distal radius and ulna. The parts labeled in the x-ray are as follows: phalanges, metacarpals, carpals, distal phalanx, proximal phalanx, first metacarpal, radius, and ulna.

FIG. 5.63 Fan lateral hand.

Lateral Projection

Lateromedial in flexion

This projection is useful when a hand injury prevents the patient from extending the fingers.

Image receptor:

Positioned by manufacturer or department protocol for proper anatomy display orientation; CR plate: 10 × 12 inches (24 ×30 cm) lengthwise.

Position of patient

- Seat the patient at the end of the radiographic table.
- Ask the patient to rest the forearm on the table and place the hand on the IR with the ulnar aspect down.

Position of part

- Center the IR to the MCP joints and adjust it so that its midline is parallel with the long axis of the hand and forearm.
- With the patient relaxing the digits to maintain the natural arch of the hand, arrange the digits so that they are perfectly superimposed (Fig. 5.64).
- Have the patient hold the thumb parallel with the IR, or, if necessary, immobilize the thumb with tape or a sponge.
- *Shield gonads.*

Central ray

- Perpendicular to the MCP joints, entering MCP joint of the second digit

Structures shown

This projection produces a lateral image of the bony structures and soft tissues of the hand in their normally flexed position (Fig. 5.65). It also shows anterior or posterior displacement in fractures of the metacarpals.

Evaluation Criteria

The following should be clearly seen:

- Evidence of proper collimation and presence of side marker placed clear of anatomy of interest
- Anatomy from fingertips to distal radius and ulna
- Flexed digits
- Superimposed phalanges and metacarpals
- Superimposed distal radius and ulna
- Thumb free of motion and superimposition
- Bony trabecular detail and surrounding soft tissues

AP Oblique Projection

Norgaard Method

Medial rotation

The Norgaard method, [13–15] sometimes referred to as the *ball-catcher's position,* assists in detecting early radiologic changes in the dorsoradial aspects of the second through fifth proximal phalangeal bases that may be associated with rheumatoid arthritis. Norgaard reported that it is often possible to make an early diagnosis of rheumatoid arthritis by using this position before laboratory tests are positive. [15]

In his 1991 article, Stapczynski [15] recommended this projection to show fractures of the base of the fifth metacarpal.

Image receptor: Positioned by manufacturer or department protocol for proper anatomy display orientation; CR plate: 10 × 12 inches (24 × 30 cm) crosswise

Position of patient

- Seat the patient at the end of the radiographic table. Norgaard recommended that both hands be radiographed in the half-supinated position for comparison.

Position of part

- Have the patient place the palms of both hands together. Center the MCP joints on the medial aspect of both hands to the IR. Both hands should be in the lateral position.
- Place two 45-degree radiolucent sponges against the posterior aspect of each hand.
- Rotate the patient's hands to a half-supinated position until the dorsal surface of each hand rests against each 45-degree sponge support (Fig. 5.66).
- Extend the patient's fingers and abduct the thumbs slightly to avoid superimposing them over the second MCP joint.

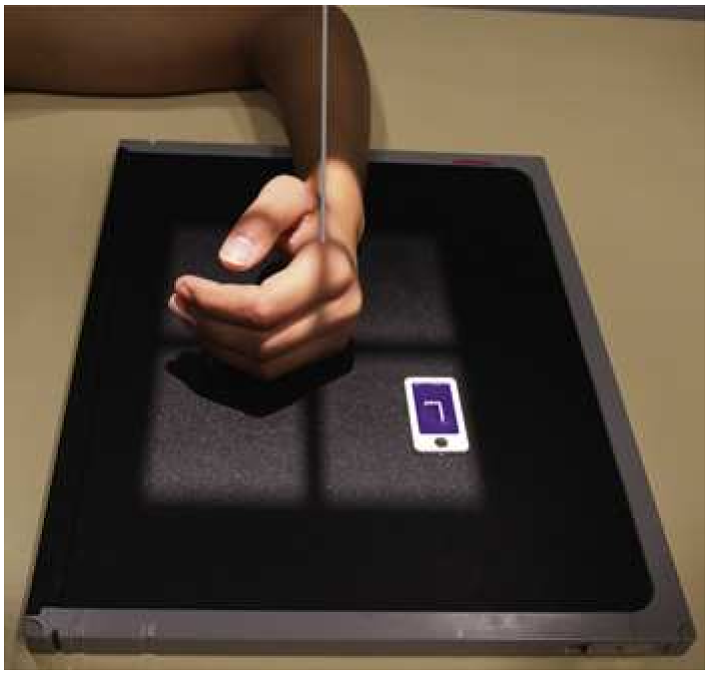


FIG. 5.64 Lateral hand in flexion.

The patient's lateral hand is in flexion and it is made into a natural arch and the digits are arranged. The thumb is parallel with the image receptor. The side marker is in the collimated exposure field. The central ray is angled perpendicular to the second digit of the M C P joint.

FIG. 5.65 Lateral hand in flexion.

- The original method of positioning the hands is often modified. The patient is positioned similar to the method described, except that the fingers are not extended. Instead, the fingers are cupped as though the patient were going to catch a ball (Fig. 5.67). Comparable diagnostic information is provided using either position.
- *Shield gonads.*

Central ray

- Perpendicular to a point midway between both hands at the level of the MCP joints for either of the two patient positions

Collimation

- Adjust radiation field to 1 inch (2.5 cm) on all sides of the digit, including 1 inch (2.5 cm) proximal to the ulnar styloid. Place side marker in the collimated exposure field.

Structures shown

An AP 45-degree oblique projection of both hands (see Fig. 5.68). The early radiologic change significant in making the diagnosis of rheumatoid arthritis is a symmetric, very slight, indistinct outline of the bone corresponding to the insertion of the joint capsule dorsoradial on the proximal end of the first phalanx of the four fingers. In addition, associated demineralization of the bone structure is always present in the area directly below the contour defect.

Evaluation Criteria

The following should be clearly seen:

- Evidence of proper collimation and presence of side marker placed clear of anatomy of interest
- Both hands from the carpal area to the tips of the digits
- Metacarpal heads and proximal phalangeal bases free of superimposition
- Bony trabecular detail and surrounding soft tissues

FIG. 5.66 AP oblique hands, semisupinated position.

The dorsal surface of each hand rests against each 45 degree sponge support. The fingers are extended. The central ray is perpendicular to a point midway between both hands. The side marker is in the collimated exposure field.

FIG. 5.67 Ball-catcher's position.

The dorsal surface of each hand is on the image receptor and the fingers are cupped. The central ray is perpendicular to a point midway between both hands. The side marker is in the collimated exposure field.

FIG. 5.68 (A) AP oblique hands, ball-catcher's position, showing where indistinct area occurs at dorsoradial aspect of proximal phalangeal base *(arrow)*. (B) Ball-catcher's position. *MCP*, Metacarpophalangeal.

(A) An x-ray shows two hands from the carpal area to the tips of the digits with symmetric, very slight, indistinct outline of the bone which is represented by an arrow. The M C P joints and the digits are labeled. (B) An x-ray shows two hands from the carpal area to the tips of the digits.

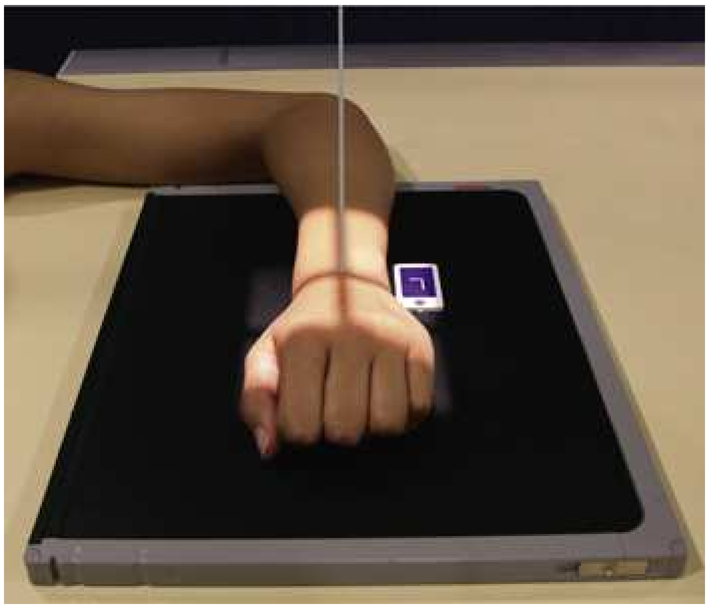


FIG. 5.69 PA wrist.

The patient's forearm is resting on the table. The wrist joint is centered to the image receptor. The digits are flexed. The side marker is in the collimated exposure field. The central ray is perpendicular to the midcarpal area.

Wrist

PA Projection

Image receptor:

Positioned by manufacturer or department protocol for proper anatomy display orientation; CR plate: 10 × 12 inches (24 × 30 cm) lengthwise.

Position of patient

- Seat the patient low enough to place the axilla in contact with the table or elevate the extremity to shoulder level on a suitable support. This position places the shoulder, elbow, and wrist joints in the same plane to permit right-angle rotation of the ulna and radius for the lateral position.

Position of part

- Have the patient rest the forearm on the table, then center the wrist joint to the IR area. The wrist (radiocarpal) joint is at a level just distal to the ulnar styloid.
- When it is difficult to determine the exact location of the radiocarpal joint because of a swollen wrist, ask the patient to flex the wrist slightly, and center the IR to the point of flexion. When the wrist is in a cast or splint, the exact point of centering can be determined by comparison with the opposite side.

• Adjust the hand and forearm to lie parallel with the long axis of the IR.
• Slightly arch the hand at the MCP joints by flexing the digits to place the wrist in close contact with the IR (Fig. 5.69).
• When necessary, place a support under the digits to immobilize them.
• *Shield gonads.*

Central ray

• Perpendicular to the midcarpal area

Collimation

• Adjust radiation field to 2.5 inches (6 cm) proximal and distal to the wrist joint and 1 inch (2.5 cm) on the sides. Place side marker in the collimated exposure field.

Structures shown

A PA projection of the carpals, distal radius and ulna, and proximal metacarpals (Fig. 5.70). The projection gives a slightly oblique rotation to the ulna. When the ulna is under examination, an AP projection should be taken.

Evaluation Criteria

The following should be clearly seen:

- Evidence of proper collimation and presence of side marker placed clear of anatomy of interest
- Distal radius and ulna, carpals, and proximal half of metacarpals
- No excessive flexion of digits to overlap and obscure metacarpals
- No rotation in carpals, metacarpals, radius, and ulna
- Open radioulnar joint space
- Bony trabecular detail and surrounding soft tissues

NOTE: To show the scaphoid and capitate better, Daffner et al.[16] recommended angling the central ray when the patient is positioned for a PA radiograph. A central ray angle of 30 degrees toward the elbow elongates the scaphoid and capitate, whereas an angle of 30 degrees toward the fingertips elongates only the capitate.

FIG. 5.70 (A) PA wrist. (B) PA wrist showing Smith fracture of distal radius *(arrow)*. *C,* Capitate; *G,* trapezium; *H,* hamate; *L,* lunate; *M,* trapezoid; *P,* pisiform; *S,* scaphoid; *T,* triquetrum.

(A) shows an x-ray view of the carpals, distal radius, ulna and proximal metcarpals. The parts labeled are as follows: ulnar styloid process, radial styloid process. (B) shows an x-ray view of the carpals, distal radius, ulna and proximal metcarpals with fracture of distal radius. It is represented by an arrow.

AP Projection

Image receptor:

Positioned by manufacturer or department protocol for proper anatomy display orientation; CR plate: 10 × 12 inches (24 × 30 cm) lengthwise.

Position of patient

- Seat the patient at the end of the radiographic table.

Position of part

- Have the patient rest the forearm on the table, with the arm and hand supinated.
- Place the IR under the wrist, centered to the carpals.
- Elevate the digits on a suitable support to place the wrist in close contact with the IR.
- Have the patient lean laterally to prevent rotation of the wrist (Fig. 5.71).
- *Shield gonads.*

Central ray

- Perpendicular to the midcarpal area

Collimation

- Adjust radiation field to 2.5 inches (6 cm) proximal and distal to the wrist joint and 1 inch (2.5 cm) on the sides. Place side marker in the collimated exposure field.

Structures shown

The *carpal interspaces* are better shown in the AP image than in the PA image. Because of the oblique direction of the interspaces, they are more closely parallel with the divergence of the x-ray beam (Fig. 5.72).

Evaluation Criteria

The following should be clearly seen:

- Evidence of proper collimation and presence of side marker placed clear of anatomy of interest
- Distal radius and ulna, carpals, and proximal half of the metacarpals
- No excessive flexion of digits to overlap and obscure metacarpals
- No rotation of the carpals, metacarpals, radius, and ulna
- Bony trabecular detail and surrounding soft tissues

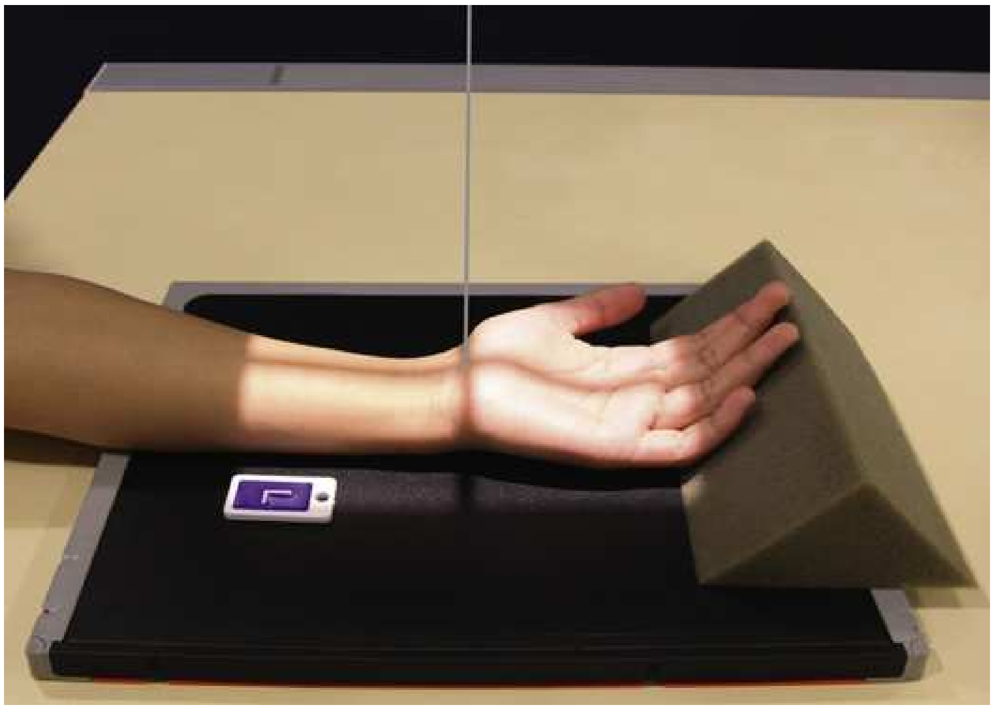


FIG. 5.71 AP wrist.

The digits are elevated on a suitable support and the wrist is placed in close contact with the I R. The I R is under the wrist, centered to the carpals. The side marker is in the collimated exposure field. The central ray is perpendicular to the midcarpal area.

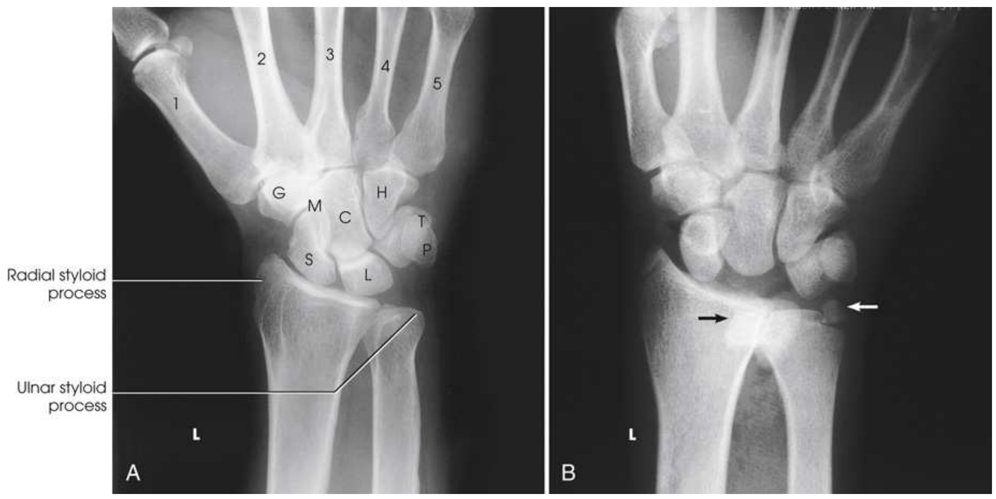


FIG. 5.72 (A) AP wrist. (B) AP wrist showing complete dislocation of lunate *(black arrow)* and fracture of ulnar styloid process *(white arrow). C,* Capitate; *G,* trapezium; *H,* hamate; *L,* lunate; *M,* trapezoid; *P,* pisiform; *S,* scaphoid; *T,* triquetrum.

(A) shows an x-ray view of the wrist with the carpal interspaces more distinct. The parts labeled are as follows: ulnar styloid process, radial styloid process. (B) shows an x-ray of the wrist. The dislocated lunate is indicated by a black arrow and the fracture of ulnar styloid process indicated by a white arrow.

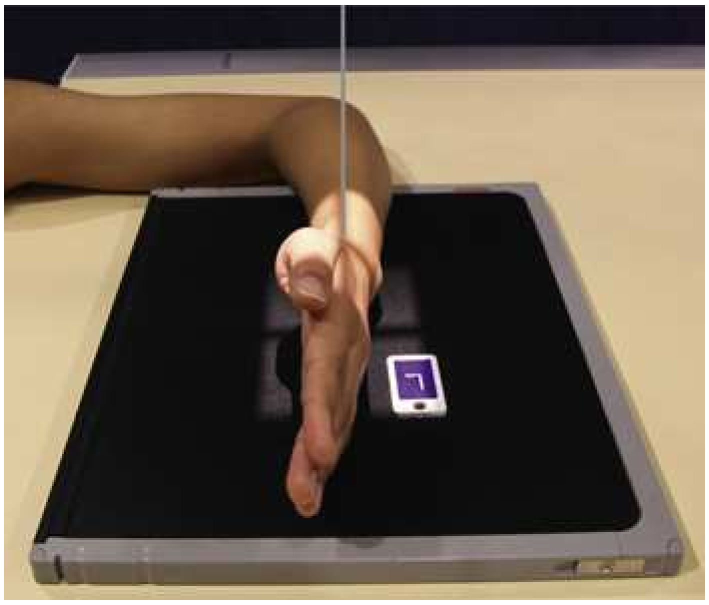


FIG. 5.73 Lateral wrist with ulnar surface to IR.

The patient's arm and forearm are resting on the table. The lateral surface of the ulna is placed on the image receptor and the wrist is in true lateral position. The side marker is in the collimated exposure field. The central ray is perpendicular to the wrist joint.

Lateral Projection

Lateromedial

Image receptor:

Positioned by manufacturer or department protocol for proper anatomy display orientation; CR plate: 10 × 12 inches (24 × 30 cm) lengthwise

Position of patient

- Seat the patient at the end of the radiographic table.
- Have the patient rest the arm and forearm on the table to ensure the upper extremity is aligned in the same plane.

Position of part

- Have the patient flex the elbow 90 degrees to rotate the ulna to the lateral position.
- Center the IR to the wrist (radiocarpal) joint.
- Adjust the forearm and hand, placing the humeral epicondyles and styloid processes superimposed and perpendicular to the IR, so that the wrist is in a true lateral position (Fig. 5.73).
- *Shield gonads.*

Central ray

- Perpendicular to the wrist joint

Collimation

- Adjust radiation field to 2.5 inches (6 cm) proximal and distal to the wrist joint and 1 inch (2.5 cm) on the palmar and dorsal surfaces. Place side marker in the collimated exposure field.

Structures shown

A lateral projection of the proximal metacarpals, carpals, and distal radius and ulna (Fig. 5.74). An image obtained with the radial surface against the IR (Fig. 5.75) is shown for comparison. This position can also be used to show anterior or posterior displacement in fractures.

FIG. 5.74 (A) Lateral wrist with ulnar surface to IR. (B) Lateral with Smith fracture *(arrow)*. This is the same patient as in Fig. 5.70B . (C) Lateral wrist showing obvious complete anterior dislocation of lunate bone. This is the same patient as in Fig. 5.72B .

(A) shows an x-ray view of the proximal metacarpals, carpals, and distal radius and ulna. The parts labeled are as follows: first metacarpal, trapezium, scaphoid, capitate, lunate, radius, and ulna. (B) shows an x-ray view of the fracture of the distal radius which is indicated by an arrow. (C) shows an x-ray view of the lateral wrist. The lunate bone is dislocated and projected to the right.

Evaluation Criteria

The following should be clearly seen:

- Evidence of proper collimation and presence of side marker placed clear of anatomy of interest
- Distal radius and ulna, carpals, and proximal half of metacarpals
- Superimposed distal radius and ulna
- Superimposed metacarpals
- Bony trabecular detail and surrounding soft tissues

NOTE: Burman et al. [17] suggested that the lateral position of the scaphoid should be obtained with the wrist in palmar flexion because this action rotates the bone anteriorly into a dorsovolar position (Fig. 5.76). However, this position is valuable only when sufficient flexion is permitted.

Fiolle [18, 19] was the first to describe a small bony growth occurring on the dorsal surface of the third CMC joint. He termed the condition *carpe bossu* (carpal boss) and found that it is shown best in a lateral position with the wrist in palmar flexion (see Fig. 5.76).

FIG. 5.75 Lateral wrist with radial surface to IR.

FIG. 5.76 Lateral wrist with palmar flexion of wrist, showing carpal boss *(arrow)*.

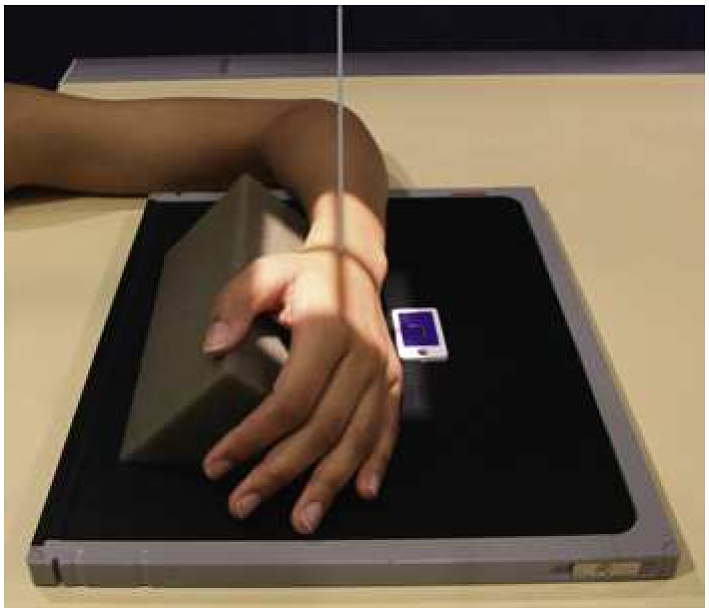


FIG. 5.77 PA oblique wrist: lateral rotation.

The patient's arm and forearm are resting on the table. A 45 degree foam wedge is placed under the elevated side of the wrist on the image receptor. The side marker is in the collimated exposure field. The central ray is perpendicular to the midcarpal area.

PA Oblique Projection

Lateral rotation

Image receptor:

Positioned by manufacturer or department protocol for proper anatomy display orientation; CR plate: 10 × 12 inches (24 × 30 cm) lengthwise.

Position of patient

- Seat the patient at the end of the radiographic table, placing the axilla in contact with the table.

Position of part

- Rest the palmar surface of the wrist on the IR.
- Adjust the IR so that its center point is under the scaphoid when the wrist is rotated from the pronated position.
- From the pronated position, rotate the wrist laterally (externally) until the coronal plane forms an angle of approximately 45 degrees with the plane of the IR. For exact positioning and to ensure duplication in follow-up examinations, place a 45-degree foam wedge under the elevated side of the wrist.
- Extend the wrist slightly, and if the digits do not touch the table, support them in place (Fig. 5.77).
- When the scaphoid is under examination, adjust the wrist in ulnar deviation. Place a sandbag across the forearm.
- *Shield gonads.*

Central ray

- Perpendicular to the midcarpal area; it enters just distal to the radius

Collimation

- Adjust radiation field to 2.5 inches (6 cm) proximal and distal to the wrist joint and 1 inch (2.5 cm) on the sides. Place side marker in the collimated exposure field.

Structures shown

The carpals on the lateral side of the wrist, particularly the trapezium and the scaphoid. The scaphoid is superimposed on itself in the direct PA projection (Figs. 5.78 and 5.79).

Evaluation Criteria

The following should be clearly seen:

- Evidence of proper collimation and presence of side marker placed clear of anatomy of interest
- Distal radius and ulna, carpals, and proximal half of metacarpals
- 45-degree rotation of anatomy
    - Slight interosseous space between the third, fourth, and fifth metacarpal bodies
    - Slight overlap of the distal radius and ulna
- Carpals on lateral side of wrist
- Trapezium and distal half of the scaphoid without superimposition
- Open trapeziotrapezoid and scaphotrapezial joint space
- Bony trabecular detail and surrounding soft tissues

FIG. 5.78 PA oblique wrist.

An x-ray shows the carpals on the lateral side of the wrist. The parts labeled in the x-ray are as follows: the first metacarpal, the trapezium, the trapezoid, the scaphoid, the lunate, the radius, and the ulna.

FIG. 5.79 PA oblique wrist with ulnar deviation.

An x-ray shows the distal radius and ulna, carpals, and proximal half of metacarpals. There is slight interosseous space between the third, fourth, and fifth metacarpal bodies. The digits and the scaphoid are labeled in the diagram.

Ap Oblique Projection [20]

Medial rotation

Image receptor:

Positioned by manufacturer or department protocol for proper anatomy display orientation; CR plate: 10 × 12 inches (24 × 30 cm) lengthwise.

Position of patient

- Seat the patient at the end of the radiographic table.
- Have the patient rest the forearm on the table in the supine position.

Position of part

- Place the IR under the wrist, and center it at the dorsal surface of the wrist.
- Rotate the wrist medially (internally) until the coronal plane forms an angle of approximately 45 degrees to the plane of the IR (Fig. 5.80).
- *Shield gonads.*

Central ray

- Perpendicular to the midcarpal area; it enters the anterior surface of the wrist midway between its medial and lateral borders

Collimation

- Adjust radiation field to 2.5 inches (6 cm) proximal and distal to the wrist joint and 1 inch (2.5 cm) on the sides. Place side marker in the collimated exposure field.

Structures shown

This position separates the pisiform from adjacent carpal bones. It also provides a more distinct radiograph of the triquetrum and hamate (compare Figs. 5.81 and 5.82).

Evaluation Criteria

The following should be clearly seen:

- Evidence of proper collimation and presence of side marker placed clear of anatomy of interest
- Distal radius and ulna, carpals, and proximal half of metacarpals
- Carpals on medial side of wrist
- Triquetrum, hook of hamate, and pisiform free of superimposition and in profile
- Bony trabecular detail and surrounding soft tissues

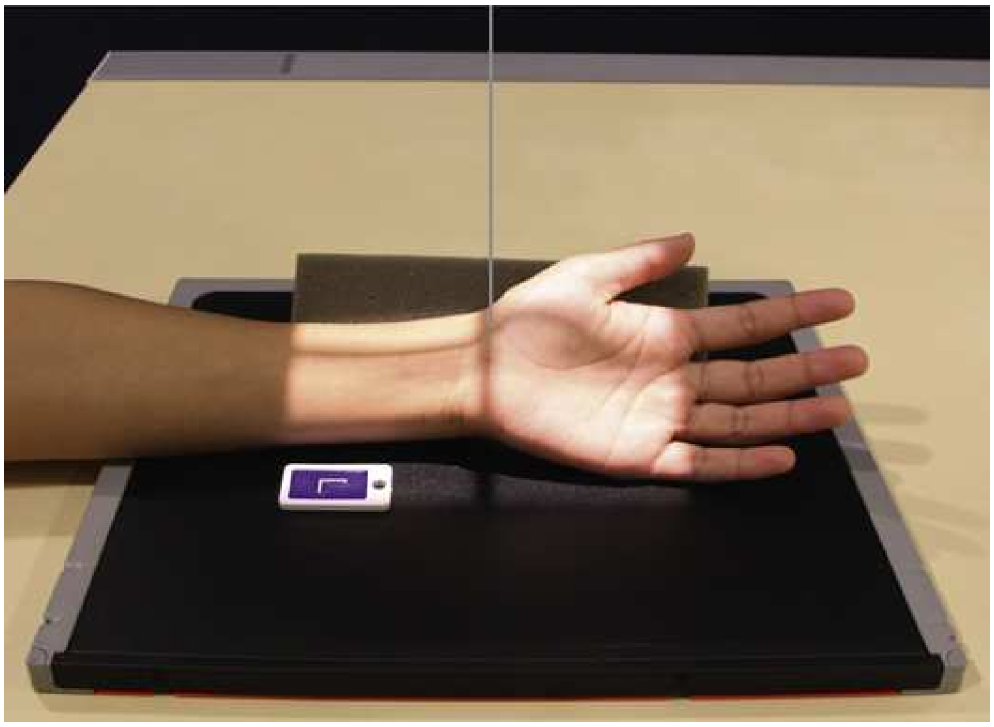


FIG. 5.80 AP oblique wrist: medial rotation.

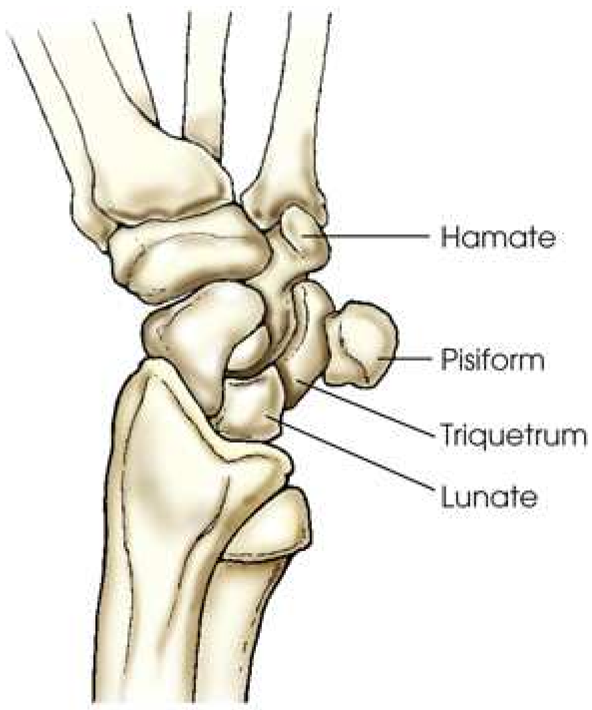


FIG. 5.81 AP oblique wrist.

FIG. 5.82 AP oblique wrist.

The x-ray view on the left and the right shows distal radius and ulna, carpals, and proximal half of metacarpals of the oblique wrist. The parts labeled in the x-ray on the left are as follows: hamate, pisiform, triquetrum, and lunate.

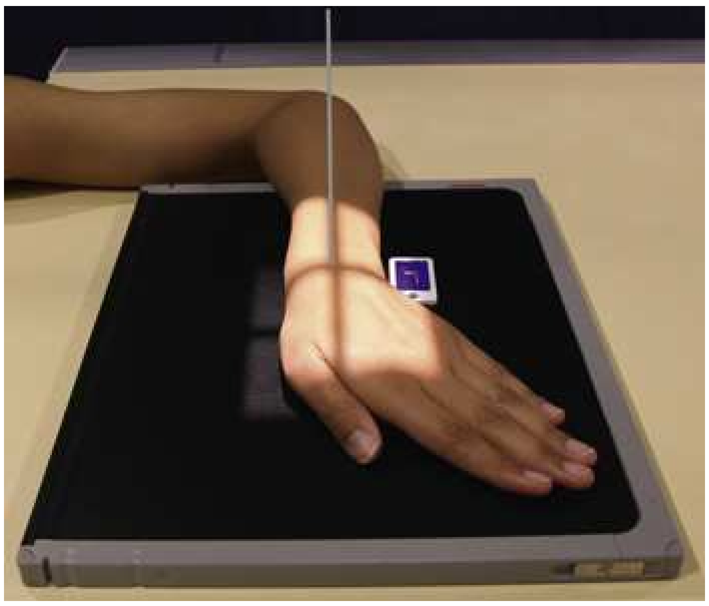


FIG. 5.83 PA wrist in ulnar deviation.

The patient's arm and forearm are resting on the table. The hand is turned outward and the wrist is in extreme ulnar deviation. The side marker is in the collimated exposure field. The central ray is perpendicular to the scaphoid.

PA Projection

Ulnar deviation [21]

Image receptor:

Positioned by manufacturer or department protocol for proper anatomy display orientation; CR plate: 10 × 12 inches (24 × 30 cm) lengthwise.

Position of patient

- Seat the patient at the end of the radiographic table, with the arm and forearm resting on the table. The elbow should be at a 90-degree angle.

Position of part

- Position the wrist on the IR for a PA projection.
- Without moving the forearm, turn the hand outward until the wrist is in extreme ulnar deviation (see Fig. 5.83).
- *Shield gonads.*

Central ray

- Perpendicular to the scaphoid
- CR angulation of 10 to 15 degrees proximally or distally sometimes required for clear delineation

Collimation

- Adjust radiation field to 2.5 inches (6 cm) proximal and distal to the wrist joint and 1 inch (2.5 cm) on the sides. Place side marker in the collimated exposure field.

Structures shown

This position reduces foreshortening of the scaphoid, which occurs with a perpendicular CR. It also opens the spaces between adjacent carpals (Fig. 5.84).

Evaluation Criteria

The following should be clearly seen:

- Evidence of proper collimation and presence of side marker placed clear of anatomy of interest
- Distal radius and ulna, carpals, and proximal half of metacarpals
- Scaphoid with adjacent articulations open
- No rotation of wrist
- Maximum ulnar deviation, as revealed by the angle formed between the longitudinal axis of the ulna and the longitudinal axis of the fifth metacarpal
- Bony trabecular detail and surrounding soft tissues

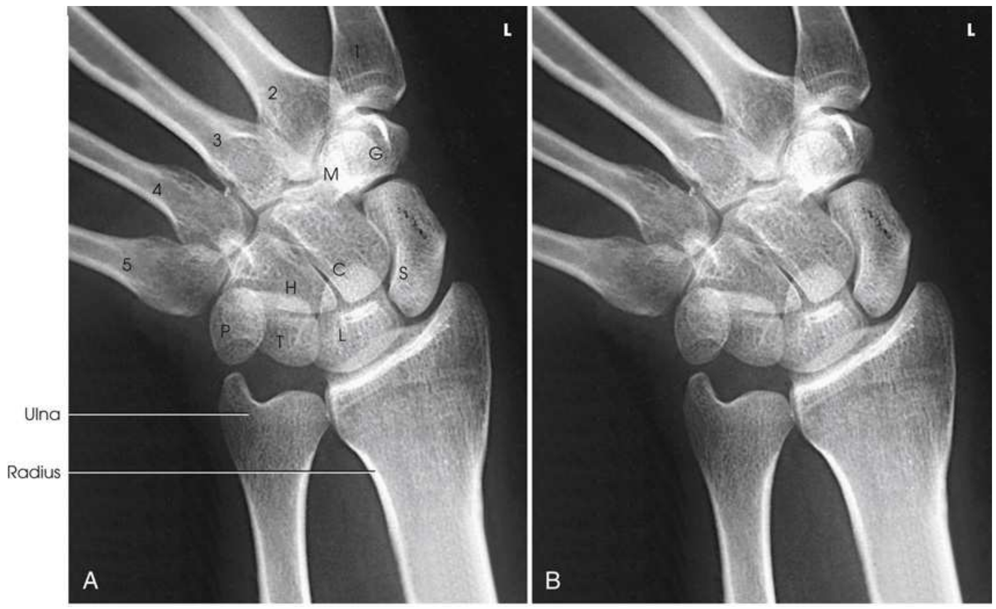


FIG. 5.84 (A) PA wrist in ulnar deviation. (B) Wrist in ulnar deviation. *C,* Capitate; *G,* trapezium; *H,* hamate; *L,* lunate; *M,* trapezoid; *P,* pisiform; *S,* scaphoid; *T,* triquetrum.

(A) and (B) shows an x-ray view of the distal radius and ulna, carpals, and proximal half of metacarpals in ulnar deviation. The articulations in the scaphoid are open. The parts labeled in (A) are ulna and radius.

PA Projection

Radial deviation [21]

Image receptor:

Positioned by manufacturer or department protocol for proper anatomy display orientation; CR plate: 10 × 12 inches (24 × 30 cm) lengthwise.

Position of patient

- Seat the patient at the end of the radiographic table, with the arm and forearm resting on the table.

Position of part

• Position the wrist on the IR for a PA projection.
• Without moving the forearm, turn the hand medially until the wrist is in extreme radial deviation (see Fig. 5.85).
• *Shield gonads.*

Central ray

• Perpendicular to midcarpal area

Collimation

• Adjust radiation field to 2.5 inches (6 cm) proximal and distal to the wrist joint and 1 inch (2.5 cm) on the sides. Place side marker in the collimated exposure field.

Structures shown

Radial deviation opens the interspaces between the carpals on the medial side of the wrist (Fig. 5.86).

Evaluation Criteria

The following should be clearly seen:

- Evidence of proper collimation and presence of side marker placed clear of anatomy of interest
- Distal radius and ulna, carpals, and proximal half of metacarpals
- Carpals and their articulations on the medial side of the wrist
- No rotation of wrist
- Maximum radial deviation, as revealed by the angle formed between the longitudinal axis of the radius and the longitudinal axis of the first metacarpal
- Bony trabecular detail and surrounding soft tissues

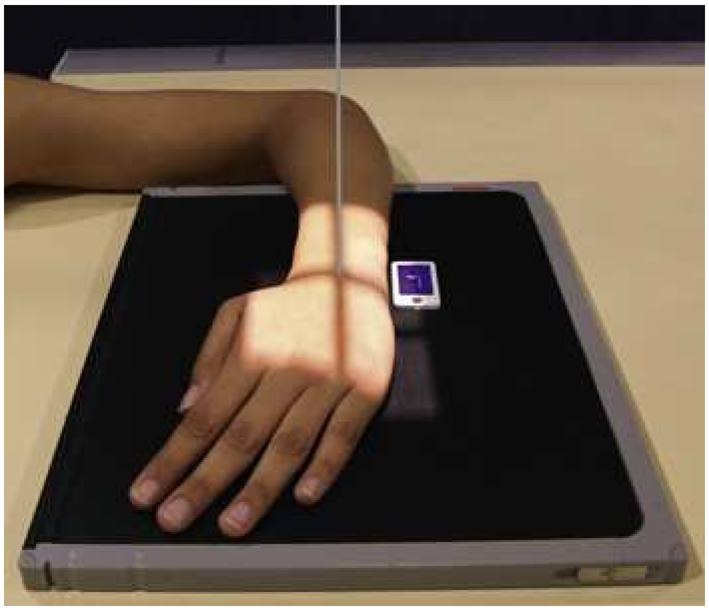


FIG. 5.85 PA wrist in radial deviation.

The patient's arm and forearm are resting on the table. The patient's hand is turned medially and the wrist is in extreme radial deviation. The side marker is in the collimated exposure field. The central ray is perpendicular to the midcarpal area.

FIG. 5.86 (A) PA wrist in radial deviation. (B) Wrist in radial deviation. *C,* Capitate; *G,* trapezium; *H,* hamate; *L,* lunate; *M,* trapezoid; *P,* pisiform; *S,* scaphoid; *T,* triquetrum.

Scaphoid

PA Axial Projection

Stecher Method [22]

Image receptor:
Positioned by manufacturer or department protocol for proper anatomy display orientation; CR plate: 10 × 12 inches (24 × 30 cm) lengthwise.

Position of patient

- Seat the patient at the end of the radiographic table, with the arm and axilla in contact with the table.
- Rest the forearm on the table.

Position of part

- Place one end of the IR on a support, and adjust the IR so that the finger end of the IR is elevated 20 degrees (Fig. 5.87).
- Adjust the wrist on the IR for a PA projection, and center the wrist to the IR.
- Bridgman [23] suggested positioning the wrist in ulnar deviation for this radiograph.
- *Shield gonads.*

Central ray

- Perpendicular to the table and directed to enter the scaphoid

Collimation

- Adjust radiation field to 2.5 inches (6 cm) proximal and distal to the wrist joint and 1 inch (2.5 cm) on the sides. Place side marker in the collimated exposure field.

Structures shown
The 20-degree angulation of the wrist places the scaphoid at right angles to the CR, so that it is projected with minimal superimposition (Figs. 5.88 and 5.89).

Evaluation Criteria

The following should be clearly seen:

- Evidence of proper collimation and presence of side marker placed clear of anatomy of interest
- Distal radius and ulna, carpals, and proximal half of the metacarpals
- Scaphoid with adjacent articulations open

- No rotation of wrist
- Bony trabecular detail and surrounding soft tissues

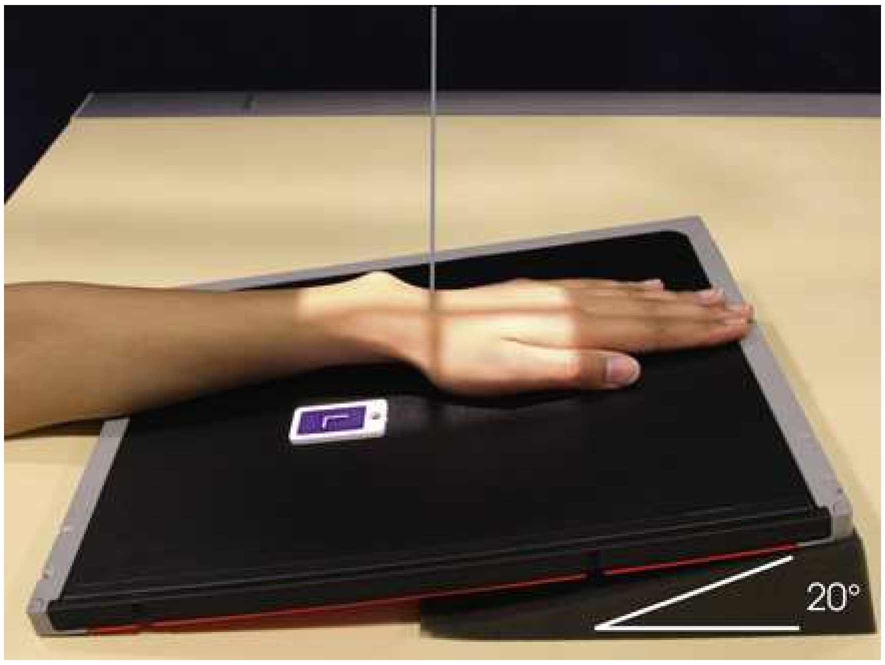


FIG. 5.87 PA axial wrist for scaphoid: Stecher method with IR angled 20 degrees.

The patient's palmar surface of the hand is placed on the image receptor. One end of the image receptor is on a support, with the finger end of the I R angled 20 degrees. The side marker is in the collimated exposure field. The central ray is perpendicular to the table and directed to enter the scaphoid.

FIG. 5.88 PA axial wrist for scaphoid: Stecher method.

An x-ray shows the distal radius and ulna, carpals, and proximal half of the metacarpals. The adjacent articulations of the scaphoid are open. The parts labeled in the diagram are listed as follows: the scaphoid, the radius, and the ulna.

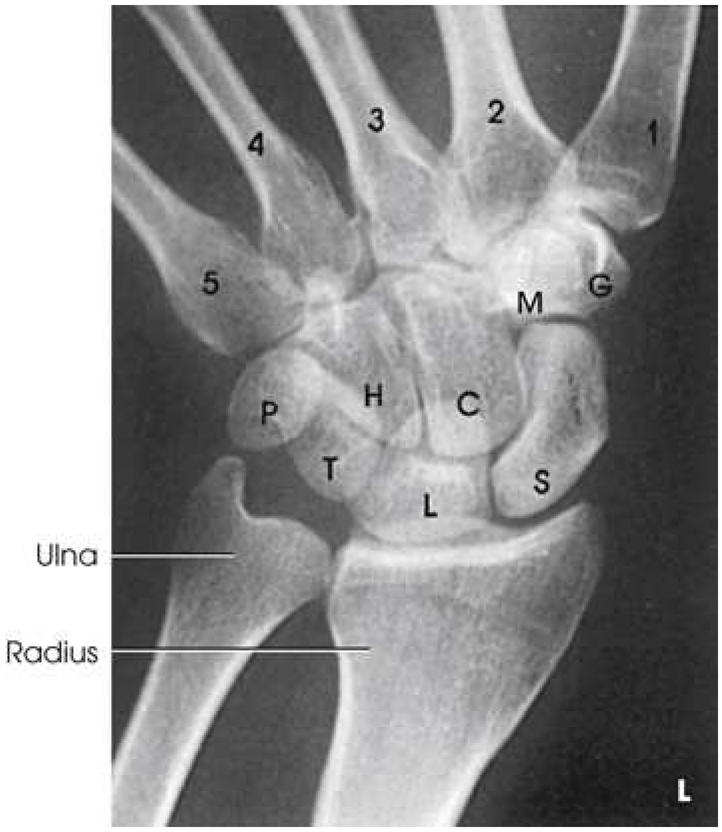


FIG. 5.89 PA axial wrist for scaphoid: Bridgman method, ulnar deviation. *C,* Capitate; *G,* trapezium; *H,* hamate; *L,* lunate; *M,* trapezoid; *P,* pisiform; *S,* scaphoid; *T,* triquetrum.

An x-ray shows the distal radius and ulna, carpals, and proximal half of the metacarpals. The adjacent articulations of the scaphoid are open. The parts labeled in are listed as follows: the carpals, digits, ulna and radius.

Variations

Stecher [22] recommended the previous method as preferable; however, a similar position can be obtained by placing the IR and wrist horizontally and directing the CR 20 degrees toward the elbow (Fig. 5.90).

To show a fracture line that angles superoinferiorly, these positions may be reversed. In other words, the wrist may be angled inferiorly, or from the horizontal position the CR may be angled toward the digits.

A third method recommended by Stecher is to have the patient clench the fist. This elevates the distal end of the scaphoid so that it lies parallel with the IR; it also widens the fracture line. The wrist is positioned as for the PA projection, and no CR angulation is used.

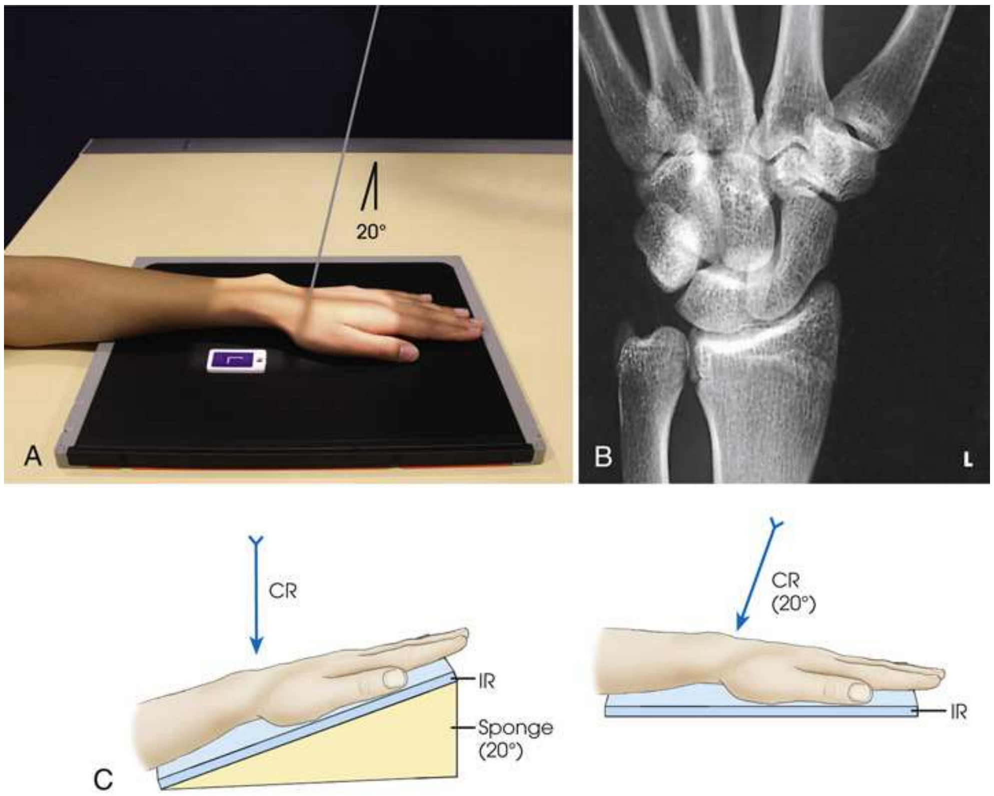


FIG. 5.90 (A) PA axial wrist for scaphoid: Stecher method with 20-degree angulation of CR. (B) PA axial wrist: Stecher method. (C) Angled IR and angled CR methods achieve same projection.

(A) shows the hand of the patient placed on the image receptor. The side marker is in the collimated exposure field. The central ray is angled 20 degrees perpendicular towards the elbow. (B) shows an x-ray view of the wrist. (C) shows the patient's palmar surface of the hand is placed on the image receptor. One end of the image receptor is on a sponge, with the finger end of the I R angled 20 degrees. The central ray is perpendicular to the table and is directed to enter the scaphoid. (D) shows the patient's palmar surface of the hand is placed on the image receptor. The central ray is angled 20 degrees perpendicular towards the elbow.

Scaphoid Series

PA and PA Axial Projections

Rafert-Long Method

Ulnar deviation

Scaphoid fractures account for 60% of all carpal bone injuries. In 1991, Rafert and Long [24] described this method of diagnosing scaphoid fractures using a four-image, multiple-angle CR series. The series is performed after routine wrist radiographs do not identify a fracture, but symptoms are suspicious for scaphoid fracture.

Image receptor:

Positioned by manufacturer or department protocol for proper anatomy display orientation; CR plate: 10 × 12 inches (24 × 30 cm) lengthwise

Position of patient

- Seat the patient at the end of the radiographic table, with the arm and forearm resting on the table.

Position of part

- Position the wrist on the IR for a PA projection.
- Without moving the forearm, turn the hand outward until the wrist is in extreme ulnar deviation (Fig. 5.91).
- *Shield gonads.*

Central ray

- Perpendicular and with multiple cephalad angles; with the hand and wrist in the same position for each projection, four separate exposures made at 0, 10, 20, and 30 degrees cephalad
- The CR should directly enter the scaphoid bone.

Collimation

- Adjust radiation field to 2.5 inches (6 cm) proximal and distal to the wrist joint and 1 inch (2.5 cm) on the sides. Place side marker in the collimated exposure field.

Structures shown

- The scaphoid is shown with minimal superimposition (Fig. 5.92).

Evaluation Criteria

The following should be clearly seen:

- Evidence of proper collimation and presence of side marker placed clear of anatomy of interest
- No rotation of the wrist
- Scaphoid with adjacent articular areas open
- Maximum ulnar deviation
- Bony trabecular detail and surrounding soft tissues

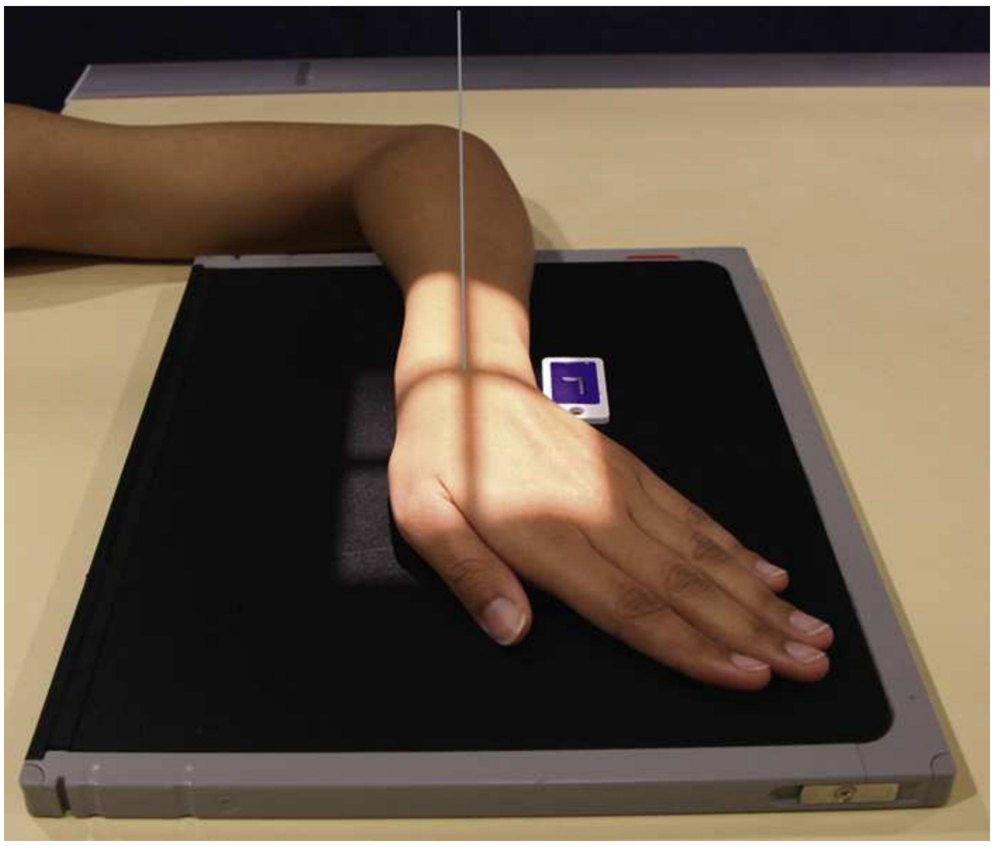


FIG. 5.91 PA wrist in ulnar deviation.

The patient's arm and forearm are resting on the table. The hand is turned outward and the wrist is in extreme ulnar deviation. The side marker is in the collimated exposure field. The central ray is directed to enter the scaphoid bone.

FIG. 5.92 PA and PA axial wrist in ulnar deviation for Rafert-Long method scaphoid series. Radiographs are all from the same patient. (A) PA wrist with 0-degree central ray angle. (B) PA axial wrist with 10-degree cephalad angle. (C) PA axial wrist with 20-degree cephalad angle. (D) PA axial wrist with 30-degree cephalad angle. From Rafert JA, Long BW. Technique for diagnosis of scaphoid fractures. *Radiol Technol.* 1991;63:16.

(A), (B), (C), and (D) shows and x-ray view of the wrist in ulnar deviation. (A) shows the scaphoid with minimal superimposition. (B) shows scaphoid with adjacent articular areas open. (C) shows the scaphoid with minimal superimposition. Diagram (D) shows scaphoid with adjacent articular areas open and it appears radiopaque.

Trapezium

PA Axial Oblique Projection

Clements-Nakayama Method

Fractures of the trapezium are rare; however, if undiagnosed, these fractures can lead to functional difficulties. In certain cases, the articular surfaces of the trapezium should be evaluated to treat patients with osteoarthritis. [25]

Image receptor:

Positioned by manufacturer or department protocol for proper anatomy display orientation; CR plate: 10 × 12 inches (24 × 30 cm) lengthwise.

Position of patient

- With the patient seated at the end of the radiographic table, place the hand on the IR in the lateral position.

Position of part

- Place the wrist in the lateral position, resting on the ulnar surface over the center of the IR.
- Place a 45-degree sponge wedge against the anterior surface, then rotate the hand to come in contact with the sponge.

- If the patient is able to achieve ulnar deviation, adjust the IR so that the long axis of the IR and the forearm align with the CR (Fig. 5.93).
- If the patient is unable to achieve ulnar deviation comfortably, align the straight wrist to the IR, and rotate the elbow end of the IR and arm 20 degrees away from the CR (Fig. 5.94).
- *Shield gonads.*

Central ray

- Angled 45 degrees distally to enter the anatomic snuff-box of the wrist and pass through the trapezium

Collimation

- Adjust radiation field to 2.5 inches (6 cm) proximal and distal to the wrist joint and 1 inch (2.5 cm) on the sides. Place side marker in the collimated exposure field.

Structures shown

The trapezium and its articulations with adjacent carpal bones (Fig. 5.95). The articulation of the trapezium and scaphoid is not shown on this image.

Evaluation Criteria

The following should be clearly seen:

- Evidence of proper collimation and presence of side marker placed clear of anatomy of interest
- Trapezium projected free of the other carpal bones with the exception of the articulation with the scaphoid
- Bony trabecular detail and surrounding soft tissues

NOTE: Holly [26] recommended a variation of this method with the hand in ulnar deviation on a 37-degree sponge wedge. The central ray is directed vertically, entering just proximal to the first metacarpal base.

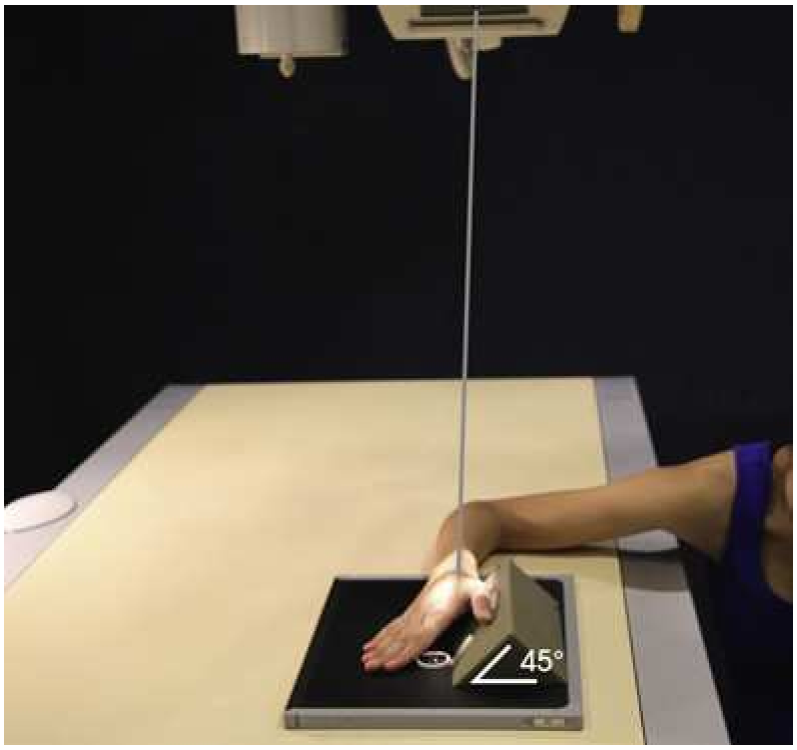


FIG. 5.93 PA axial oblique wrist for trapezium: Clements-Nakayama method; alignment with ulnar deviation.

A patient's ulnar surface is placed at the center of the image receptor. A 45 degree sponge wedge is placed against the anterior surface. The side marker is in the collimated exposure field. The central ray is angled 45 degrees distally to enter the anatomic snuff-box of the wrist.

FIG. 5.94 PA axial oblique wrist for trapezium: Clements-Nakayama method; alignment without ulnar deviation.

A patient's ulnar surface is placed at the center of the image receptor. A 45 degree sponge wedge is placed against the anterior surface. The elbow end of the I R is rotated. The side marker is in the collimated exposure field. The central ray is angled 45 degrees distally to enter the anatomic snuff-box of the wrist.

FIG. 5.95 PA axial oblique wrist for trapezium: Clements-Nakayama method.

Diagram shows an x-ray view of the wrist. The trapezium is projected free of the other carpal bones with the exception of the articulation with the scaphoid. The trapezium and the Scaphoid are labeled on the diagram.

Carpal Bridge

Tangential Projection

Image receptor:

Positioned by manufacturer or department protocol for proper anatomy display orientation; CR plate: 10 × 12 inches (24 × 30 cm) lengthwise.

Position of patient

- Seat or stand the patient at the side of the radiographic table to permit the required manipulation of the arm or x-ray tube.

Position of part

- The originators [27] of this projection recommended that the hand lie palm upward on the IR with the hand at right angle to the forearm (Fig. 5.96).
- When the wrist is too painful to be adjusted in the position just described, a similar image can be obtained by elevating the forearm on sandbags or other suitable support. Then with the wrist flexed in right-angle position, place the IR in the vertical position (Fig. 5.97).
- *Shield gonads.*

Central ray

- Directed to a point approximately 1½ inches (3.8 cm) proximal to the wrist joint at a caudal angle of 45 degrees

Collimation

- Adjust radiation field to 2.5 inches (6 cm) proximal and distal to the wrist joint and 1 inch (2.5 cm) on the sides. Place side marker in the collimated exposure field.

Structures shown

The carpal bridge is shown on the image in Figs. 5.98 and 5.99. The originators recommended this procedure to show fractures of the scaphoid, lunate dislocations, calcifications, and foreign bodies in the dorsum of the wrist, and chip fractures of the dorsal aspect of the carpal bones.

Evaluation Criteria

The following should be clearly seen:

- Evidence of proper collimation and presence of side marker placed clear of anatomy of interest
- Dorsal surface of the carpals free of superimposition by the metacarpal bases
- Bony trabecular detail and surrounding soft tissues

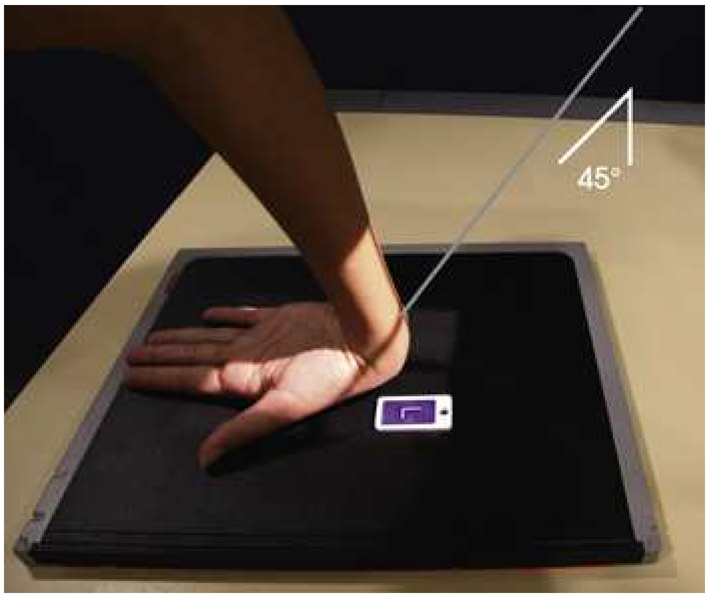


FIG. 5.96 Tangential carpal bridge, original method.

The hand of the patient is lying palm upward on the I R with the hand at right angle to the forearm. The side marker is in the collimated exposure field. The central ray is directed to the wrist joint at a caudal angle of 45 degrees.

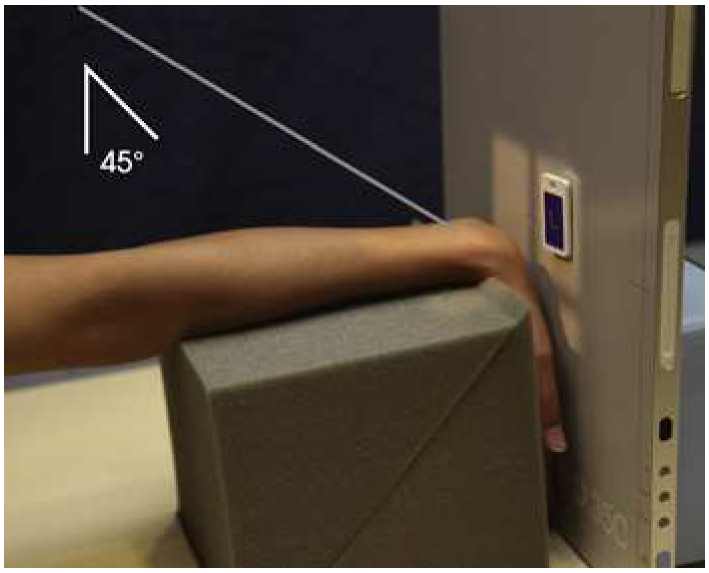


FIG. 5.97 Tangential carpal bridge, modified method.

The forearm of the patient is elevated by placing a sandbag for support. The wrist is flexed in right angle position and the I R is placed in the vertical position at an angle of 45 degrees. The side marker is in the collimated exposure field. The central ray is directed to the wrist joint at a caudal angle of 45 degrees.

FIG. 5.98 Tangential carpal bridge, original method.

An x-ray shows the dorsal surface of the carpals free of superimposition by the metacarpal bases. The parts labeled in the diagram are listed as follows: lunate, triquetrum, trapezium, and scaphoid capitate. The upper part appear grainy.

FIG. 5.99 Tangential carpal bridge, modified method.

Carpal Canal

Tangential Projection

Gaynor-Hart Method [28]

The carpal canal contains the tendons of the flexors of the fingers and the median nerve. Compression of the median nerve results in pain and/or numbness. Radiography is performed to identify abnormality of the bones or soft tissue of the canal.

Fractures of the hook of hamate, pisiform, and trapezium are increasingly seen in athletes. The tangential projection is helpful in identifying fractures of these carpal bones. This projection was added as an essential projection based on the 1997 survey performed by Bontrager. [29]

Image receptor:

Positioned by manufacturer or department protocol for proper anatomy display orientation; CR plate: 10 × 12 inches (24 × 30 cm) lengthwise.

Inferosuperior

Position of patient

- Seat the patient at the end of the radiographic table so that the forearm can be adjusted to lie parallel with the long axis of the table.

Position of part

- Hyperextend the wrist. Center the IR to the joint at the level of the radial styloid process.
- For support, a thin radiolucent pad may be placed under the lower forearm.
- Adjust the position of the hand to make its long axis as vertical as possible.
- To prevent superimposition of the shadows of the hamate and pisiform bones, rotate the hand slightly toward the radial side.
- Have the patient grasp the digits with the opposite hand or use a suitable device to hold the wrist in the extended position (Fig. 5.100).
- *Shield gonads.*

Central ray

- Directed to the palm of the hand at a point approximately 1 inch (2.5 cm) distal to the base of the third metacarpal and at an angle of 25 to 30 degrees to the long axis of the hand
- When the wrist cannot be extended to within 15 degrees of vertical, McQuillen Martensen [30] suggested that the CR first be aligned parallel to the palmar surface, then angled an additional 15 degrees toward the palm.

Collimation

- Adjust radiation field to 1 inch (2.5 cm) on the three sides of the shadow of the wrist. Place side marker in the collimated exposure field.

Structures shown

This image of the carpal canal (carpal tunnel) shows the palmar aspect of the trapezium; the tubercle of the trapezium; and the scaphoid, capitate, hook of hamate, triquetrum, and entire pisiform (Fig. 5.101).

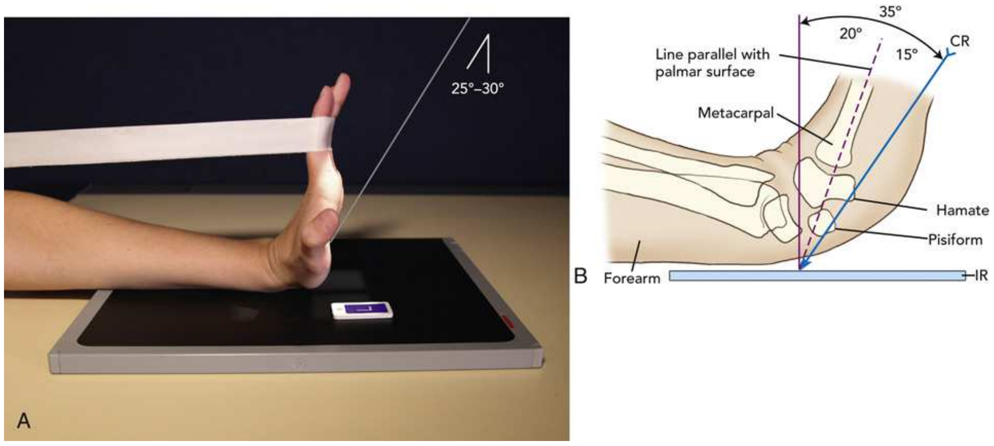


FIG. 5.100 (A) Tangential (inferosuperior) carpal canal: Gaynor-Hart method. (B) Suggested CR alignment when wrist cannot be extended within 15 degrees of vertical. CR is angled 15 degrees more than angle of metacarpals. B, Modified from McQuillen Martensen K. *Radiographic image analysis*. 3rd ed. St Louis: Saunders; 2010.

(A) shows the patient's wrist held in an extended position with a rubber band. The palm of the hand is distal to the base of the third metacarpal. The central ray is angled 25 to 30 degrees to the long axis of the hand. (B) shows the forearm resting on the image receptor. The CR is aligned parallel to the palmar surface, then angled an additional 15 degrees toward the palm.

Superoinferior

Position of patient

- When the patient cannot assume or maintain the previously described wrist position, a similar image may be obtained.
- Have the patient dorsiflex the wrist as much as is tolerable and lean forward to place the carpal canal tangent to the IR (Fig. 5.102). The canal is easily palpable on the palmar aspect of the wrist as the concavity between the trapezium laterally and hook of hamate and pisiform medially.

Position of part

- When dorsiflexion of the wrist is limited, Marshall [31] suggested placing a 45-degree angle sponge under the palmar surface of the hand. The sponge slightly elevates the wrist to place the carpal canal tangent to the CR. A slight degree of magnification exists because of the increased object-to-IR distance (OID) (Fig. 5.103).

Central ray

- Tangential to the carpal canal at the level of the midpoint of the wrist

Collimation

- Adjust radiation field to include palmar aspect of wrist, proximal one-third of metacarpals, and 1 inch (2.5 cm) on the sides. Place side marker in the collimated exposure field.

Evaluation Criteria

With either approach, the following should be clearly seen:

- Evidence of proper collimation and presence of side marker placed clear of anatomy of interest
- Carpals in an arch arrangement
- Pisiform in profile and free of superimposition
- Hamulus of hamate
- Bony trabecular detail and surrounding soft tissues

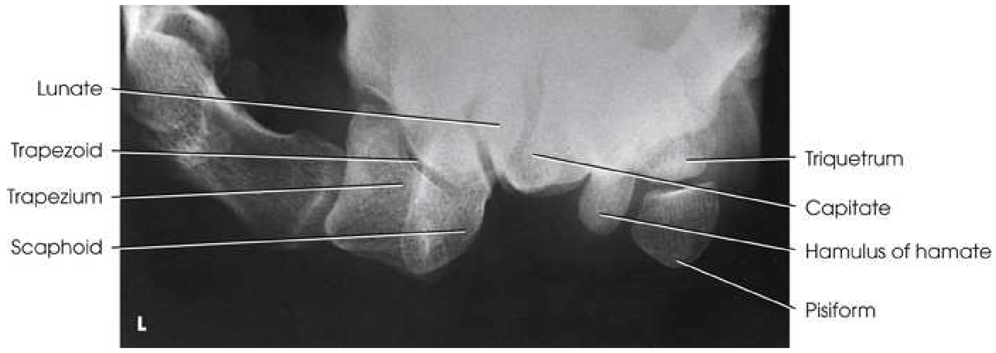


FIG. 5.101 Tangential (inferosuperior) carpal canal: Gaynor-Hart method.

An x-ray shows the palmar aspect of the trapezium; the tubercle of the trapezium; and the scaphoid, capitate, hook of hamate, triquetrum, and entire pisiform. The parts labeled in the diagram are listed as follows: lunate, trapezoid, scaphoid, trapezium, triquetrum, capitate, hamulus of hamate, and pisiform.

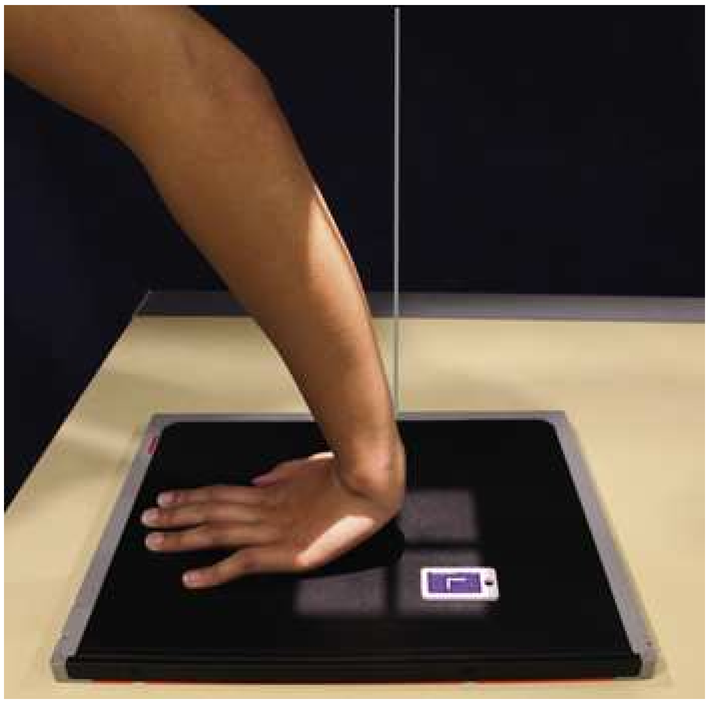


FIG. 5.102 Tangential (superoinferior) carpal canal.

The wrist of the patient is dorsiflexed and the carpal canal is placed tangent to the I R. A 45 degree angle sponge is placed under the palmar surface of the hand. The side marker is in the collimated exposure field. The central ray is at the level of the midpoint of the wrist.

FIG. 5.103 Tangential (superoinferior) carpal canal.

Forearm

AP Projection

Image receptor:

Positioned by manufacturer or department protocol for proper anatomy display orientation; CR plate: 14 × 17 inches (35 × 43 cm) lengthwise.

Position of patient

- Seat the patient close to the radiographic table and low enough to place the entire extremity in the same plane.

Position of part

- Supinate the hand, extend the elbow, and place the dorsal surface of the forearm against the IR.
- Adjust the IR so that the long axis is parallel with the forearm.
- Have the patient lean laterally until the forearm is in a true supinated position (Fig. 5.104).
- Because the proximal forearm is commonly rotated in this position, palpate and adjust the humeral epicondyles to be equidistant from the IR.
- Ensure that the hand is supinated (Fig. 5.105). Pronation of the hand crosses the radius over the ulna at its proximal third and rotates the humerus medially, resulting in an oblique projection of the forearm (Fig. 5.106).
- *Shield gonads.*

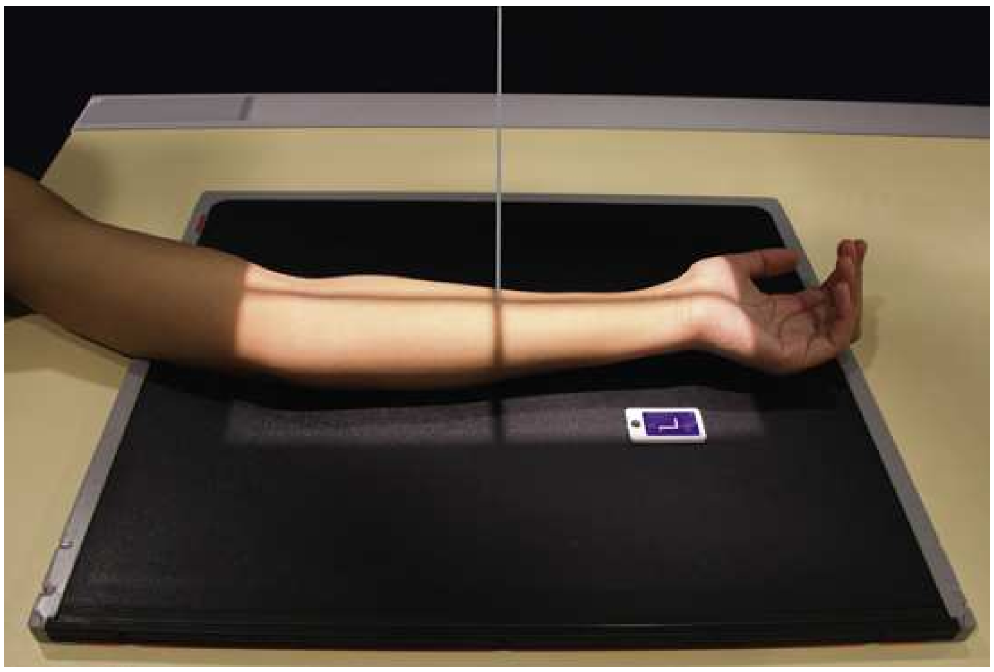


FIG. 5.104 AP forearm.

The forearm of the patient is placed in a true supinated position on the image receptor. The side marker is in the collimated exposure field. The central ray is perpendicular to the midpoint of the forearm.

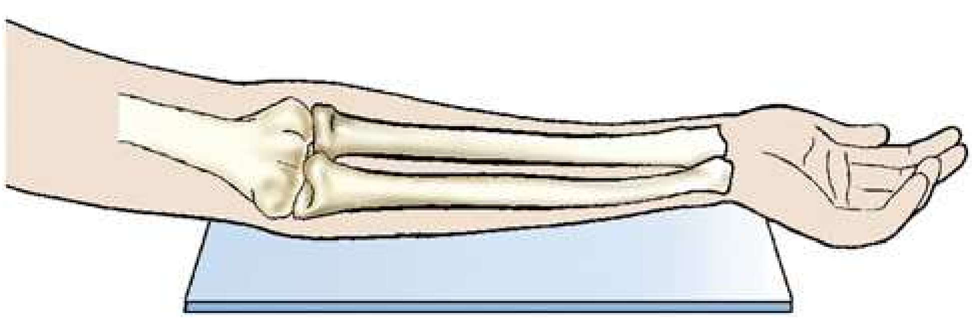


FIG. 5.105 AP forearm with hand supinated.

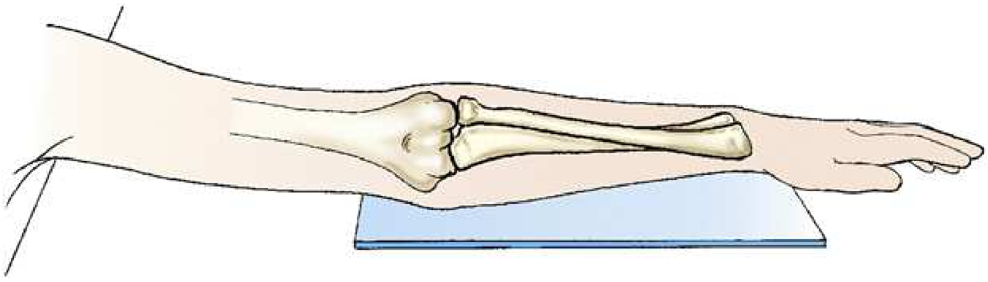


FIG. 5.106 AP forearm with hand pronated—incorrect.

Central ray

- Perpendicular to the midpoint of the forearm

Collimation

- Adjust radiation field to 2 inches (5 cm) distal to the wrist joint and proximal to the elbow joint and 1 inch (2.5 cm) on the sides. Place side marker in the collimated exposure field.

Structures shown

The elbow joint, the radius and ulna, and the proximal row of slightly distorted carpal bones (Fig. 5.107).

Evaluation Criteria

The following should be clearly seen:

- Evidence of proper collimation and presence of side marker placed clear of anatomy of interest
- Entire forearm, including wrist and distal humerus
- Slight superimposition of the radial head, neck, and tuberosity over the proximal ulna
- No elongation or foreshortening of the humeral epicondyles
- Partially open elbow joint if the shoulder was placed in the same plane as the forearm
- Open radioulnar space
- Bony trabecular detail and surrounding soft tissues

FIG. 5.107 (A) AP forearm with fractured radius and ulna *(arrows)*. (B) AP forearm showing both joints.

(A) shows forearm with fractured radius and ulna which are indicated by two arrows. The parts labeled are listed as follows: medial epicondyle, lateral epicondyle, epiphysis, radial head, radial neck, radial tuberosity, ulnar body, radial body, ulnar styloid process, and radial styloid process. (B) shows slight superimposition of the radial head, neck, and tuberosity over the proximal ulna. There is open radioulnar space.

Lateral Projection

Lateromedial

Image receptor:

Positioned by manufacturer or department protocol for proper anatomy display orientation; CR plate: 14 × 17 inches (35 × 43 cm) lengthwise.

Position of patient

- Seat the patient close to the radiographic table and low enough that the humerus, shoulder joint, and elbow lie in the same plane.

Position of part

- Flex the elbow 90 degrees and place the medial aspect of the forearm against the IR.
- Adjust the IR so that the long axis is parallel with the forearm.
- Adjust the extremity in a true lateral position, ensuring the humeral epicondyles and styloid processes are superimposed and perpendicular to the IR. The thumb side of the hand must be up (Fig. 5.108).
- *Shield gonads.*

Central ray

- Perpendicular to the midpoint of the forearm

Collimation

- Adjust radiation field to 2 inches (5 cm) distal to the wrist joint and proximal to the elbow joint, and 1 inch (2.5 cm) on the sides. Place side marker in the collimated exposure field.

Structures shown

The elbow joint, the radius and ulna, and the proximal row of superimposed carpal bones (Fig. 5.109).

Evaluation Criteria

The following should be clearly seen:

- Evidence of proper collimation and presence of side marker placed clear of anatomy of interest
- Entire forearm, including wrist and distal humerus in a true lateral position:
  - Superimposition of the radius and ulna at their distal end
  - Superimposition of the radial head over the coronoid process
  - Radial tuberosity facing anteriorly
  - Superimposed humeral epicondyles
- Elbow flexed 90 degrees
- Bony trabecular detail and surrounding soft tissues

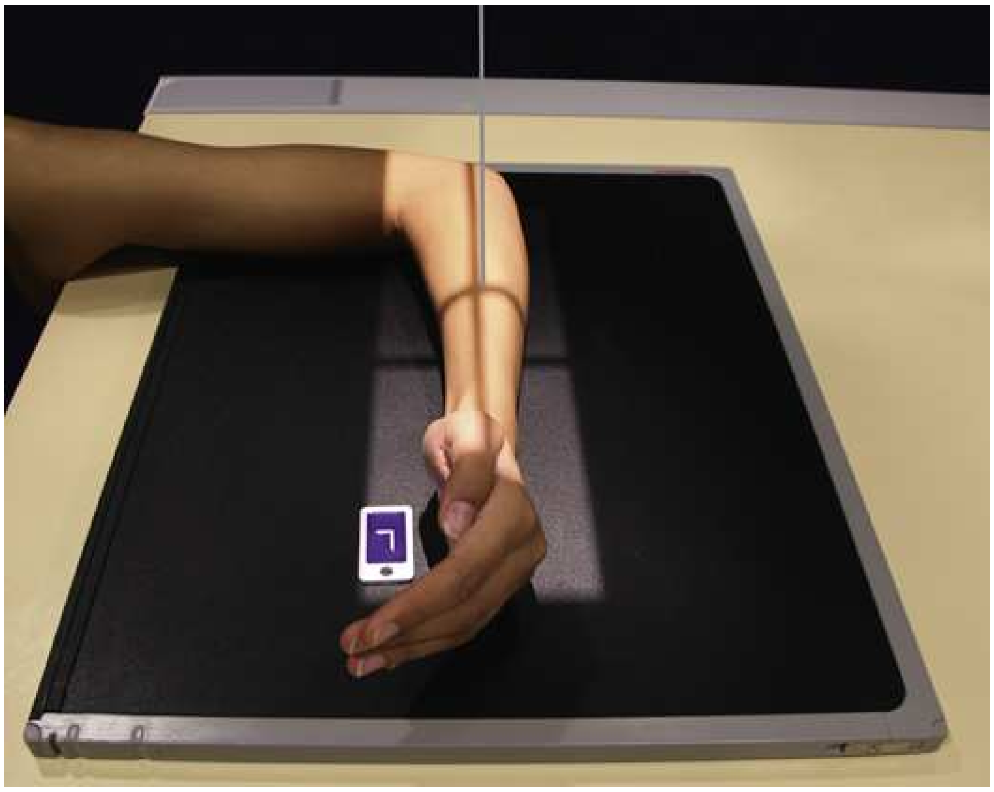


FIG. 5.108 Lateral forearm.

The patient's elbow is flexed and the medial aspect of the forearm is placed against the image receptor and the thumb side of the hand is facing up. The side marker is in the collimated exposure field. The central ray is perpendicular to the midpoint of the forearm.

FIG. 5.109 Lateral forearm.

Two x-ray views shows the forearm, including wrist and distal humerus in a true lateral position. The parts labeled on the radiograph on the left are listed as follows: olecranon process, humeral epicondyle, coronoid process, radial head, radial tuberosity, ulnar body, radial body, and ulnar styloid process.

Elbow

AP Projection

Image receptor:

Positioned by manufacturer or department protocol for proper anatomy display orientation; CR plate: 10 × 12 inches (24 × 30 cm) lengthwise.

Position of patient

- Seat the patient near the radiographic table and low enough to place the shoulder joint, humerus, and elbow joint in the same plane.

Position of part

- Extend the elbow, supinate the hand, and center the IR to the elbow joint.
- Adjust the IR to make it parallel with the long axis of the part (see Fig. 5.110).
- Have the patient lean laterally until the humeral epicondyles and anterior surface of the elbow are parallel with the plane of the IR.
- Supinate the hand to prevent rotation of the bones of the forearm.
- *Shield gonads.*

Central ray

- Perpendicular to the elbow joint

Collimation

- Adjust radiation field to 3 inches (8 cm) proximal and distal to the elbow joint and 1 inch (2.5 cm) on the sides. Place side marker in the collimated exposure field.

Structures shown

An AP projection of the elbow joint, distal arm, and proximal forearm (Fig. 5.111).

Evaluation Criteria

The following should be clearly seen:

- Evidence of proper collimation and presence of side marker placed clear of anatomy of interest
- Radial head, neck, and tuberosity slightly superimposed over the proximal ulna
- Elbow joint centered to the exposure field
- Open humeroradial joint
- No rotation of humeral epicondyles (coronoid and olecranon fossae approximately equidistant to epicondyles)
- Bony trabecular detail and surrounding soft tissues

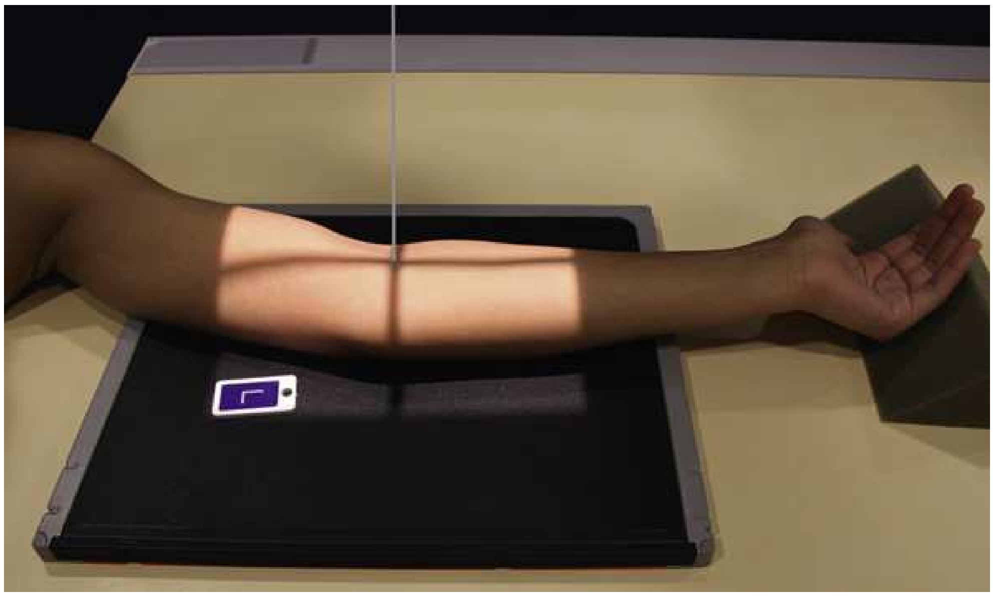


FIG. 5.110 AP elbow.

The patient's elbow is extended and the hand is supinated on the image receptor which is centered to the elbow joint. The side marker is in the collimated exposure field. The central ray is perpendicular to the elbow joint.

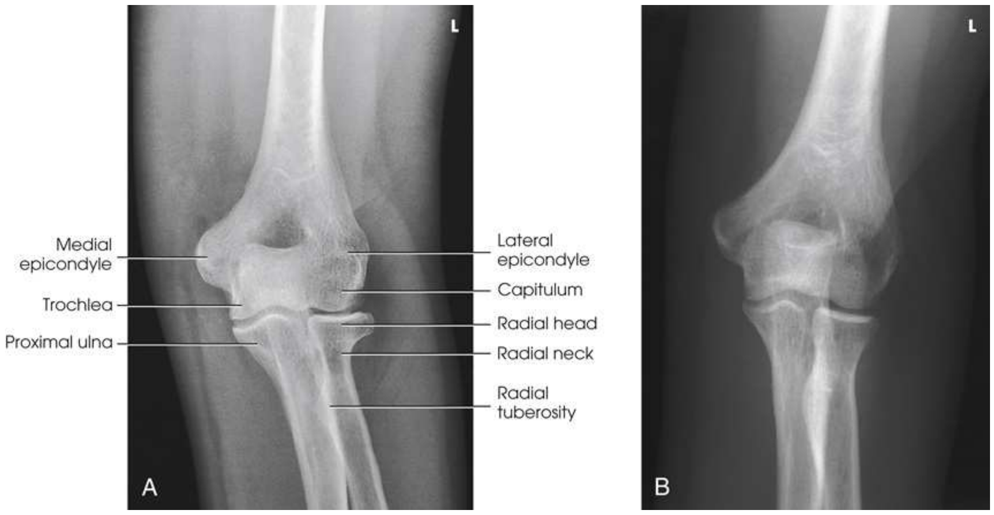


FIG. 5.111 (A) AP elbow with wide latitude exposure technique for soft tissue detail. (B) AP elbow with normal exposure technique.

(A) shows the elbow with wide latitude exposure technique. The elbow joint centered to the exposure field and appears radiopaque. The parts labeled are listed as follows: medial epicondyle, lateral epicondyle, capitulum, radial head, radial tuberosity, radial neck, trochlea, and proximal ulna. (B) shows the elbow with normal exposure technique.

Lateral Projection

Lateromedial

Griswold [2] gave two reasons for the importance of flexing the elbow 90 degrees: (1) The olecranon process can be seen in profile, and (2) the elbow fat pads are the least compressed. In partial or complete extension, the olecranon process elevates the posterior elbow fat pad and simulates joint pathology.

Image receptor:

Positioned by manufacturer or department protocol for proper anatomy display orientation; CR plate: 10 × 12 inches (24 × 30 cm) lengthwise.

Position of patient

- Seat the patient at the end of the radiographic table, low enough to place the humerus and the elbow joint in the same plane.

Position of part

- From the supine position, flex the elbow 90 degrees, and place the humerus and forearm in contact with the table.
- Center the IR to the elbow joint. Adjust the elbow joint so that its long axis is parallel with the long axis of the forearm (Fig. 5.112). On patients with muscular forearms, elevate the wrist to place the forearm parallel with the IR.
- To obtain a lateral projection of the elbow, adjust the hand and wrist in the lateral position and ensure that the humeral epicondyles are perpendicular to the plane of the IR.
- *Shield gonads.*

Central ray

- Perpendicular to the elbow joint, regardless of its location on the IR

Collimation

- Adjust radiation field to 3 inches (8 cm) proximal and distal to the elbow joint. Place side marker in the collimated exposure field.

Structures shown

The lateral projection shows the elbow joint, distal arm, and proximal forearm (see Figs. 5.113 and 5.114).

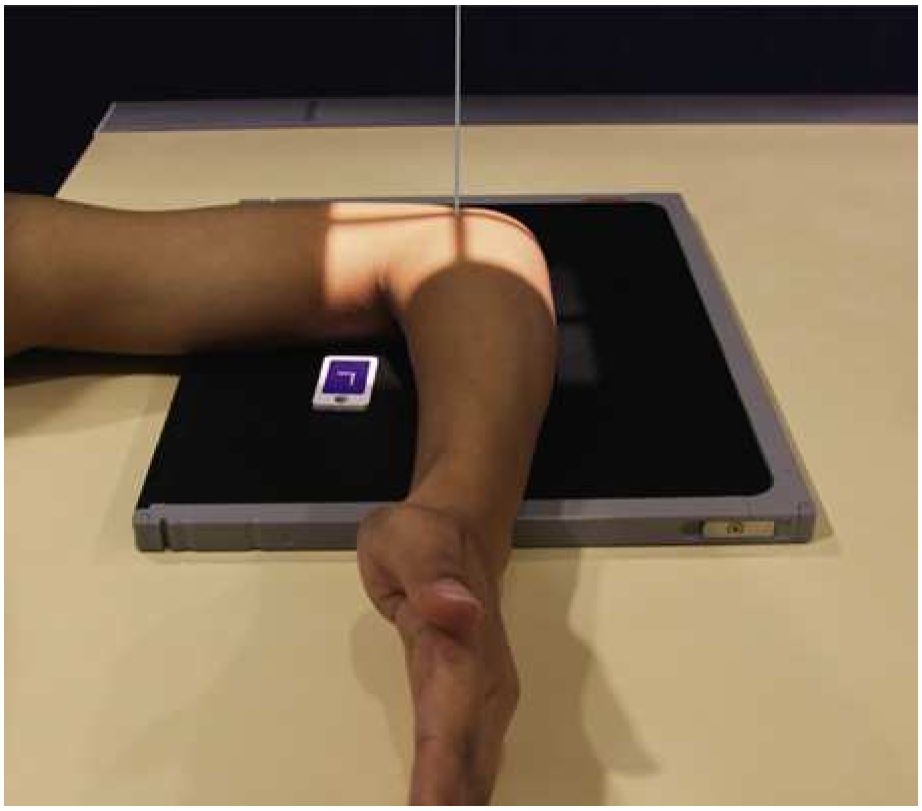


FIG. 5.112 Lateral elbow.

The humerus and the forearm is placed in contact with the table. The long axis of the elbow joint is parallel with the long axis of the forearm. The I R is centered to the elbow joint. The side marker is in the collimated exposure field. The central ray is perpendicular to the elbow joint.

FIG. 5.113 Lateral elbow.

Evaluation Criteria

The following should be clearly seen:

- Evidence of proper collimation and presence of side marker placed clear of anatomy of interest
- Elbow joint centered to the exposure field
- Elbow in a true lateral position:
  - Superimposed humeral epicondyles
  - Radial tuberosity facing anteriorly
  - Radial head partially superimposing the coronoid process
  - Olecranon process in profile
- Elbow flexed 90 degrees
- Bony trabecular detail and any elevated fat pads in the soft tissue at the anterior and posterior distal humerus and the anterior proximal forearm

NOTE: When injury to the soft tissue around the elbow is suspected, the joint should be flexed only 30 or 35 degrees (Fig. 5.115). This partial flexion does not compress or stretch the soft structures as does the full 90-degree lateral flexion. The posterior fat pad may become visible in this position.

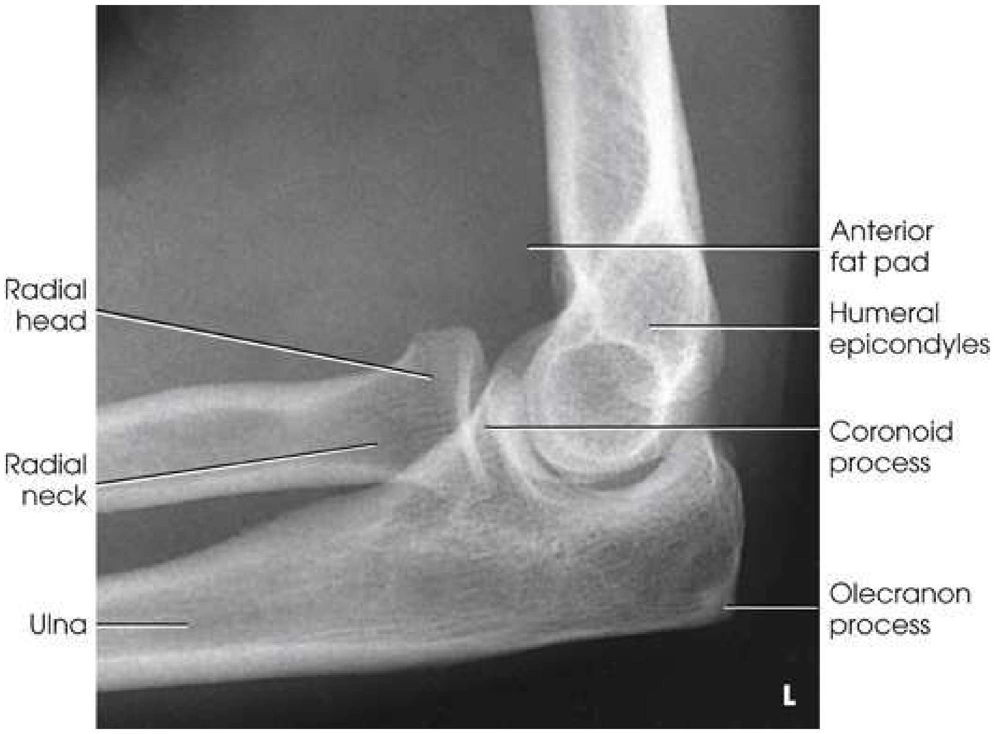


FIG. 5.114 Lateral elbow.

An x-ray shows the elbow joint, distal arm, and proximal forearm. The parts labeled are listed as follows: radial head, radial neck, ulna, anterior fat pad, humeral epicondyles, coronoid process, and olecranon process.

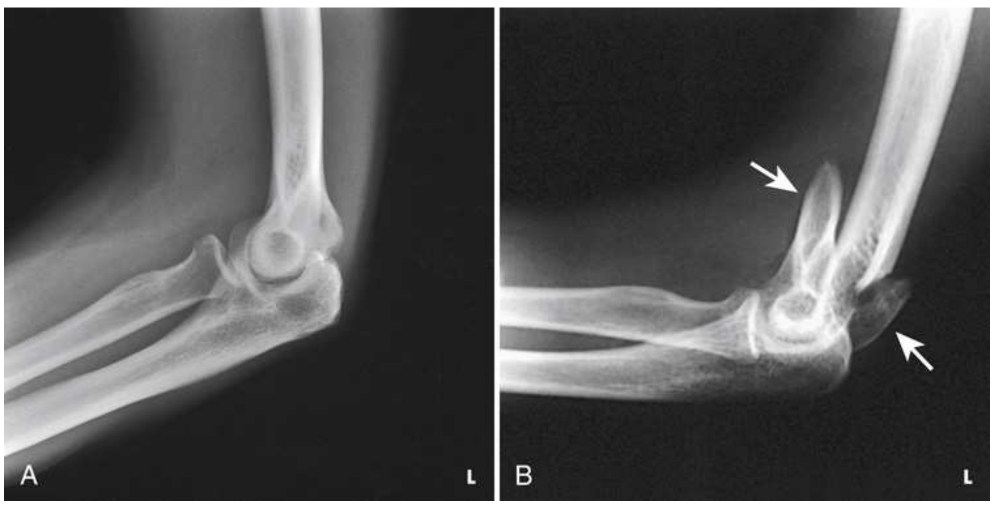


FIG. 5.115 (A) Lateral elbow in partial flexion position for soft tissue image. (B) Lateral elbow of patient who fell from a tree, resulting in impaction fracture *(arrows)* of distal humerus.

(A) An x-ray shows the partial flexion position of the elbow showing the posterior fat pad. It looks like a mirror image of the alphabet L. (B) An x-ray shows the impaction fracture of distal humerus which is indicated by two white arrows.

AP Oblique Projection

Medial rotation

Image receptor:

Positioned by manufacturer or department protocol for proper anatomy display orientation; CR plate: 10 × 12 inches (24 × 30 cm) lengthwise.

Position of patient

- Seat the patient at the end of the radiographic table, with the arm extended and in contact with the table.

Position of part

- Extend the extremity in anatomic position, ensuring the extremity is in the same plane and parallel with the IR plane.
- Center the midpoint of the IR to the elbow joint
- Medially (internally) rotate the upper extremity to place the humeral epicondyles 45 degrees from true anatomic position. This degree of obliquity usually clears the coronoid process of the radial head. The hand may be pronated or at a 45-degree angle (Fig. 5.116).

NOTE: Pronation of the hand only may not rotate the elbow joint the necessary 45 degrees to demonstrate the ulnar coronoid process in profile.

- *Shield gonads.*

Central ray

- Perpendicular to the elbow joint

Collimation

- Adjust radiation field to 3 inches (8 cm) proximal and distal to the elbow joint and 1 inch (2.5 cm) on the sides. Place side marker in the collimated exposure field.

Structures shown

An oblique projection of the elbow with the coronoid process projected free of superimposition (Fig. 5.117).

Evaluation Criteria

The following should be clearly seen:

- Evidence of proper collimation and presence of side marker placed clear of anatomy of interest
- Elbow joint centered to the exposure field
- 45-degree medial rotation of elbow:
  - Coronoid process in profile
  - Elongated medial humeral epicondyle
  - Ulna superimposed by the radial head and neck
- Trochlea
- Olecranon process within the olecranon fossa
- Bony trabecular detail and surrounding soft tissues

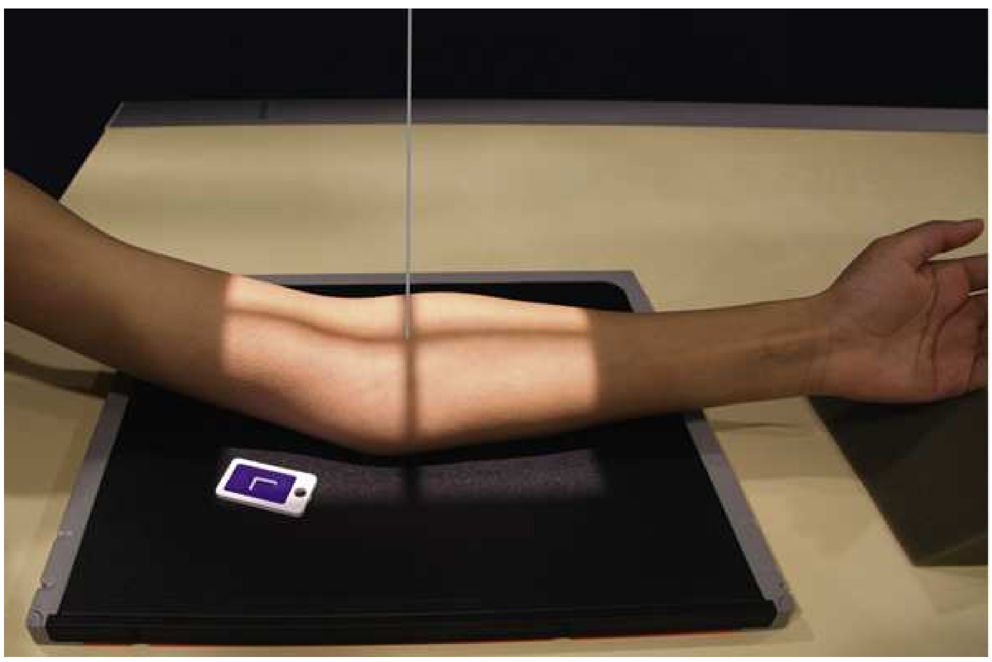


FIG. 5.116 AP oblique elbow: medial rotation.

The patient's elbow is extended and the hand is supinated on the image receptor which is centered to the elbow joint. The side marker is in the collimated exposure field. The central ray is perpendicular to the elbow joint.

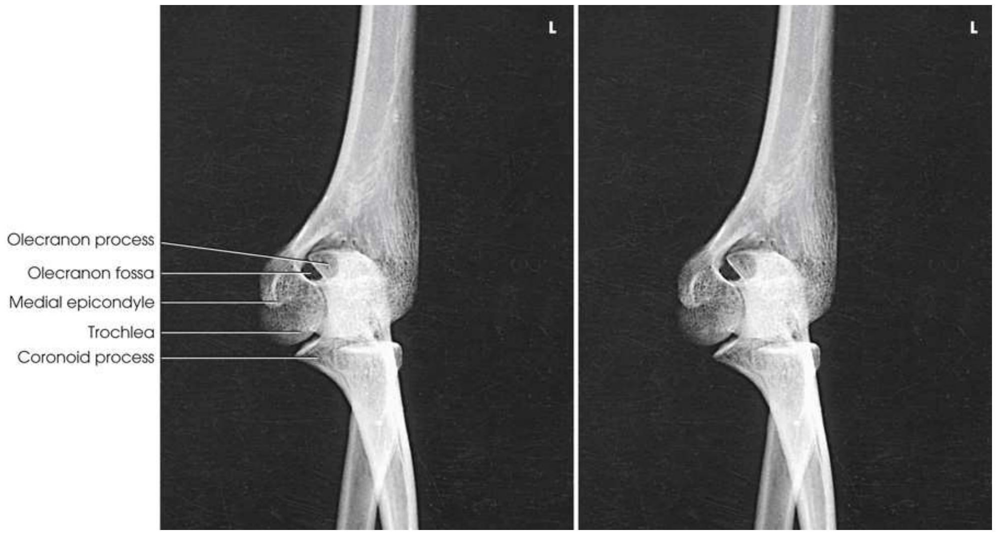


FIG. 5.117 AP oblique elbow.

Two x-ray views of the elbow with the coronoid process projected free of superimposition. The parts labeled in the x-ray on the left are listed as follows: olecranon process, olecranon fossa, medial epicondyle, trochlea, and coronoid process.

AP Oblique Projection

Lateral rotation

Image receptor:

Positioned by manufacturer or department protocol for proper anatomy display orientation; CR plate: 10 × 12 inches (24 × 30 cm) lengthwise.

Position of patient

- Seat the patient at the end of the radiographic table, with the arm extended and in contact with the table.

Position of part

- Extend the patient's arm in position for an AP projection, and center the midpoint of the IR to the elbow joint.
- Rotate the hand laterally (externally) to place the posterior surface of the elbow at a 45-degree angle (Fig. 5.118). When proper lateral rotation is achieved, the patient's first and second digits should touch the table.
- *Shield gonads.*

Central ray

- Perpendicular to the elbow joint

Collimation

- Adjust radiation field to 3 inches (8 cm) proximal and distal to the elbow joint and 1 inch (2.5 cm) on the sides. Place side marker in the collimated exposure field.

Structures shown

An oblique projection of the elbow with the radial head and neck projected free of superimposition of the ulna (Fig. 5.119).

Evaluation Criteria

The following should be clearly seen:

- Evidence of proper collimation and presence of side marker placed clear of anatomy of interest
- Elbow joint centered to the exposure field
- 45-degree lateral rotation of elbow:
  - Radial head, neck, and tuberosity projected free of the ulna
  - Elongated lateral humeral epicondyle
- Capitulum

- Bony trabecular detail and surrounding soft tissues

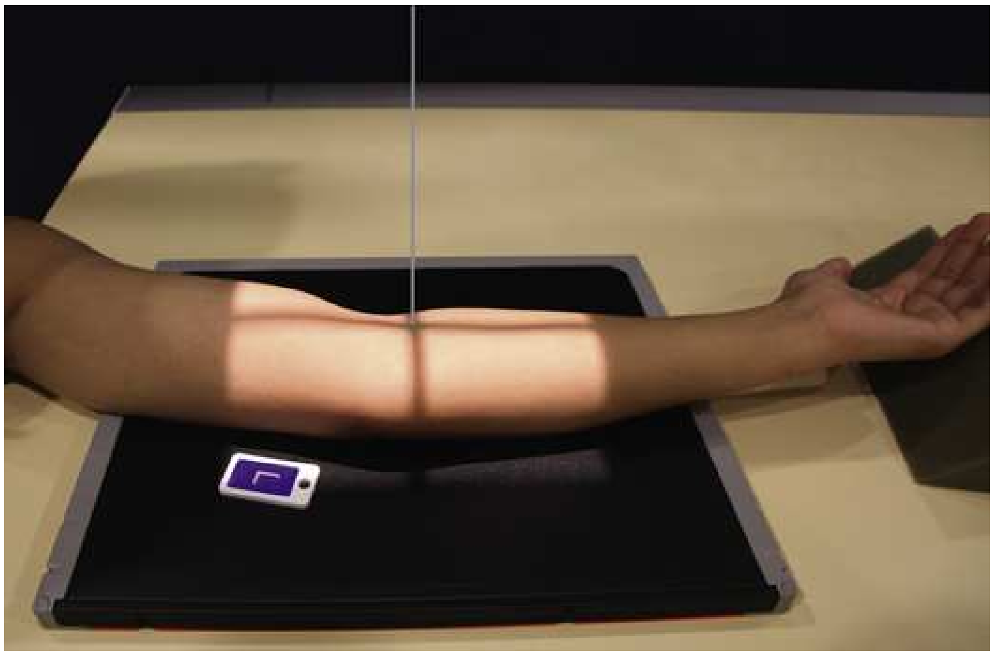


FIG. 5.118 AP oblique elbow: lateral rotation.

The patient's hand is rotated laterally and the posterior surface of the elbow is on the image receptor. The side marker is in the collimated exposure field. The central ray is perpendicular to the elbow joint.

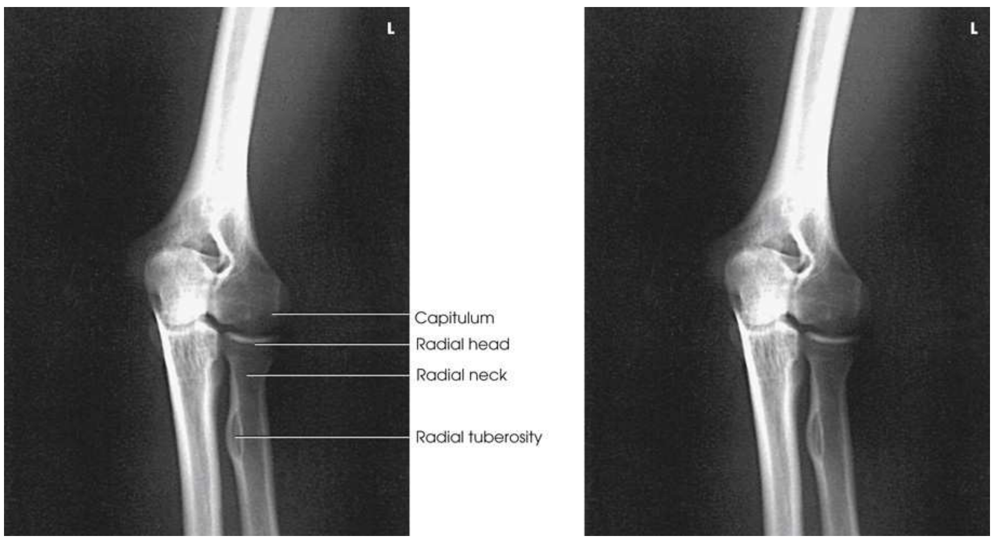


FIG. 5.119 AP oblique elbow.

Two x-ray views shows the elbow with the radial head and neck projected free of superimposition of the ulna. The parts labeled on the x-ray on the left are listed as follows: capitulum, radial head, radial neck, and radial tuberosity.

Distal Humerus

AP Projection

Partial flexion

When the patient cannot completely extend the elbow, the lateral position is easily performed; however, two AP projections must be obtained to avoid distortion. Separate AP projections of the distal humerus and proximal forearm are required.

Image receptor:

Positioned by manufacturer or department protocol for proper anatomy display orientation; CR plate: 10 × 12 inches (24 × 30 cm) lengthwise.

Position of patient

- Seat the patient low enough to place the entire humerus in the same plane. Support the elevated forearm.

Position of part

- If possible, supinate the hand. Place the IR under the elbow, centered to the condyloid area of the humerus (Fig. 5.120).
- *Shield gonads.*

Central ray

- Perpendicular to the humerus, traversing the elbow joint
- Depending on the degree of flexion, angle the CR distally into the joint.

Collimation

- Adjust radiation field to 3 inches (8 cm) proximal and distal to the elbow joint and 1 inch (2.5 cm) on the sides. Place side marker in the collimated exposure field.

Structures shown

The distal humerus when the elbow cannot be fully extended (Figs. 5.121 and 5.122).

Evaluation Criteria

The following should be clearly seen:

- Evidence of proper collimation and presence of side marker placed clear of anatomy of interest
- Distal humerus without rotation or distortion
- Proximal radius superimposed over the ulna
- Closed elbow joint
- Greatly foreshortened proximal forearm
- Bony trabecular detail of the distal humerus and surrounding soft tissues of the elbow

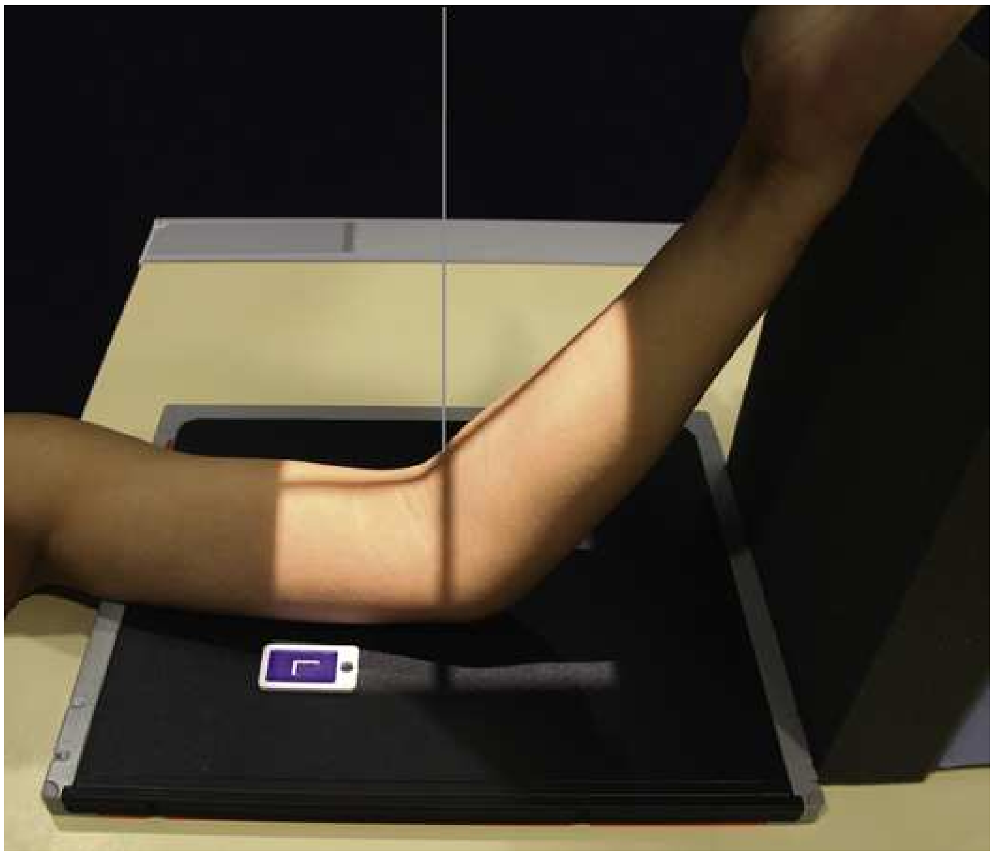


FIG. 5.120 AP elbow, partially flexed.

The patient's hand is supinated and the arm is supported on a stand. The I R is placed under the elbow and the central ray is centered to the condyloid area of the humerus. The side marker is in the collimated exposure field.

FIG. 5.121 AP elbow, partially flexed, showing distal humerus.

The x-ray view of the distal humerus when the elbow cannot be fully extended. The upper part appear grainy and the lower part appear bright. The parts labeled in the-ray are as follows: lateral epicondyle, capitulum, trochlea, radial tuberosity, and proximal ulna.

FIG. 5.122 AP elbow, partially flexed, showing distal humerus. White proximal radius and ulna result from overlap of anterior dislocated elbow (see Fig. 5.125).

Proximal Forearm

AP Projection

Partial flexion

Image receptor:
Positioned by manufacturer or department protocol for proper anatomy display orientation; CR plate: 10 × 12 inches (24 × 30 cm) lengthwise.

Position of patient

- Seat the patient at the end of the radiographic table, with the hand supinated.

Position of part

- Seat the patient high enough to permit the dorsal surface of the forearm to rest on the table (Fig. 5.123).

NOTE: If this position is impossible, elevate the extremity on a support, adjust the extremity in the lateral position, place the IR in the vertical position behind the upper end of the forearm, and direct the CR horizontally.

- *Shield gonads.*

Central ray

- Perpendicular to the elbow joint and long axis of the forearm
- Adjust the IR so that the CR passes to its midpoint.

Collimation

- Adjust radiation field to 3 inches (8 cm) proximal and distal to the elbow joint and 1 inch (2.5 cm) on the sides. Place side marker in the collimated exposure field.

Structures shown

The proximal forearm when the elbow cannot be fully extended (Figs. 5.124 and 5.125).

Evaluation Criteria

The following should be clearly seen:

- Evidence of proper collimation and presence of side marker placed clear of anatomy of interest
- Proximal radius and ulna without rotation or distortion
- Radial head, neck, and tuberosity slightly superimposed over the proximal ulna
- Partially open elbow joint
- Foreshortened distal humerus
- Bony trabecular detail of the proximal radius and ulna, as well as the soft tissues surrounding the elbow

NOTE: Holly [32] described a method of obtaining the AP projection of the radial head. The patient is positioned as described for the distal humerus. The elbow is extended as much as possible, and the forearm is supported. The forearm should be supinated enough to place the horizontal plane of the wrist at an angle of 30 degrees from horizontal.

FIG. 5.123 AP elbow, partially flexed.

The dorsal surface of the patient's forearm is resting on the image receptor placed in vertical position. The side marker is in the collimated exposure field. The central ray is perpendicular to the elbow joint and long axis of the forearm.

FIG. 5.124 AP elbow, partially flexed, showing proximal forearm. This is a view of the dislocated elbow of the patient shown in Fig. 5.125. White distal humerus is due to dislocated humerus overlapping proximal radius and ulna.

FIG. 5.125 Lateral elbow showing dislocation on same patient as shown in Figs. 5.122 and 5.124.

The x-ray shows proximal forearm and the elbow is not extended. The elbow joint is partially open. It also shows a white distal humerus. Radial head, neck, and tuberosity are slightly superimposed over the proximal ulna.

Distal Humerus

AP Projection

Acute flexion

When fractures around the elbow are being treated using the Jones orthopedic technique (complete flexion), the lateral position offers little difficulty, but the frontal projection must be made through the superimposed bones of the AP arm and PA forearm. This projection is sometimes known as the *Jones method,* although no "Jones" reference has been found.

Image receptor:

Positioned by manufacturer or department protocol for proper anatomy display orientation; CR plate: 10 × 12 inches (24 × 30 cm) lengthwise.

Position of patient

- Seat the patient at the end of the radiographic table, with the elbow fully flexed (unless contraindicated).

Position of part

- Center the IR proximal to the epicondylar area of the humerus. The long axis of the arm and forearm should be parallel with the long axis of the IR (Figs. 5.126 and 5.127).
- Adjust the arm or the radiographic tube and IR to prevent rotation.
- *Shield gonads.*

Central ray

- Perpendicular to the humerus, approximately 2 inches (5 cm) superior to the olecranon process

Collimation

- Adjust radiation field to include the proximal half of the forearm and 1 inch (2.5 cm) beyond the olecranon process and sides on the elbow. Place side marker in the collimated exposure field.

Structures shown

This position superimposes the proximal forearm and distal humerus. The olecranon process should be clearly shown (Fig. 5.128).

Evaluation Criteria

The following should be clearly seen:

- Evidence of proper collimation and presence of side marker placed clear of anatomy of interest
- Forearm and humerus superimposed, without rotation
- Olecranon process and distal humerus
- Bony trabecular detail and surrounding soft tissues

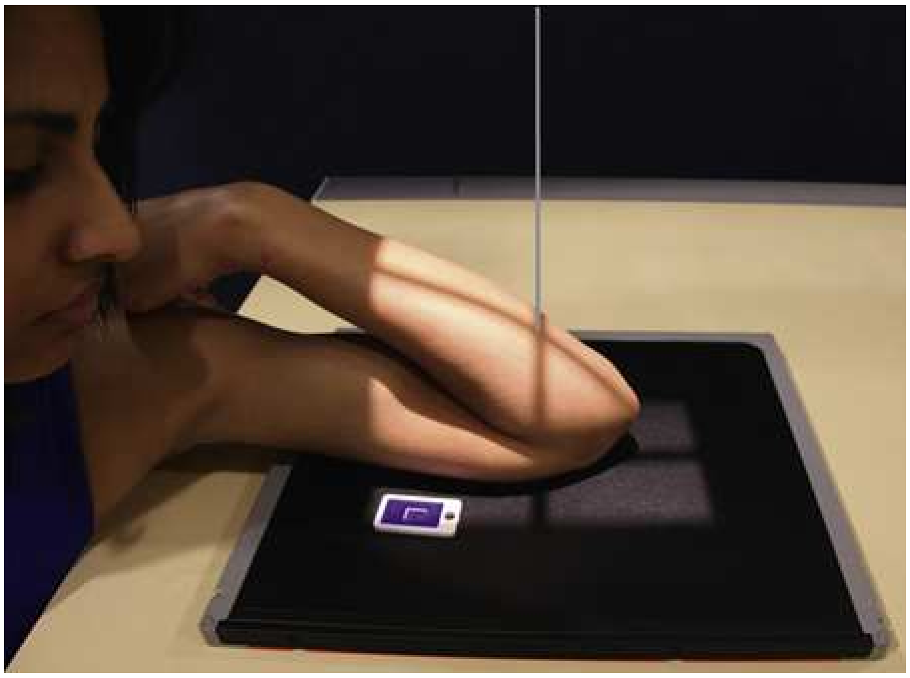


FIG. 5.126 AP distal humerus: acute flexion of elbow.

The patient is sitting with her elbow flexed on the image receptor. The long axis of the arm and forearm is parallel with the long axis of the I R. The side marker is in the collimated exposure field. The central ray is perpendicular to the humerus and superior to the olecranon process.

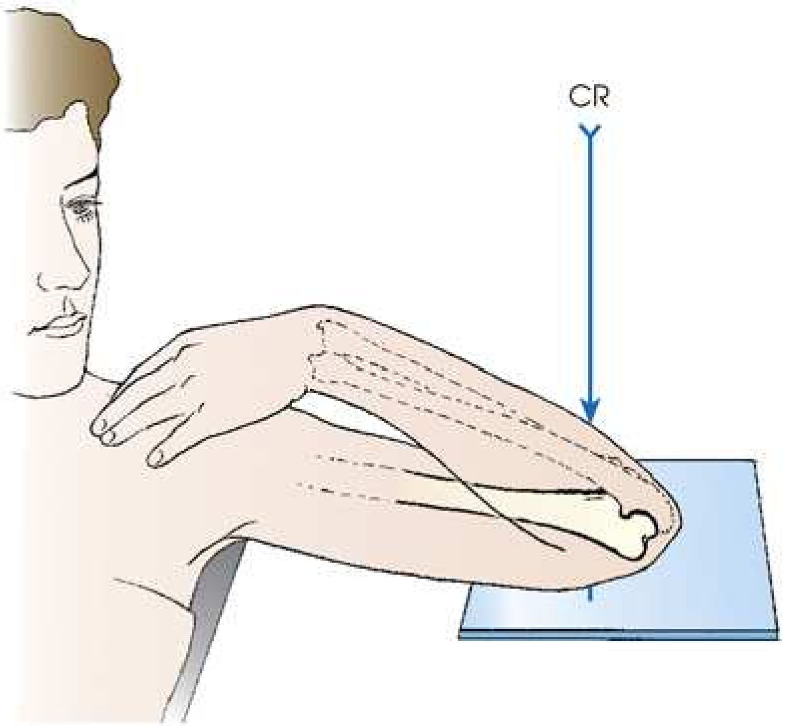


FIG. 5.127 AP distal humerus: acute flexion of elbow.

Diagram shows a patient sitting with elbow flexed on the image receptor. The long axis of the arm and forearm is parallel with the long axis of the I R. The central ray is perpendicular to the humerus and superior to the olecranon process.

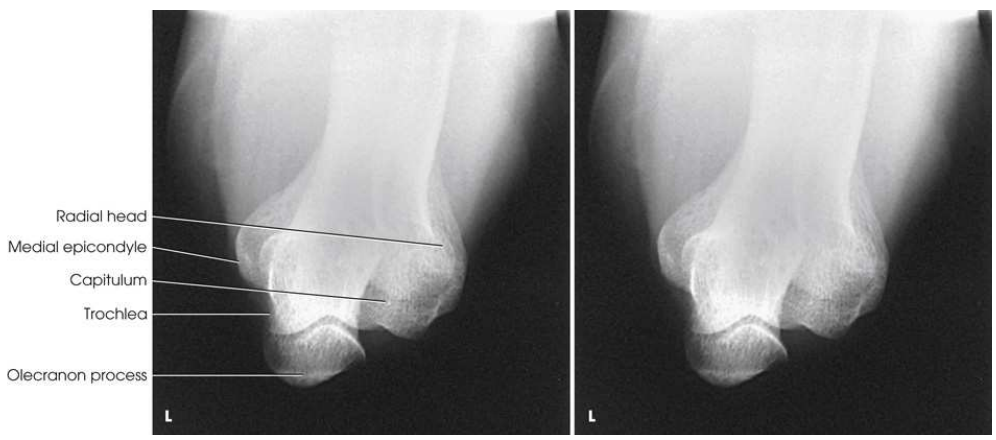


FIG. 5.128 AP distal humerus: acute flexion of elbow.

Two x-ray views shows the distal humerus with acute flexion of elbow. The proximal forearm and the distal humerus are superimposed and appear radiopaque. The parts labeled in the x-ray on the left are as follows: radial head, medial epicondyle, capitulum, trochlea, and olecranon process.

Proximal Forearm

PA Projection

Acute flexion

Image receptor:

Positioned by manufacturer or department protocol for proper anatomy display orientation; CR plate: 10 × 12 inches (24 × 30 cm) lengthwise.

Position of patient

- Seat the patient at the end of the radiographic table with the elbow fully flexed.

Position of part

- Center the flexed elbow joint to the center of the IR. The long axis of the superimposed forearm and arm should be parallel with the long axis of the IR (Figs. 5.129 and 5.130).
- Move the IR toward the shoulder so that the CR passes to the midpoint.
- *Shield gonads.*

Central ray

- Angled perpendicular to the flexed forearm, entering approximately 2 inches (5 cm) distal to the olecranon process

Collimation

- Adjust radiation field to include the proximal half of the forearm and 1 inch (2.5 cm) beyond the olecranon process and sides on the elbow. Place side marker in the collimated exposure field.

Structures shown

This position superimposes the proximal forearm and distal humerus (Fig. 5.131). The elbow joint should be more open than for the projection of the distal humerus.

Evaluation Criteria

The following should be clearly seen:

- Evidence of proper collimation and presence of side marker placed clear of anatomy of interest
- Forearm and humerus superimposed, without rotation
- Proximal radius and ulna
- Bony trabecular detail and surrounding soft tissues

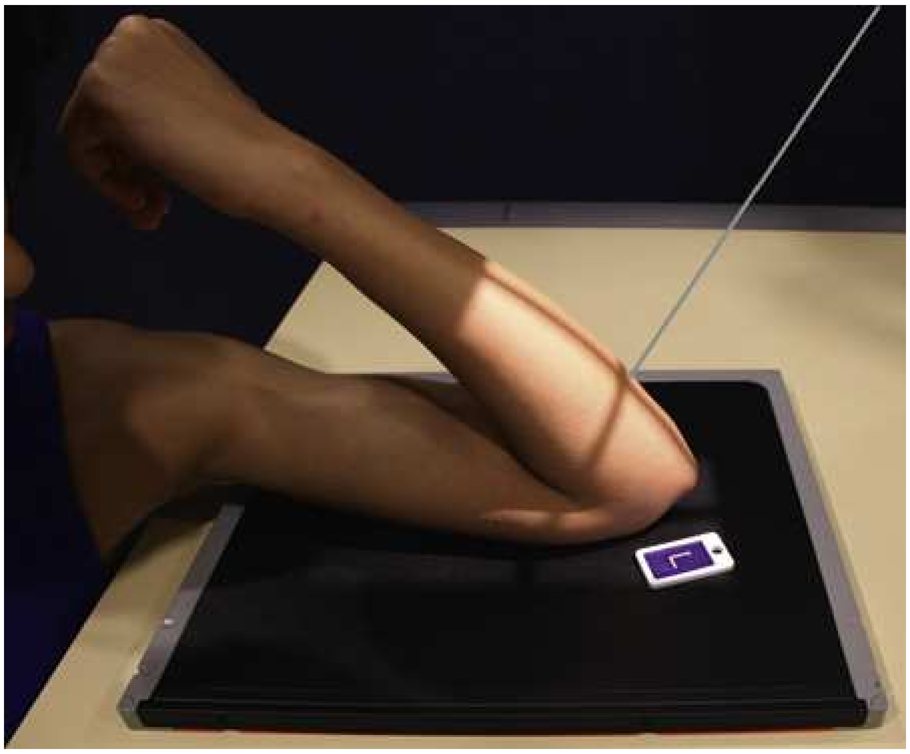


FIG. 5.129 PA proximal forearm: full flexion of elbow.

The patient is sitting with her elbow flexed on the image receptor. The long axis of the superimposed forearm and arm is parallel with the long axis of the I R. The side marker is in the collimated exposure field. The central ray is angled perpendicular to the flexed forearm, distal to the olecranon process.

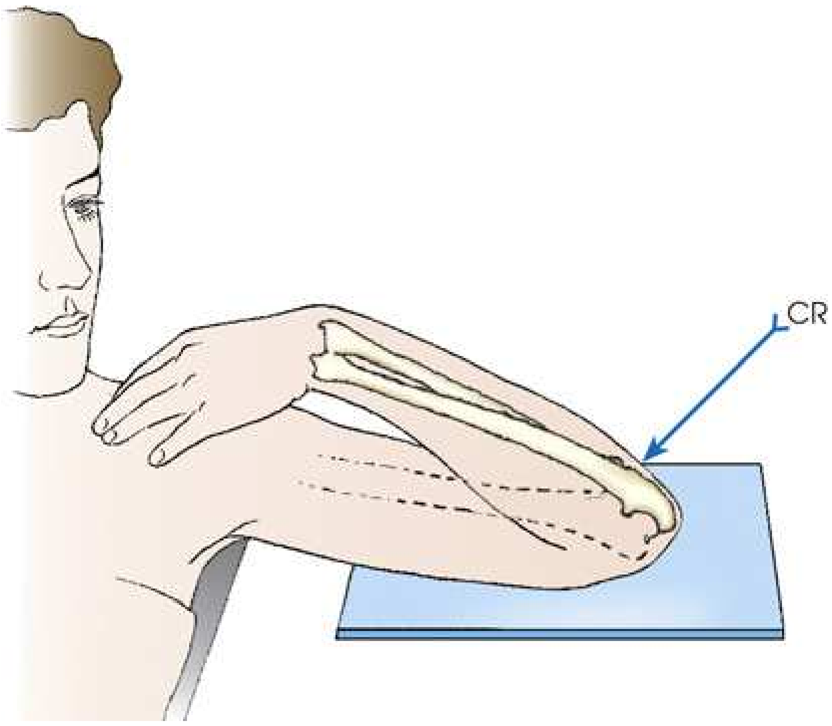


FIG. 5.130 PA proximal forearm: full flexion of elbow.

The patient is sitting with elbow flexed on the image receptor. The long axis of the superimposed forearm and arm is parallel with the long axis of the I R. The central ray is angled perpendicular to the flexed forearm, distal to the olecranon process.

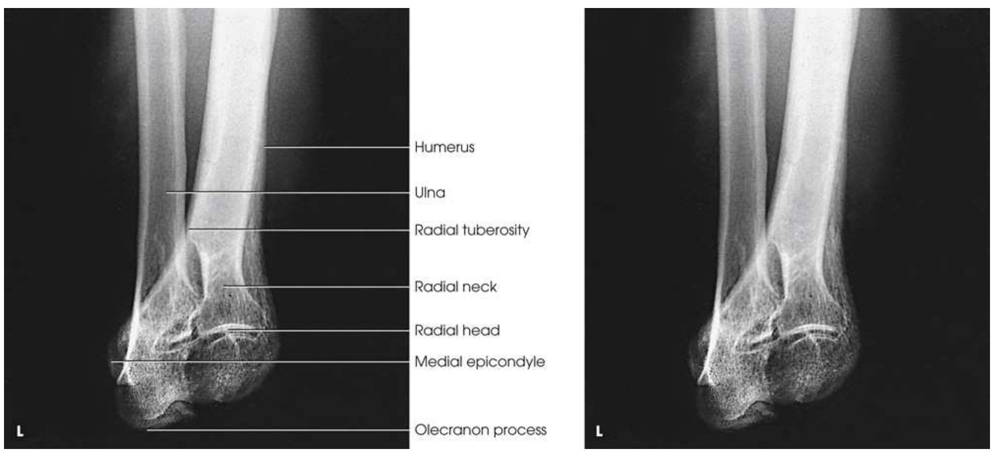


FIG. 5.131 PA proximal forearm: full flexion of elbow.

Two x-ray views shows the open elbow joint and it appears grainy. The parts labeled in the x-rayon the left are as follows: humerus, ulna, radial tuberosity, radial neck, radial head, medial epicondyle, and olecranon process.

Radial Head

Lateral Projection

Lateromedial

Four-position series

To show the entire circumference of the radial head free of superimposition, four projections with varying positions of the hand are performed. If using computed radiography, replace the IR for each exposure.

Image receptor:

Positioned by manufacturer or department protocol for proper anatomy display orientation; CR plate: 10 × 12 inches (24 × 30 cm) lengthwise.

Position of patient

- Seat the patient low enough to place the entire arm in the same horizontal plane.

Position of part

- Flex the elbow 90 degrees, center the joint to the IR, and place the joint in the lateral position.
- Make the first exposure with the hand supinated as much as is possible (Fig. 5.132).
- Make the second exposure with the hand in the lateral position (i.e., with the thumb surface up) (Fig. 5.133).
- Make the third exposure with the hand pronated (Fig. 5.134).
- Make the fourth exposure with the hand in extreme internal rotation (i.e., resting on the thumb surface) (Fig. 5.135).
- *Shield gonads.*

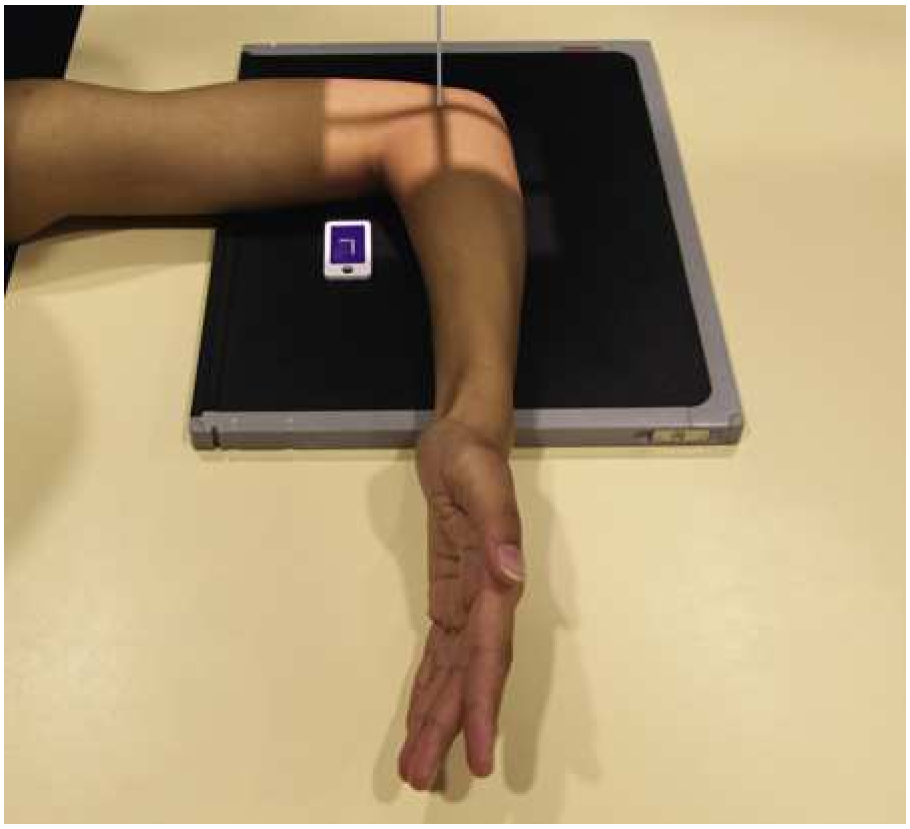


FIG. 5.132 Lateral elbow, radius with hand supinated as much as possible.

The patient's elbow is flexed 90 degrees and the joint is centered on the image receptor in the lateral position. The side marker is in the collimated exposure field. The central ray is perpendicular to the elbow joint.

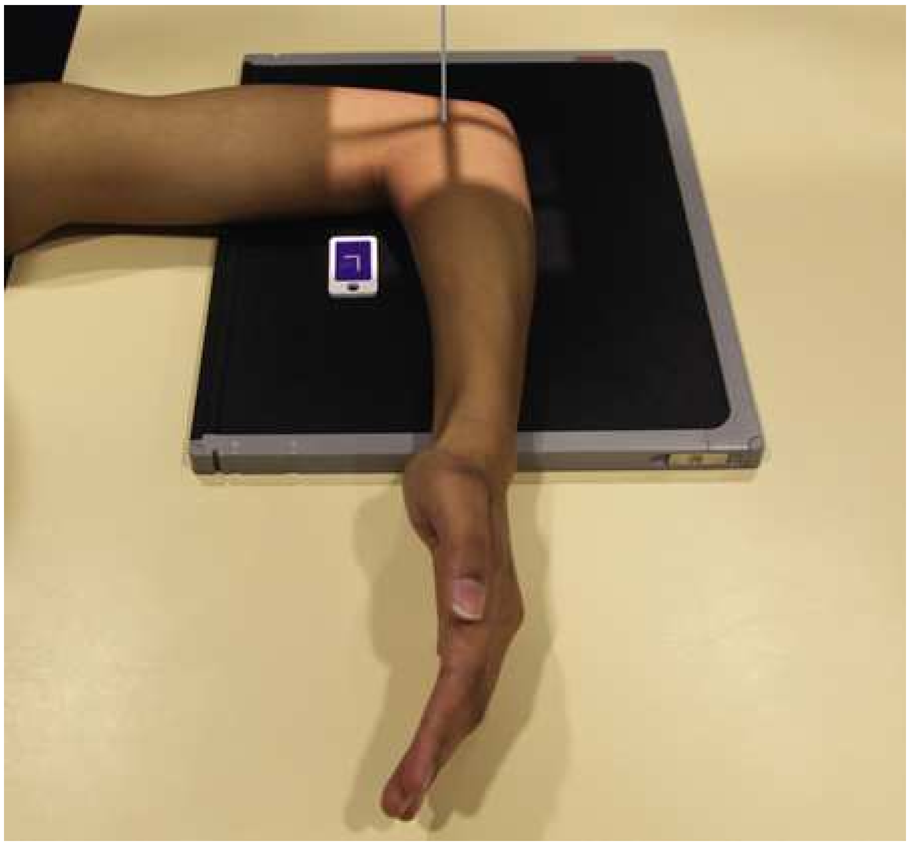


FIG. 5.133 Lateral elbow, radius with hand lateral.

The patient's elbow is flexed 90 degrees and the joint is centered on the image receptor in the lateral position with the thumb surface up. The side marker is in the collimated exposure field. The central ray is perpendicular to the elbow joint.

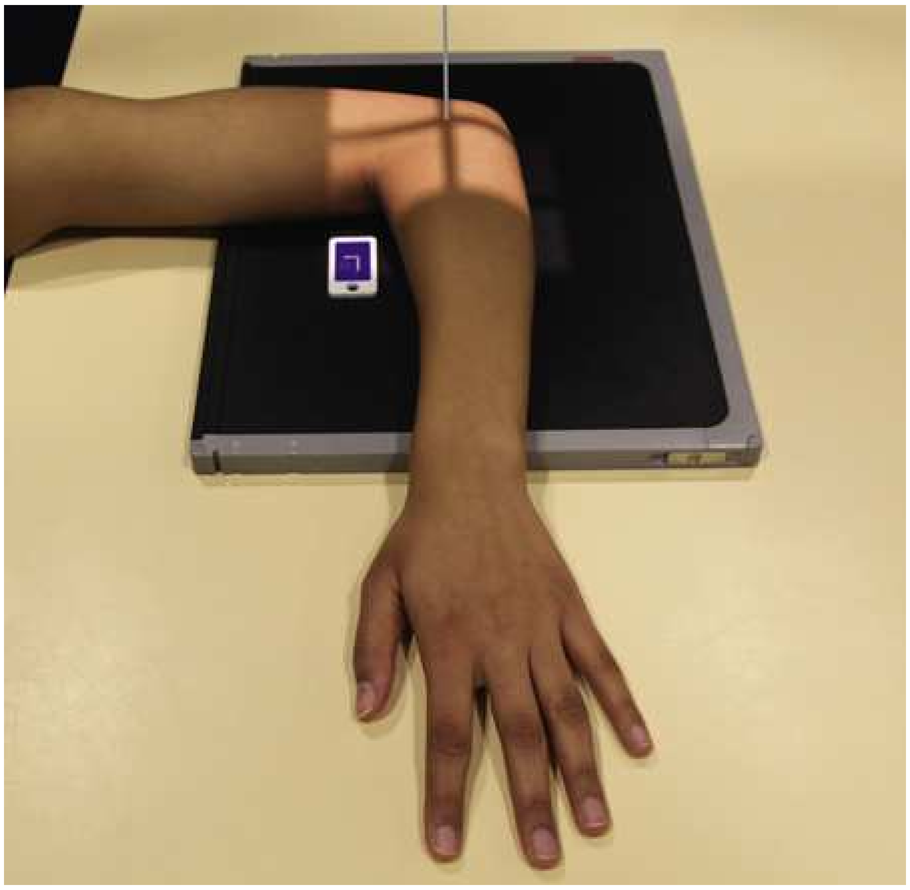


FIG. 5.134 Lateral elbow, radius with hand pronated.

The patient's elbow is flexed 90 degrees and the joint is centered on the image receptor with the hand pronated. The side marker is in the collimated exposure field. The central ray is perpendicular to the elbow joint.

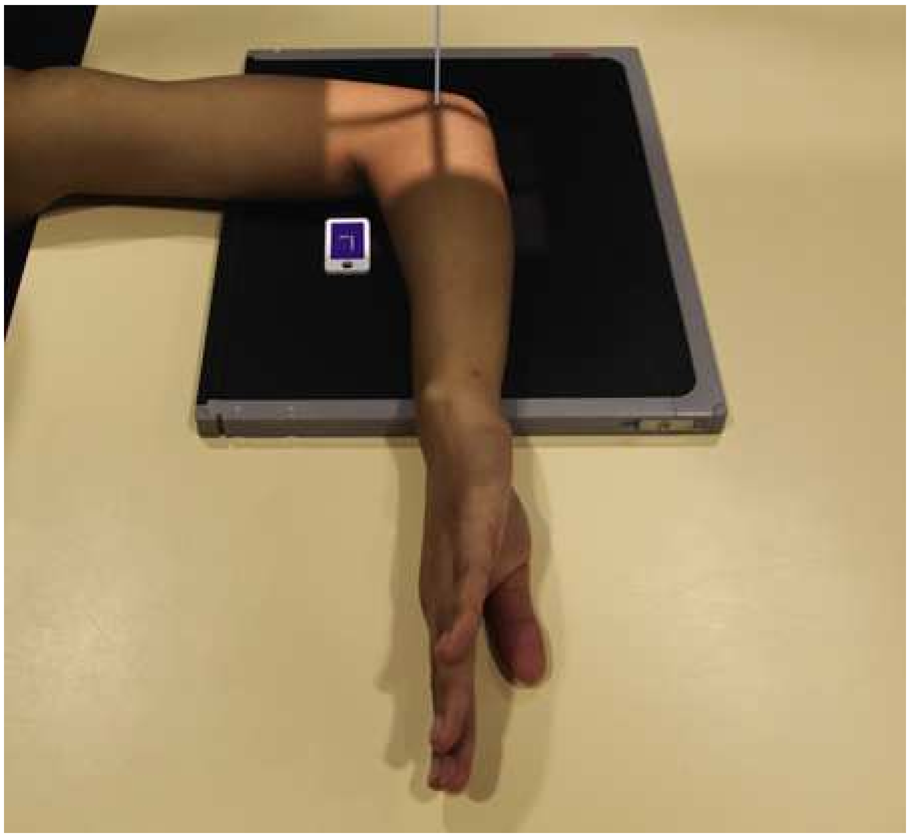


FIG. 5.135 Lateral elbow, radius with hand internally rotated.

The patient's elbow is flexed 90 degrees and the joint is centered on the image receptor with the hand in extreme internal rotation, resting on the thumb surface. The side marker is in the collimated exposure field. The central ray is perpendicular to the elbow joint.

Central ray

- Perpendicular to the elbow joint

Collimation

- Adjust radiation field to 3 inches (8 cm) proximal and distal to the elbow joint. Place side marker in the collimated exposure field.

Structures shown

The radial head is projected in varying degrees of rotation (Figs. 5.136 through 5.139).

Evaluation Criteria

The following should be clearly seen:

- Evidence of proper collimation and presence of side marker placed clear of anatomy of interest
- Radial tuberosity facing anteriorly for the first and second images and posteriorly for the third and fourth images (see Figs. 5.136 through 5.139)
- Elbow flexed 90 degrees
- Radial head partially superimposing the coronoid process but seen in all images
- Bony trabecular detail and surrounding soft tissues

FIG. 5.136 Lateral elbow, radius with hand supinated.

FIG. 5.137 Lateral elbow, radius with hand lateral.

FIG. 5.138 Lateral elbow, radius with hand pronated (radial tuberosity, *arrow*).

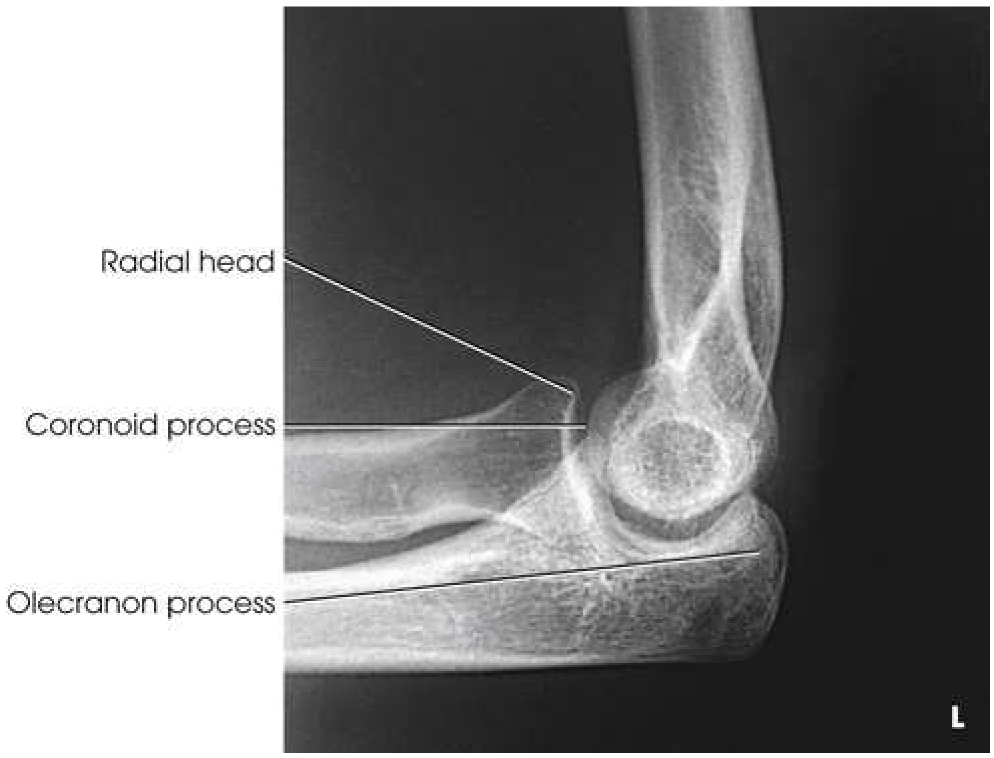


FIG. 5.139 Lateral elbow, radius with hand internally rotated.

Radial Head and Coronoid Process

Axiolateral Projection

Coyle Method

Lateral

NOTE: This projection was devised for obtaining images of the radial head and coronoid process on patients who cannot fully extend the elbow for medial and lateral oblique projections.[33] It is particularly useful in imaging a traumatized elbow.

Image receptor:

Positioned by manufacturer or department protocol for proper anatomy display orientation; CR plate: 10 × 12 inches (24 × 30 cm) lengthwise.

Position of patient

- Seat the patient at the end of the radiographic table.
- Position the patient supine for imaging a traumatized elbow.

Position of part

Seated position

- Seat the patient at the end of the radiographic table, low enough to place the humerus, elbow, and wrist joints on the same plane.
- Pronate the hand and flex the elbow 90 degrees to show the radial head or 80 degrees to show the coronoid process.
- Center the IR to the elbow joint. For patients with muscular forearms, elevate the wrist to place the forearm parallel with the IR (Fig. 5.140).

Supine position for trauma

- In most instances of trauma, the patient is lying in the supine position on a cart. The projection is easily performed in this position.
- Elevate the distal humerus on a radiolucent sponge.
- Place the IR in vertical position centered to the elbow joint.
- Epicondyles should be approximately perpendicular to the IR.
- Slowly flex the elbow 90 degrees to show the radial head or 80 degrees for the coronoid process. Turn the hand so that the palmar aspect is facing medially. An assistant may need to hold the hand depending on the severity of trauma (Fig. 5.141).
- *Shield gonads.*

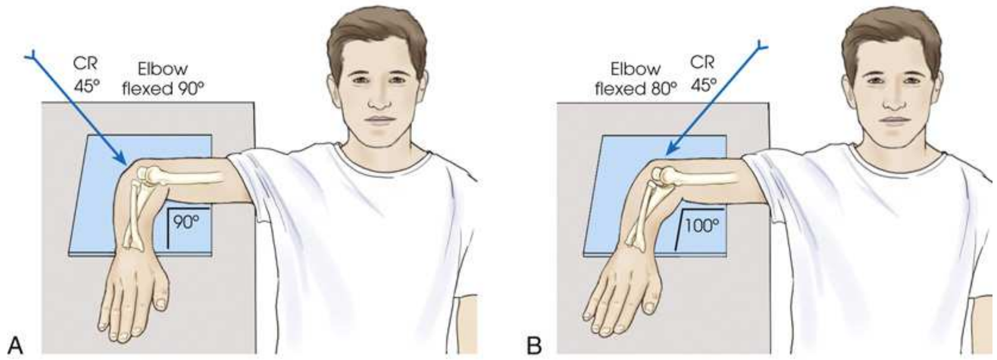


FIG. 5.140 (A) Axiolateral projection of elbow (Coyle method) to show radial head and capitulum. Forearm is 90 degrees, and CR is directed 45 degrees toward shoulder. (B) To show coronoid process and trochlea, forearm is positioned at 80 degrees, and CR is directed 45 degrees away from shoulder.

Diagram (A) shows the patient placing the humerus, elbow, and wrist joints on the image receptor. The elbow is flexed 90 degrees. The central ray is directed 45 degrees toward shoulder. Diagram (B) shows the patient placing the humerus, elbow, and wrist joints on the image receptor. The elbow is flexed 80 degrees. The central ray is directed 45 degrees away from shoulder.

Central ray

Seated position

Radial head

- Directed toward the shoulder at an angle of 45 degrees to the radial head; CR enters the joint at midelbow (see Fig. 5.140A)

Coronoid process

- Directed away from the shoulder at an angle of 45 degrees to the coronoid process; CR enters the joint at midelbow (see Fig. 5.140B)

Supine position for trauma

Radial head

- The horizontal CR is directed cephalad at an angle of 45 degrees to the radial head, entering the joint at midelbow (see Fig. 5.141A).

Coronoid process

- The horizontal CR is directed caudad at an angle of 45 degrees to the coronoid process, entering the joint at midelbow (see Fig. 5.141B).

Collimation

- Adjust radiation field to 3 inches (8 cm) proximal and distal to the elbow joint. Place side marker in the collimated exposure field.

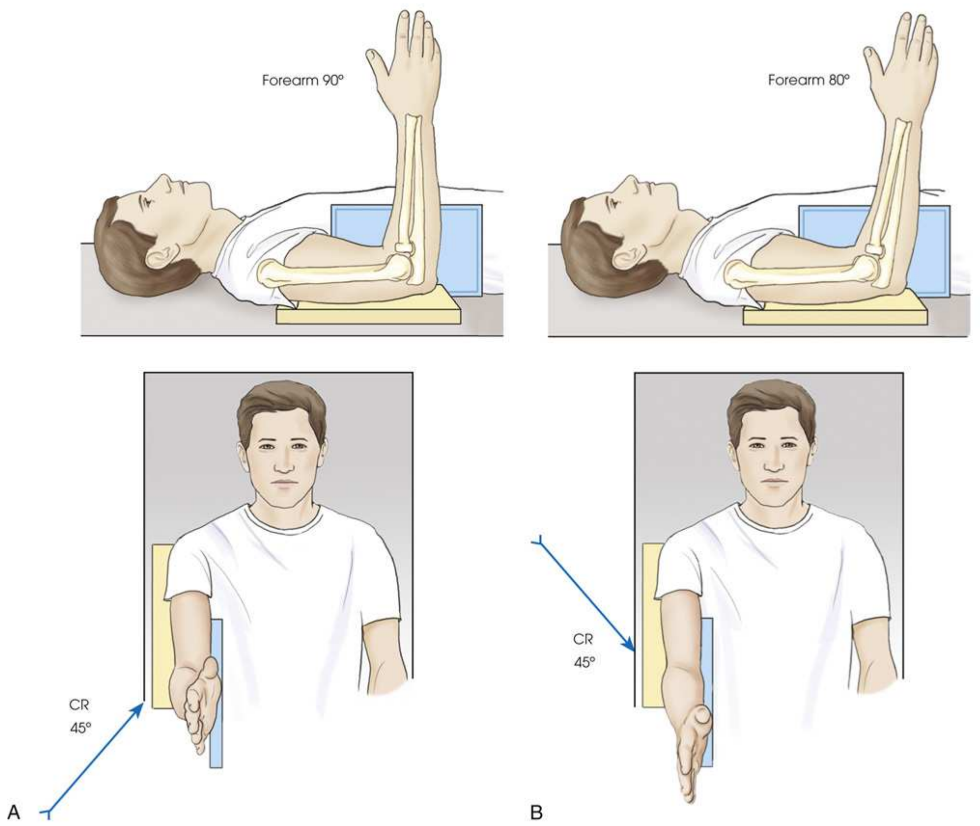


FIG. 5.141 Axiolateral projection of elbow (Coyle method) in trauma. (A) Patient is supine with humerus on a block, arm is 90 degrees, and CR is directed cephalad for radial head and capitulum. (B) Arm is 80 degrees, and CR is directed caudad to show coronoid process and trochlea.

The two diagrams (A) shows the side and top view of a patient lying supine with the humerus placed on a block. The forearm is 90 degrees. The horizontal central ray is directed cephalad at an angle of 45 degrees to the radial head. The two diagrams (B) shows the side and top view of a patient lying supine with the humerus placed on a block. The forearm is 80 degrees. The horizontal central ray is directed caudad at an angle of 45 degrees to the coronoid process.

Structures shown

The resulting projections show an open elbow joint between the radial head and capitulum (Fig. 5.142) or between the coronoid process and trochlea (Fig. 5.143), with the area of interest in profile. These projections are used to show pathologic processes or trauma in the area of the radial head and coronoid process. The value of the projections is evident in the trauma images shown in Fig. 5.144. [34]

Evaluation Criteria

The following should be clearly seen:

Radial Head

- Evidence of proper collimation and presence of side marker placed clear of anatomy of interest
- Open joint space between radial head and capitulum
- Radial head, neck, and tuberosity in profile and free from superimposition with the exception of a small portion of the coronoid process
- Humeral epicondyles distorted owing to CR angulation
- Radial tuberosity facing posteriorly
- Elbow flexed 90 degrees
- Bony trabecular detail and surrounding soft tissues

Coronoid Process

- Evidence of proper collimation and presence of side marker placed clear of anatomy of interest
- Open joint space between coronoid process and trochlea

- Coronoid process in profile and elongated
- Radial head and neck superimposed by ulna
- Elbow flexed 80 degrees
- Bony trabecular detail and surrounding soft tissues

Research: This projection was researched and standardized for the atlas by Tammy Curtis, MS, RT(R).

FIG. 5.142 Axiolateral elbow (Coyle method) with radial head and capitulum shown.

FIG. 5.143 Axiolateral elbow (Coyle method) with coronoid process and trochlea shown. From Bontrager KL, Lampignano JP. *Textbook of radiographic positioning and related anatomy*. 7th ed. St Louis: Mosby; 2009.

FIG. 5.144 (A) Lateral projection of elbow shows fracture of radial head, but bony overlap prevents exact evaluation of extent of fracture line. (B) Axiolateral projection (Coyle method) clearly shows displaced articular fracture involving posterior third of radial head. Used with permission from Greenspan A, Norman A, Rosen H. Radial head capitulum view in elbow trauma: clinical applications and anatomic correlation. *AJR Am J Roentgenol.* 1984;143:355.

Distal Humerus

PA Axial Projection

Image receptor:

Positioned by manufacturer or department protocol for proper anatomy display orientation; CR plate: 10 × 12 inches (24 × 30 cm) lengthwise.

Position of patient

- Seat the patient high enough to enable the forearm to rest on the radiographic table, with the arm in the vertical position. The patient must be seated so that the forearm can be adjusted parallel with the long axis of the table.

Position of part

- Ask the patient to rest the forearm on the table, and then adjust the forearm so that its long axis is parallel with the table.
- Center a point midway between the epicondyles and the center of the IR.
- Flex the patient's elbow to place the arm in a nearly vertical position so that the humerus forms an angle of approximately 75 degrees from the forearm (approximately 15 degrees between the CR and the long axis of the humerus).
- Confirm that the patient is not leaning anteriorly or posteriorly.
- Supinate the hand to prevent rotation of the humerus and ulna, and have the patient immobilize it with the opposite hand (Fig. 5.145).
- *Shield gonads.*

Central ray

- Perpendicular to the ulnar sulcus, entering at a point just medial to the olecranon process

Collimation

- Adjust radiation field to include distal third of humerus and extend 2 inches (5 cm) beyond the olecranon process and 1 inch (2.5 cm) beyond the sides on the elbow. Place side marker in the collimated exposure field.

Structures shown

The epicondyles, trochlea, ulnar sulcus (groove between the medial epicondyle and the trochlea), and olecranon fossa (Fig. 5.146). The projection is used in radiohumeral bursitis (tennis elbow) to detect otherwise obscured calcifications located in the ulnar sulcus.

NOTE: Long and Rafert [35] describe an AP oblique distal humerus projection that specifically shows the ulnar sulcus.

Evaluation Criteria

The following should be clearly seen:

- Evidence of proper collimation and presence of side marker placed clear of anatomy of interest
- Outline of the ulnar sulcus (groove)

- Forearm and humerus superimposed, without rotation
- Bony trabecular detail and surrounding soft tissues

FIG. 5.145 PA axial distal humerus.

A patient is resting the forearm on the image receptor. The arm in vertical position and the the humerus forms an angle 75 degrees from the forearm. The side marker is in the collimated exposure field. The central ray is perpendicular to the ulnar sulcus.

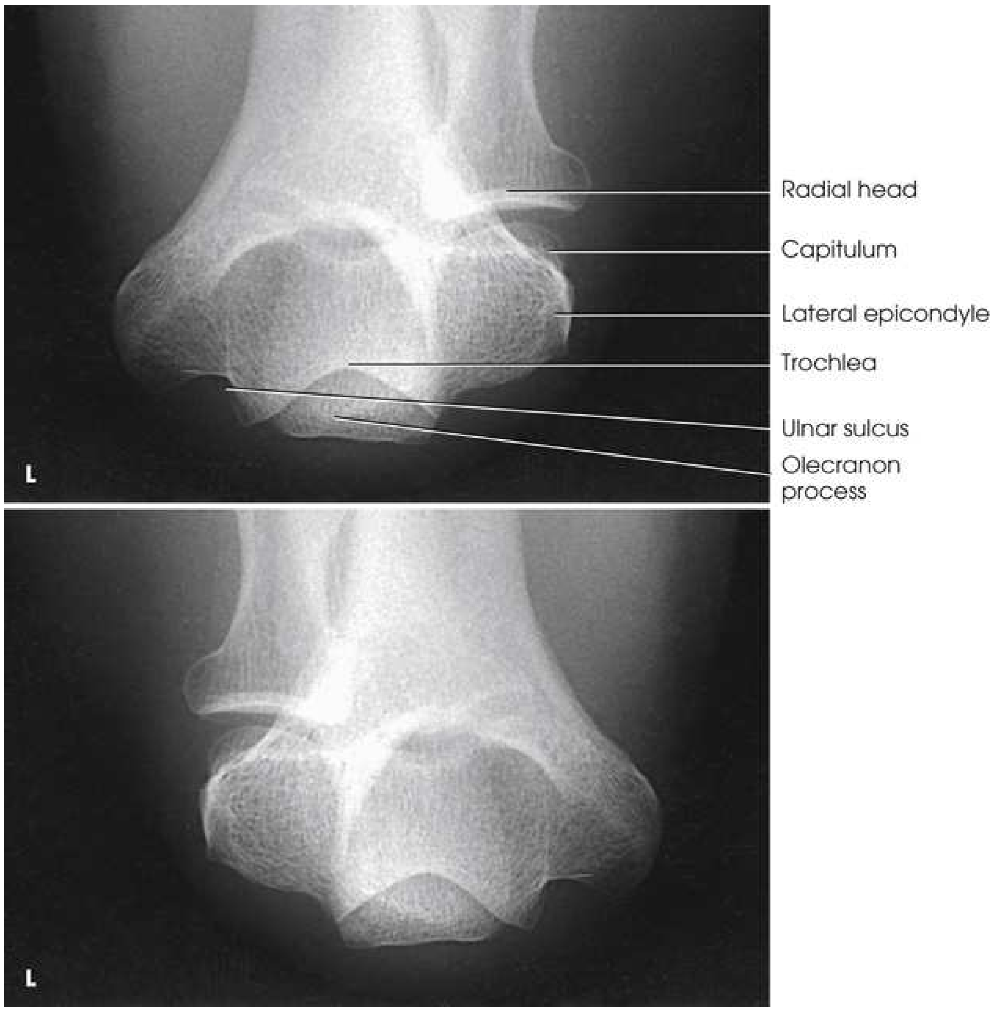


FIG. 5.146 PA axial distal humerus.

(A) shows an x-ray view of the distal humerus. The parts labeled are as follows: radial head, capitulum, lateral epicondyle, trochlea, ulnar sulcus, and olecranon process. (B) An x-ray shows the outline of the ulnar sulcus (groove).

Olecranon Process

PA Axial Projection

Image receptor:

Positioned by manufacturer or department protocol for proper anatomy display orientation; CR plate: 10 × 12 inches (24 × 30 cm) lengthwise.

Position of patient

- Seat the patient at the end of the radiographic table, high enough that the forearm can rest flat on the IR.

Position of part

- Adjust the arm at an angle of 45 to 50 degrees from the vertical position and ensure that the patient is not leaning anteriorly or posteriorly.
- Supinate the hand, and have the patient immobilize it with the opposite hand.
- Center a point midway between the epicondyles and the center of the IR.
- *Shield gonads.*

Central ray

- Perpendicular to the olecranon process to show the dorsum of the olecranon process and at a 20-degree angle toward the wrist to show the curved extremity and articular margin of the olecranon process (Fig. 5.147)

Collimation

- Adjust radiation field to include distal fourth of humerus and extend 1 inch (2.5 cm) beyond the olecranon process and the sides on the elbow. Place side marker in the collimated exposure field.

Structures shown

The olecranon process and the articular margin of the olecranon and humerus (Figs. 5.148 through 5.150).

Evaluation Criteria

The following should be clearly seen:

- Evidence of proper collimation and presence of side marker placed clear of anatomy of interest
- Olecranon process in profile
- Forearm and humerus superimposed, without rotation
- Bony trabecular detail and surrounding soft tissues

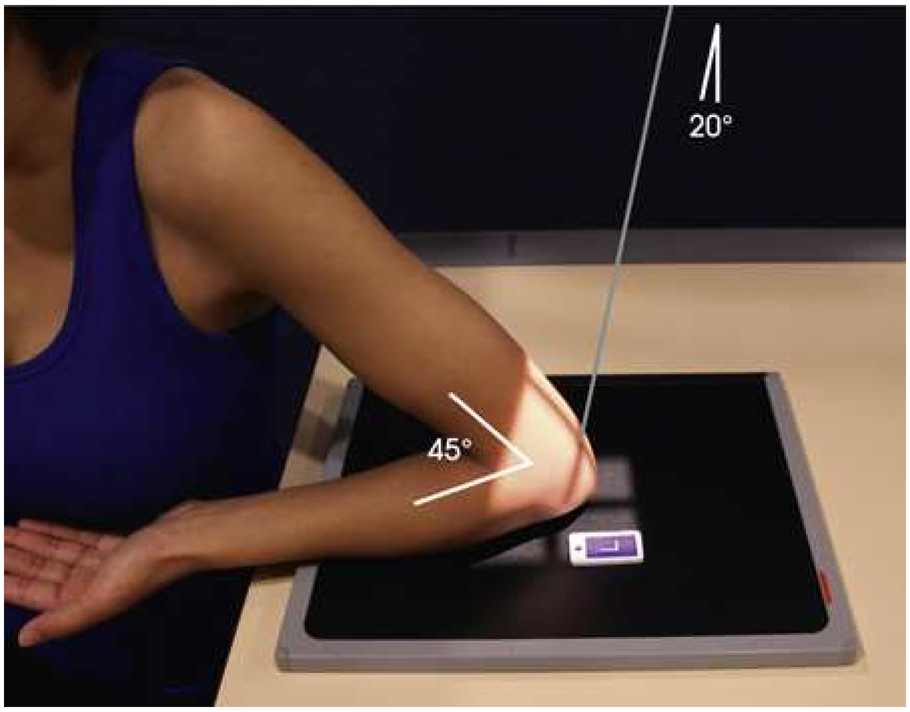


FIG. 5.147 PA axial olecranon process with central ray angled 20 degrees.

The patient's elbow is flexed and the arm is placed in a vertical position at an angle of 45 to 50 degrees from the vertical position. The side marker is in the collimated exposure field. The central ray is angled perpendicular to the olecranon process at 20 degree angle.

FIG. 5.148 PA axial olecranon process.

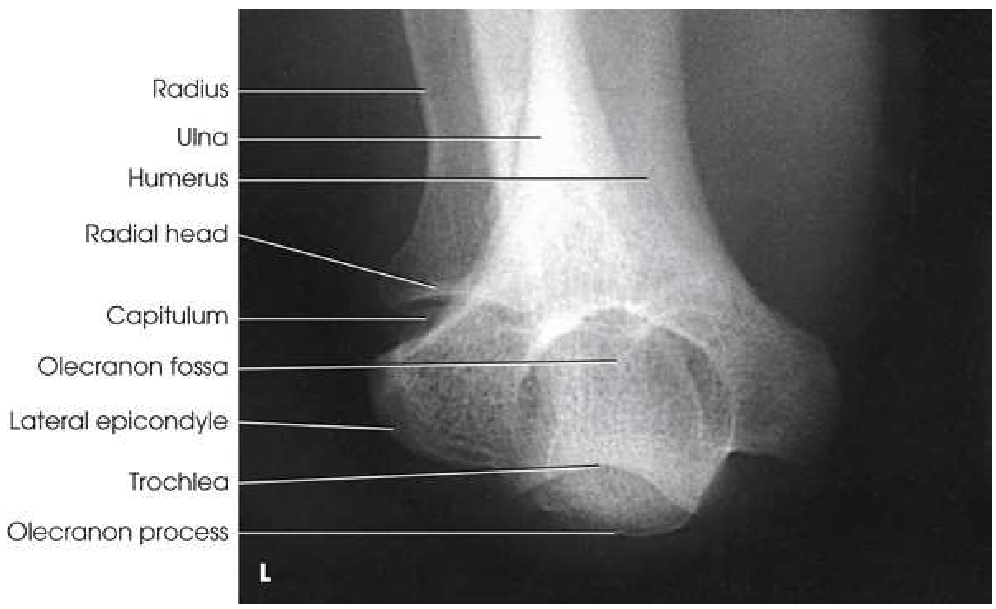


FIG. 5.149 PA axial olecranon process with central ray angulation of 0 degrees.

An x-ray shows the olecranon process and the articular margin of the olecranon and humerus. It appears grainy. The parts labeled are as follows: radius, ulna, humerus, radial head, capitulum, olecranon fossa, lateral epicondyle, trochlea, and olecranon process.

FIG. 5.150 PA axial olecranon process with central ray angulation of 20 degrees.

Humerus

AP Projection

Upright

Shoulder and arm abnormalities, whether traumatic or pathologic in origin, are extremely painful. For this reason, an upright position, either standing or seated, should be used whenever possible. The upright position allows rotation of the patient's body as required, the arm can be positioned quickly and accurately with minimal discomfort to the patient.

Image receptor + grid:

Positioned by manufacturer or department protocol for proper anatomy display orientation; CR plate: 14 × 17 inches (35 × 43 cm) lengthwise.

Position of patient

- Place the patient in a seated-upright or standing position facing the x-ray tube.
- Fig. 5.151 illustrates the body position used for an AP projection of a freely movable arm. The body position, whether oblique or facing toward or away from the IR, is unimportant as long as an AP radiograph of the arm is obtained.

Position of part

- Adjust the height of the IR to place its upper margin approximately 1½ inches (3.8 cm) above the level of the humeral head.
- Abduct the arm slightly and supinate the hand.
- A coronal plane passing through the epicondyles should be parallel with the IR plane for the AP (or PA) projection (see Fig. 5.151).
- *Shield gonads.*
- *Respiration:* Suspend.

Central ray

- Perpendicular to the midportion of the humerus and the center of the IR

Collimation

- Adjust radiation field to 2 inches (5 cm) distal to the elbow joint and superior to the shoulder and 1 inch (2.5 cm) on the sides. Place side marker in the collimated exposure field.

Structures shown

The AP projection shows the entire length of the humerus. The accuracy of the position is shown by the epicondyles (Fig. 5.152).

Evaluation Criteria

The following should be clearly seen:

- Evidence of proper collimation and presence of side marker placed clear of anatomy of interest
- Elbow and shoulder joints visible but slightly distorted due to beam divergence
- Humeral epicondyles without rotation
- Humeral head and greater tubercle in profile
- Outline of the lesser tubercle, located between the humeral head and the greater tubercle
- Bony trabecular detail and surrounding soft tissues

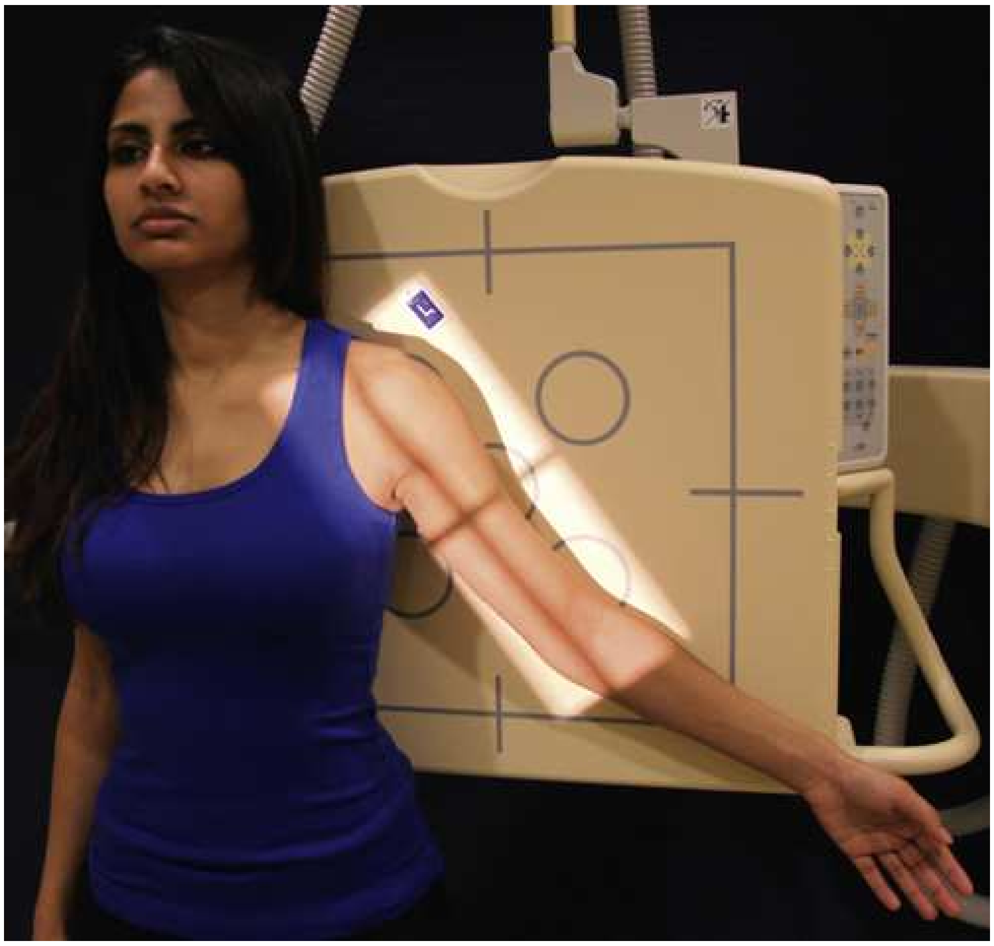


FIG. 5.151 Upright position for AP humerus.

The patient's is standing close to the vertical grid with her arm abducted and the hand supinated. A coronal plane passing through the epicondyle divides it into four quadrants. The central ray is perpendicular to the midportion of the humerus.

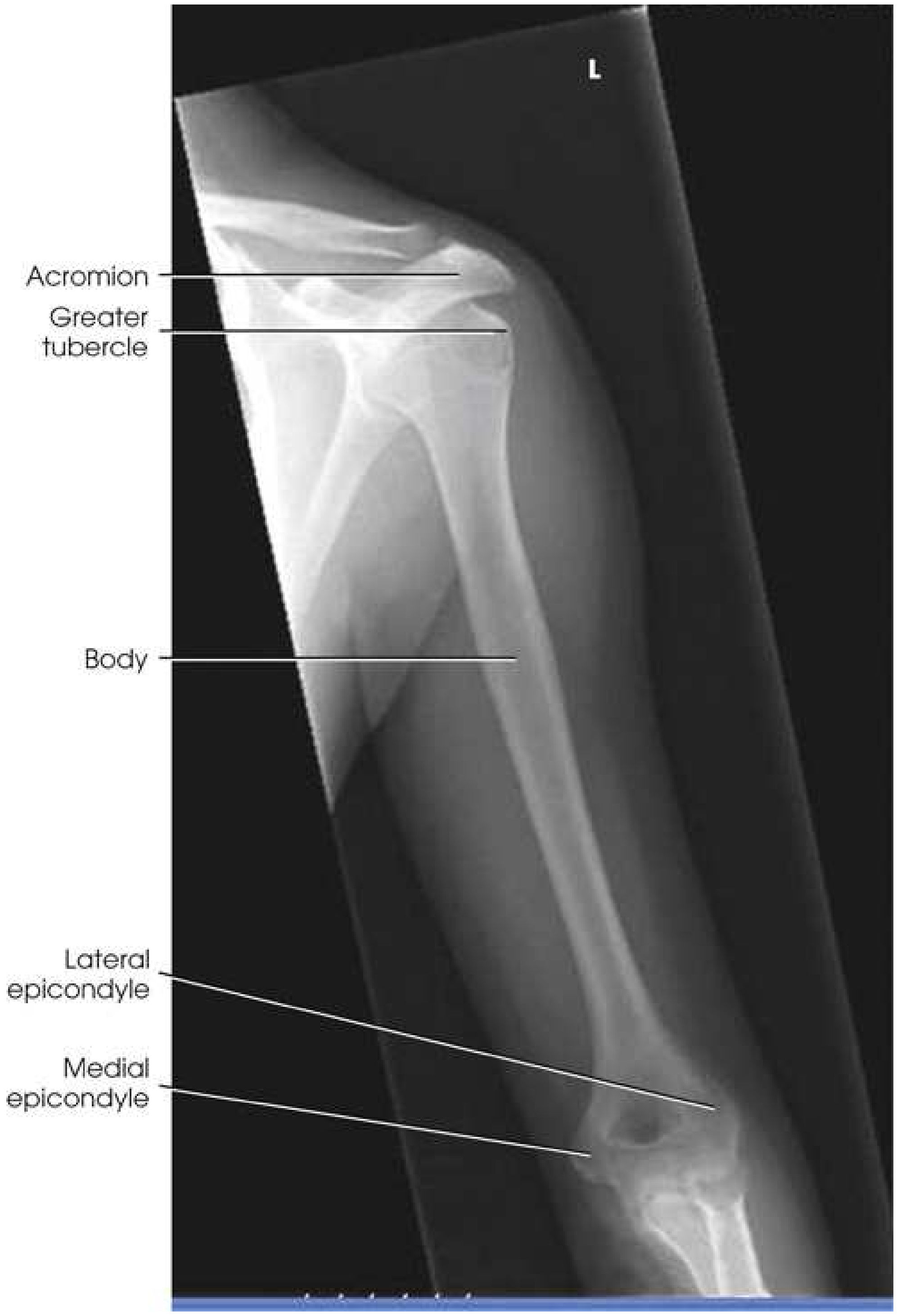


FIG. 5.152 Upright AP humerus.

Lateral Projection

Lateromedial, mediolateral

Upright

Image receptor + grid:

Positioned by manufacturer or department protocol for proper anatomy display orientation; CR plate: 14 × 17 inches (35 × 43 cm) lengthwise.

Position of patient

- Place the patient in a seated-upright or standing position facing the x-ray tube. The body position, whether oblique or facing toward or away from the IR, is not critical as long as a true lateral projection of the arm is obtained.

Position of part

- Place the top margin of the IR approximately 1½ inches (3.8 cm) above the level of the humeral head.

- Unless contraindicated by possible fracture, internally rotate the arm, flex the elbow approximately 90 degrees, and place the patient's anterior hand on the hip. This places the humerus in lateral position. A coronal plane passing through the epicondyles should be perpendicular with the IR plane (Fig. 5.153).
- A patient with a broken humerus may be easier to position by performing a mediolateral projection as shown in Fig. 5.154. Face the sitting or standing patient toward the IR and incline the thorax as necessary to align the humerus for the mediolateral projection. If the patient is not already holding the hand of the broken arm, have the patient do so.
- *Shield gonads.*
- *Respiration:* Suspend.

Central ray

- Perpendicular to the midportion of the humerus and the center of the IR

Collimation

- Adjust radiation field to 2 inches (5 cm) distal to the elbow joint and superior to the shoulder and 1 inch (2.5 cm) on the sides. Place side marker in the collimated exposure field.

Structures shown

The lateral projection shows the entire length of the humerus. A true lateral image is confirmed by superimposed epicondyles (Fig. 5.155).

Evaluation Criteria

The following should be clearly seen:

- Evidence of proper collimation and presence of side marker placed clear of anatomy of interest
- Elbow and shoulder joints visible but slightly distorted due to beam divergence
- Superimposed humeral epicondyles
- Lesser tubercle in profile on medial aspect
- Greater tubercle superimposed over the humeral head
- Bony trabecular detail and surrounding soft tissues

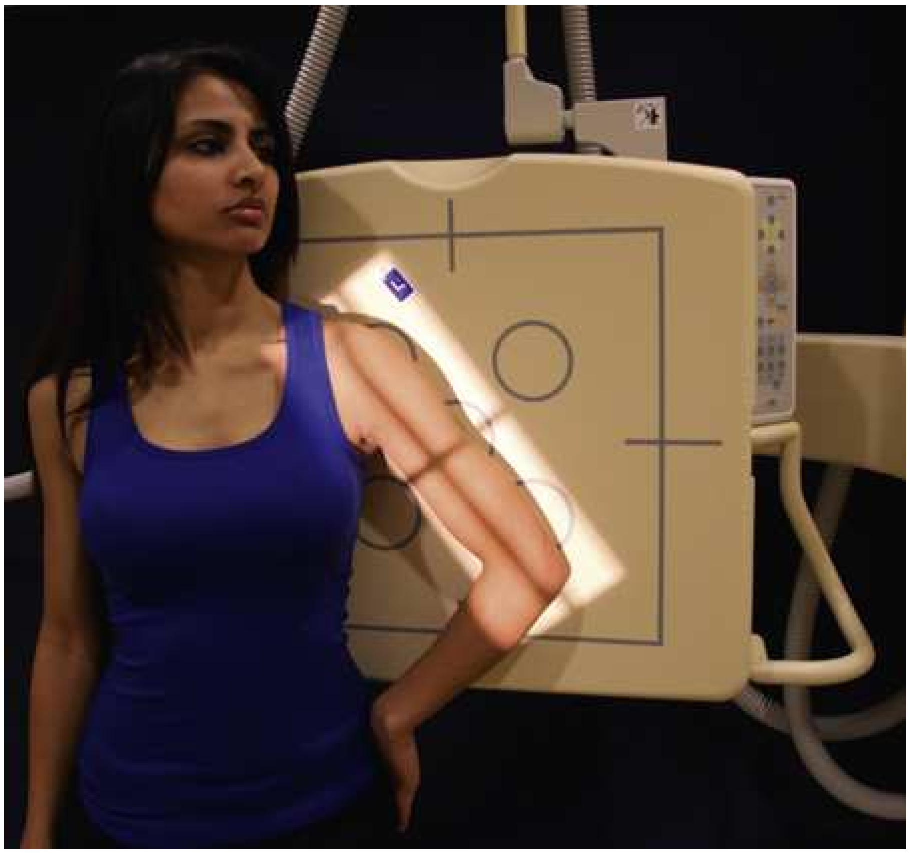


FIG. 5.153 Upright position for lateral (lateromedial) humerus. Note hand placement on hip.

The patient's is standing close to the vertical grid with her arm rotated internally and the elbow is flexed. The patient's anterior hand is placed on the hip. A coronal plane passing through the epicondyle divides it into four quadrants. The central ray is perpendicular to the midportion of the humerus.

FIG. 5.154 A patient with broken humerus may be easier to position for mediolateral projection as shown.

The patient's is standing facing the vertical grid with the thorax inclined. She is standing holding the broken arm with the other arm. A coronal plane passing through the epicondyle divides it into four quadrants. The central ray is perpendicular to the midportion of the humerus.

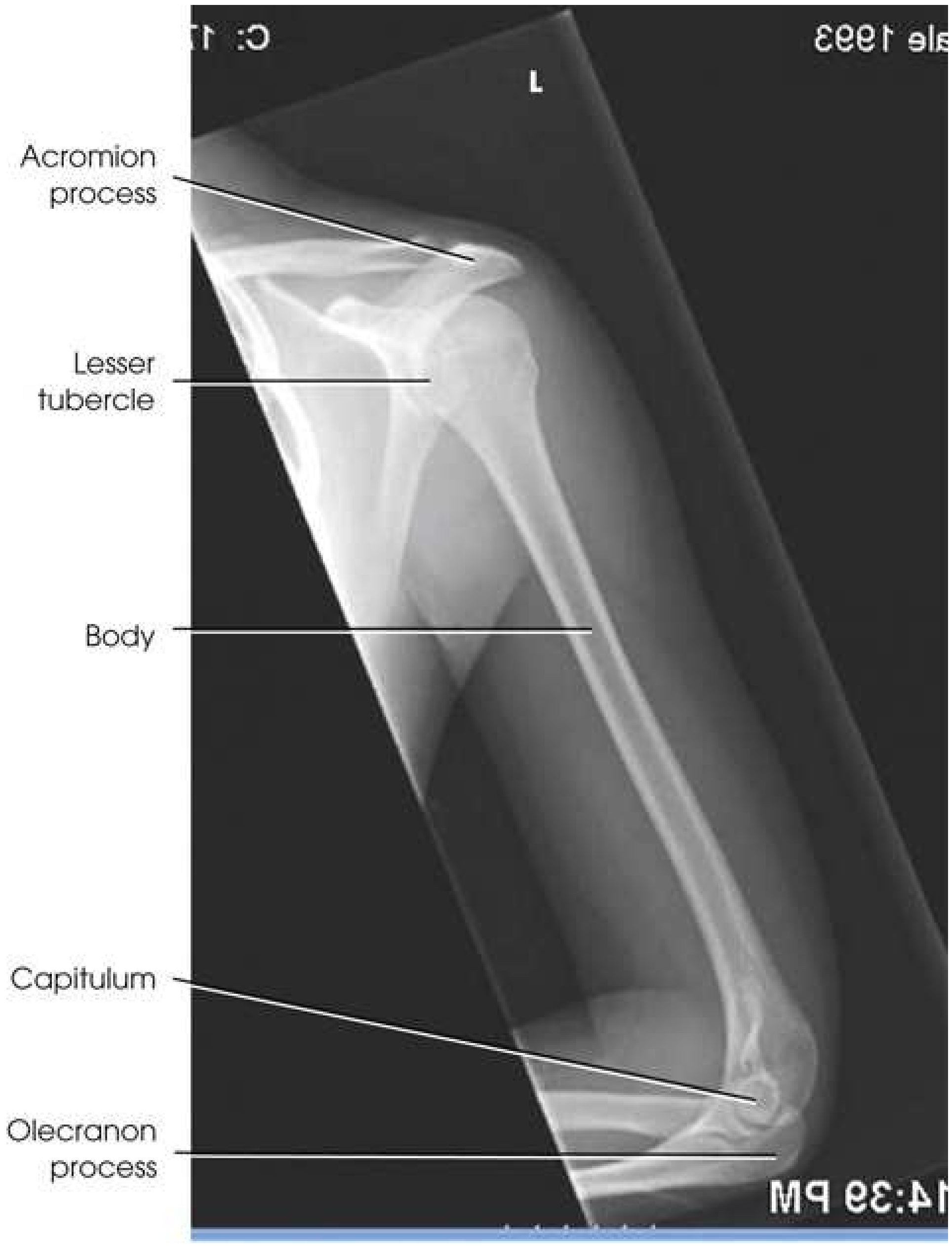


FIG. 5.155 Upright lateral humerus.

An x-ray shows the elbow and shoulder joints visible but slightly distorted. The parts labeled are listed from top to bottom as follows: acromion process, lesser tubercle, body, capitulum, and olecranon process

AP Projection

Recumbent

Image receptor + grid:

Positioned by manufacturer or department protocol for proper anatomy display orientation; CR plate: 14 × 17 inches (35 × 43 cm) lengthwise.

Position of patient

- With the patient in the supine position, adjust the IR to include the entire length of the humerus.

Position of part

- Place the upper margin of the IR approximately 1½ inches (3.8 cm) above the humeral head.
- Elevate the opposite shoulder on a sandbag to place the affected arm in contact with the IR, or elevate the arm and IR on sandbags.
- Unless contraindicated, supinate the hand, extend the elbow, and rotate the extremity to place the epicondyles parallel with the plane of the IR (see Fig. 5.156).
- *Shield gonads.*
- *Respiration:* Suspend.

Central ray

- Perpendicular to the midportion of the humerus and the center of the IR

Collimation

- Adjust radiation field to 2 inches (5 cm) distal to the elbow joint and superior to the shoulder and 1 inch (2.5 cm) on the sides. Place side marker in the collimated exposure field.

Structures shown

The AP projection shows the entire length of the humerus. The accuracy of the position is shown by the epicondyles (see Fig. 5.156).

Evaluation Criteria

The following should be clearly seen:

- Evidence of proper collimation and presence of side marker placed clear of anatomy of interest
- Elbow and shoulder joints visible but slightly distorted due to beam divergence
- Humeral epicondyles without rotation
- Humeral head and greater tubercle in profile
- Outline of the lesser tubercle, located between the humeral head and the greater tubercle
- Bony trabecular detail and surrounding soft tissues

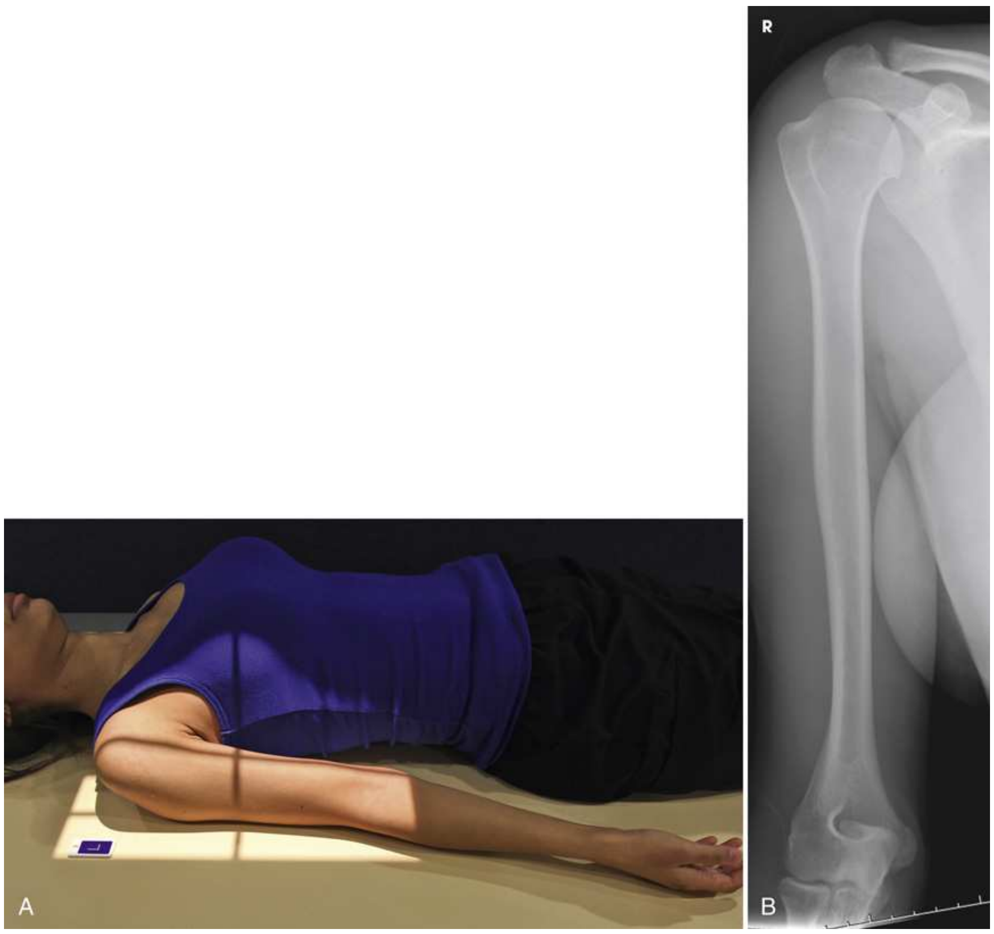


FIG. 5.156 (A) Recumbent position for AP humerus. Note that hand is supinated. (B) AP humerus in correct position.

(A) shows a patient lying in supine position on the image receptor. The hand of the patient is supinated and the elbow is extended. The central ray is perpendicular to the midportion of the humerus. (B) The x-ray shows the entire length of the humerus. The elbow and shoulder joints visible but slightly distorted.

Lateral Projection

Lateromedial

Recumbent

Image receptor + grid:

Positioned by manufacturer or department protocol for proper anatomy display orientation; CR plate: 14 × 17 inches (35 × 43 cm) lengthwise.

Position of patient

- Place the patient in the supine position with the humerus centered to the IR or use a Bucky tray.

Position of part

- Adjust the top of the IR to be approximately 1½ inches (3.8 cm) above the level of the head of the humerus.
- Unless contraindicated by possible fracture, abduct the arm and center the IR under it.
- Rotate the forearm medially to place the epicondyles perpendicular to the plane of the IR, and rest the *posterior aspect* of the hand against the patient's side. This movement turns the epicondyles in the lateral position without flexing the elbow (see Fig. 5.153). (The elbow may be flexed slightly for comfort.)
- Adjust the position of the IR to include the entire length of the humerus (Fig. 5.157).
- *Shield gonads.*
- *Respiration:* Suspend.

Central ray

- Perpendicular to the midportion of the humerus and the center of the IR

Collimation

- Adjust radiation field to 2 inches (5 cm) distal to the elbow joint and superior to the shoulder and 1 inch (2.5 cm) on the sides. Place side marker in the collimated exposure field.

Structures shown

The lateral projection shows the entire length of the humerus. A true lateral image is confirmed by superimposed epicondyles (see Fig. 5.157).

Evaluation Criteria

The following should be clearly seen:

- Evidence of proper collimation and presence of side marker placed clear of anatomy of interest
- Elbow and shoulder joints visible but slightly distorted due to beam divergence

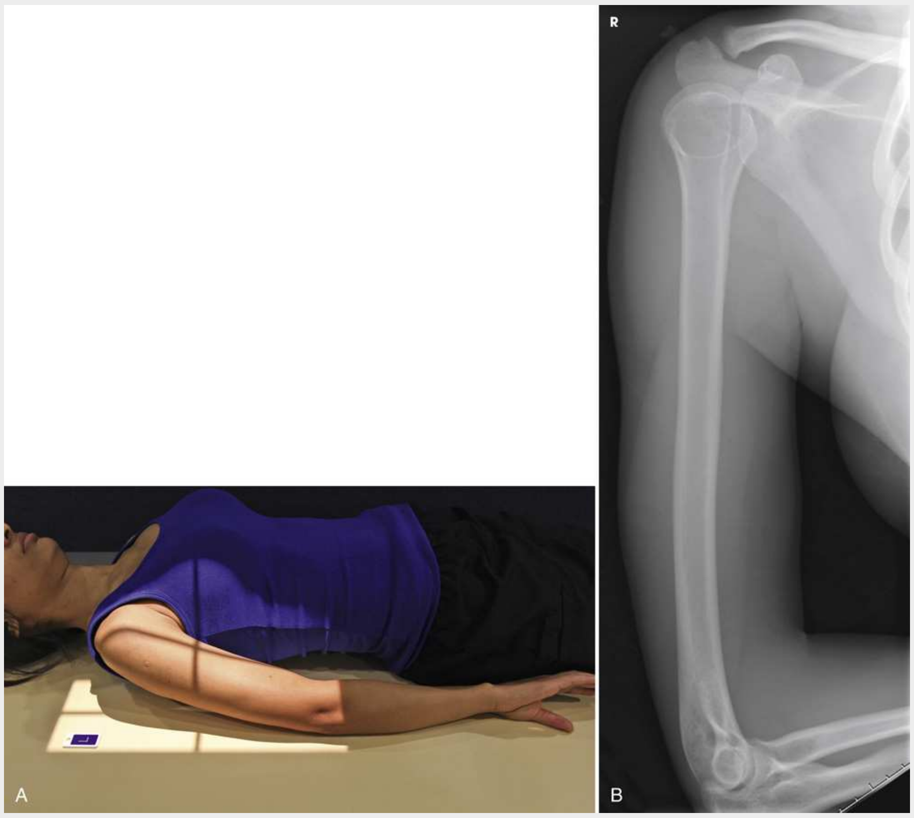


FIG. 5.157 (A) Recumbent position for lateral humerus. Note posterior aspect of the patient's hand against thigh. (B) Lateral humerus, supine position. Note epicondyles are perpendicular to IR. Distal aspect of forearm could not be included because of patient's condition, separate lateral elbow was performed.

(A) shows a patient lying in supine position on the image receptor. The posterior aspect of the patient's hand is against the thigh. The central ray is perpendicular to the midportion of the humerus. (B) The x-ray shows the entire length of the humerus. The elbow and shoulder joints visible but slightly distorted.

- Superimposed humeral epicondyles
- Lesser tubercle in profile
- Greater tubercle superimposed over the humeral head
- Bony trabecular detail and surrounding soft tissues

Lateral Projection

Lateromedial

Recumbent or lateral recumbent

Image receptor:

Positioned by manufacturer or department protocol for proper anatomy display orientation; CR plate: 10 × 12 inches (24 × 30 cm) lengthwise.

Position of patient

- When a known or suspected fracture exists, position the patient in the recumbent or lateral recumbent position, place the IR close to the axilla, and center the humerus to the midline of the IR.
- Unless contraindicated, flex the elbow, turn the thumb surface of the hand up, and rest the humerus on a suitable support (see Fig. 5.158).
- Adjust the position of the body to place the lateral surface of the humerus perpendicular to the CR.
- *Shield gonads.*
- *Respiration:* Suspend.

Central ray

Recumbent

- Horizontal and perpendicular to the midportion of the humerus and the center of the IR

Lateral recumbent

• Directed to the center of the IR, which exposes only the distal humerus (see Fig. 5.158)

Collimation

• Adjust radiation field to 2 inches (5 cm) distal to the elbow joint and 1 inch (2.5 cm) on the sides; top collimator margin should extend no farther than edge of the IR

Structures shown

The lateral projection shows the distal humerus (Fig. 5.159).

Evaluation Criteria

The following should be clearly seen:

- Evidence of proper collimation and presence of side marker placed clear of anatomy of interest
- Distal humerus
- Superimposed epicondyles
- Bony trabecular detail and surrounding soft tissues

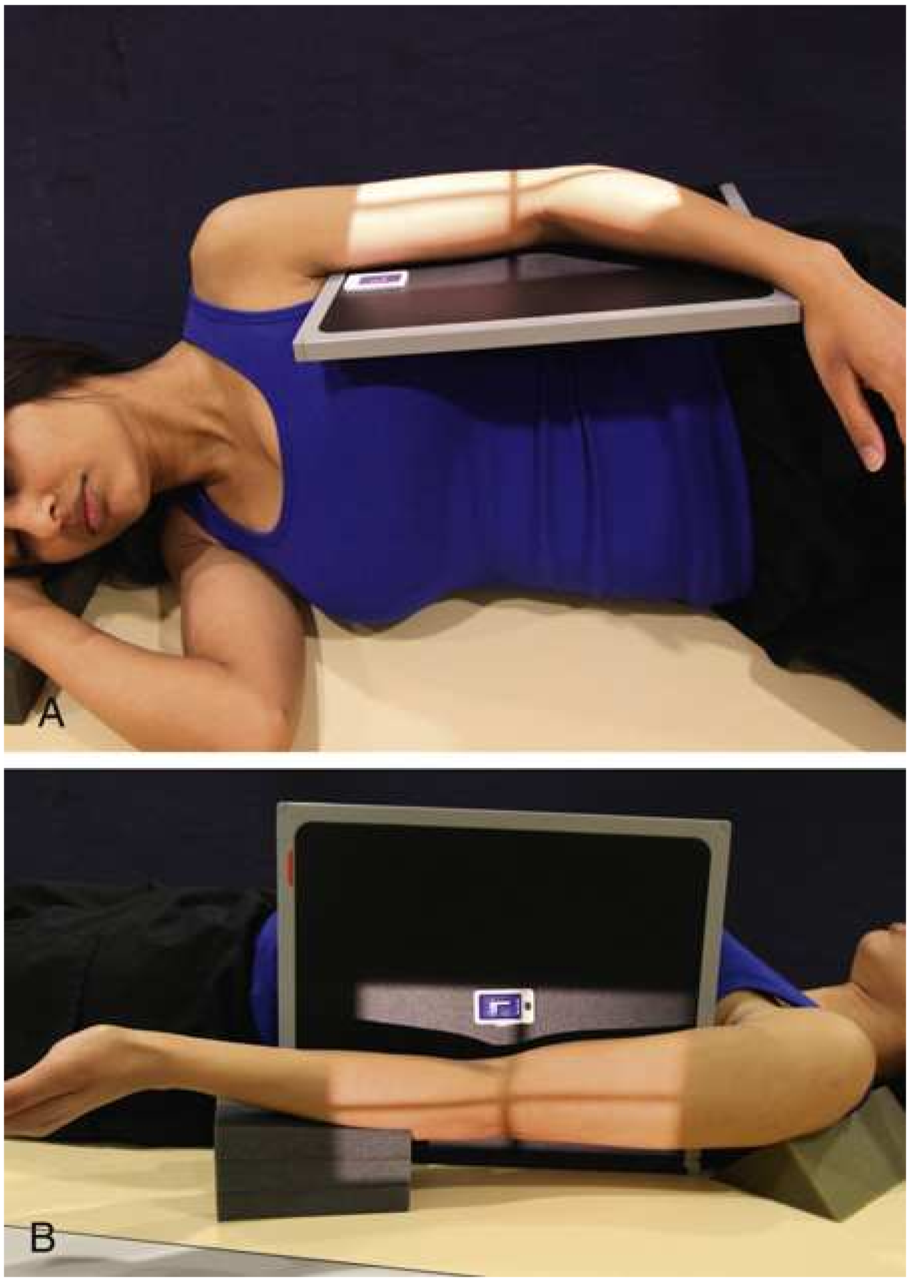


FIG. 5.158 (A) Lateral recumbent body position to show distal lateral humerus. (B) Patient and IR positioned for trauma cross-table lateral projection of humerus.

(A) shows a patient positioned in lateral recumbent position with her hand under her head. The image receptor is placed close to the axilla and the humerius is centered to the midline of the I R. The side marker is in the collimated exposure field. The central ray is horizontal and perpendicular to the midportion of the humerus. (B) shows a patient lying in a supine position. The elbow is flexed and the thumb surface of the hand is up. The humerus is on a support and the shoulder is supported. The side marker is in the collimated exposure field. The central ray is horizontal and perpendicular to the midportion of the humerus.

FIG. 5.159 (A) Lateral recumbent humerus, showing healing fracture *(arrow)*. (B) Lateral recumbent humerus showing comminuted fracture. Radiograph had to be obtained using lateral recumbent position owing to the patient's pain.

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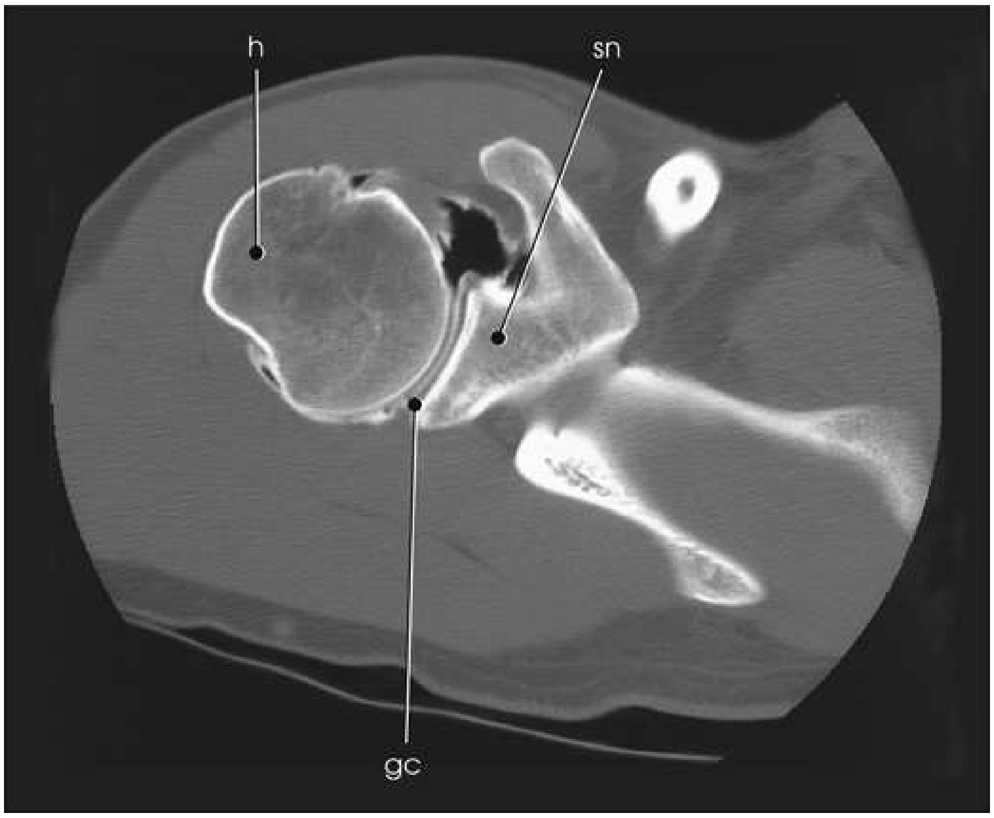
6: Shoulder Girdle



OUTLINE

Summary of Projections

Projections, Positions, and Methods

Page	Essential	Anatomy	Projection	Position	Method
229		Shoulder	AP	External, neutral, internal rotation humerus	
234		Shoulder joint: *glenoid cavity*	AP oblique	RPO or LPO	GRASHEY
236		Shoulder joint: *glenoid cavity*	AP oblique	RPO or LPO	APPLE
238		Shoulder	Transthoracic lateral	R or L	LAWRENCE
240		Shoulder joint	Inferosuperior axial		LAWRENCE
240		Shoulder joint	Inferosuperior axial		RAFERT ET AL. MODIFICATION
242		Shoulder joint	Inferosuperior axial		WEST POINT
244		Shoulder joint	Superoinferior axial		
245		Shoulder joint: *scapular Y*	PA oblique	RAO or LAO	
248		Shoulder joint: *supraspinatus “outlet”*	Tangential	RAO or LAO	NEER
249		Shoulder joint	AP axial		
250		Shoulder joint: *proximal humerus*	AP axial		STRYKER “NOTCH”
251		Shoulder joint: *glenoid cavity*	AP axial oblique	RPO or LPO	GARTH
253		Proximal humerus: *intertubercular groove*	Tangential		FISK MODIFICATION
255		Acromioclavicular articulations	AP	Bilateral	PEARSON
257		Acromioclavicular articulations	AP axial		ALEXANDER
259		Clavicle	AP		
260		Clavicle	AP axial	Lordotic	
262		Clavicle	PA		
263		Clavicle	PA axial		
264		Scapula	AP		
266		Scapula	Lateral	RAO or LAO	
269		Scapula	AP oblique	RPO or LPO	
271		Scapula: *coracoid process*	AP axial		
273		Scapular spine	Tangential		LAQUERRIÈRE-PIERQUIN

The icons in the Essential column indicate projections frequently performed in the United States and Canada. Students should become competent in these projections.

AP, Anteroposterior; *L,* left; *LAO,* left anterior oblique; *LPO,* left posterior oblique; *PA,* posteroanterior; *R,* right; *RAO,* right anterior oblique; *RPO,* right posterior oblique.

Anatomy

Shoulder Girdle

The *shoulder girdle* is formed by two bones—the *clavicle* and *scapula.* The function of these bones is to connect the upper limb to the trunk. Although the alignment of these two bones is considered a girdle, it is incomplete in the back. The girdle is completed in front by the sternum, which articulates with the medial end of the clavicle. The scapulae are widely separated in the back. The proximal portion of the humerus is part of the upper limb and not the shoulder girdle proper. However, because the proximal humerus is included in the shoulder joint, its anatomy is considered with that of the shoulder girdle (Figs. 6.1 and 6.2).

Clavicle

The *clavicle,* classified as a long bone, has a body and two articular extremities (see Fig. 6.1). The clavicle lies in a horizontal oblique plane just above the first rib and forms the anterior part of the shoulder girdle. The lateral aspect is termed the *acromial extremity*, and it articulates with the acromion of the scapula. The *medial* aspect, termed the *sternal extremity*, articulates with the manubrium of the sternum and the first costal cartilage. The clavicle, which serves as a fulcrum for the movements of the arm, is doubly curved for strength. The curvature is more acute in males than in females.

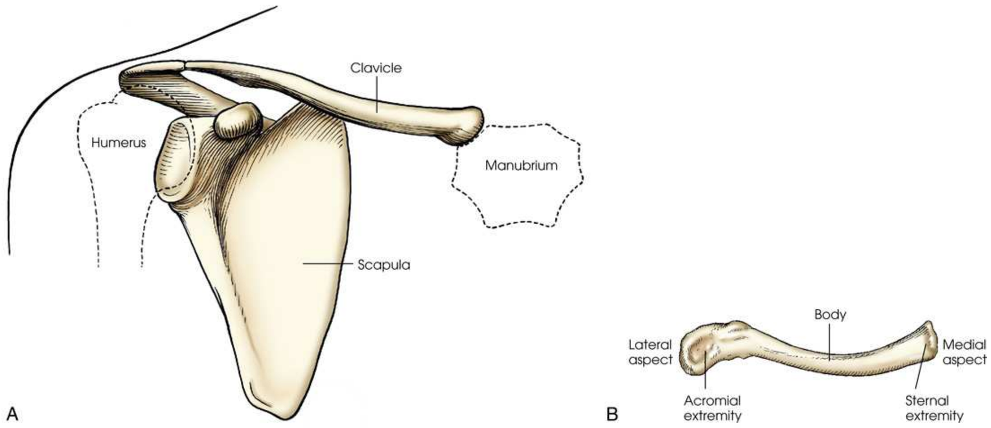


FIG. 6.1 (A) Anterior aspect of shoulder girdle: clavicle and scapula. Girdle attaches to humerus and manubrium of sternum. (B) Superior aspect of right clavicle.

Diagram (A) shows the long bone that is the clavicle attached to the scapula and the two articular extremities humerus and manubrium of the sternum. Diagram (B) shows the doubly curved clavicle. The parts labeled in the diagram are as follows: body, lateral aspect, medial aspect, acromial extremity, and sternal extremity.

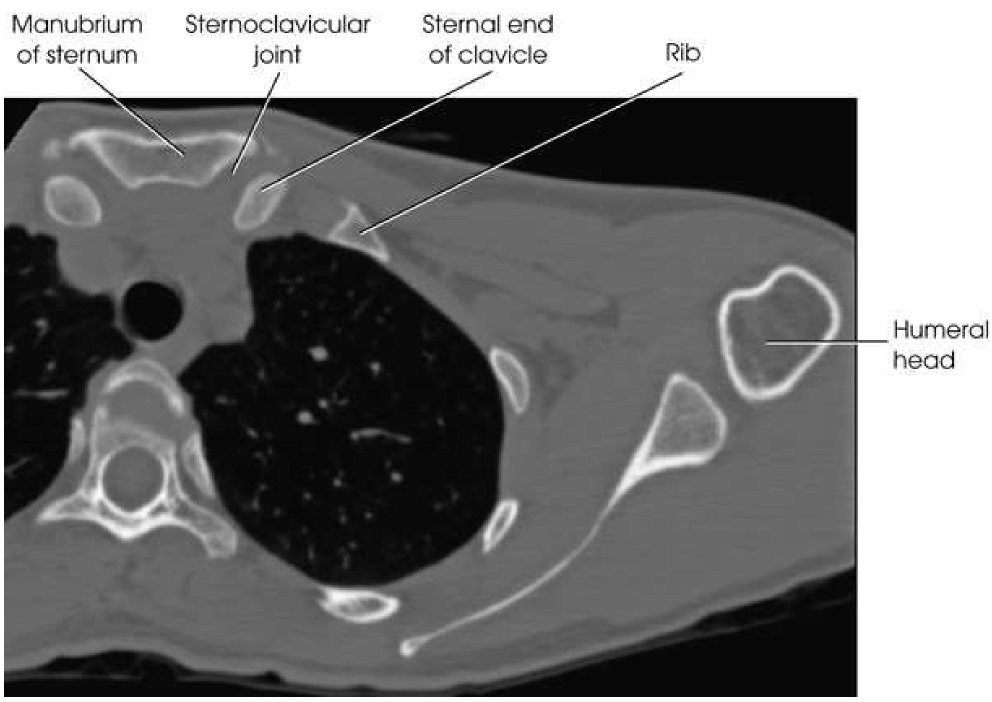


FIG. 6.2 Axial CT scan of shoulder showing relationship of anatomy. Note 45- to 60-degree angle of scapula.

An axial C T scan shows the manubrium of the sternum shaped like a trapezoid, the sternoclavicular joint between the manubrium of the sternum and sternal end of the clavicle, the rib is shaped like a triangle, and the humeral head is shaped like an irregular square. The middle part appears dark and the parts marked have white outlines.

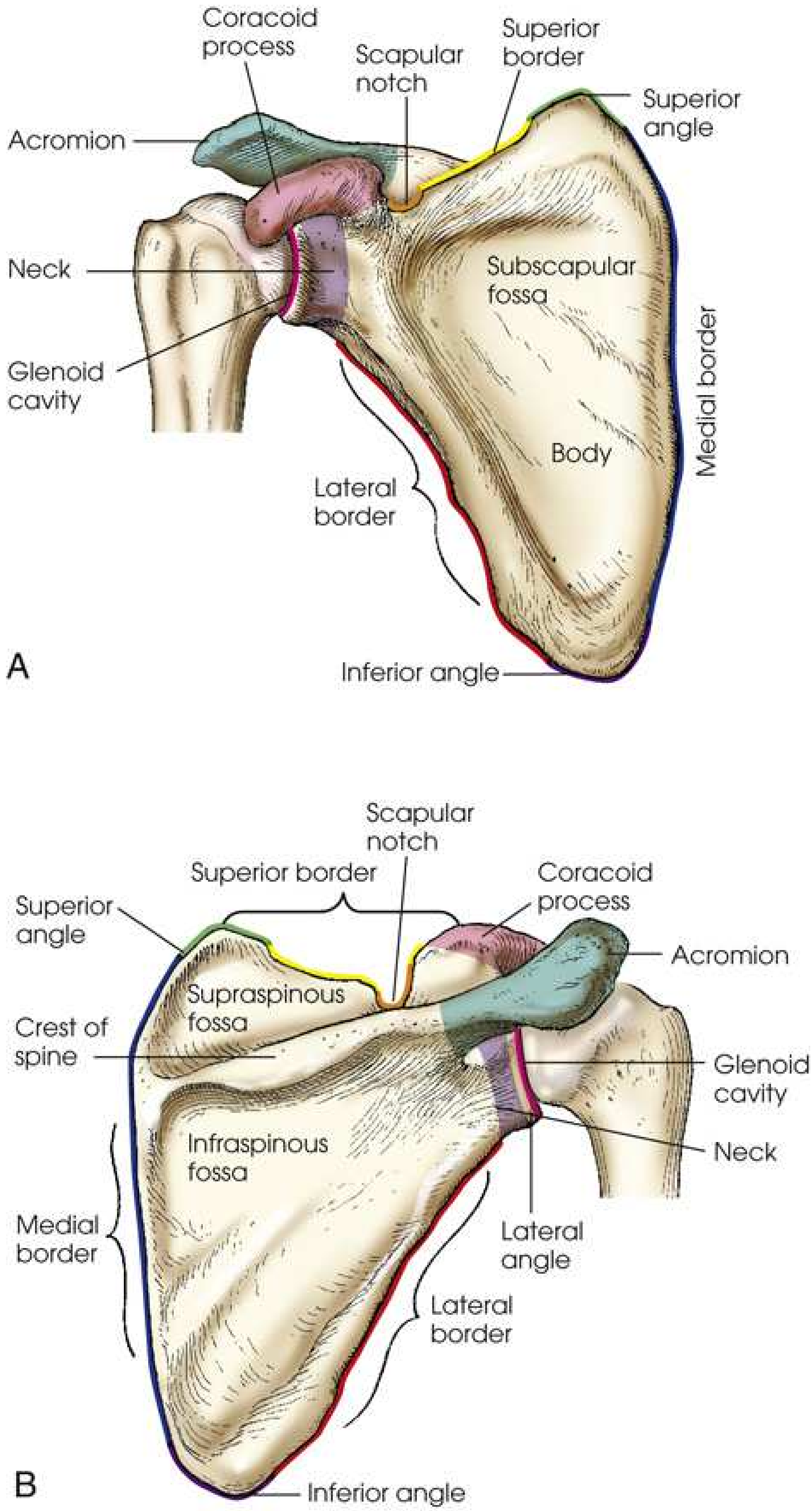


FIG. 6.3 Scapula. Color-coded (A) costal surface (anterior aspect) and (B) dorsal surface (posterior aspect). *Black*, Lateral angle (B only); *blue*, medial border; *green*, superior angle; *lavender-shaded*, neck; *magenta*, glenoid cavity; *orange*, scapular notch; *pink-shaded*, coracoid; *purple*, inferior angle; *red*, lateral border; *turquoise-shaded*, acromion; *yellow*, superior border.

Diagram (A) shows the triangular flat bone scapula that has two surfaces and three borders. The parts labeled in the diagram are listed as follows: coracoid process, scapular notch, superior border, superior angle, acromion, neck, subscapular fossa, glenoid cavity, medial border, body, lateral border, and inferior angle. Diagram (B) shows the posterior aspect of the scapula. The body of the bone is arched from top to bottom. The parts labeled in the diagram are listed as follows: superior border, scapular notch, coracoid process, acromion, glenoid cavity, neck, lateral angle, lateral border, inferior angle, superior angle, supraspinous fossa, a crest of the spine, infraspinous fossa, and medial border.

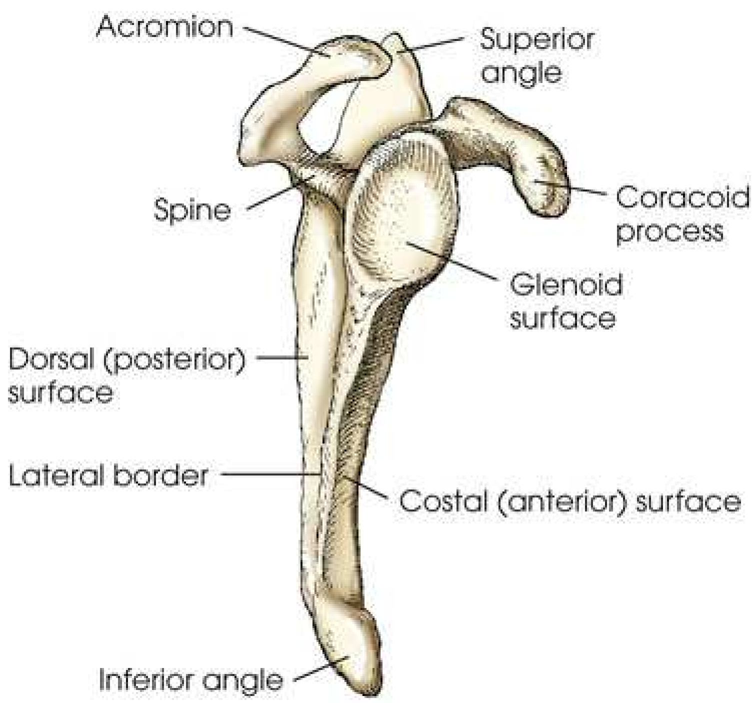


FIG. 6.4 Lateral aspect of scapula.

Diagram shows the surfaces of the scapula that serves as the attachment. The parts labeled in the diagram are listed as follows: acromion, spine, dorsal or posterior surface, lateral border, inferior angle, costal or anterior surface, glenoid surface, coracoid process, and superior angle.

Scapula

The *scapula,* classified as a flat bone, forms the posterior part of the shoulder girdle (Figs. 6.3 and 6.4). Triangular in shape, the scapula has two surfaces, three borders, and three angles. Lying on the superoposterior thorax between the second and seventh ribs, the *medial border* of the scapula runs parallel with the vertebral column. The body of the bone is arched from top to bottom for greater strength, and its surfaces serve as the attachment sites of numerous muscles. The flat aspect of the bone lies at approximately a 45- to 60-degree angle in relation to the anatomic position (see Fig. 6.2).

The *costal (anterior) surface* of the scapula is slightly concave and contains the *subscapular fossa*. It is filled almost entirely by the attachment of the subscapularis muscle. The anterior serratus muscle attaches to the medial border of the costal surface from the *superior angle* to the *inferior angle*.

The *dorsal (posterior) surface* is divided into two portions by a prominent spinous process. The *crest of spine* arises at the superior third of the medial border from a smooth, triangular area and runs obliquely superior to end in a flattened, ovoid projection called the *acromion*. The area above the spine is called the *supraspinous fossa* and gives origin to the supraspinatus muscle. The infraspinatus muscle arises from the portion below the spine, which is called the *infraspinous fossa*. The teres minor muscle arises from the superior two-thirds of the lateral border of the dorsal surface, and the teres major arises from the distal third and the inferior angle. The dorsal surface of the medial border affords attachment of the levator muscles of the scapulae, greater rhomboid muscle, and lesser rhomboid muscle.

The *superior border* extends from the superior angle to the *coracoid process,* and its lateral end has a deep depression, the *scapular notch*. The *medial border* extends from the superior to the inferior angles. The *lateral border* extends from the *glenoid cavity* to the inferior angle.

The *superior angle* is formed by the junction of the superior and medial borders. The *inferior angle* is formed by the junction of the medial (vertebral) and lateral borders and lies over the seventh rib. The *lateral angle,* the thickest part of the body of the scapula, ends in a shallow, oval depression called the *glenoid cavity*. The constricted region around the glenoid cavity is called the *neck* of the scapula. The coracoid process arises from a thick base that extends from the scapular notch to the superior portion of the neck of the scapula. This process first projects anteriorly and medially and then curves on itself to project laterally. The coracoid process can be palpated just distal and slightly medial to the acromioclavicular (AC) articulation. The acromion, coracoid process, superior angle, and inferior angle are common positioning landmarks for shoulder radiography.

Humerus

The proximal end of the *humerus* consists of a head, an anatomic neck, two prominent processes called the *greater* and *lesser tubercles,* and the surgical neck (Fig. 6.5). The *head* is large, smooth, and rounded, and it lies in an oblique plane on the superomedial side of the humerus. Just below the head, lying in the same oblique plane, is the narrow, constricted *anatomic neck*. The constriction of the body just below the tubercles is called the *surgical neck,* which is the site of many fractures.

The *lesser tubercle* is situated on the anterior surface of the bone, immediately below the anatomic neck (Figs. 6.6 and 6.7; also see Fig. 6.5). The tendon of the subscapular muscle inserts at the lesser tubercle. The *greater tubercle* is located on the lateral surface of the bone, just below the anatomic neck, and is separated from the lesser tubercle by a deep depression called the *intertubercular (bicipital) groove*. The superior surface of the greater tubercle slopes posteriorly at an angle of approximately 25 degrees and has three flattened impressions for muscle insertions. The anterior impression is the highest of the three and affords attachment to the tendon of the supraspinatus muscle. The middle impression is the point of insertion of the infraspinatus muscle. The tendon of the upper fibers of the teres minor muscle inserts at the posterior impression (the lower fibers insert into the *body* of the bone immediately below this point).

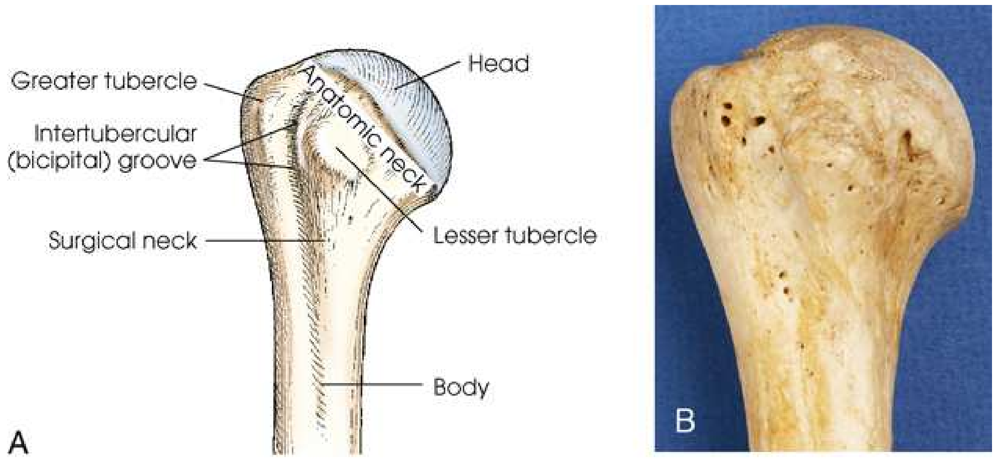


FIG. 6.5 (A) Anterior aspect of right proximal humerus. (B) Photograph of anterior aspect of proximal humerus.

Diagram (A) shows the humerus with a large, smooth, and rounded head. Below the head is a narrow, constricted anatomic neck. The parts labeled in the diagram are listed as follows: greater tubercle, intertubercular or bicipital groove, surgical neck, head, lesser tubercle, and body. (B) shows the anterior aspect of the proximal humerus with a large, smooth, and rounded head. Below the head is a narrow, constricted anatomic neck.

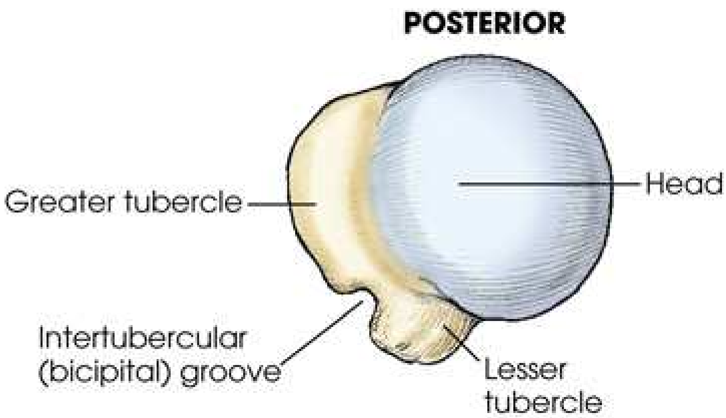


FIG. 6.6 Superior aspect of humerus.

The head is round and the intertubercular bicipital groove is a small depression between the greater tubercle and the lesser tubercle. The parts labeled in the diagram are listed as follows: greater tubercle, head, intertubercular or bicipital groove, and lesser tubercle.

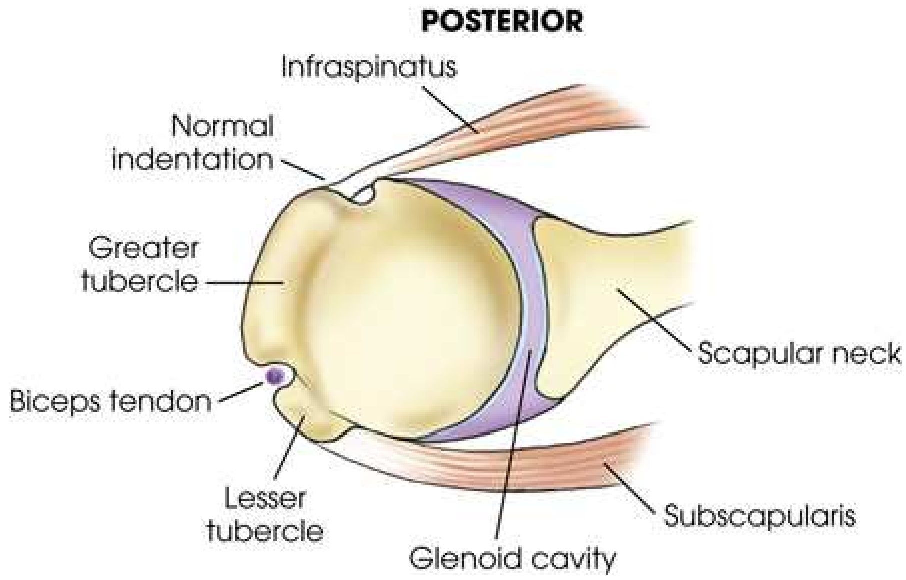


FIG. 6.7 Superior aspect of humerus. Horizontal section through scapulohumeral joint showing normal anatomic relationships.

Diagram shows the horizontal section through the scapulohumeral joint. The parts labeled in the diagram are listed as follows: infraspinatus, normal indentation, greater tubercle, biceps tendon, lesser tubercle, glenoid cavity, subscapularis, and scapular neck.

Bursae are small, synovial fluid–filled sacs that relieve pressure and reduce friction in tissue. They are often found between the bones and the skin, and they allow the skin to move easily when the joint is moved. Bursae are also found between bones and ligaments, muscles, or tendons. One of the largest bursae of the shoulder is the *subacromial bursa* (Fig. 6.8). It is located under the acromion and lies between the deltoid muscle and the shoulder joint capsule. The subacromial bursa does not normally communicate with the joint. Other bursae of the shoulder are found superior to the acromion, between the coracoid process and the joint capsule, and between the capsule and the tendon of the subscapular muscle. Bursae become important radiographically when injury or age causes the deposition of calcium.

Shoulder Girdle Articulations

The three joints of the shoulder girdle are summarized in Table 6.1, and a detailed description follows.

Scapulohumeral Articulation

The *scapulohumeral articulation* between the glenoid cavity and the head of the humerus forms a *synovial ball-and-socket* joint, allowing movement in all directions (Figs. 6.9 and 6.10). This joint is often referred to as the *glenohumeral* joint. Although many muscles connect with, support, and enter into the function of the shoulder joint, radiographers are chiefly concerned with the insertion points of the short rotator cuff muscles (Fig. 6.11). The insertion points of these muscles—the subscapular, supraspinatus, infraspinatus, and teres minor—have already been described.

TABLE 6.1

	Structural classification		
Joint	**Tissue**	**Type**	**Movement**
Scapulohumeral	Synovial	Ball and socket	Freely movable
Acromioclavicular	Synovial	Gliding	Freely movable
Sternoclavicular	Synovial	Double gliding	Freely movable

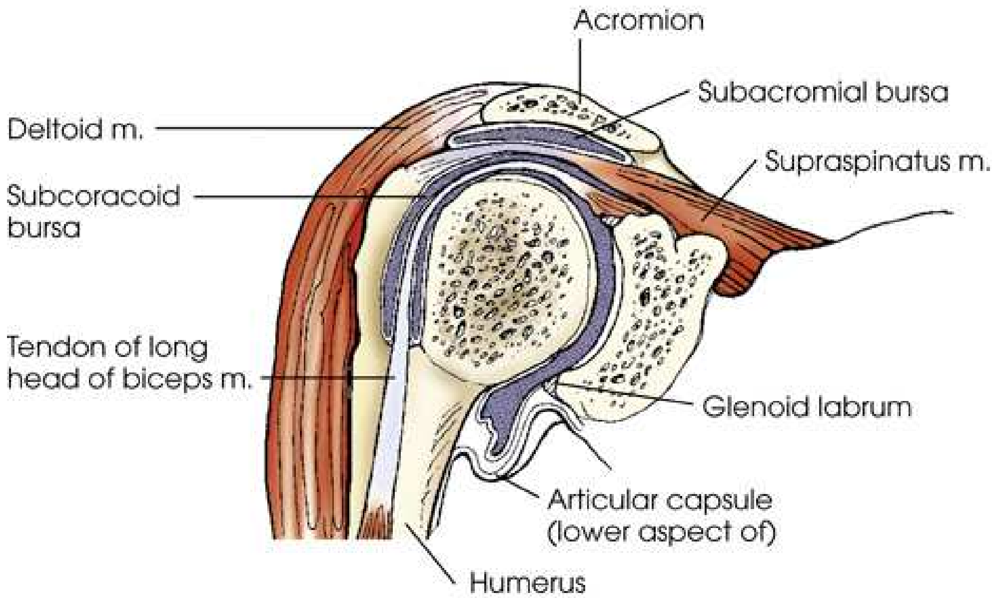


FIG. 6.8 Right shoulder bursae and muscles.

Diagram shows the right shoulder bursae and muscles. The parts labeled in the diagram are listed as follows: acromion, subacromial bursa, supraspinatus muscle, glenoid labrum, the lower aspect of the articular capsule, humerus, tendon of the long head of biceps muscle, subcoracoid bursa, and deltoid muscle. The supraspinatus muscle and the deltoid muscle are marked in red.

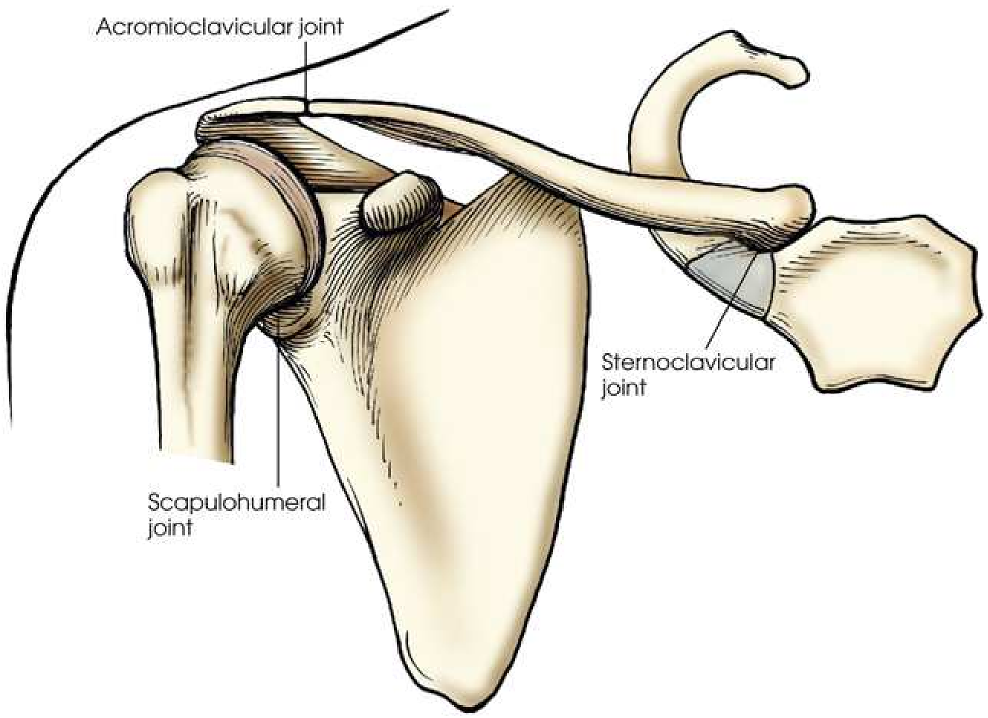


FIG. 6.9 Articulations of scapula and humerus.

Diagram shows the articulations of the scapula and humerus. The parts labeled in the diagram are listed as follows: acromioclavicular joint, scapulohumeral joint, and sternoclavicular joint. The sternoclavicular joint is highlighted. The scapulohumeral articulation between the glenoid cavity and the head of the humerus forms a synovial ball-and-socket joint.

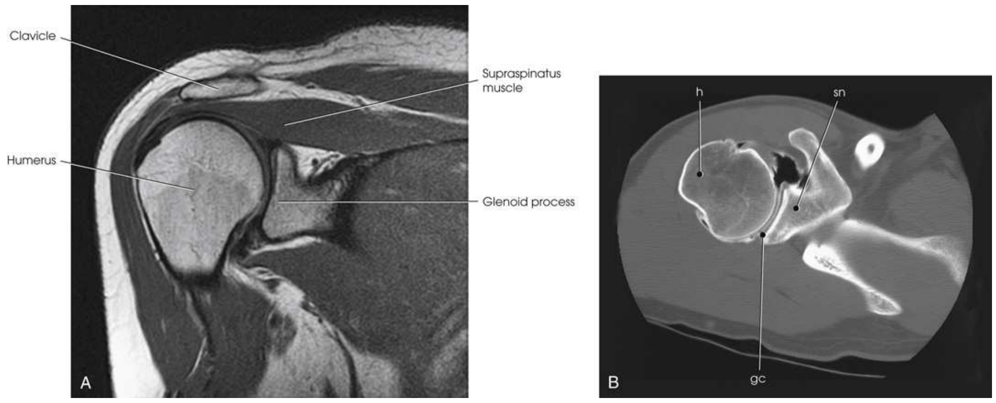


FIG. 6.10 (A) Coronal MRI of shoulder. Note articular cartilage around humeral head and muscles closely surrounding bone. (B) Axial CT of shoulder, midjoint. Note position of bones relative to each other and articular cartilage in glenoid cavity. *gc,* Glenoid cavity; *h,* humerus; *sn,* scapular neck. From Kelley LL, Petersen CM. *Sectional anatomy for imaging professionals*. 2nd ed. St Louis: Mosby; 2007.

(A) shows the Coronal M R I of the shoulder. The parts labeled in the diagram are listed as follows: clavicle, humerus, supraspinatus muscle, and glenoid process. The clavicle is oval-shaped. The humerus and the clavicle appear grey, the glenoid process is dark and the supraspinatus muscle is darker than the other parts. (B) An axial C T shows the synovial ball-and-socket joint. The parts labeled are the humerus that appears like a ball, the scapular that the neck appears like a socket, and the glenoid cavity in between them.

An articular capsule completely encloses the shoulder joint. The tendon of the long head of the biceps brachii muscle, which arises from the superior margin of the glenoid cavity, passes through the capsule of the shoulder joint, goes between its fibrous and synovial layers, arches over the head of the humerus, and descends through the intertubercular (bicipital) groove. The short head of the biceps arises from the coracoid process and, with the long head of the muscle, inserts in the radial tuberosity. Because it crosses with the shoulder and elbow joints, the biceps help to synchronize their action.

The interaction of movement among the wrist, elbow, and shoulder joints makes the position of the hand important in radiography of the upper limb. Any rotation of the hand also rotates the joints. The best approach to the study of the mechanics of joint and muscle action is to perform all movements ascribed to each joint and carefully note the reaction in remote parts.

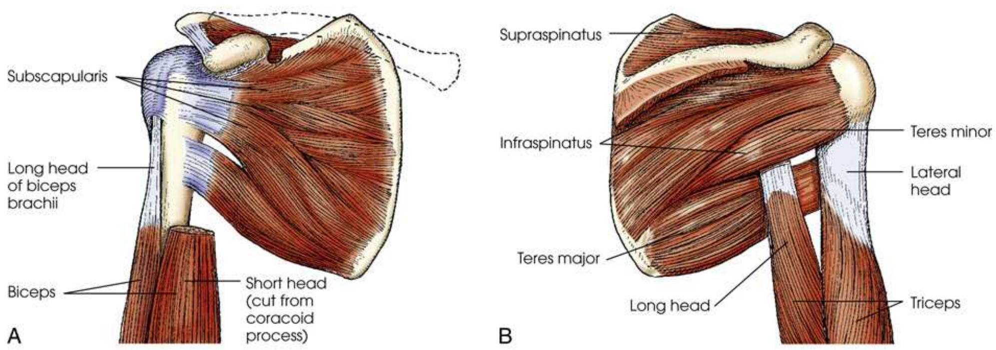


FIG. 6.11 (A) Muscles on costal (anterior) surface of scapula and proximal humerus. (B) Muscles on dorsal (posterior) surface of scapula and proximal humerus.

(A) shows the insertion points of the muscles on the anterior scapula and proximal humerus. The parts labeled in the diagram are listed as follows: subscapularis, long head of biceps brachii, biceps, and the short head that is cut from the coracoid process. The clavicle is represented by a dashes line. (B) shows the insertion points of the muscles in the posterior scapula and proximal humerus. The parts labeled in the diagram are listed as follows: supraspinatus, infraspinatus, teres minor, lateral head, teres major, long head, and triceps.

Acromioclavicular Articulation

The *AC* articulation between the *acromion* of the scapula and the acromial extremity of the *clavicle* forms a *synovial gliding joint* (Fig. 6.12). It permits gliding and rotary (elevation, depression, protraction, and retraction) movement. Because the end of the clavicle rides higher than the adjacent surface of the acromion, the slope of the surfaces tends to favor displacement of the acromion downward and under the clavicle.

Sternoclavicular Articulation

The *sternoclavicular* (SC) articulation is formed by the sternal extremity of the clavicle with two bones: the manubrium and the first rib cartilage (see Fig. 6.12). The union of the clavicle with the manubrium of the sternum is the only bony union between the upper limb and trunk. This articulation is a *synovial double-gliding* joint. However, the joint is adapted by a fibrocartilaginous disk to provide movements similar to a ball-and-socket joint: circumduction, elevation, depression, and forward and backward movements. The clavicle carries the scapula with it through any movement.

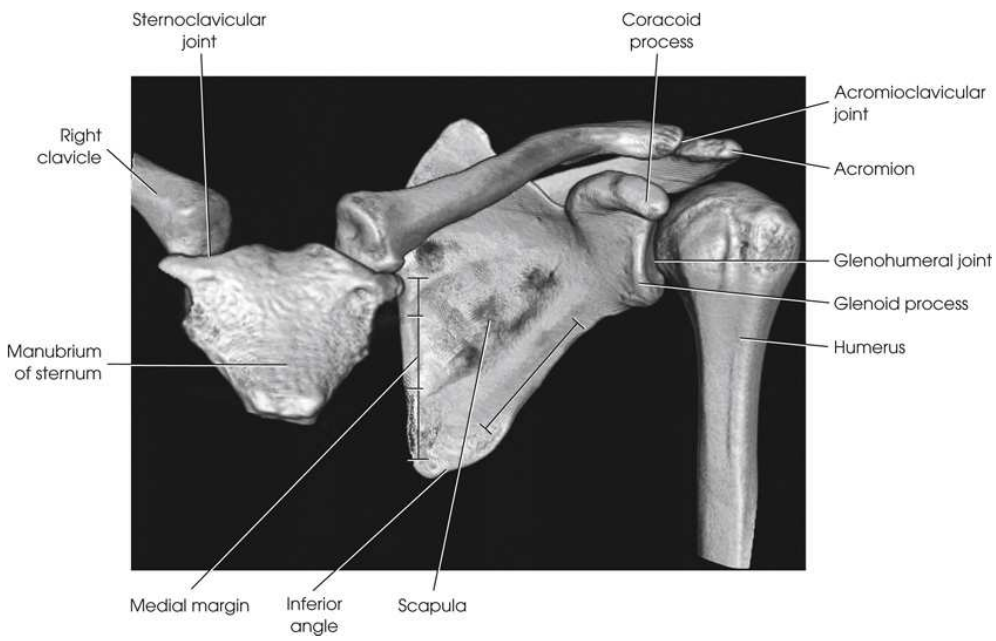


FIG. 6.12 Three-dimensional CT image of shoulder girdle. Note three articulations.

The three-dimensional C T image of the shoulder girdle shows the three articulations. The parts labeled are listed as follows: sternoclavicular joint, coracoid process, acromioclavicular joint, acromion, glenohumeral joint, glenoid process, humerus, scapula, medial margin, inferior angle, manubrium of the sternum, and right clavicle. The scapula is darker.

Summary of Anatomy

Shoulder girdle

Clavicle
Scapula

Clavicle

Body
Acromial extremity
Sternal extremity

Scapula

Medial border
Body
Costal surface
Subscapular fossa
Superior angle
Inferior angle
Dorsal surface
Crest of spine
Acromion
Supraspinous fossa
Infraspinous fossa
Superior border
Coracoid process
Scapular notch
Lateral border
Glenoid cavity
Lateral angle
Neck

Humerus (proximal aspect)

Head

Anatomic neck
Surgical neck
Intertubercular groove
Greater tubercles
Lesser tubercles
Body
Bursae
Subacromial bursa

Shoulder articulations

Scapulohumeral
Acromioclavicular
Sternoclavicular

Abbreviations Used in Chapter 6

AC	Acromioclavicular
SC	Sternoclavicular

See Addendum A for a summary of all abbreviations used in Volume 1.

Summary of Pathology

Condition	Definition
Bursitis	Inflammation of the bursa
Dislocation	Displacement of a bone from the joint space
Fracture	Disruption in the continuity of bone
Hill-Sachs defect	Impacted fracture of posterolateral aspect of the humeral head with dislocation
Metastasis	Transfer of a cancerous lesion from one area to another
Osteoarthritis or degenerative joint disease	Form of arthritis marked by progressive cartilage deterioration in synovial joints and vertebrae
Osteopetrosis	Increased density of atypically soft bone
Osteoporosis	Loss of bone density
Rheumatoid arthritis	Chronic, systemic, inflammatory collagen disease
Tendinitis	Inflammation of the tendon and tendon-muscle attachment
Tumor	New tissue growth where cell proliferation is uncontrolled
Chondrosarcoma	Malignant tumor arising from cartilage cells

Eponymous (named) pathologies are listed in nonpossessive form to conform to the *AMA manual of style: a guide for authors and editors*, ed 10, Oxford, Oxford University Press, 2009.

These techniques were accurate for the equipment used to produce each exposure. However, use caution when applying them in your department because "there is considerable variability in image receptor response owing to varying scatter sensitivity, the use of grids with different grid ratios, collimation, beam filtration, the choice of kilovoltage, source-to-image distance, and image receptor size."[a]

This chart was created in collaboration with Dennis Bowman, AS, RT(R), Clinical Instructor, Community Hospital of the Monterey Peninsula, Monterey, CA. http://digitalradiographysolutions.com/.

Shoulder Girdle

Part	cm	kVp[b]	SID[c]	Collimation	CR[d]		DR[e]	
					mAs	Dose (mGy)[f]	mAs	Dose (mGy)[f]
Shoulder—*AP*[g]	18	85	40″	11″ × 9″ (28 × 23 cm)	10[h]	1.328	4.5[h]	0.593
Shoulder—*transthoracic lateral*[g]	40	85	40″	6″ × 10″ (15 × 25 cm)	56	12.45	28	6.200
Shoulder—*inferosuperior axial*[g]	18	75	40″	7″ × 5″ (18 × 13 cm)	5[h]	0.423	2.5[h]	0.234
Shoulder—*PA oblique scapular Y*[g]	24	85	40″	6″ × 6″ (15 × 15 cm)	18[h]	2.570	10[h]	1.421
Intertubercular (bicipital) groove[i]	10	70	40″	3″ × 3″ (8 × 8 cm)	4[h]	0.149	2[h]	0.074
AC articulation—*AP*[g]	14	81	40″	3.5″ × 3.5″ (9 × 9 cm)	11[h]	0.692	5.6[h]	0.349
Clavicle—*AP, PA*[g]	16	81	40″	7″ × 4″ (18 × 10 cm)	10[h]	0.934	5.0[h]	0.464
Scapula—*AP*[g]	18	85	40″	7″ × 8″ (18 × 20 cm)	11[h]	1.422	5.5[h]	0.719
Scapula—*lateral*[g]	24	85	40″	6″ × 8″ (15 × 20 cm)	14[h]	2.082	8[h]	1.187

[a] ACR-AAPM-SIMM Practice Parameter for Digital Radiography, Revised 2017.

[b] kVp values are for a high-frequency generator.

[c] 40-inch minimum; 44 to 48 inches recommended to improve spatial resolution (mAs increase needed, but no increase in patient dose will result).

[d] AGFA CR MD 4.0 General IP, CR 75.0 reader, 400 speed class, with 6:1 (178LPI) grid when needed.

[e] GE Definium 8000, with 13:1 grid when needed.

[f] All doses are skin entrance for average adult (160- to 200-pound male, 150- to 190-pound female) at part thickness indicated.

[g] Bucky/grid.

[h] Small focal spot.

[i] Tabletop, nongrid.

Radiography

Shoulder

Radiation Protection

Protection of the patient from unnecessary radiation is a professional responsibility of the radiographer. In this chapter, the *Shield gonads* statement at the end of the *Position of part* section indicates that the patient is to be protected from unnecessary radiation by using proper collimation.

Shoulder

AP Projection

External, neutral, internal rotation humerus

NOTE: Do not have the patient rotate the arm if fracture or dislocation is suspected.

Image receptor + grid: Positioned by manufacturer or department protocol for proper anatomy display orientation; CR plate: 10 × 12 inches (24 × 30 cm), crosswise to include entire clavicle, lengthwise to include more humerus.

Position of patient

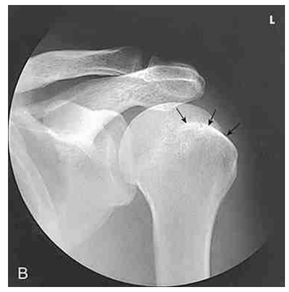
- Examine the patient in the upright or supine position, with coronal plane of thorax parallel to the IR. Shoulder and arm lesions, whether traumatic or pathologic in origin, are extremely sensitive to movement and pressure. For this reason, the upright position should be used whenever possible.

Position of part

- Center the shoulder joint to the midline of the grid.
- Center the IR at 1 inch (2.5 cm) inferior to the coracoid process.

TABLE 6.2

Hand position and its effect on the proximal humerus

Description	Hand position	Proximal humerus position
Supinating hand and adjusting epicondyles parallel to the plane of the IR positions the humerus in *external rotation*	 A hand of the patient is supinated and the humerus is in external rotation. The epicondyles are parallel to the plane of the image receptor.	 An x-ray shows the greater tubercle in the humerus indicated by an arrow. AP shoulder. External rotation humerus. Greater tubercle *(arrow)*
Palm of the hand placed against hip and epicondyles adjusted at approximately a 45-degree angle with the plane of the IR positions the humerus in *neutral rotation*	 The palm of the hand is placed against the thigh. The humerus is in neutral rotation.	 An x-ray shows the greater tubercle in the humerus indicated by three black arrows. AP shoulder. Neutral rotation humerus. Greater tubercle *(arrows)*
Posterior aspect of hand may be placed against hip and epicondyles adjusted perpendicular to the plane of the IR to position the humerus in *internal rotation*	 The patient's elbow is flexed and the arm is rotated internally and the back of the hand is resting on the hip.	 An x-ray shows the greater tubercle in the humerus indicated by three black arrows. The lesser tubercle is indicated by a black arrowhead. AP shoulder. Internal rotation humerus. Greater tubercle *(arrows)*; lesser tubercle in profile *(arrowhead)*

AP, Anteroposterior; *IR*, image receptor.

External rotation humerus

- Ask the patient to supinate the hand, unless contraindicated (Table 6.2).
- Abduct the arm slightly, and rotate it so that the epicondyles are parallel with the plane of the IR. Externally rotating the entire arm from the neutral position places the shoulder and the entire humerus in the true anatomic position (Fig. 6.13A).

Neutral rotation humerus

- Ask the patient to rest the palm of the hand against the thigh (see Table 6.2). This position of the arm rolls the humerus slightly internally into a neutral position, placing the epicondyles at an angle of approximately 45 degrees with the plane of the IR.

Internal rotation humerus

- Ask the patient to flex the elbow, rotate the arm internally, and rest the back of the hand on the hip (see Table 6.2).
- Adjust the arm to place the epicondyles perpendicular to the plane of the IR (Fig. 6.13B).
- *Shield gonads.*
- *Respiration*: Suspend.

Central ray

- Perpendicular to a point 1 inch (2.5 cm) inferior to the coracoid process, which can be palpated inferior to the clavicle and medial to the humeral head.

Collimation

- Adjust radiation field to approximately 10 × 12 inches (24 × 30 cm) on the collimator. If crosswise, include 1.5 inches (3.8 cm) above the shoulder, 1 inch (2.5 cm) beyond the lateral aspect of the shoulder, the sternal end of the clavicle and the proximal third of the humerus. If lengthwise, more humerus and less clavicle will be included. Place side marker in the collimated exposure field.

Compensating Filter

Use of a specially designed compensating filter for the shoulder, called a boomerang, improves the quality of the image. See Chapter 1 for photograph. These filters are particularly useful for this projection because all bony and soft tissue structures can be seen without the need to "window."

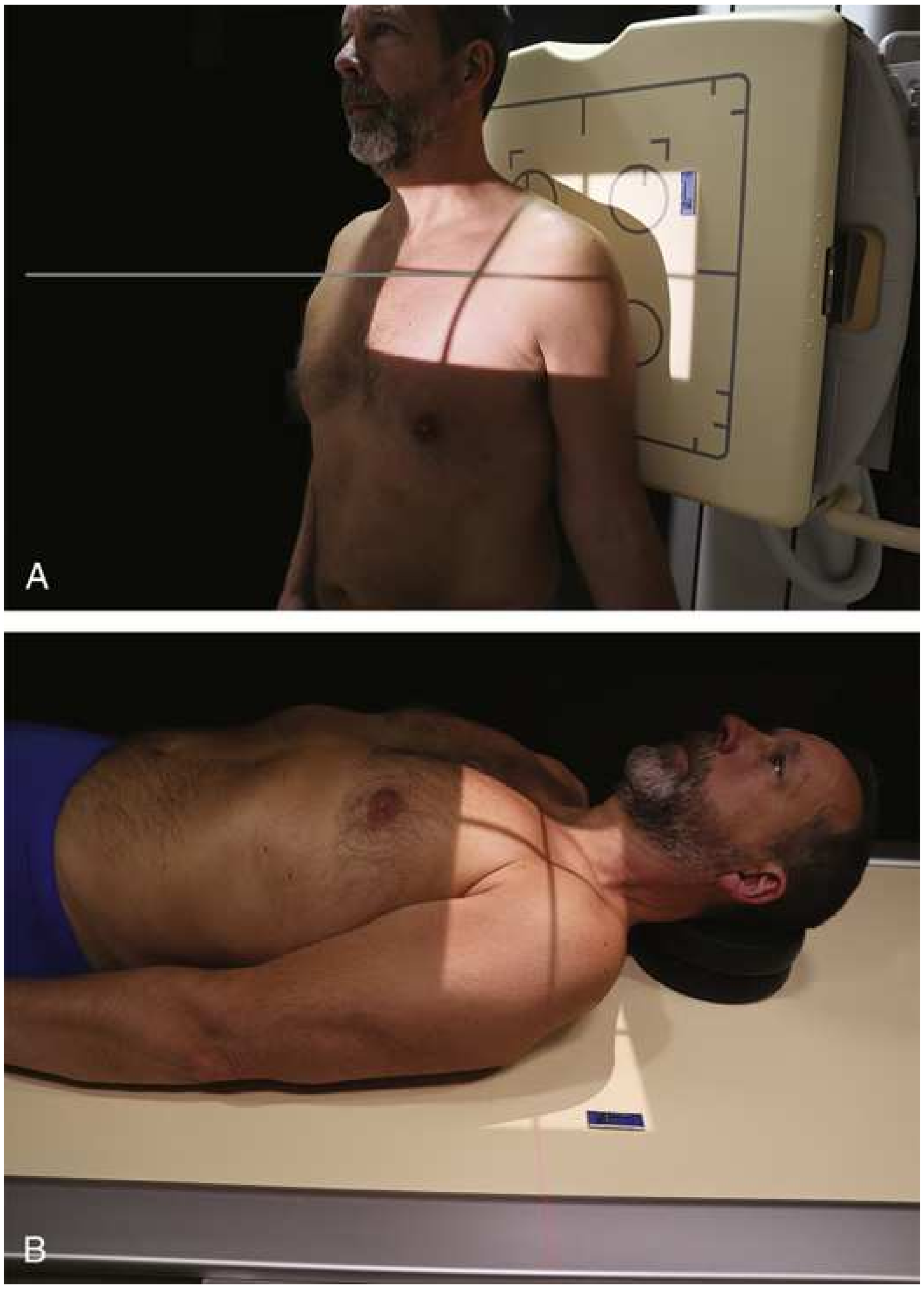


FIG. 6.13 (A) AP shoulder, external rotation humerus, standing position. (B) AP shoulder, internal rotation humerus, supine position.

(A) A patient is standing close to the vertical grid. The arm is slightly abducted and is externally rotated. The central ray is perpendicular to a point inferior to the coracoid process. (B) A patient is lying in the supine position on the image receptor. The epicondyles are perpendicular to the plane of the I R. The side marker is in the collimated exposure field. The central ray is perpendicular to a point inferior to the coracoid process.

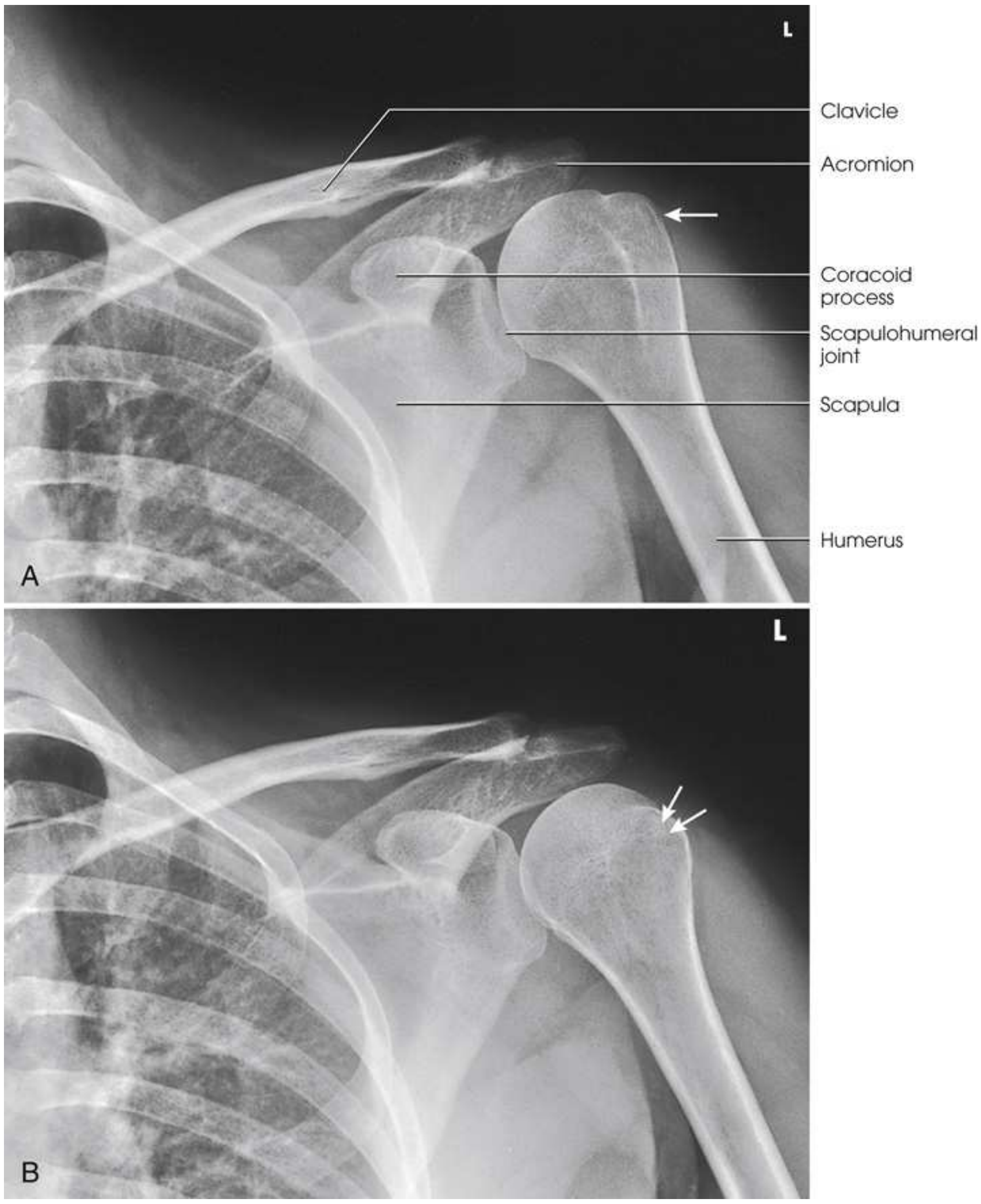


FIG. 6.14 (A) AP shoulder, external rotation humerus: greater tubercle in profile *(arrow)*. (B) AP shoulder, neutral rotation humerus: greater tubercle *(arrows)*.

(A) The x-ray shows the greater tubercle marked by a white arrow. The parts labeled are as follows. clavicle, acromion, coracoid process, scapulohumeral joint, scapula, and humerus. The internal organs appear dark. (B) The x-ray shows the greater tubercle marked by two white arrows. The internal organs appear dark. The humeral head is slightly overlapping the glenoid cavity.

Structures shown

The bony and soft structures of the shoulder and proximal humerus in the anatomic position (Figs. 6.14 through 6.16). The scapulohumeral joint relationship is seen.

External rotation: The greater tubercle of the humerus and the site of insertion of the supraspinatus tendon are visualized (see Fig. 6.14A).
Neutral rotation: The posterior part of the supraspinatus insertion, which sometimes profiles small calcific deposits not otherwise visualized (see Fig. 6.14B), is seen.
Internal rotation: The proximal humerus is seen in a true lateral position. When the arm can be abducted enough to clear the lesser tubercle from the lateral angle of the scapula, the site of the subscapular tendon insertion is seen (see Fig. 6.15).

Evaluation Criteria

The following should be clearly seen:

- Evidence of proper collimation and presence of side marker placed clear of anatomy of interest
- Superior scapula, clavicle (entire if IR crosswise, lateral half if IR lengthwise), and proximal humerus
- Bony trabecular detail and surrounding soft tissues

External Rotation

- Humeral head in profile
- Greater tubercle in profile on lateral aspect of the humerus
- Scapulohumeral joint visualized with slight overlap of humeral head on glenoid cavity
- Outline of lesser tubercle between the humeral head and greater tubercle

Neutral Rotation

- Greater tubercle partially superimposing the humeral head
- Humeral head in partial profile
- Slight overlap of the humeral head on the glenoid cavity

Internal Rotation

- Lesser tubercle in profile and pointing medially
- Outline of the greater tubercle superimposing the humeral head
- Greater amount of humeral overlap of the glenoid cavity than in external and neutral positions

FIG. 6.15 AP shoulder, internal rotation humerus: greater tubercle *(arrow)*; lesser tubercle in profile *(arrowhead)*.

The x-ray shows the greater tubercle marked by an arrow on the right and the lesser tubercle is marked by an arrowhead on the left. The outline of the greater tubercle superimposing the humeral head is clear.

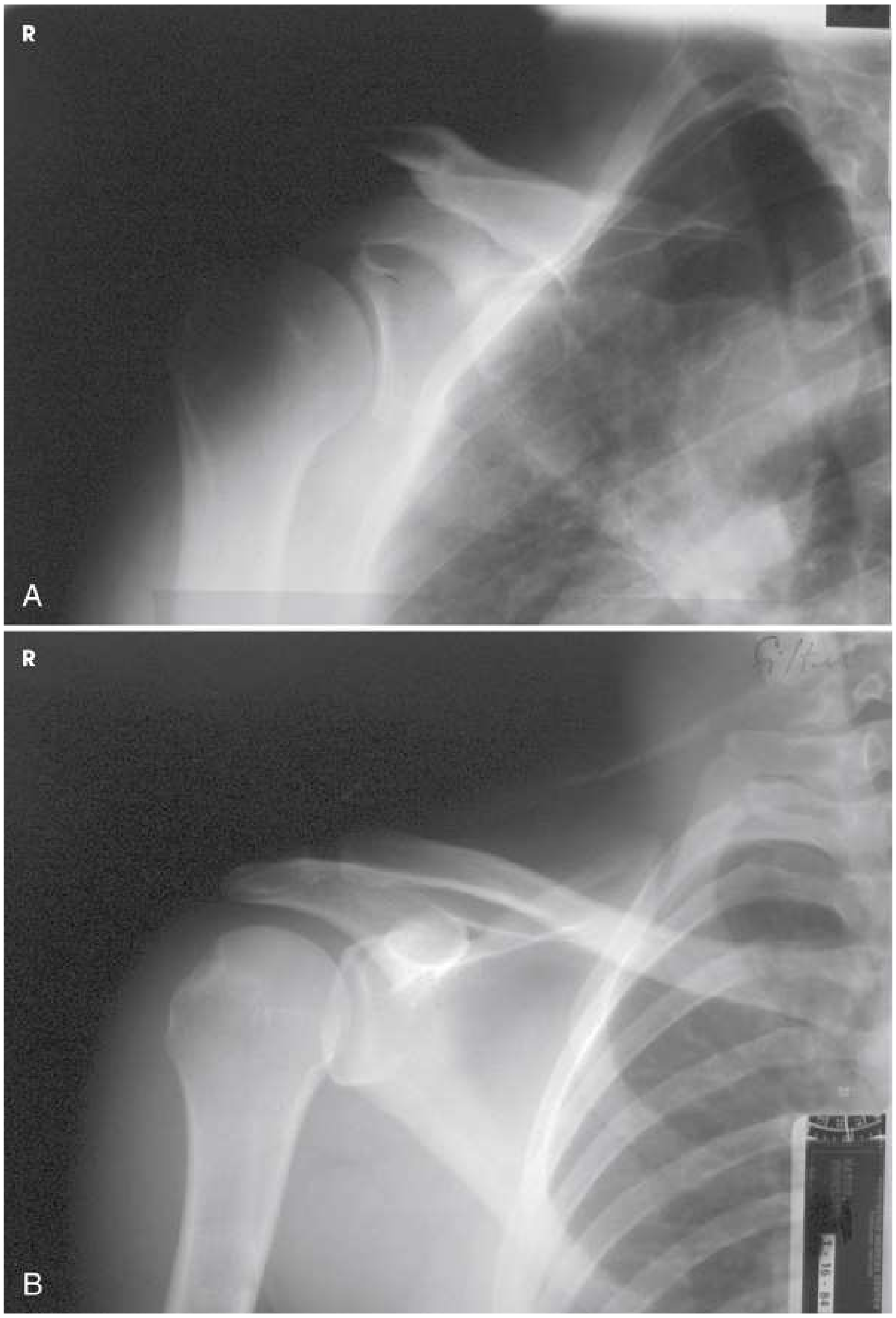


FIG. 6.16 (A) AP oblique projection of right shoulder without use of compensating filter. (B) AP projection of same patient with compensating filter. Note improved visualization of bony and soft tissue areas with filter.

(A) shows the x-ray view without a compensating filter. The bony and the soft tissue areas are hazy and blurry. (B) shows the x-ray view with a compensating filter. There is improved visualization of bony and soft tissue areas.

Shoulder Joint

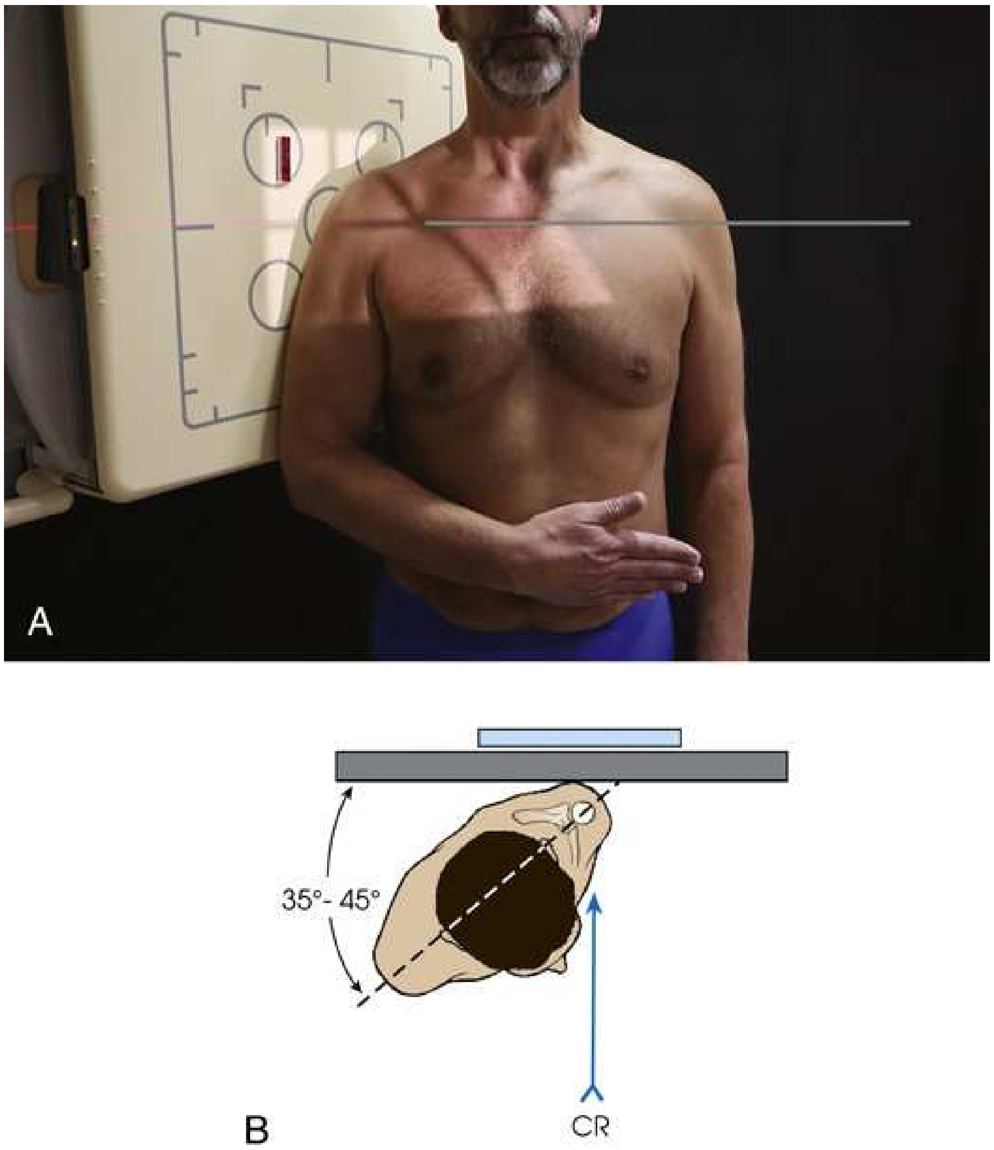


FIG. 6.17 (A) Upright AP oblique glenoid cavity: Grashey method. (B) Note position of shoulder and patient in relationship to IR.

(A) shows a patient standing in an upright position near the vertical grid. The superolateral border of the shoulder is placed against the I R. The side marker is in the collimated exposure field. The central ray is perpendicular to the image receptor. (B) shows a patient standing in an upright position near the vertical grid. The body is rotated 35 to 45 degrees toward the affected side. The central ray is perpendicular to the image receptor.

FIG. 6.18 Recumbent AP oblique glenoid cavity: Grashey method.

A patient is in the recumbent position. The elevated shoulder is supported by sandbags. The arm of the patient is in internal rotation and the palm of the hand is on the abdomen. The side marker is in the collimated exposure field. The central ray is perpendicular to the image receptor.

Glenoid Cavity

AP Oblique Projection

Grashey Method

RPO or LPO position

Image receptor + grid: Positioned by manufacturer or department protocol for proper anatomy display orientation; CR plate: 10 × 12 inches (24 × 30 cm), crosswise to include entire clavicle, lengthwise to include more humerus.

Position of patient

- Place the patient in the supine or upright position. The upright position is more comfortable for the patient and assists in accurate adjustment of the part.

Position of part

- Center the IR to the scapulohumeral joint. The joint is 2 inches (5 cm) medial and 2 inches (5 cm) inferior to the superolateral border of the shoulder.
- Rotate the body 35 to 45 degrees toward the affected side (Fig. 6.17).
- Adjust the degree of rotation to place the scapula parallel with the plane of the IR. This is accomplished by orienting the plane through the superior angle of the scapula and acromial tip, parallel to the IR.[a] The head of the humerus is in contact with the IR.
- If the patient is in the recumbent position, the body may need to be rotated more than 45 degrees (up to 60 degrees) to place the scapula parallel to the IR.
- Support the elevated shoulder and hip on sandbags (Fig. 6.18).
- Abduct the arm slightly in internal rotation and place the palm of the hand on the abdomen. Other arm positions may be dictated by department protocol.
- *Shield gonads.*
- *Respiration:* Suspend.

Central ray

- Perpendicular to the IR; the CR should be at a point 2 inches (5 cm) medial and 2 inches (5 cm) inferior to the superolateral border of the shoulder

Collimation

• Adjust radiation field to approximately 8 × 10 inches (18 × 24 cm) on the collimator. If crosswise, include 1.5 inches (3.8 cm) above the shoulder, 1 inch (2.5 cm) beyond the lateral aspect of the shoulder, the lateral half of the clavicle, and the proximal third of the humerus. If lengthwise, more humerus and less clavicle will be included. Place side marker in the collimated exposure field.

Structures shown

The joint space between the humeral head and the glenoid cavity (scapulohumeral or glenohumeral joint) (Figs. 6.19 and 6.20).

Evaluation Criteria

The following should be clearly seen:

- Evidence of proper collimation and presence of side marker placed clear of anatomy of interest
- Open joint space between the humeral head and glenoid cavity
- Glenoid cavity in profile
- Bony trabecular detail and surrounding soft tissues

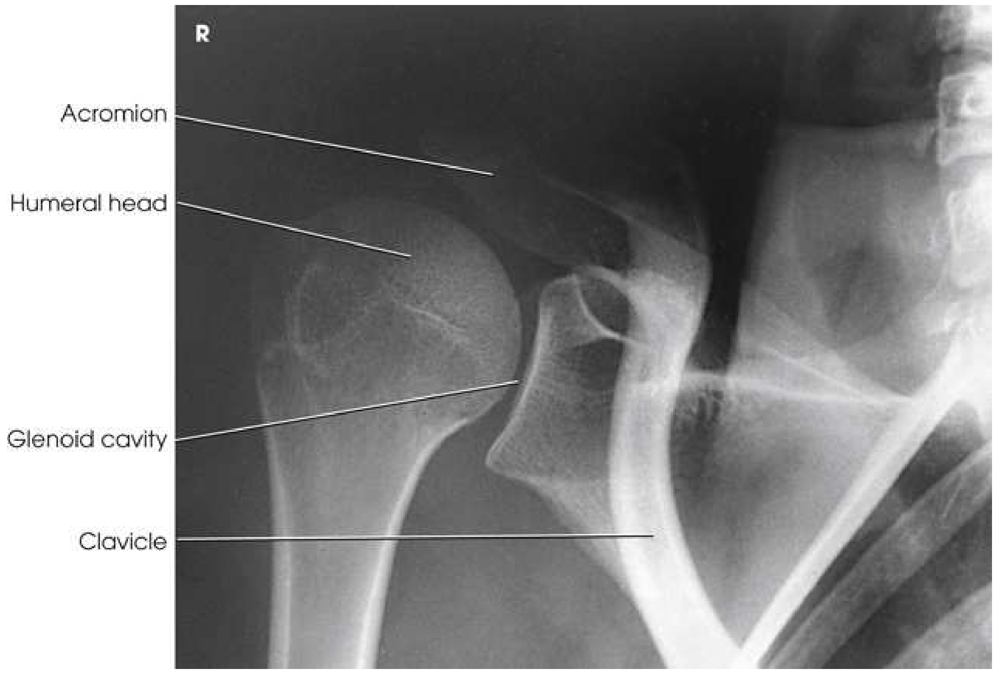


FIG. 6.19 AP oblique glenoid cavity: Grashey method.

The x-ray shows the open joint space between the humeral head and the glenoid cavity. The acromion and the humeral head appear dark than other bony elements. The parts labeled are listed from top to the bottom as follows. the acromion, humeral head, glenoid cavity, and clavicle.

FIG. 6.20 AP oblique glenoid cavity: Grashey method showing moderate deterioration of scapulohumeral joint.

Glenoid Cavity

AP Oblique Projection

Apple Method

RPO or LPO position

The Apple method [2] is similar to the Grashey method but uses weighted abduction to show loss of articular cartilage in the scapulohumeral joint.

Image receptor + grid: Positioned by manufacturer or department protocol for proper anatomy display orientation; CR plate: 10 × 12 inches (24 × 30 cm) crosswise.

Position of patient

- Place the patient in a seated or upright position.

Position of part

- Center the IR to the scapulohumeral joint.
- Rotate the body approximately 35 to 45 degrees toward the affected side (Fig. 6.21).
- The posterior surface of the affected side is closest to the IR.
- The scapula should be positioned parallel to the plane of the IR (see Grashey method for positioning details).
- The patient should hold a 1-lb weight in the hand on the same side as the affected shoulder in a neutral position.
- While holding the weight, the patient should abduct the arm 90 degrees from the midline of the body (Fig. 6.21A).
- *Shield gonads.*
- *Respiration:* Suspend.

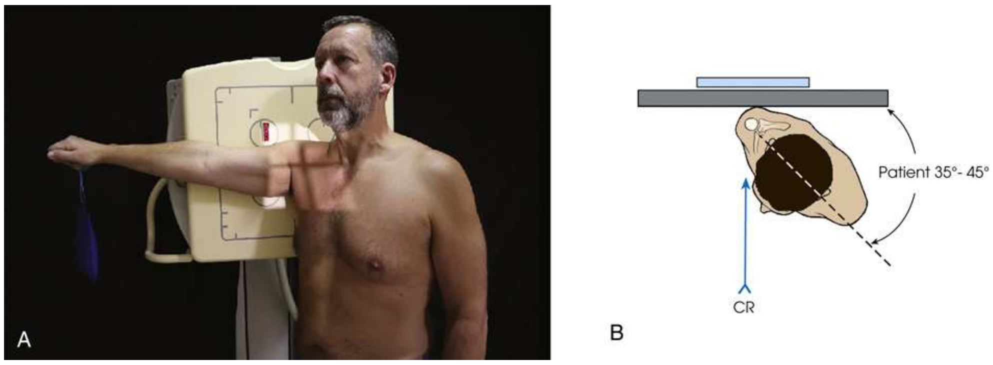


FIG. 6.21 AP oblique projection: Apple method. (A) Patient in 35- to 45-degree RPO position, holding a weight with affected arm at right angle abduction. (B) Diagram showing amount of body rotation and central ray entrance point.

(A) shows a patient standing with his arm abducted 90 degrees from the midline of the body. The patient is holding a weight in the hand abducted. The body is rotated 35 to 45 degrees toward the affected side. The side marker is in the collimated exposure field. The central ray is perpendicular to the I R at the level of the coracoid process. (B) shows the body of the patient rotated 35 to 45 degrees toward the affected side. The central ray is perpendicular to the I R at the level of the coracoid process.

Central ray

- Perpendicular to the IR at the level of the coracoid process

Collimation

Adjust radiation field to approximately 8 × 10 inches (18 × 24 cm) on the collimator. Adjust as needed to include 1.5 inches (3.8 cm) above the shoulder, 1 inch (2.5 cm) beyond the lateral aspect of the shoulder, the lateral half of the clavicle, and the proximal third of the humerus. Place side marker in the collimated exposure field.

NOTE: To avoid motion, have the correct technical factors set on the generator and be ready to make the exposure before the patient abducts the arm.

Structures shown

The scapulohumeral joint (Fig. 6.22), with joint space narrowing if present.

Evaluation Criteria

The following should be clearly seen:

- Evidence of proper collimation and presence of side marker placed clear of anatomy of interest
- Glenoid cavity in profile
- The arm in a 90-degree abducted position
- Open joint space between the humeral head and the glenoid cavity
- Bony trabecular detail and surrounding soft tissues

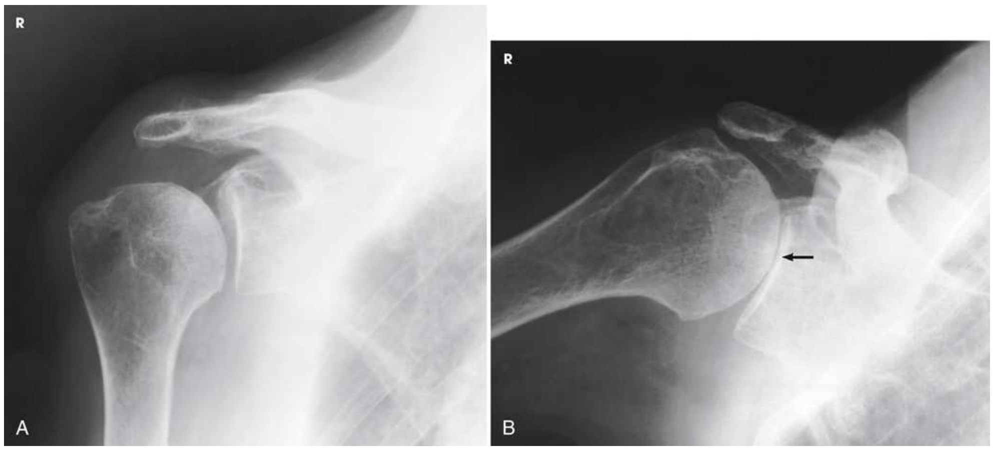


FIG. 6.22 (A) AP oblique projection: Grashey method, with shoulder showing normal scapulohumeral joint space. (B) AP oblique projection: Apple method, with weighted abduction showing loss of articular cartilage *(arrow)*.

(A) The x-ray shows the open joint space between the humeral head and the glenoid cavity. (B) shows the narrowing of joint space between the humeral head and glenoid cavity. It is marked by a black arrow. The bony elements below it appear radiopaque.

Shoulder

Transthoracic Lateral Projection

Lawrence Method

Right or left position

The Lawrence [3] method is used when trauma exists and the arm cannot be rotated or abducted because of an injury. This method results in a projection 90 degrees from the AP projection and shows the relationship between the proximal humerus and the scapula.

Image receptor + grid: Positioned by manufacturer or department protocol for proper anatomy display orientation; CR plate: 10 × 12 inches (24 × 30 cm) lengthwise.

Position of patient

- Although this projection can be carried out with the patient in the upright or supine position. The upright position may be less painful for a trauma patient, and it also allows easier adjustment of the shoulder.
- For upright positioning, seat or stand the patient in the lateral position before a vertical grid device (Fig. 6.23).
- If an upright position is impossible, place the patient in a dorsal decubitus position on the table with radiolucent pads elevating the head and shoulders (Fig. 6.24).

Position of part

- Have the patient raise the noninjured arm, rest the forearm on the head, and elevate the shoulder as much as possible (see Fig. 6.23). Elevation of the noninjured shoulder drops the injured side, separating the shoulders to prevent superimposition. Ensure that the midcoronal plane is perpendicular to the IR.
- No attempt should be made to rotate or otherwise to move the injured arm.
- Center the IR to the surgical neck area of the affected humerus.
- *Shield gonads.*
- *Respiration:* Full inspiration. Having the lungs full of air improves the contrast and decreases the exposure necessary to penetrate the body.
- If the patient can be sufficiently immobilized to prevent voluntary motion, a breathing technique can be used to blur the pulmonary vasculature. In this case, instruct the patient to practice slow, deep breathing. A minimum exposure time of 3 seconds (4 to 5 seconds is desirable) gives excellent results when low milliamperage is used.

Central ray

- Perpendicular to the IR, entering the midcoronal plane at the level of the surgical neck
- If the patient cannot elevate the unaffected shoulder, angle the CR 10 to 15 degrees cephalad to obtain a comparable radiograph.

Collimation

• Adjust radiation field to 10 × 12 inches (24 × 30 cm) on the collimator. The field of light on the skin appears smaller because of the distance from the IR. Do not collimate larger than stated size. Place side marker in the collimated exposure field.

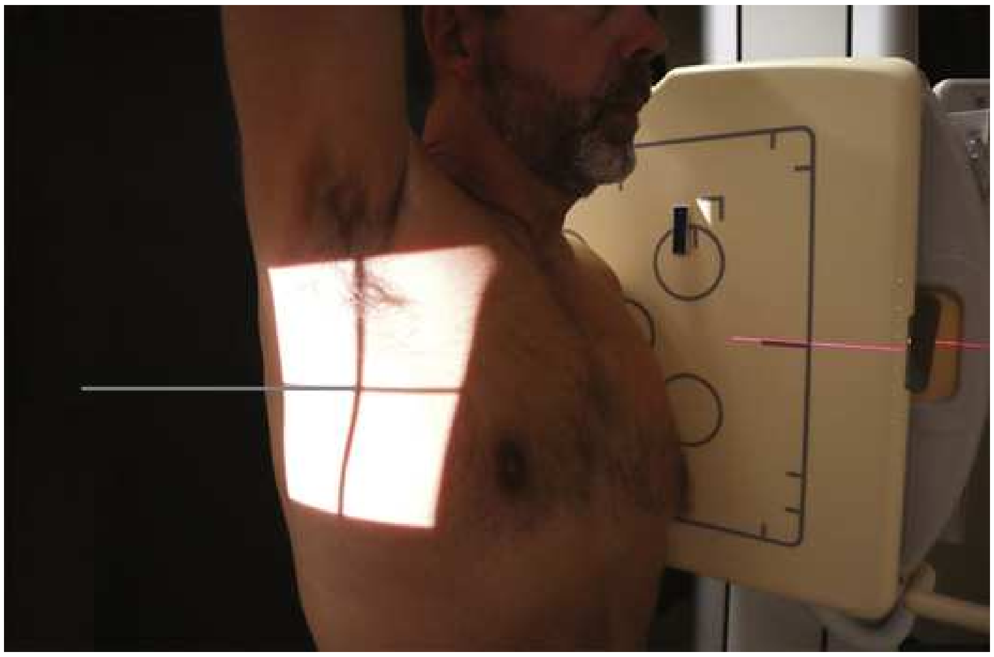


FIG. 6.23 Upright transthoracic lateral shoulder: Lawrence method.

The patient is standing in the lateral position in front of a vertical grid device. The non-injured arm of the patient is raised. The side marker is in the collimated exposure field. The central ray is perpendicular to the I R entering the midcoronal plane at the level of the surgical neck.

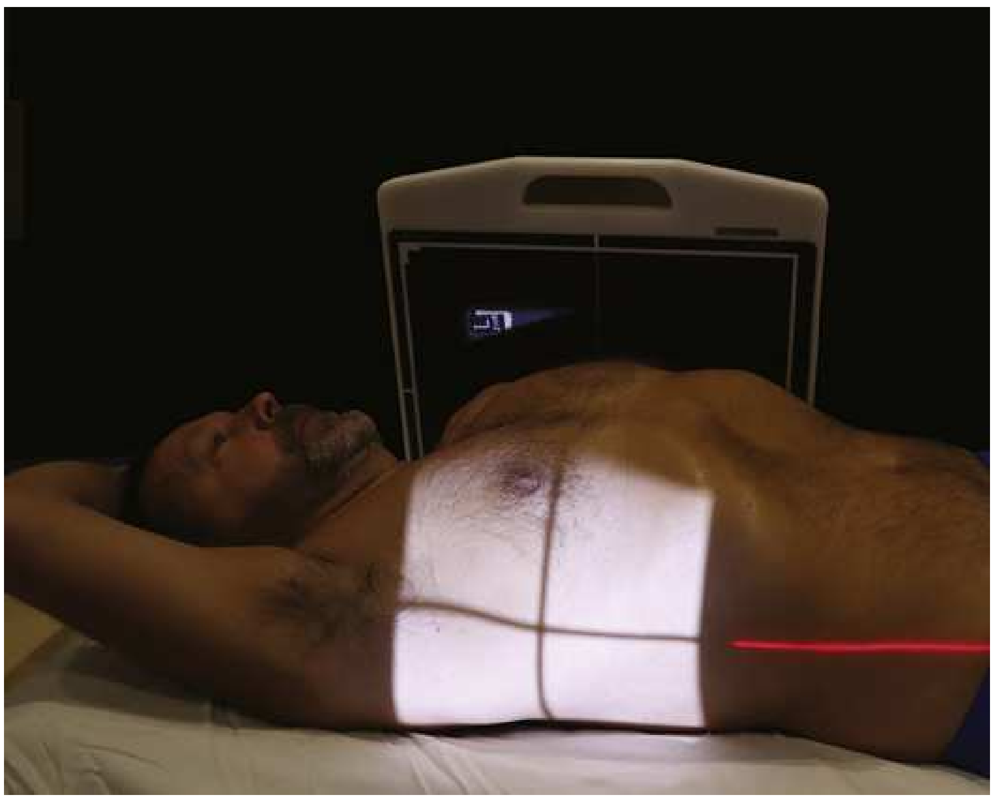


FIG. 6.24 Dorsal decubitus transthoracic lateral shoulder: Lawrence method.

The patient is in a dorsal decubitus position on the table. The non-injured arm is raised and the forearm is placed under the head. The side marker is in the collimated exposure field. The central ray is perpendicular to the I R entering the midcoronal plane at the level of the surgical neck.

Structures shown

A lateral image of the shoulder and proximal humerus is projected through the thorax (Figs. 6.25 and 6.26).

Evaluation Criteria

The following should be clearly seen:

- Evidence of proper collimation and presence of side marker placed clear of anatomy of interest
- Scapula, clavicle, and proximal humerus seen through the lung field
- Scapula superimposed over the thoracic spine
- Unaffected clavicle and humerus projected above the shoulder closest to the IR

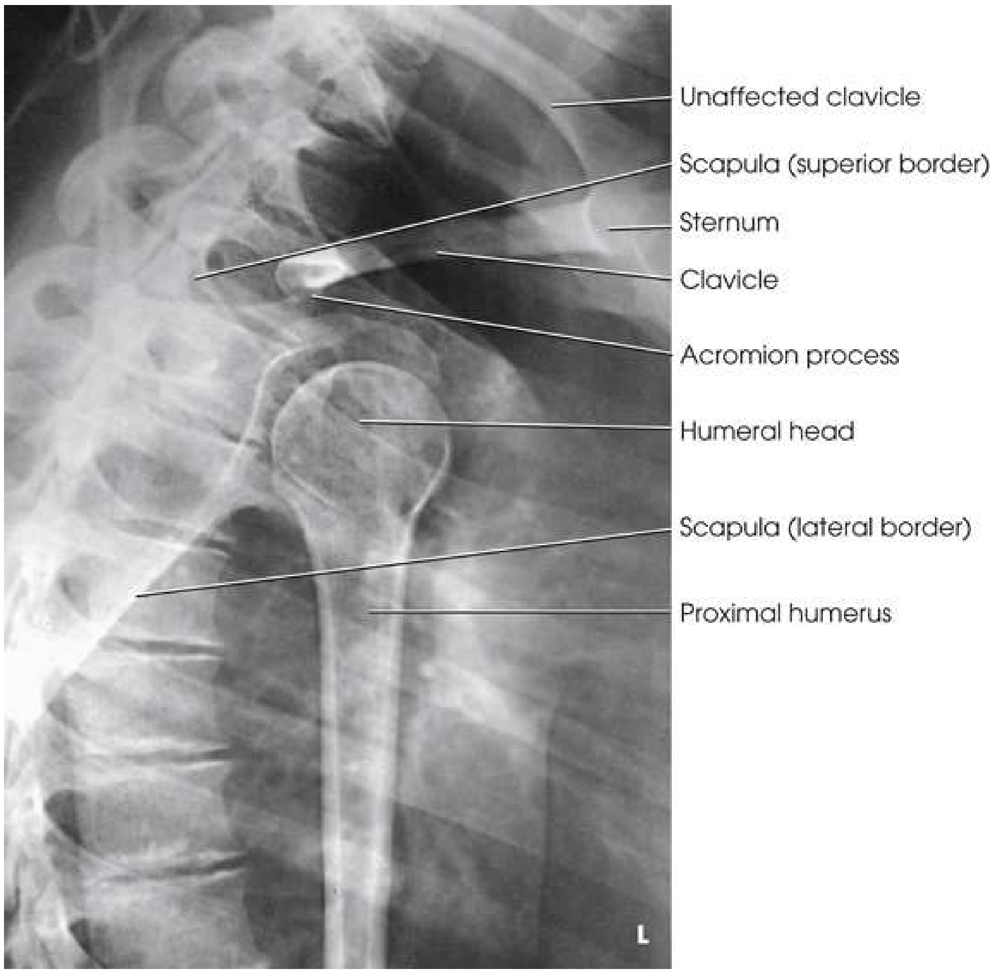


FIG. 6.25 Transthoracic lateral shoulder: Lawrence method.

The lateral image of the shoulder and proximal humerus projected through the thorax. It appears hazy. The parts labeled are listed as follows: unaffected clavicle, scapula (superior border), sternum, clavicle, acromion process, humeral head, scapula (lateral border), and proximal humerus.

FIG. 6.26 Transthoracic lateral shoulder (patient breathing): Lawrence method.

Shoulder Joint

Inferosuperior Axial Projection

Lawrence Method [4]

Inferosuperior Axial Projection

Rafert et al. [5] Modification

Image receptor + grid: Positioned by manufacturer or department protocol for proper anatomy display orientation; CR plate: 10 × 12 inches (24 × 30 cm) grid crosswise, placed in the vertical orientation in contact with the superior surface of the shoulder.

Position of patient

- With the patient in the supine position, elevate the head, shoulders, and elbow approximately 3 inches (7.6 cm) on a radiolucent sponge.

Position of part

Lawrence method

- As much as possible, abduct the arm of the affected side at right angles to the long axis of the body. A minimum of 20 degrees is required to prevent superimposition of the arm on the shoulder.
- Keep the humerus in *external rotation,* then adjust the forearm and hand in a comfortable position, grasping a vertical support or extended on sandbags or a firm pillow. Support may be necessary under the forearm and hand. Provide the patient with an extension board for the arm.
- Have the patient turn the head away from the side being examined so that the IR can be placed against the neck.
- Place the IR on the edge against the shoulder and as close as possible to the neck.
- Support the IR in position with sandbags or use a vertical IR holder (Fig. 6.27).

Rafert modification

- Anterior dislocation of the humeral head can result in a wedge-shaped compression fracture of the articular surface of the humeral head, called the *Hill-Sachs defect.* [6] The fracture is located on the posterolateral humeral head. An *exaggerated external rotation* of the arm may be required to see the defect.
- With the patient in position exactly as for the Lawrence method, externally rotate the extended arm until the hand forms a 45-degree oblique angle. The thumb is pointing downward (Fig. 6.28).
- Assist the patient in rotating the arm to avoid overstressing the shoulder joint.
- *Shield gonads.*
- *Respiration:* Suspend.

Central ray

Lawrence method

- Horizontally through the axilla to the region of the AC articulation. The degree of medial angulation of the CR depends on the degree of abduction of the arm. The degree of medial angulation is often between 15 degrees and 30 degrees. The greater the abduction, the greater the angle.

Rafert modification

- Horizontal and angled approximately 15 degrees medially, entering the axilla and passing through the AC joint.

Collimation

- Adjust radiation field to 12 inches (30 cm) in width on the collimator and to 1 inch (2.5 cm) above the anterior shadow of the shoulder. Place side marker in the collimated exposure field.

Structures shown

An inferosuperior axial image of the proximal humerus, scapulohumeral joint, lateral portion of the coracoid process, and AC articulation. The insertion site of the subscapular tendon on the lesser tubercle of the humerus and the point of insertion of the teres minor tendon on the greater tubercle of the humerus are also shown. A Hill-Sachs compression fracture on the posterolateral humeral head may be seen using the Rafert modification (Figs. 6.29 and 6.30).

Evaluation Criteria

The following should be clearly seen:

- Evidence of proper collimation and presence of side marker placed clear of anatomy of interest
- Scapulohumeral joint with slight overlap
- Coracoid process, pointing anteriorly
- Lesser tubercle in profile and directed anteriorly
- AC joint, acromion, and acromial end of clavicle projected through the humeral head
- Bony trabecular detail and surrounding soft tissues

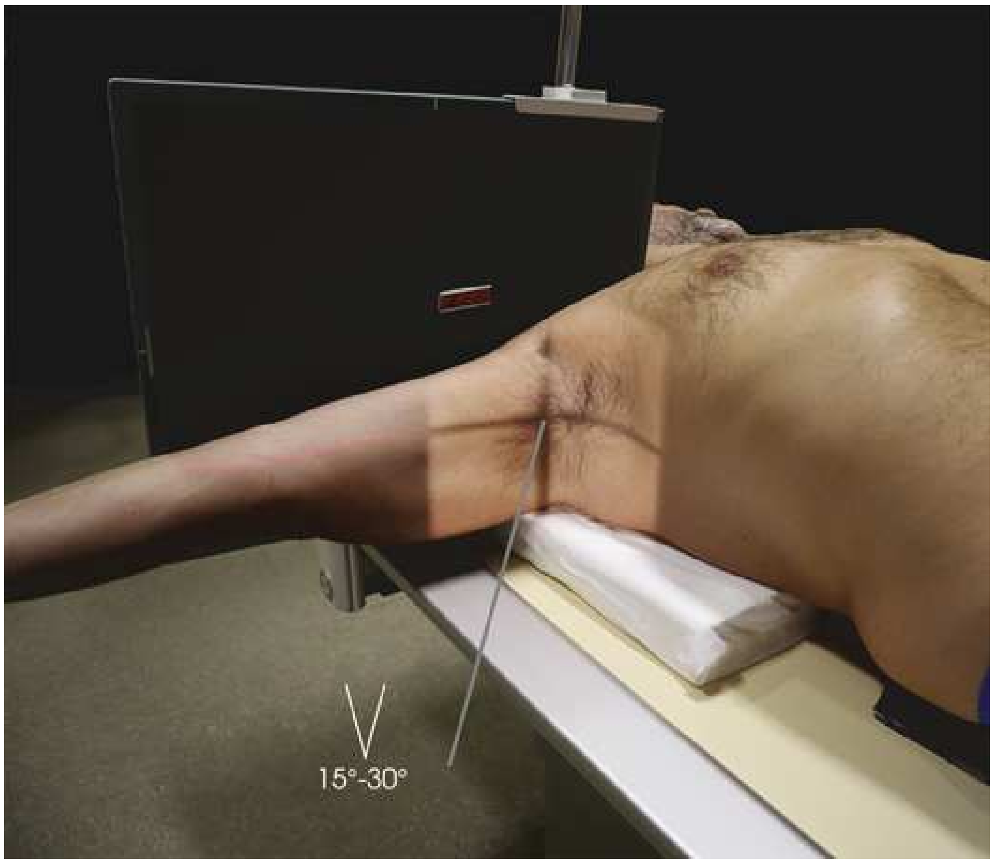


FIG. 6.27 Inferosuperior axial shoulder joint: Lawrence method.

The patient is lying with his head turned away and the I R is placed against his neck on the edge against the shoulder. The degree of medial angulation is between 15 degrees and 30 degrees. The side marker is in the collimated exposure field. The central ray is directed horizontally through the axilla.

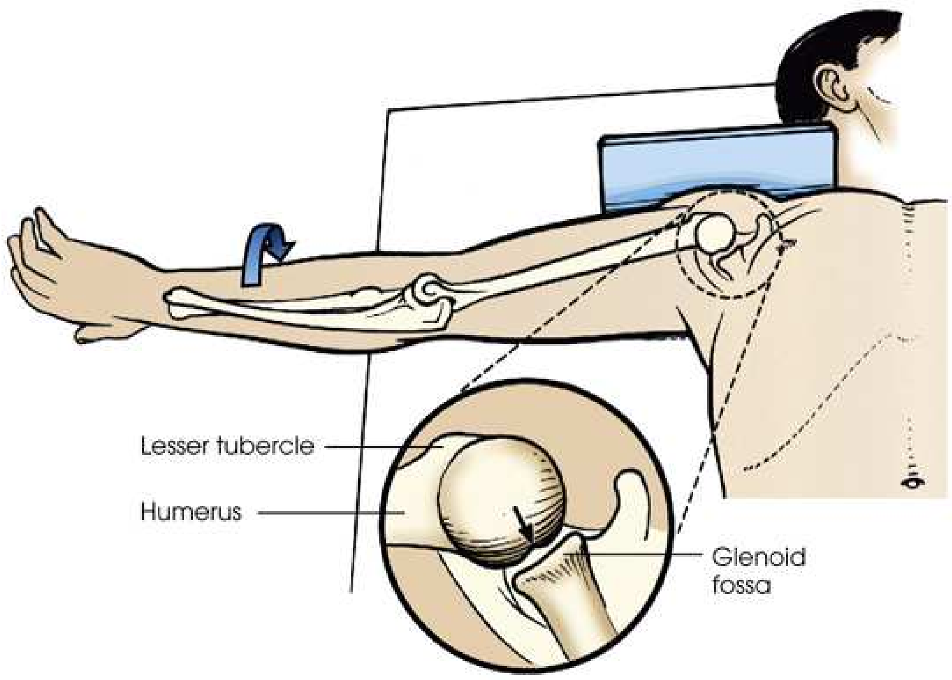


FIG. 6.28 Inferosuperior axial shoulder joint: Rafert modification. Note exaggerated external rotation of arm and thumb pointing downward. If present, a Hill-Sachs defect would show as a wedge-shaped depression on posterior aspect of articulating surface of humeral head *(arrow)*. From Rafert JA, Long BW, Hernandez EM, Kreipke DL. Axillary shoulder with exaggerated rotation: the Hill-Sachs defect. *Radiol Technol.* 1990;62:18.

The patient is lying with his head turned away and the I R is placed against his neck on the edge against the shoulder. The arm is rotated and the thumb is pointing downward. An enlarged view of the inferosuperior axial shoulder joint has the following parts marked on it: lesser tubercle, humerus, glenoid fossa.

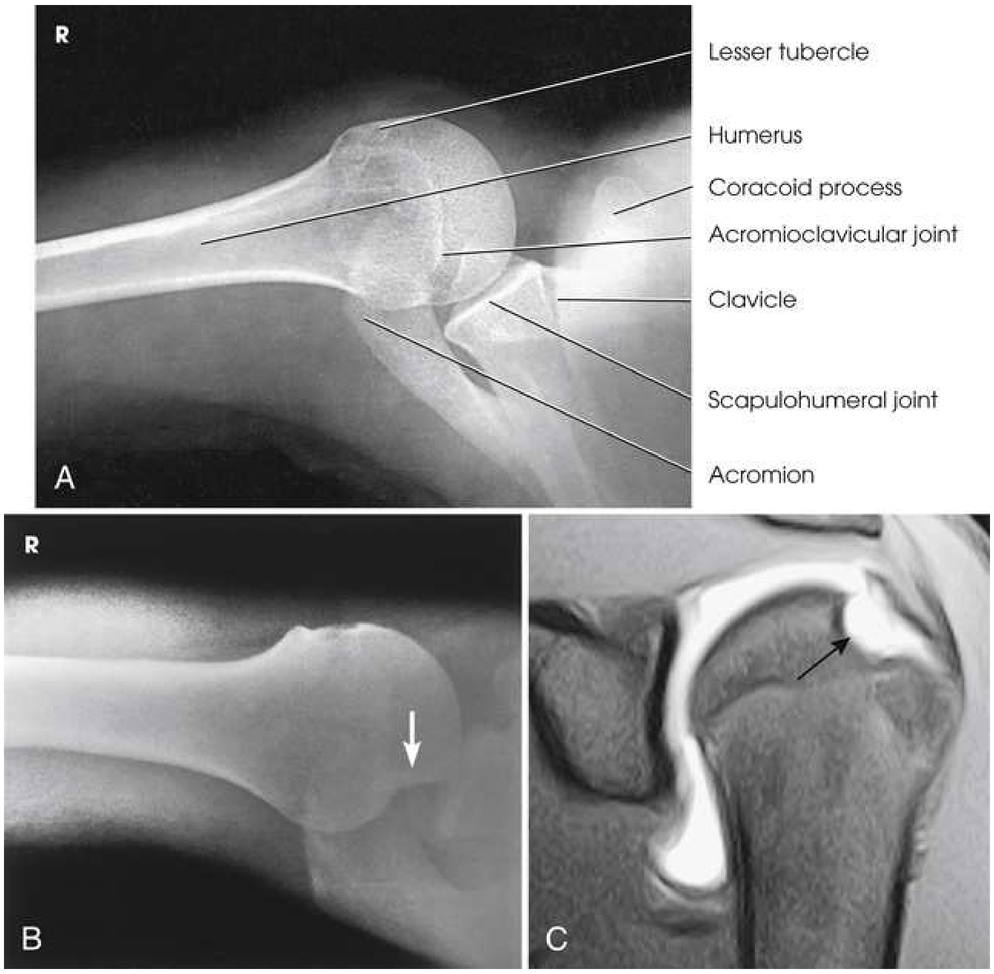


FIG. 6.29 (A) Inferosuperior axial shoulder joint: Lawrence method. (B) Inferosuperior axial shoulder joint: Rafert modification showing Hill-Sachs defect *(arrow)*. (C) Coronal MRI of shoulder joint showing Hill-Sachs defect *(arrow)* after recurrent shoulder dislocation. A and B, From Rafert JA, Long BW, Hernandez EM, Kreipke DL. Axillary shoulder with exaggerated rotation: the Hill-Sachs defect. *Radiol Technol.* 1990;62:18. C, From Jackson SA, Thomas RM. *Cross-imaging made easy,* New York: Churchill Livingstone; 2004.

(A) An x-ray shows the inferosuperior axial shoulder joint. The following parts are marked on it: lesser tubercle, humerus, coracoid process, acromioclavicular joint, clavicle, scapulohumeral joint, acromion. (B) An x-ray view of the hell-sachs defect marked by a white downward arrow. It appears grainy. (C) The Coronal M R I of shoulder joint showing hill Sachs defect appears white and is marked by a black arrow.

FIG. 6.30 Inferosuperior axial shoulder joint: Lawrence method showing comminuted fracture of humerus. The patient came into emergency department with arm extended out.

FIG. 6.31 Inferosuperior axial shoulder joint: West Point method.

The patient is lying in the prone position with his head turned away. The arm of the affected hand is rotated and the forearm rests over a Bucky tray, which is used for support. The side marker is in the collimated exposure field. The central ray is directed at a dual-angle of 25 degrees anteriorly from the horizontal and 25 degrees medially.

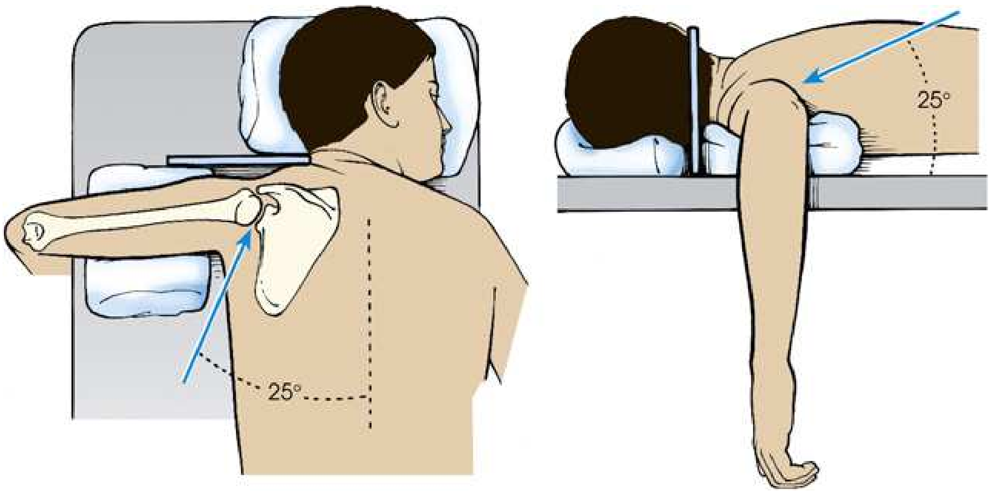


FIG. 6.32 West Point method with anterior and medial central ray angulation.

Diagram on the left shows the patient is lying in the prone position with his head turned away. The arm of the affected side is abducted to and is rotated. The forearm rests over the edge of a bucky tray, which is used for support. The I R is centered to the superior aspect of the shoulder with the edge of the I R in contact with the neck. The central ray is directed at a dual-angle of 25 degrees anteriorly from the horizontal and 25 degrees medially. Diagram on the right shows the side view of the patient lying in the prone position with his head turned away. The forearm rests over the edge of a bucky tray, which is used for support. The I R is centered to the superior aspect of the shoulder with the edge of the I R in contact with the neck. The central ray is directed at a dual-angle of 25 degrees anteriorly from the horizontal and 25 degrees medially.

Inferosuperior Axial Projection

West Point Method

The West Point [7] method is used when chronic instability of the shoulder is suspected and to show bony abnormalities of the anterior inferior glenoid rim. Associated Hill-Sachs defect of the posterior lateral aspect of the humeral head is also shown.

Image receptor + grid: Positioned by manufacturer or department protocol for proper anatomy display orientation; CR plate: 10 × 12 inches (24 × 30 cm) crosswise, placed in the vertical orientation in contact with the superior surface of the shoulder.

Position of patient

- Adjust the patient in the prone position with approximately a 3-inch (7.6-cm) pad under the shoulder being examined.
- Turn the patient's head away from the side being examined.

Position of part

- Abduct the arm of the affected side by *90 degrees* and rotate it so that the forearm rests over the edge of the table or a Bucky tray, which may be used for support (Figs. 6.31 and 6.32).
- Place a vertically supported IR against the superior aspect of the shoulder with the edge of the IR in contact with the neck.
- Support the IR with sandbags or a vertical IR holder.
- *Shield gonads.*
- *Respiration:* Suspend.

Central ray

- Directed at a dual angle of 25 degrees *anteriorly* from the horizontal and 25 degrees *medially.* The CR enters approximately 5 inches (13 cm) inferior and 1½ inches (3.8 cm) medial to the acromial edge and exits the glenoid cavity.

Collimation

- Adjust radiation field to 12 inches (30 cm) in width on the collimator and to 1 inch (2.5 cm) above the posterior shadow of the shoulder. Place side marker in the collimated exposure field.

Structures shown

Bony abnormalities of the anterior inferior rim of the glenoid and Hill-Sachs defects of the posterolateral humeral head in patients with chronic instability of the shoulder (Fig. 6.33).

Evaluation Criteria

The following should be clearly seen:

- Evidence of proper collimation and presence of side marker placed clear of anatomy of interest
- Scapulohumeral joint with slight overlap
- Humeral head projected free of the coracoid process
- Acromion superimposed over the posterior portion of the humeral head
- Bony trabecular detail and surrounding soft tissues

FIG. 6.33 Inferosuperior axial shoulder joint: West Point method. Courtesy April S. Apple, RT(R), FASRT.

Superoinferior Axial Projection

Image receptor + grid: Positioned by manufacturer or department protocol for proper anatomy display orientation; CR plate: 10 × 12 inches (24 × 30 cm), placed lengthwise for accurate centering to shoulder joint.

Position of patient

- Seat the patient at the end of the table on a stool or chair high enough to enable extension of the shoulder under examination well over the IR.

Position of part

- Place the IR near the end of the table and parallel with its long axis.
- Have the patient lean laterally over the IR until the shoulder joint is over the midpoint of the IR.
- Bring the elbow to rest on the table.
- Flex the patient's elbow 90 degrees and place the hand in the prone position (Fig. 6.34).
- Have the patient tilt the head toward the unaffected shoulder.
- To obtain direct lateral positioning of the head of the humerus, adjust any anterior or posterior leaning of the body to place the humeral epicondyles in the vertical position.
- *Shield gonads.*
- *Respiration:* Suspend.

Central ray

- Angled 5 to 15 degrees through the shoulder joint and toward the elbow; a greater angle is required when the patient cannot extend the shoulder over the IR.

Collimation

- Adjust radiation field to 10 inches (24 cm) in width on the collimator and to 1 inch (2.5 cm) beyond the anterior and posterior shadows of the shoulder. Place side marker in the collimated exposure field.

Structures shown

A superoinferior axial image shows the joint relationship of the proximal end of the humerus and the glenoid cavity (Fig. 6.35). The AC articulation, the outer portion of the coracoid process, and the points of insertion of the subscapularis muscle (at body of scapula) and teres minor muscle (at inferior axillary border) are shown.

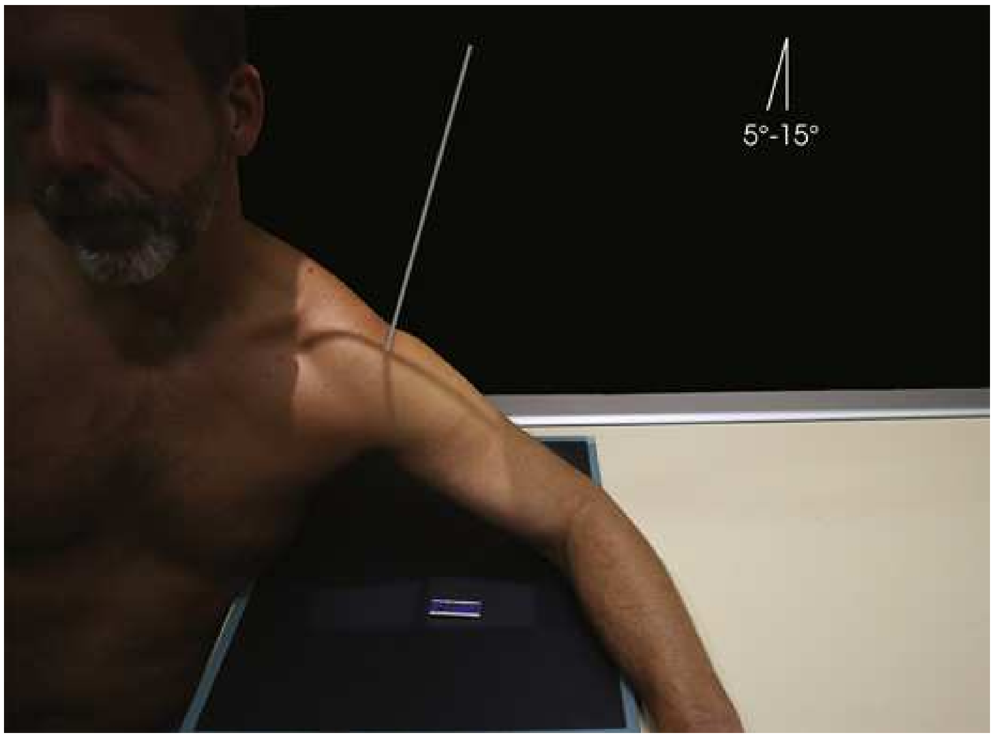


FIG. 6.34 Superoinferior axial shoulder joint: standard IR.

The patient is leaning laterally over the I R. The patient's elbow is flexed 90 degrees and the hand is placed in the prone position. The I R is placed near the end of the table and parallel with its long axis. The side marker is in the collimated exposure field. The central ray is angled 5 to 15 degrees through the shoulder joint.

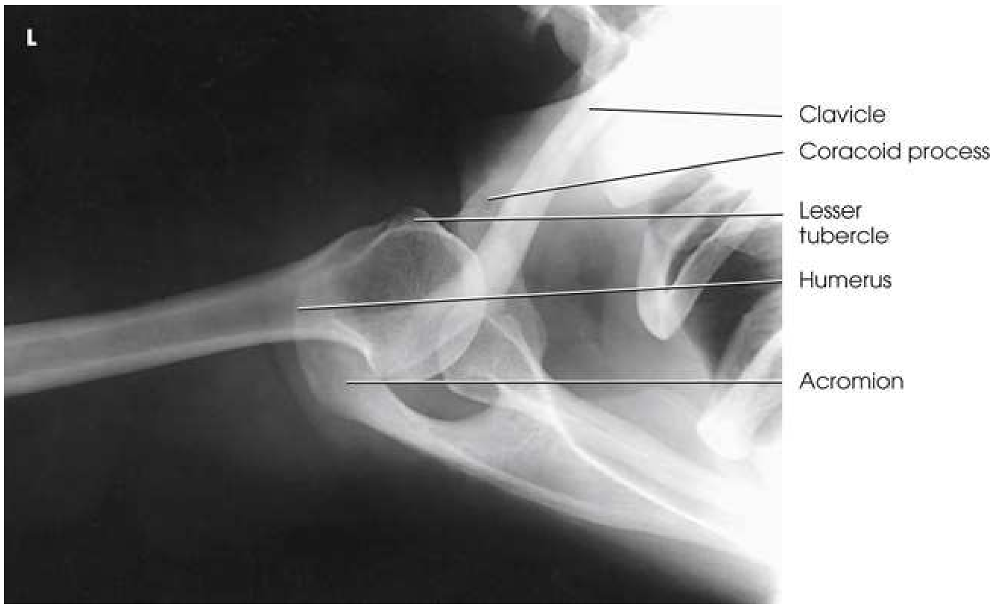


FIG. 6.35 Superoinferior axial shoulder joint.

The x-ray shows the joint relationship of the proximal end of the humerus and the glenoid cavity. The parts labeled are listed from top to the bottom as follows. clavicle, coracoid process, lesser tubercle, humerus, and acromion. The soft tissues appear dark and the bony elements are bright.

Evaluation Criteria

The following should be clearly seen:

- Evidence of proper collimation and presence of side marker placed clear of anatomy of interest
- Scapulohumeral joint (not open on patients with limited flexibility)
- Coracoid process projected above the clavicle
- Lesser tubercle in profile
- AC joint through the humeral head
- Bony trabecular detail and surrounding soft tissues

Scapular Y

PA Oblique Projection

RAO or LAO position

This projection, described by Rubin et al.,[8] obtained its name due to the appearance of the scapula. The body of the scapula forms the vertical component of the Y, and the acromion and the coracoid process form the upper limbs. This projection is useful in the evaluation of suspected shoulder dislocations.

Image receptor + grid: Positioned by manufacturer or department protocol for proper anatomy display orientation; CR plate: 10 × 12 inches (24 × 30 cm) lengthwise.

Position of patient

- Radiograph the patient in the upright or recumbent body position; the upright position is preferred.
- When the patient is severely injured and recumbent, modify the anterior oblique position by placing the patient in the posterior oblique position. This position does not require the patient to lie on the injured shoulder.

Position of part

- Position the anterior surface of the shoulder being examined against the upright Bucky.
- Rotate the patient so that the midcoronal plane forms an angle of 45 to 60 degrees to the IR. The position of the arm is not critical because it does not alter the relationship of the humeral head to the glenoid cavity (Fig. 6.36). Palpate the scapula, and place its flat surface perpendicular to the IR. According to Johnston et al.,[1] this is accomplished by orienting the plane through the superior angle of the scapula and acromial tip, perpendicular to the IR.
- Position the center of the IR at the level of the scapulohumeral joint.
- *Shield gonads.*
- *Respiration:* Suspend.

Compensating Filter

Use of a specially designed compensating filter for the shoulder, called a boomerang, improves the quality of the image because of the large amount of primary beam radiation striking the IR.

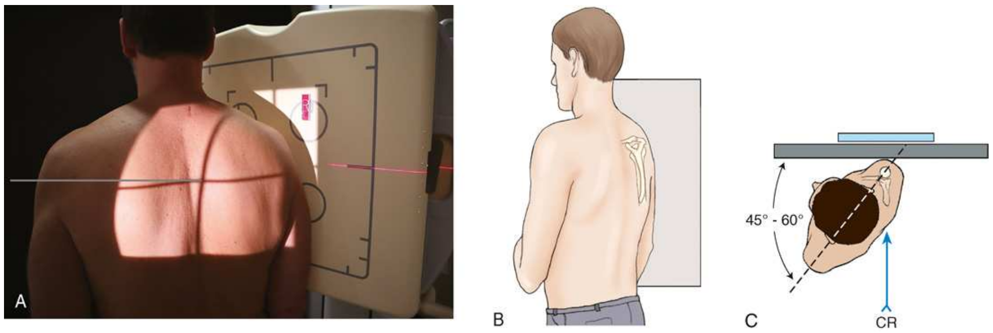


FIG. 6.36 (A) PA oblique shoulder joint. (B) Perspective from x-ray tube showing scapula centered in true lateral position. (C) Top-down view showing positioning landmarks used for proper orientation of scapular body.

(A) shows the patient standing in the upright position against the vertical grid. The anterior surface of the shoulder is positioned against the upright bucky. The side marker is in the collimated exposure field. The central ray is perpendicular to the scapulohumeral joint. (B) shows the patient standing with his anterior surface positioned against the grid. The scapula highlighted is centered in a true lateral position. (C) shows the top view of the patient standing in an upright position against the vertical grid. The anterior surface of the shoulder is positioned against the upright bucky. The patient is rotated and the midcoronal plane forms an angle of 45 to 60 degrees to the I R. The central ray is perpendicular to the scapulohumeral joint.

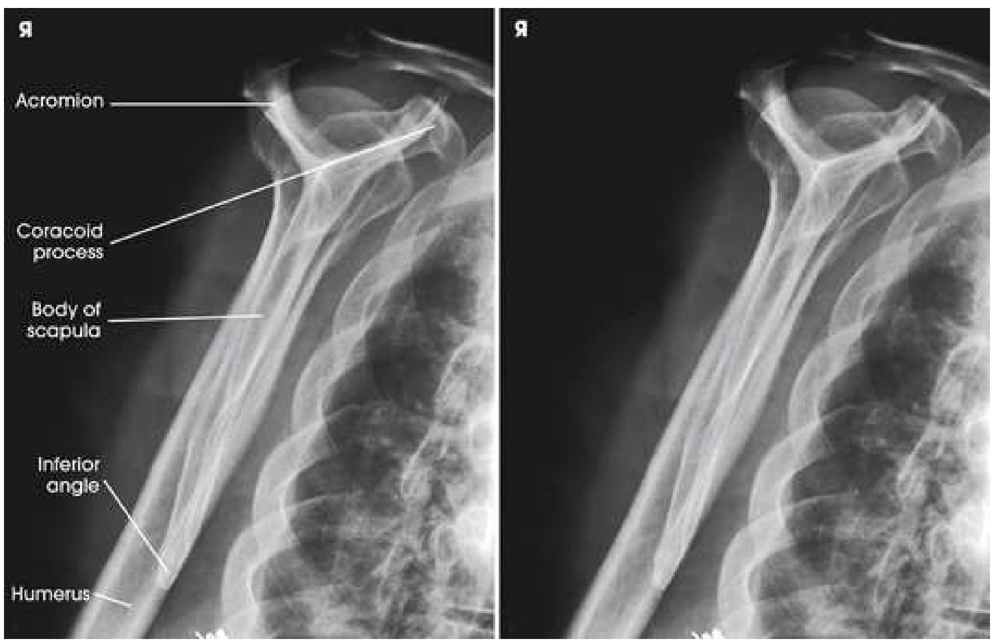


FIG. 6.37 PA oblique shoulder joint. Note scapular Y components—body, acromion, and coracoid process.

Two x-ray views show the body of the scapula forming the vertical component of the Y. The lungs appear dark. The parts labeled in the x-ray on the left are listed from top to the bottom as follows: acromion, coracoid process, the body of scapula, inferior angle, and humerus.

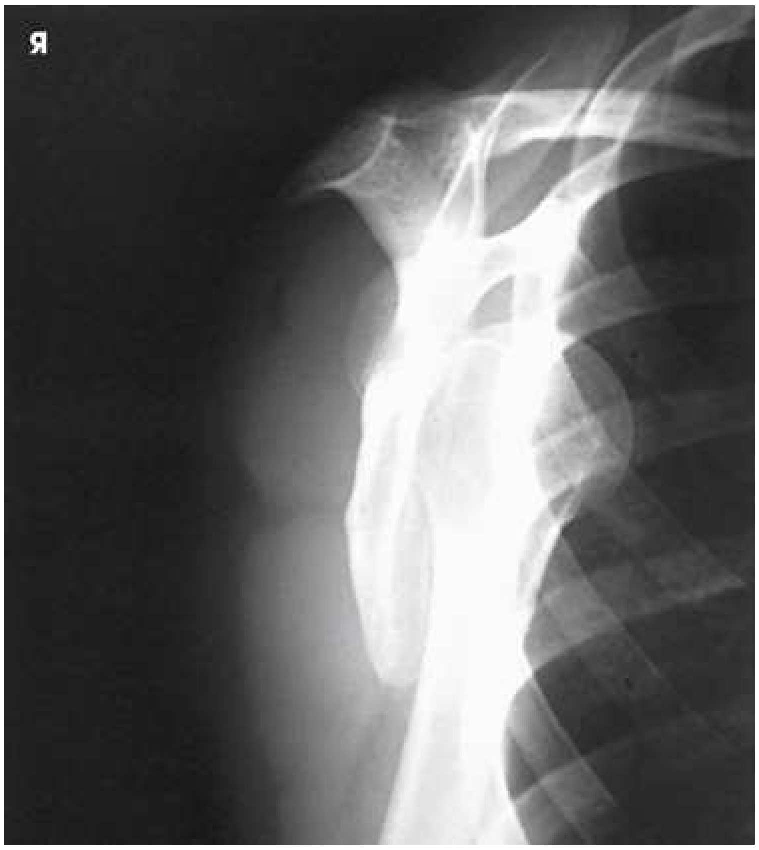


FIG. 6.38 PA oblique shoulder joint showing anterior dislocation (humeral head projected beneath coracoid process).

FIG. 6.39 AP shoulder (same patient as in Fig. 6.38).

Central ray

- Perpendicular to the scapulohumeral joint (Table 6.3)

Collimation

- Adjust radiation field to 12 inches (30 cm) in length on the collimator and to 1 inch (2.5 cm) beyond the lateral shadow. Place side marker in the collimated exposure field.

Structures shown

The scapular Y is shown on an oblique image of the shoulder. In the normal shoulder, the humeral head is directly superimposed over the junction of the Y (Fig. 6.37). In anterior (subcoracoid) dislocations, the humeral head is beneath the coracoid process (Fig. 6.38); in posterior (subacromial) dislocations, it is projected beneath the acromion. An AP shoulder projection is shown for comparison (Fig. 6.39).

Evaluation Criteria

The following should be clearly seen:

- Evidence of proper collimation and presence of side marker placed clear of anatomy of interest
- Humeral head and glenoid cavity superimposed
- Humeral shaft and scapular body superimposed
- No superimposition of the scapular body over the bony thorax
- Acromion projected laterally and free of superimposition
- Coracoid possibly superimposed or projected below the clavicle
- Scapula in lateral profile with lateral and vertebral borders superimposed
- Bony trabecular detail and surrounding soft tissues

TABLE 6.3

Name	Body rotation	Scapula relationship to IR	Central ray angle[a]	Central ray entrance point[a]	Arm position[a]
Shoulder joint: Neer method	45–60 degrees	Perpendicular	10–15 degrees caudad	Superior humeral border	At side
Shoulder joint: scapular Y	45–60 degrees	Perpendicular	0 degrees	Scapulohumeral joint	At side
Scapula lateral	45–60 degrees	Perpendicular	0 degrees	Center of medial border of scapula	Variable

The diagram on the left shows the top view of the patient standing in the upright position against the vertical grid. The patient is rotated and the midcoronal plane forms an angle of 45 to 60 degrees to the I R. The anterior surface of the shoulder is positioned against the upright bucky. The central ray is perpendicular to the scapulohumeral joint. The diagram on the right shows the scapula and the anterior surface of the shoulder is positioned against the upright bucky. For the shoulder joint by Neer method, the central ray angle is 10 to 15 degrees. For the shoulder joint by scapular Y, the central ray angle is 0 degrees. For scapula lateral, the central ray angle is 0 degrees.

[a] Central ray angles and entrance points and arm positions are the only differences among these three projections.

Supraspinatus "Outlet"

Tangential Projection

Neer Method

RAO or LAO position

This radiographic projection is useful to show tangentially the coracoacromial arch or outlet to diagnose shoulder impingement.[9, 10] The tangential image is obtained by projecting the x-ray beam under the acromion and AC joint, which defines the superior border of the coracoacromial outlet.

Image receptor + grid: Positioned by manufacturer or department protocol for proper anatomy display orientation; CR plate: 10 × 12 inches (24 × 30 cm) lengthwise.

Position of patient

- Place the patient in a seated or standing position facing the vertical grid device.

Position of part

- With the patient's affected shoulder centered and in contact with the IR, rotate the patient's unaffected side away from the IR. Palpate the flat aspect of the affected scapula, and place it perpendicular to the IR. The degree of patient obliquity varies from patient to patient. The average degree of patient rotation varies from 45 to 60 degrees from the plane of the IR (Fig. 6.40).
- Place the patient's arm at the patient's side.
- *Shield gonads.*
- *Respiration:* Suspend.

Central ray

- Angled 10 to 15 degrees caudad, entering the superior aspect of the humeral head (see Table 6.3)

Collimation

- Adjust radiation field to 12 inches (30 cm) in length on the collimator and to 1 inch (2.5 cm) beyond the lateral shadow. Place side marker in the collimated exposure field.

Structures shown

The tangential outlet image shows the posterior surface of the acromion and the AC joint identified as the superior border of the coracoacromial outlet (Figs. 6.41 and 6.42).

Evaluation Criteria

The following should be clearly seen:

- Evidence of proper collimation and presence of side marker placed clear of anatomy of interest
- Humeral head projected below the AC joint
- Humeral head and AC joint with bony detail
- Humerus and scapular body, generally parallel
- Bony trabecular detail and surrounding soft tissues

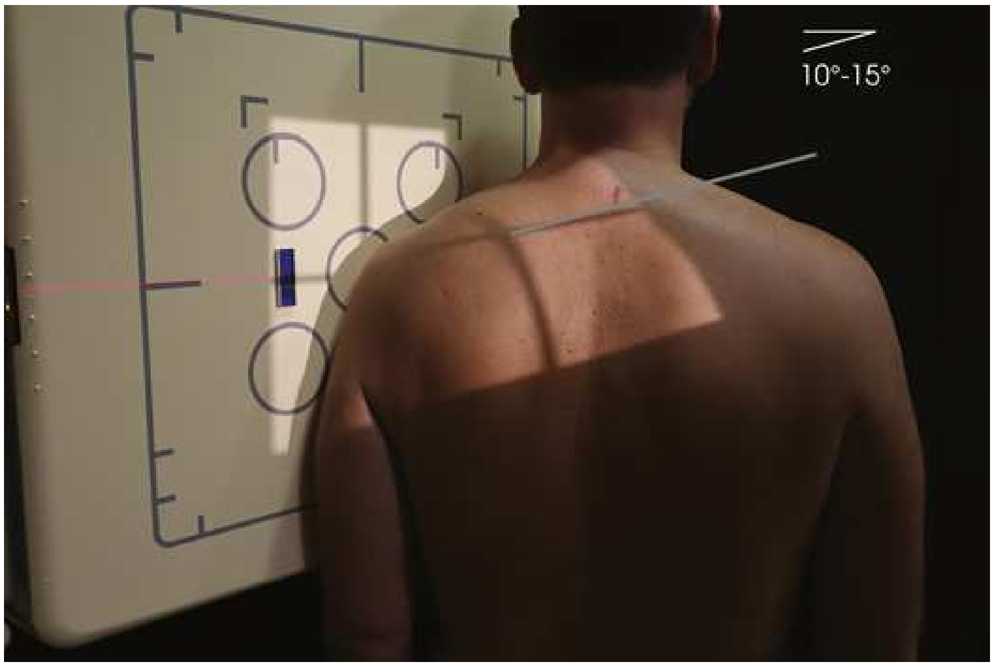


FIG. 6.40 Tangential supraspinatus "outlet" projection.

The patient is rotated and is standing facing the vertical grid device. The patient's affected shoulder is centered and is in contact with the I R. The side marker is in the collimated exposure field. The central ray is angled 10 to 15 degrees caudad.

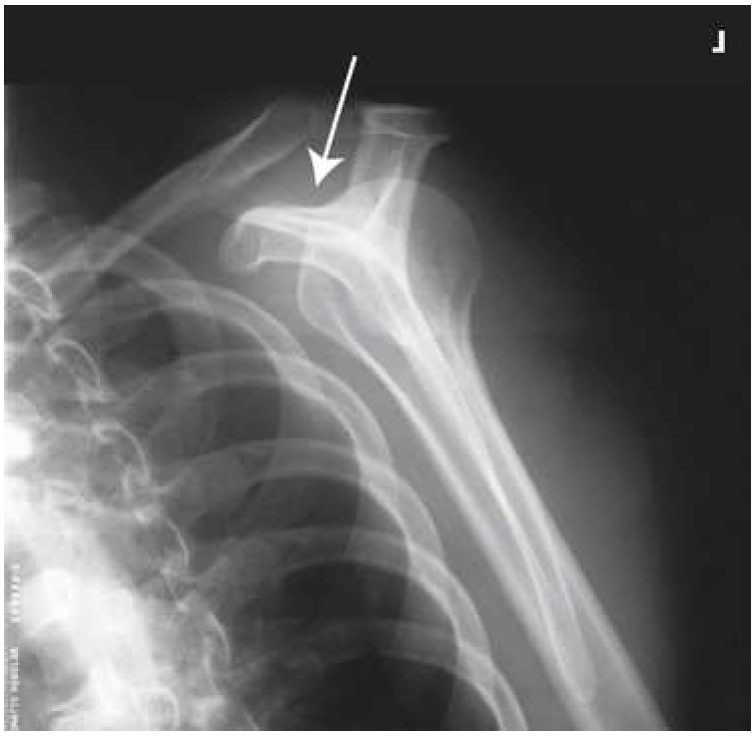


FIG. 6.41 Shoulder joint: Neer method. Supraspinatus outlet *(arrow)*.

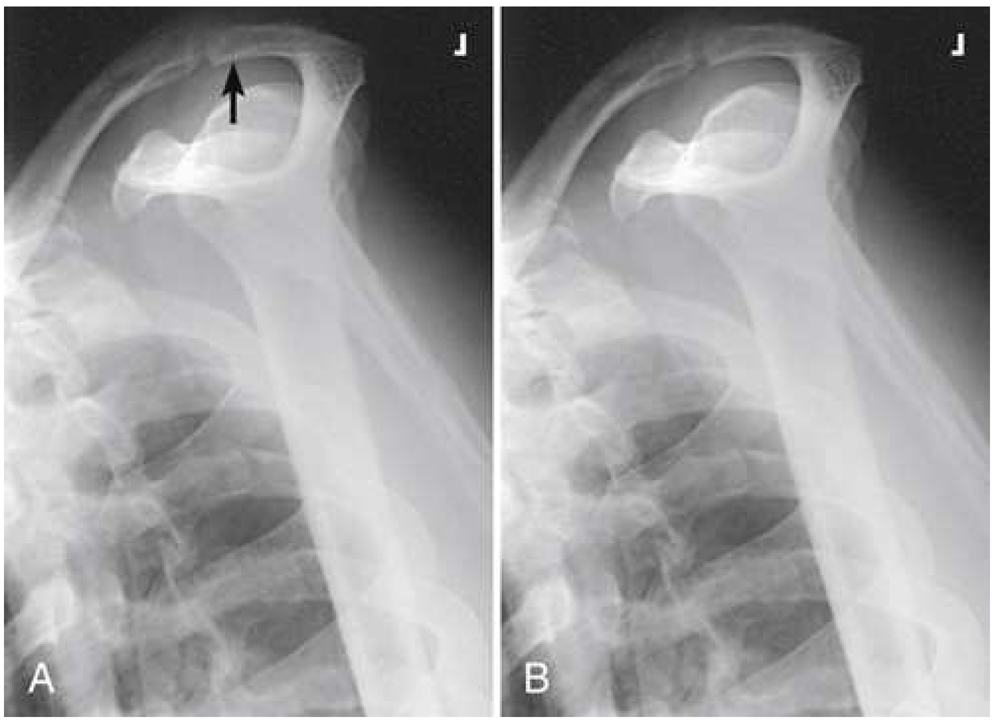


FIG. 6.42 (A) Tangential supraspinatus outlet projection showing impingement of shoulder outlet by subacromial spur *(arrow)*. (B) Radiograph of same patient as in Fig. 6.41 after surgical removal of posterolateral surface of clavicle.

(A) The x-ray shows the impingement of the shoulder outlet by subacromial spur is marked by an arrow. It appears hazy. (B) The x-ray shows the posterolateral surface of the clavicle removed. It appears hazy.

AP Axial Projection

Image receptor + grid: Positioned by manufacturer or department protocol for proper anatomy display orientation; CR plate: 10 × 12 inches (24 × 30 cm) crosswise.

Position of patient

- Position the patient in the upright or supine position.

Position of part

- Center the scapulohumeral joint of the shoulder being examined to the midline of the grid (Fig. 6.43).

- *Shield gonads.*
- *Respiration:* Suspend.

Central ray

- Directed through the scapulohumeral joint at a cephalic angle of 35 degrees

Collimation

- Adjust radiation field to 1-inch beyond the skin shadows on the superior and lateral sides. Place side marker in the collimated exposure field.

Structures shown

The axial image shows the relationship of the head of the humerus to the glenoid cavity. This is useful in diagnosing cases of posterior dislocation (Fig. 6.44). It also shows the entire coracoid process.

Evaluation Criteria

The following should be clearly seen:

- Evidence of proper collimation and presence of side marker placed clear of anatomy of interest
- Scapulohumeral joint
- Proximal humerus
- Clavicle projected above superior angle of scapula
- Coracoid process
- Bony trabecular detail and surrounding soft tissues

FIG. 6.43 AP axial shoulder joint.

The patient is in the supine position. The scapulohumeral joint is in the midline of the grid. The side marker is in the collimated exposure field. The central ray is directed through the scapulohumeral joint at a cephalic angle of 35 degrees.

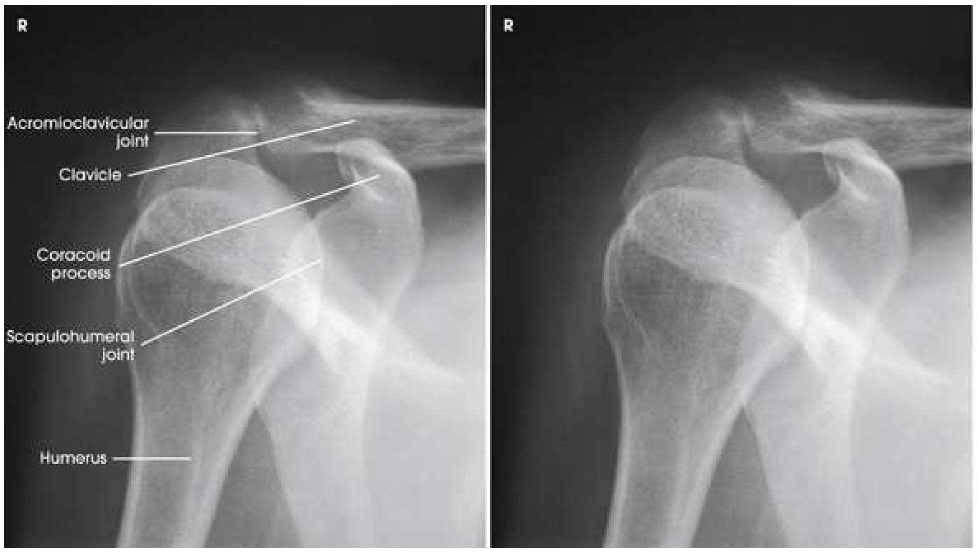


FIG. 6.44 AP axial shoulder joint.

Two x-ray views show the head of the humerus to the glenoid cavity and the entire coracoid process. The parts labeled in the x-ray on the left are listed from top to the bottom as follows: acromioclavicular joint, clavicle, coracoid process, scapulohumeral joint, and humerus.

Proximal Humerus

AP Axial Projection

Stryker Notch Method

Anterior dislocations of the shoulder frequently result in posterior defects involving the posterolateral head of the humerus. Such defects, called *Hill-Sachs defects,* [6] are often not shown using conventional radiographic positions. Hall et al. [11] described the notch projection, from ideas expressed by Stryker, as being useful to show this humeral defect.

Image receptor + grid: Positioned by manufacturer or department protocol for proper anatomy display orientation; CR plate: 10 × 12 inches (24 × 30 cm) lengthwise.

Position of patient

- Place the patient on the radiographic table in the supine position.

Position of part

- With the coracoid process of the affected shoulder centered to the table, ask the patient to flex the arm slightly beyond 90 degrees and place the palm of the hand on top of the head with fingertips resting on the head. (This hand position places the humerus in a slight internal rotation position.) The body of the humerus is adjusted to be vertical so that it is parallel to the midsagittal plane of the body (Fig. 6.45).
- *Shield gonads.*
- *Respiration:* Suspend.

Central ray

- Angled 10 degrees cephalad, entering the coracoid process

Collimation

- Adjust radiation field to 10 × 12 inches (24 × 30 cm) on the collimator. Adjust as needed to include 1 inch beyond the superior and lateral shoulder borders. Place side marker in the collimated exposure field.

Structures shown

The posterosuperior and posterolateral areas of the humeral head (Figs. 6.46 and 6.47).

Evaluation Criteria

The following should be clearly seen:

- Evidence of proper collimation and presence of side marker placed clear of anatomy of interest

- Overlapping of coracoid process and clavicle
- Posterolateral lateral aspect of humeral head in profile
- Long axis of the humerus aligned with the long axis of the patient's body
- Bony trabecular detail and surrounding soft tissues

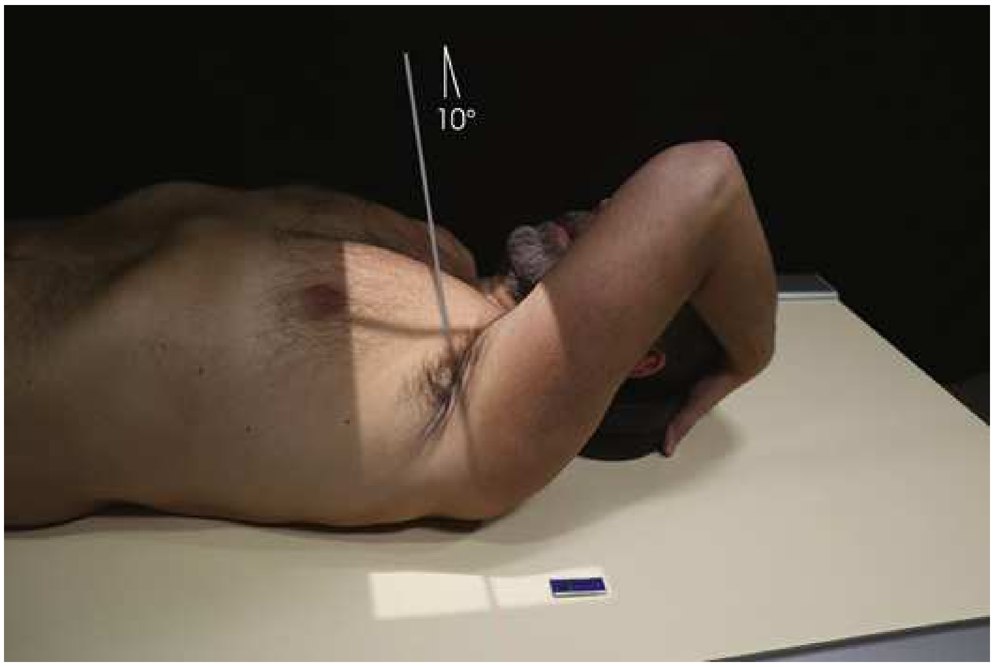


FIG. 6.45 AP axial humeral notch: Stryker notch method.

The patient is in the supine position on the radiographic table. The arm of the patient is flexed and the palm of the hand is placed on top of the head with fingertips resting on the head. The side marker is in the collimated exposure field. The central ray is angled 10 degrees cephalad entering the coracoid process.

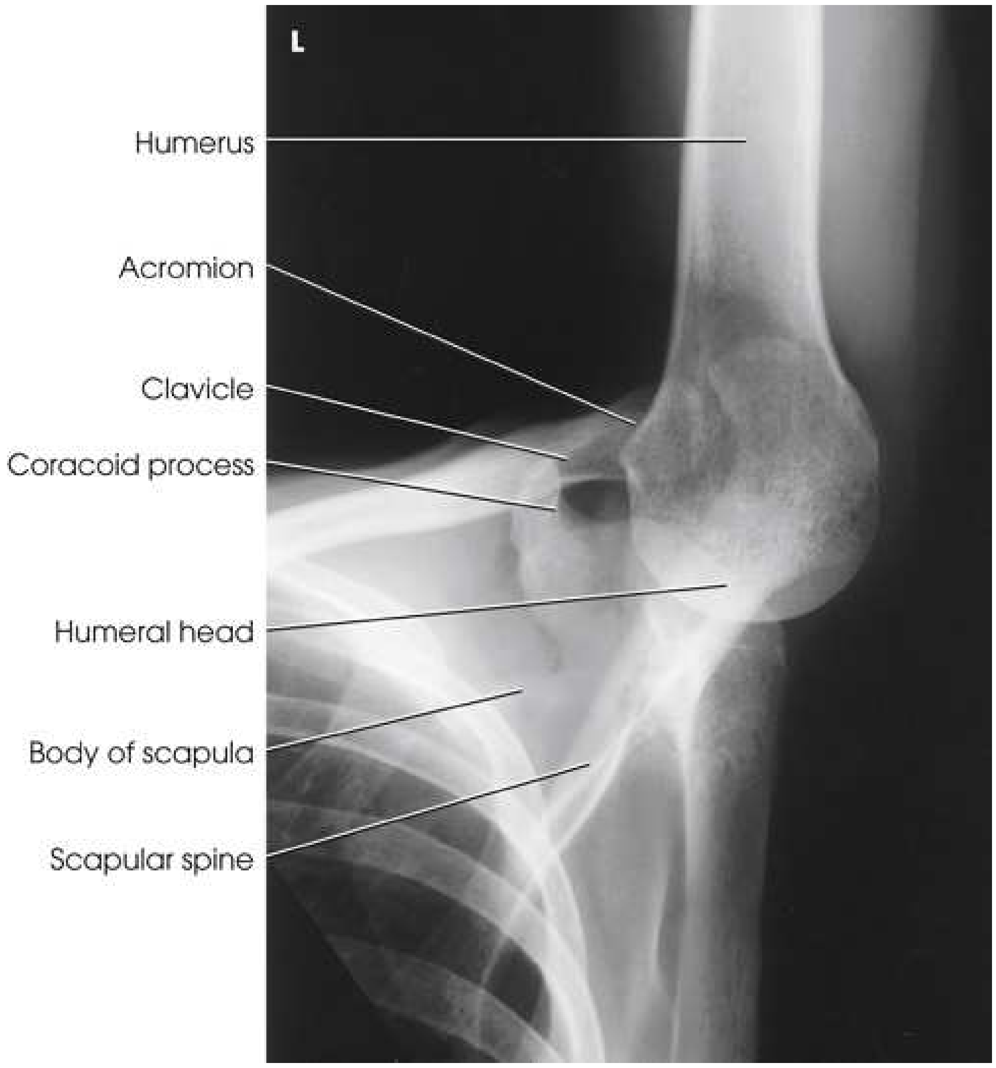


FIG. 6.46 AP axial humeral notch: Stryker notch method.

The x-ray shows the posterosuperior and posterolateral areas of the humeral head. The parts labeled in the x-ray are listed from top to the bottom as follows: humerus, acromion, clavicle, coracoid process, humeral head, the body of scapula, and scapular spine. The humeral head appears bright and the humerus is grainy.

FIG. 6.47 Same projection as in Fig. 6.46 in a patient with small Hill-Sachs defect *(arrow)*.

Glenoid Cavity

Ap Axial Oblique Projection

Garth Method

RPO or LPO position

This projection is recommended for assessing acute shoulder trauma and for identifying posterior scapulohumeral dislocations, glenoid fractures, Hill-Sachs lesions, and soft tissue calcifications. [12]

Image receptor + grid: Positioned by manufacturer or department protocol for proper anatomy display orientation; CR plate: 10 × 12 inches (24 × 30 cm) lengthwise.

Position of patient

- Place the patient in the supine, seated, or upright position.

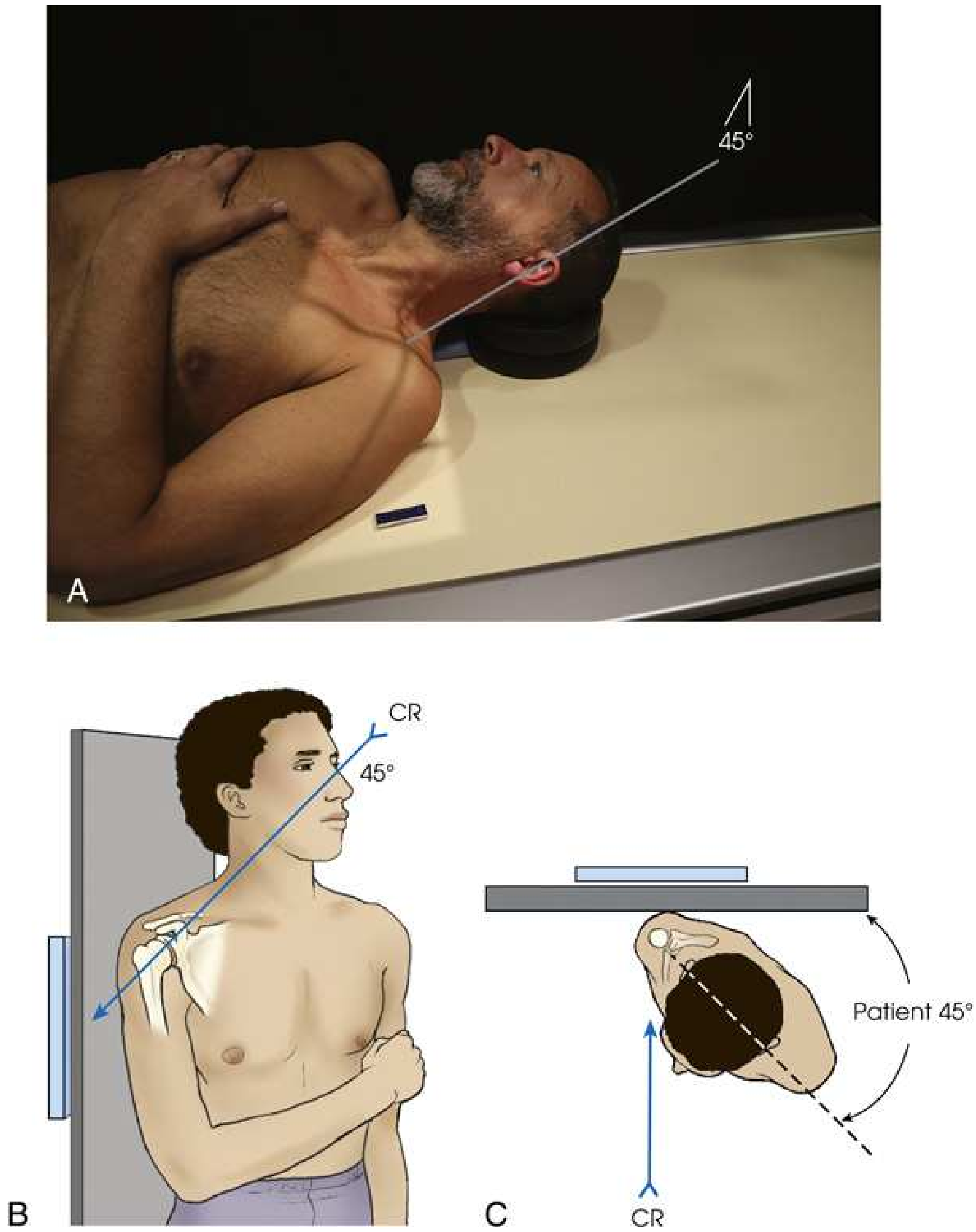


FIG. 6.48 (A) AP axial oblique: Garth method, supine LPO position. Note 45-degree CR. (B) AP axial oblique: Garth method, upright RPO. (C) Top view of same position as in (B). Note 45-degree patient position.

(A) shows the patient lying in the supine position. The elbow of the affected arm is flexed and the arm is placed across the chest. The side marker is in the collimated exposure field. The central ray is angled 45 degrees caudad through the scapulohumeral joint. (B) shows the patient in the upright position. The body is rotated approximately 45 degrees toward the affected side. The elbow of the affected arm is flexed and the arm is placed across the chest. The central ray is angled 45 degrees caudad through the scapulohumeral joint. (C) shows the top view of the patient in the upright position. The body is rotated approximately 45 degrees toward the affected side. The elbow of the affected arm is flexed and the arm is placed across the chest. The central ray is angled 45 degrees caudad through the scapulohumeral joint.

Position of part

- Center the IR to the glenohumeral joint.
- Rotate the body approximately 45 degrees toward the affected side.
- The posterior surface of the affected side is closest to the IR.
- Flex the elbow of the affected arm and place arm across the chest (Fig. 6.48).
- *Shield gonads.*
- *Respiration:* Suspend.

Central ray

- Angled 45 degrees caudad through the scapulohumeral joint

Collimation

- Adjust radiation field to 10 × 12 inches (24 × 30 cm) on the collimator. Adjust as needed to include 1.5 inches (3.8 cm) above the shoulder, 1 inch (2.5 cm) beyond the lateral aspect of the shoulder, the lateral half of the clavicle, and the proximal third of the humerus. Place side marker in the collimated exposure field.

Structures shown

The scapulohumeral joint, humeral head, coracoid process, and scapular head and neck (Fig. 6.49).

Evaluation Criteria

The following should be clearly seen:

- Evidence of proper collimation and presence of side marker placed clear of anatomy of interest
- The scapulohumeral joint, humeral head, lateral angle, and scapular neck free of superimposition
- The coracoid process should be well visualized.
- Posterior dislocations project the humeral head *superiorly* from the glenoid cavity, and anterior dislocations project *inferiorly*.
- Bony trabecular detail and surrounding soft tissues

FIG. 6.49 AP axial oblique: Garth method showing anterior dislocation of proximal humerus. Humeral head is shown below coracoid process, a common appearance with anterior dislocation. Courtesy Bruce W. Long, MS, RT[R][CV], and John A. Rafert, MS, RT[R].

Proximal Humerus

Intertubercular (Bicipital) Groove

Tangential Projection

Fisk Modification

Various modifications of the intertubercular (bicipital) groove image have been devised. In all cases the CR is aligned to be tangential to the intertubercular (bicipital) groove, which lies on the anterior surface of the humerus. [13]

The x-ray tube head assembly may limit the performance of this examination. Some radiographic units have large collimators or handles, or both, that limit flexibility in positioning. A mobile radiographic unit may be used to reduce this difficulty.

Image receptor:

Positioned by manufacturer or department protocol for proper anatomy display orientation; CR plate: 10 × 12 inches (24 × 30 cm) crosswise.

Position of patient

- Place the patient in the supine, seated, or standing position.
- To improve centering, extend the chin or rotate the head away from the affected side.

Position of part

- With the patient supine, palpate the anterior surface of the shoulder to locate the intertubercular (bicipital) groove.
- With the patient's hand in the supinated position, place the IR against the superior surface of the shoulder and immobilize the IR as shown in Fig. 6.50.
- *Shield gonads.*
- *Respiration:* Suspend.

Fisk modification

Fisk first described this position with the patient standing at the end of the radiographic table. This uses a greater object-to-image receptor distance (OID). The following steps are then taken with the Fisk technique:

- Instruct the patient to flex the elbow and lean forward far enough to place the posterior surface of the forearm on the table. The patient supports and grasps the IR as depicted in Fig. 6.51.
- For radiation protection and for reduction of backscatter to the IR from the forearm, place a lead shielding between the IR back and the forearm.
- Place a sandbag under the hand to place the IR horizontal.
- Have the patient lean forward or backward as required to place the vertical humerus at an angle of 10 to 15 degrees.

FIG. 6.50 Supine tangential intertubercular groove.

The patient is in the supine position on the radiographic table. The patient's hand is in the supinated position and the I R is placed against the superior surface of the shoulder. A sandbag is under the hand. The side marker is in the collimated exposure field. The central ray is angled 10 to 15 degrees posterior (downward from horizontal) to the long axis of the humerus.

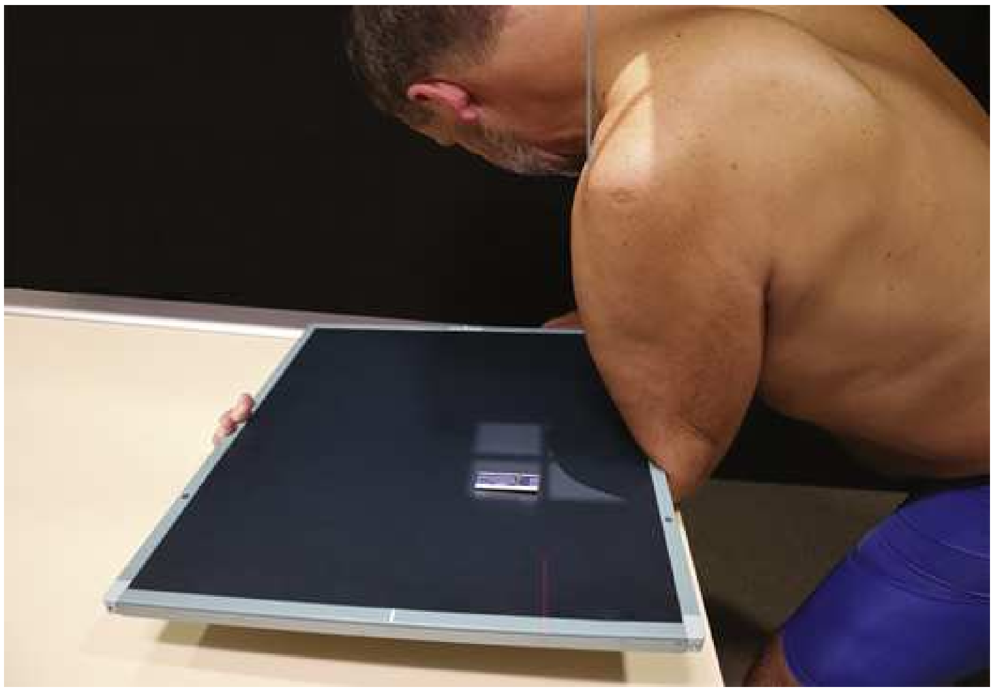


FIG. 6.51 Standing tangential intertubercular groove: Fisk modification.

The patient flexing his elbow and is leaning forward towards the table. The posterior surface of the forearm is on the table and the patient is grasping the I R. The side marker is in the collimated exposure field. The central ray is perpendicular to the I R.

Central ray

- Angled 10 to 15 degrees posterior (downward from horizontal) to the long axis of the humerus for the supine position (see Fig. 6.50)

Fisk modification

- Perpendicular to the IR when the patient is leaning forward and the vertical humerus is positioned 10 to 15 degrees (see Fig. 6.51)

Collimation

- Adjust radiation field to 4 × 4 inches (10 × 10 cm) on the collimator. Adjust as needed to include 1 inch beyond the superior and lateral shoulder shadow. Place side marker in the collimated exposure field.

Structures shown

The tangential image profiles the intertubercular (bicipital) groove free from superimposition of the surrounding shoulder structures (Figs. 6.52 and 6.53).

Evaluation Criteria

The following should be clearly seen:

- Evidence of proper collimation and presence of side marker placed clear of anatomy of interest
- Intertubercular (bicipital) groove in profile
- Bony trabecular detail and surrounding soft tissues

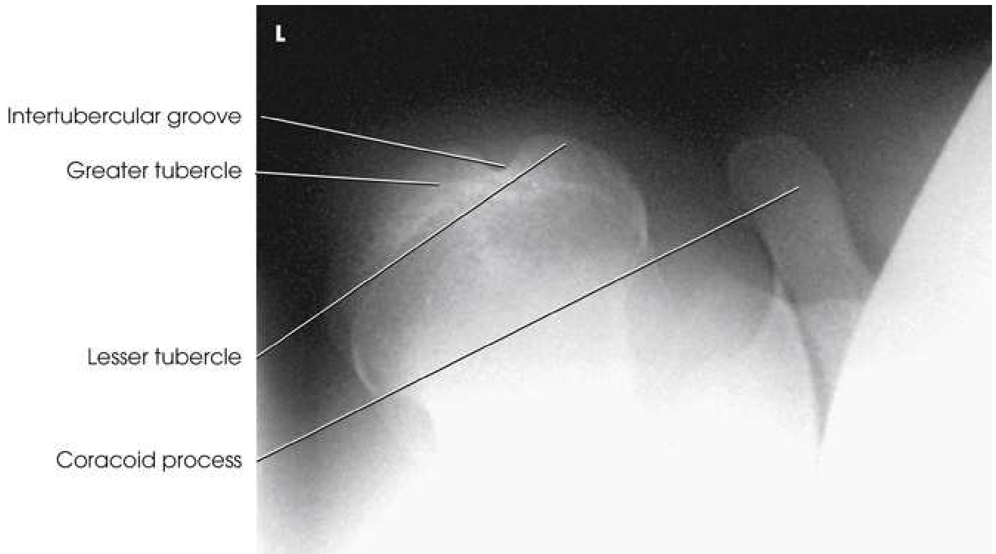


FIG. 6.52 Supine tangential intertubercular groove.

The x-ray shows the intertubercular (bicipital) groove. It appears grainy. The parts labeled in the x-ray are listed from top to the bottom as follows: the intertubercular groove, the greater tubercle, the lesser tubercle, and the coracoid process.

FIG. 6.53 Standing tangential intertubercular groove: Fisk modification.

Acromioclavicular Articulations

AP Projection

Pearson Method

Bilateral

Image receptor + grid: Positioned by manufacturer or department protocol for proper anatomy display orientation; CR plate: 14 × 17 inches (35 × 43 cm) or two 10 × 12 inches (24 × 30 cm), as needed to fit the patient.

SID:

72 inches (183 cm). A longer SID reduces magnification, which enables both joints to be included on one image. The longer SID also reduces the distortion of the joint space resulting from beam divergence.

Position of patient

- Place the patient in an upright body position, either seated or standing, because dislocation of the AC joint tends to reduce itself in the recumbent position. The positioning is easily modified to obtain a PA projection.

Position of part

- Place the patient in the upright position before a vertical grid device, then adjust the height of the IR so that the midpoint of the IR lies at the same level as the AC joints (Fig. 6.54).
- Center the midline of the body to the midline of the grid.
- Ensure that the weight of the body is equally distributed on the feet to avoid rotation.
- With the patient's arms hanging by the sides, adjust the shoulders to lie in the same horizontal plane. It is important that the arms hang unsupported.
- Make two exposures: one in which the patient is standing upright *without* weights attached, and a second in which the patient has *equal weights* (5 to 10 lb) affixed to each wrist.[14, 15]
- After the first exposure, slowly affix the weights to the patient's wrist, using a band or strap.
- Instruct the patient not to favor (tense up) the injured shoulder.
- *Avoid having the patient hold weights in each hand;* this tends to make the shoulder muscles contract, reducing the possibility of showing a small AC separation (Fig. 6.55).
- *Shield gonads.* Also use a thyroid collar because the thyroid gland is exposed to the primary beam.
- *Respiration:* Suspend.

Central ray

- Perpendicular to the midline of the body at the level of the AC joints for a single projection; directed at each respective AC joint when two separate exposures are necessary for each shoulder in broad-shouldered patients

Collimation

- Adjust radiation field to 6 × 17 inches (15 × 43 cm) on the collimator for both joints with a single exposure
- Or to 6 × 8 inches (15 × 20 cm) for separate exposures of each joint
- Place side marker in the collimated exposure field.

FIG. 6.54 Bilateral AP AC articulations.

The patient is in the upright position before a vertical grid device. The I R lies at the same level as the A C joints. The midline of the body is in the midline of the grid. The side marker is in the collimated exposure field. The central ray is perpendicular to the midline of the body.

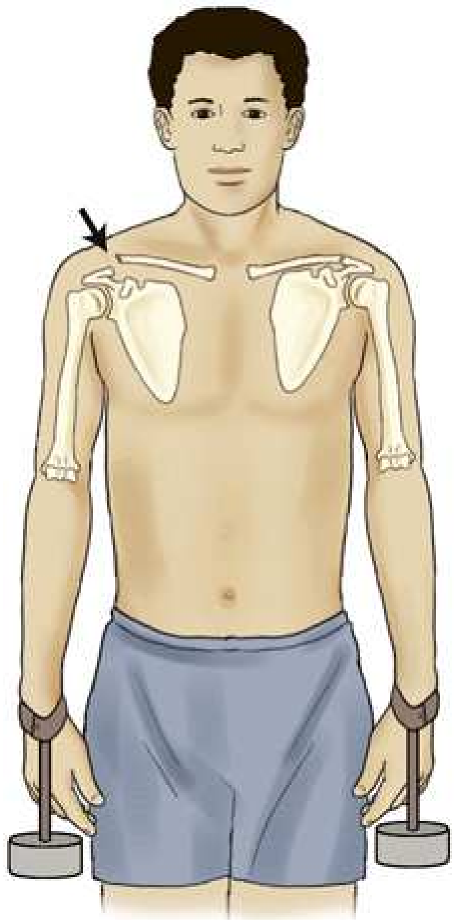


FIG. 6.55 Weights should be attached to wrists as shown and not held in hands. Note how separation of AC joint is shown by pulling of weights.

Structures shown

Bilateral images of the AC joints (Figs. 6.56 and 6.57). This projection is used to show dislocation, separation, and function of the joints.

Evaluation Criteria

The following should be clearly seen:

- Evidence of proper collimation and presence of side markers placed clear of anatomy of interest
- Both AC joints, with and without weights, included on one or two radiographs
- No rotation or leaning by the patient
- AC joint separation, if present, clearly seen on the images with weights
- Bony trabecular detail and surrounding soft tissues

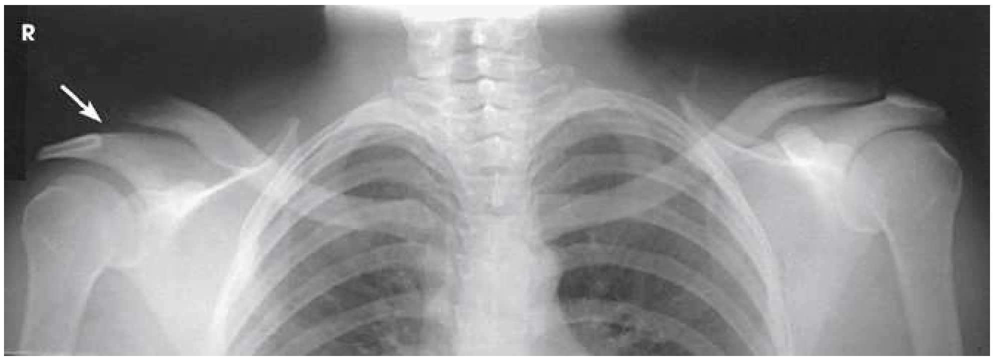


FIG. 6.56 Bilateral AP AC joints showing normal left joint and separation of right joint *(arrow)*.

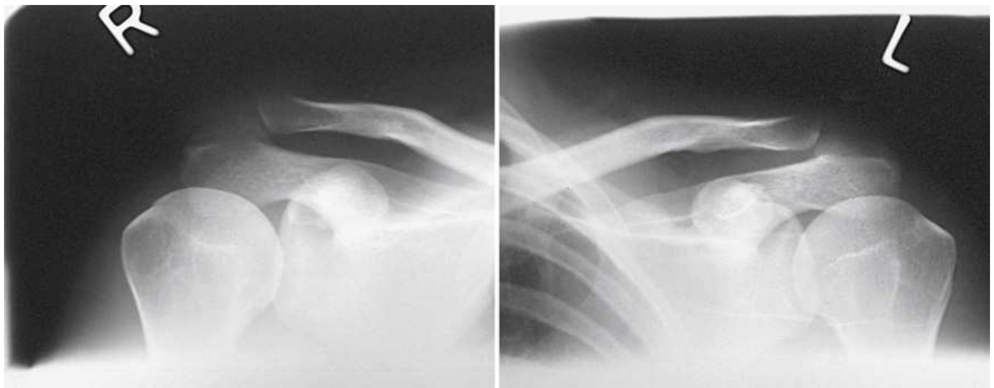


FIG. 6.57 Normal AC joints requiring two separate radiographs.

AP Axial Projection

Alexander Method

Alexander [16] suggested that AP and PA axial oblique projections be used in cases of suspected AC subluxation or dislocation. Each side is examined separately.

Image receptor + grid: Positioned by manufacturer or department protocol for proper anatomy display orientation; CR plate: 10 × 12 inches (24 × 30 cm) lengthwise.

Position of patient

- Place the patient in the upright position, either standing or seated.

Position of part

- Have the patient place the back against the vertical grid device and sit or stand upright.
- Center the affected shoulder under examination to the grid.
- Adjust the height of the IR so that the midpoint is at the level of the AC joint.
- Adjust the patient's position to center the coracoid process to the IR (Fig. 6.58).
- *Shield gonads.*
- *Respiration:* Suspend.

Central ray

- Directed to the coracoid process at a cephalic angle of 15 degrees (Fig. 6.59). This angulation projects the AC joint above the acromion.

FIG. 6.58 Unilateral AP axial AC articulation: Alexander method.

The patient is standing with his back placed against the vertical grid device. The side marker is in the collimated exposure field. The central ray is directed to the coracoid process at a cephalic angle of 15 degrees.

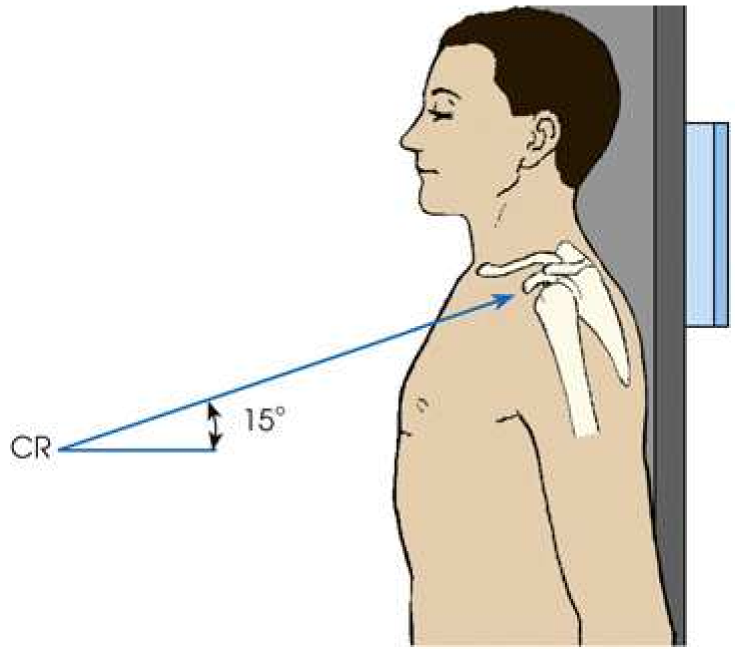


FIG. 6.59 AP axial AC articulation: Alexander method.

Collimation

• Adjust radiation field to 6 × 8 inches (15 × 20 cm) on the collimator. Place side marker in the collimated exposure field.

Structures shown

The AC joint projected slightly superiorly compared with an AP projection (Fig. 6.60).

Evaluation Criteria

The following should be clearly seen:

- Evidence of proper collimation and presence of side marker placed clear of anatomy of interest
- AC joint and clavicle projected above the acromion
- Bony trabecular detail and surrounding soft tissues

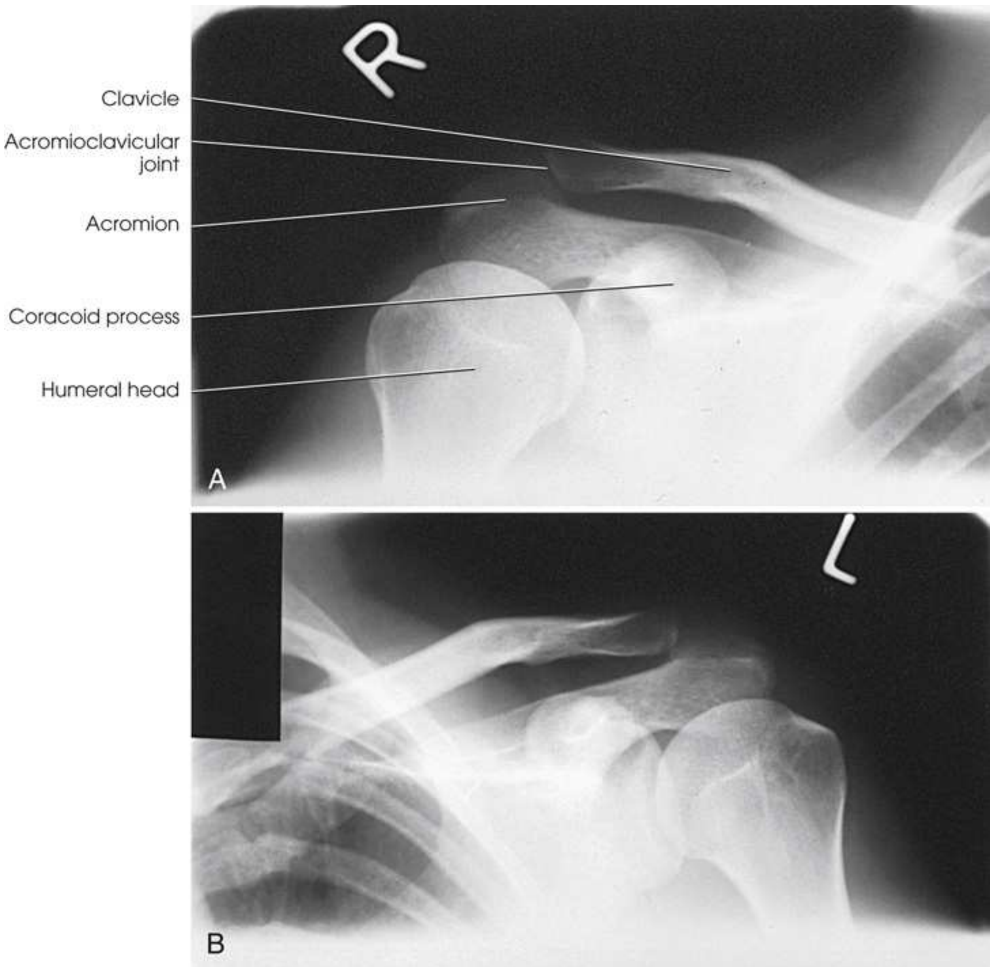


FIG. 6.60 (A) and (B) AP axial AC articulation: Alexander method.

(A) The x-ray shows the closeup image of the A C joint projected slightly superiorly. The parts labeled in the x-ray are as follows: clavicle, acromioclavicular joint, acromion, coracoid process, and humeral head. (B) shows the part of the rib and the A C joint. The ribs and the coracoid process appear radiopaque.

Clavicle

AP Projection

Image receptor + grid: Positioned by manufacturer or department protocol for proper anatomy display orientation; CR plate: 10 × 12 inches (24 × 30 cm) crosswise.

Position of patient

- Place the patient in the supine or upright position.
- If the clavicle is being examined for a fracture or a destructive disease, or if the patient cannot be placed in the upright position, use the supine position to reduce the possibility of fragment displacement or additional injury.

Position of part

- Adjust the body to center the clavicle to the midline of the table or vertical grid device.
- Place the arms along the sides of the body and adjust the shoulders to lie in the same horizontal plane.
- Center the clavicle to the IR (Fig. 6.61).
- *Shield gonads.*
- *Respiration:* Suspend at the end of exhalation to obtain a more uniform-density image.

Central ray

- Perpendicular to the midshaft of the clavicle

Collimation

- Adjust radiation field to 8 × 12 inches (18 × 30 cm) on the collimator. Adjust as needed to include 1.5 inches (3.8 cm) above the shoulder, 1 inch (2.5 cm) beyond the lateral aspect of the shoulder, and the entire clavicle. Place side marker in the collimated exposure field.

Structures shown

An AP image of the entire clavicle (Fig. 6.62).

Evaluation Criteria

The following should be clearly seen:

- Evidence of proper collimation and presence of side marker placed clear of anatomy of interest
- Entire clavicle centered on the image
- Lateral half of the clavicle above the scapula, with the medial half superimposing the thorax
- Bony trabecular detail and surrounding soft tissues

FIG. 6.61 AP clavicle.

The patient is standing with his back placed against the vertical grid device. The clavicle is centered to the I R. The side marker is in the collimated exposure field. The central ray is perpendicular to the midshaft of the clavicle.

FIG. 6.62 AP clavicle.

AP Axial Projection

NOTE: If the patient is injured or is unable to assume the lordotic position, a slightly distorted image results when the tube is angled. An optional approach for improved spatial resolution is the PA axial projection.

Image receptor + grid: Positioned by manufacturer or department protocol for proper anatomy display orientation; CR plate: 10 × 12 inches (24 × 30 cm) crosswise.

Position of patient

- Stand or seat the patient with the back against the vertical IR device.
- If the patient cannot stand or sit upright, place the patient supine on the table.

Position of part

Standing position

- Adjust the body to center the clavicle to the vertical grid device.
- Place the arms along the sides of the body and adjust the shoulders to lie in the same horizontal plane.
- Center the clavicle to the IR (Fig. 6.63A).

Standing lordotic position

- Have the patient step forward about 1 foot, then lean backward in a position of extreme lordosis. Temporarily support the patient in the lordotic position to estimate the required CR angulation, then have the patient reassume the upright position while the equipment is adjusted.
- Return the patient to the lordotic position, with the neck and shoulder resting against the vertical grid device (see Fig. 6.63B).
- Center the clavicle to the center of the IR (see Fig. 6.63B).

Supine position

- Adjust the body to center the clavicle to the table Bucky.
- Center the IR to the clavicle (Fig. 6.64).
- *Shield gonads.*
- *Respiration:* Suspend at the end of full inspiration to elevate and angle the clavicle further.

Central ray

- Directed to enter the midshaft of the clavicle.
- Cephalic CR angulation can vary depending on the thickness of the chest; thinner patients require increased angulation to project the clavicle above the scapula and ribs.
- For the *standing position,* 15 to 30 degrees is recommended
- For the *standing lordotic position,* 0 to 15 degrees is recommended.
- For the *supine position,* 15 to 30 degrees is recommended.

Collimation

- Adjust radiation field to 8 × 12 inches (18 × 30 cm) on the collimator. Adjust as needed to include 1.5 inches (3.8 cm) above the shoulder, 1 inch (2.5 cm) beyond the lateral aspect of the shoulder, and the entire clavicle. Place side marker in the collimated exposure field.

Structures shown

An AP axial image of the clavicle is projected above the ribs (see Fig. 6.65).

Evaluation Criteria

The following should be clearly seen:

- Evidence of proper collimation and presence of side marker placed clear of anatomy of interest
- Entire clavicle along with AC and SC joints
- Lateral two-thirds of the clavicle projected above the ribs and scapula with the medial end superimposing the thorax
- Clavicle in a more horizontal orientation, as compared with the AP projection
- Bony trabecular detail and surrounding soft tissues

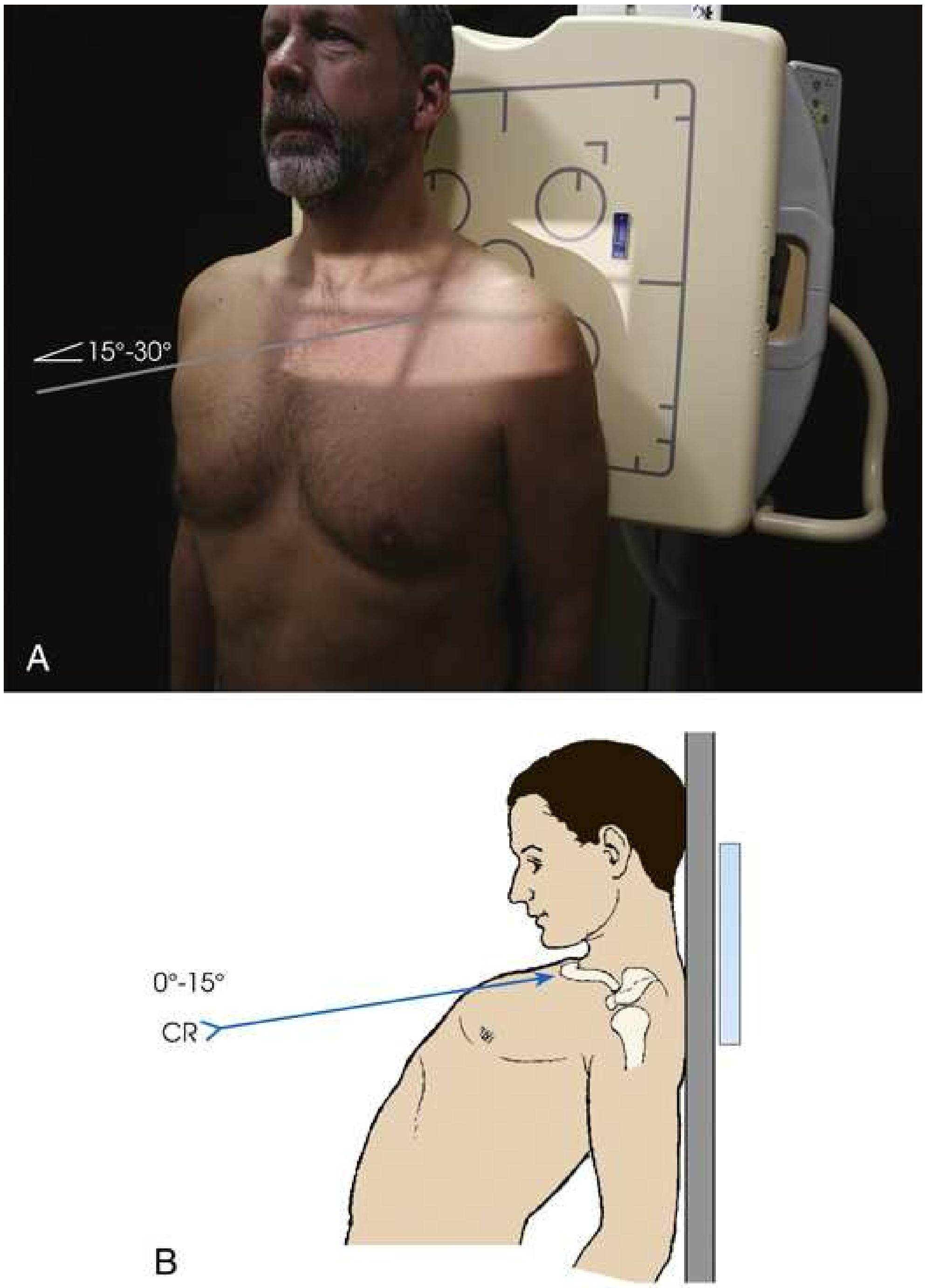


FIG. 6.63 (A) AP axial clavicle, upright position. (B) AP axial clavicle, upright lordotic position.

(A) shows the patient standing in the upright position with his back placed against the vertical grid device. The side marker is in the collimated exposure field. The central ray is adjusted 15 to 30 degrees. Diagram (B) shows the patient standing and leaning backward in a position of extreme lordosis. The neck and the shoulder are resting against the vertical grid device. The central ray is adjusted from 0 to 15 degrees.

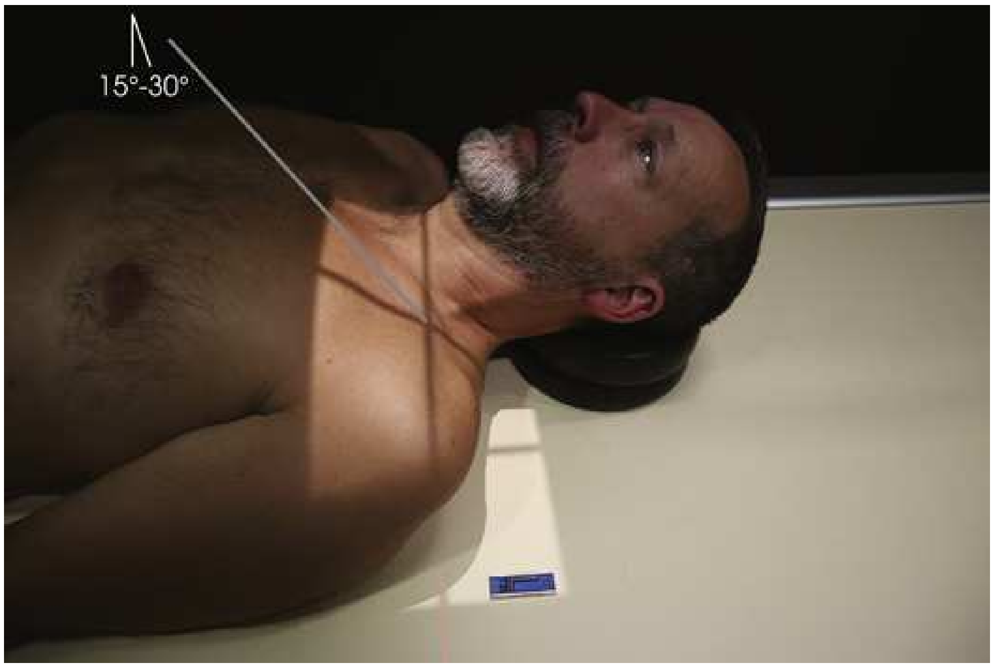


FIG. 6.64 AP axial clavicle, supine position.

The patient is lying in the supine position on the radiographic table. The side marker is in the collimated exposure field. The I R is centered on the clavicle. The central ray is adjusted 15 to 30 degrees to enter the midshaft of the clavicle.

FIG. 6.65 AP axial clavicle. Same patient as Fig. 6.62. Note less superimposition of the clavicle and thorax.

PA Projection

The PA projection is generally well accepted by the patient who can stand, and it is most useful when improved spatial resolution is desired. The advantage of the PA projection is that the clavicle is closer to the IR, reducing the OID and magnification. Positioning is similar to that of the AP projection. Differences are as follows:

- The patient is standing upright (back toward the x-ray tube) or is prone (Fig. 6.66).
- The perpendicular CR exits the midshaft of the clavicle (Fig. 6.67).

Structures shown and evaluation criteria are the same as for the AP projection.

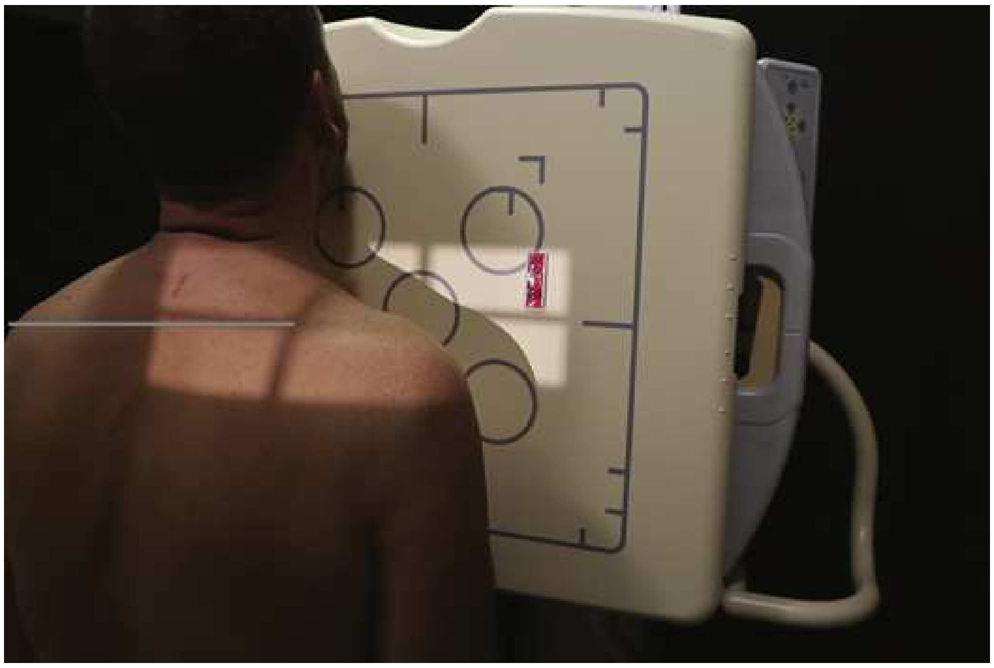


FIG. 6.66 PA clavicle.

FIG. 6.67 PA clavicle.

PA Axial Projection

Positioning of the PA axial clavicle is similar to the AP axial projection described previously. The differences are as follows:

- The patient is prone or standing, facing the vertical grid device.
- The CR is angled 15 to 30 degrees caudad (Fig. 6.68).

Structures shown and evaluation criteria are the same as described previously for the AP axial projection.

FIG. 6.68 PA axial clavicle.

The patient is prone and is facing the vertical grid device. The side marker is in the collimated exposure field. The C R is angled 15 to 30 degrees caudad. The x-ray shows the entire clavicle. The clavicle is labeled on the x-ray.

FIG. 6.69 AP scapula.

The patient is in the supine position. The arm is abducted to a right angle and the elbow is flexed. The patient's body is centered to the midline of the grid. The side marker is in the collimated exposure field. The central ray is perpendicular to the mid-scapular area.

Scapula

AP Projection

Image receptor + grid: Positioned by manufacturer or department protocol for proper anatomy display orientation; CR plate: 10 × 12 inches (24 × 30 cm) lengthwise.

Position of patient

- Place the patient in the upright or supine position. The upright position is usually more comfortable for patients.

Position of part

- Adjust the patient's body and center the affected scapula to the midline of the grid.
- Abduct the arm to a right angle with the body to draw the scapula laterally. Flex the elbow and support the hand in a comfortable position.
- For this projection, do not rotate the body toward the affected side because the resultant obliquity would offset the effect of drawing the scapula laterally (see Fig. 6.69).
- Position the top of the IR 2 inches (5 cm) above the top of the shoulder.
- *Shield gonads.*
- *Respiration:* Make this exposure during slow breathing to obliterate lung detail.

Central ray

- Perpendicular to the midscapular area at a point approximately 2 inches (5 cm) inferior to the coracoid process

Collimation

- Adjust radiation field to 10 × 12 inches (24 × 30 cm) on the collimator. Include 1.5 inches (3.8 cm) above the shoulder, 2 inches (5 cm) beyond the lateral aspect of the shoulder, the lateral half of the clavicle, and 1 inch (2.5 cm) below the inferior angle of the scapula. Place side marker in the collimated exposure field.

Structures shown

An AP projection of the scapula (Fig. 6.70).

Evaluation Criteria

The following should be clearly seen:

- Evidence of proper collimation and presence of side marker placed clear of anatomy of interest
- Lateral portion of the scapula free of superimposition from the ribs
- Scapula horizontal and not slanted
- Scapular detail through the superimposed lung and ribs (shallow breathing should help to obliterate lung detail)
- Acromion and inferior angle
- Bony trabecular detail and surrounding soft tissues

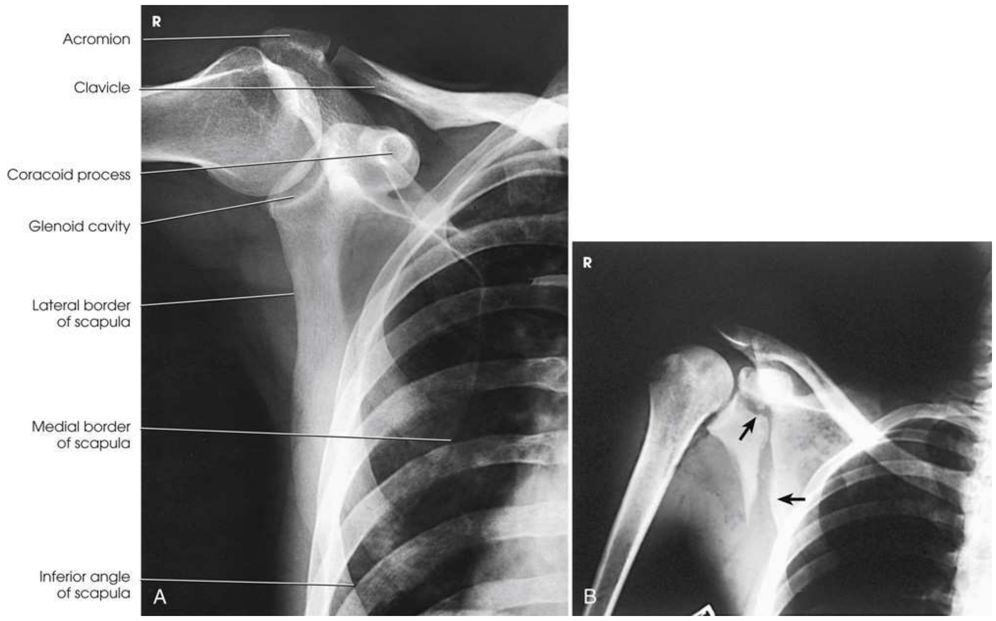


FIG. 6.70 (A) AP scapula. (B) AP scapula showing fracture of scapula through glenoid cavity and extending inferiorly *(arrows)*.

(A) shows the x-ray view of the scapula. The parts labeled in the x-ray are marked from top to bottom as follows: acromion, clavicle, coracoid process, glenoid cavity, lateral border of the scapula, medial border of the scapula, and inferior angle of the scapula. (B) The x-ray shows the fracture of the scapula. It is marked by two black arrows.

Lateral Projection

RAO or LAO body position

Image receptor + grid: Positioned by manufacturer or department protocol for proper anatomy display orientation; CR plate: 10 × 12 inches (24 × 30 cm) lengthwise.

Position of patient

- Place the patient in the upright position, standing or seated, facing a vertical grid device.
- The prone position can be used, but the projection is more difficult to perform.

Position of part

- Adjust the patient in RAO or LAO position, with the affected scapula centered to the grid. The average patient requires a 45- to 60-degree rotation from the plane of the IR. According to Johnston et al.,[1] proper patient rotation is accomplished by orienting the plane through the superior angle of the scapula and acromial tip, perpendicular to the IR.
- Position of the arm depends on the area of the scapula to be shown.
  - For delineation of the *acromion* and the *coracoid process* of the scapula, have the patient flex the elbow and place the back of the hand on the posterior thorax at a level sufficient to prevent the humerus from overlapping the scapula (Figs. 6.71 and 6.72). Mazujian[17] suggested that the patient place the arm across the upper chest by grasping the opposite shoulder, as shown in Fig. 6.73.
  - To show the *body* of the scapula, ask the patient to extend the arm upward and rest the forearm on the head (Fig. 6.74) or alternatively across the upper chest by grasping the opposite shoulder (see Fig. 6.73).
- After placing the arm in any of these positions, grasp the lateral and medial borders of the scapula between the thumb and index finger of one hand. Make a final adjustment of the body rotation, placing the body of the scapula perpendicular to the plane of the IR.
- *Shield gonads.*
- *Respiration:* Suspend.

Central ray

- Perpendicular to the midmedial border of the protruding scapula (see Table 6.3)

Collimation

- Adjust radiation field to 12 inches (30 cm) in length on the collimator, 1.5 inches (3.8 cm) above the shoulder, and 1 inch (2.5 cm) beyond the lateral shadow. Place side marker in the collimated exposure field.

Compensating Filter

Use of a specially designed compensating filter for the shoulder, called a boomerang, improves the quality of the image because of the large amount of primary beam radiation striking the IR.

Structures shown

A lateral image of the scapula. The placement of the arm determines the portion of the superior scapula that is superimposed over the humerus.

Evaluation Criteria

The following should be clearly seen:

- Evidence of proper collimation and presence of side marker placed clear of anatomy of interest
- Lateral and medial scapular borders superimposed
- No superimposition of the scapular body on the ribs
- No superimposition of the humerus on the area of interest
- Inclusion of the acromion and inferior angle
- Bony trabecular detail and surrounding soft tissues

NOTE: For trauma patients, this projection can be performed using the LPO or RPO position (see Chapter 12 in Volume 2).

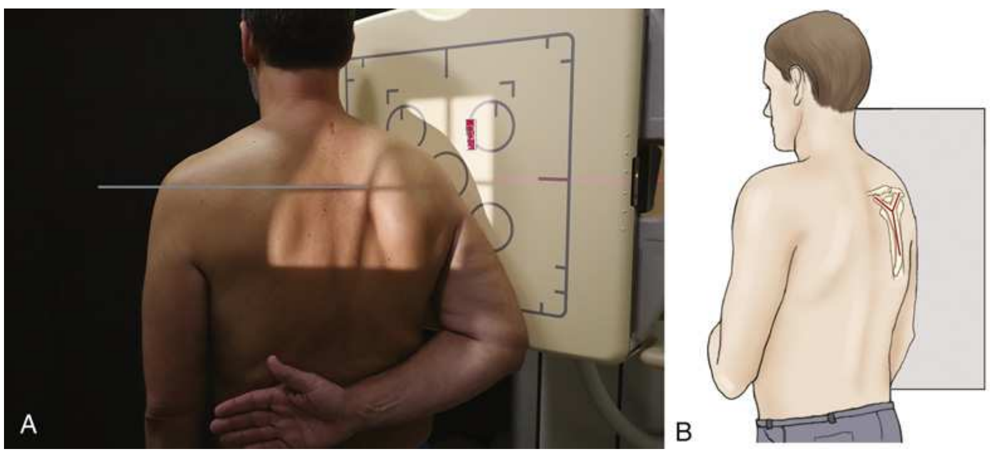


FIG. 6.71 (A) Lateral scapula, RAO body position. Arm is positioned to demonstrate the acromion and coracoid process. (B) Perspective from x-ray tube showing scapula centered in true lateral position.

The patient is standing in the upright position against the image receptor. The patient's elbow is flexed and the back of the hand is placed on the posterior thorax. The side marker is in the collimated exposure field. The central ray is perpendicular to the midmedial border of the protruding scapula. (B) shows the patient standing in the upright position against the image receptor. The elbow is flexed. The Y-shaped area in the scapula is highlighted.

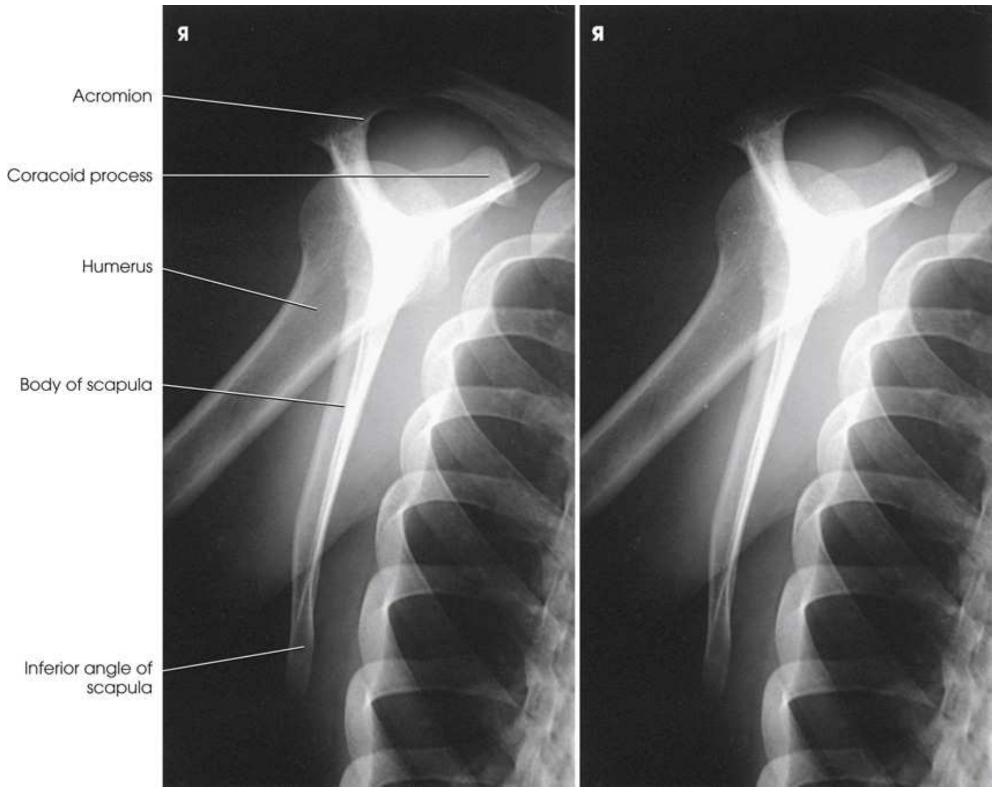


FIG. 6.72 Lateral scapula with arm on posterior chest.

Two x-ray views show a Y-shaped outline of the scapula. The parts labeled in the x-ray on the left are marked from top to the bottom as follows: acromion, coracoid process, humerus, the body of scapula, and inferior angle of the scapula.

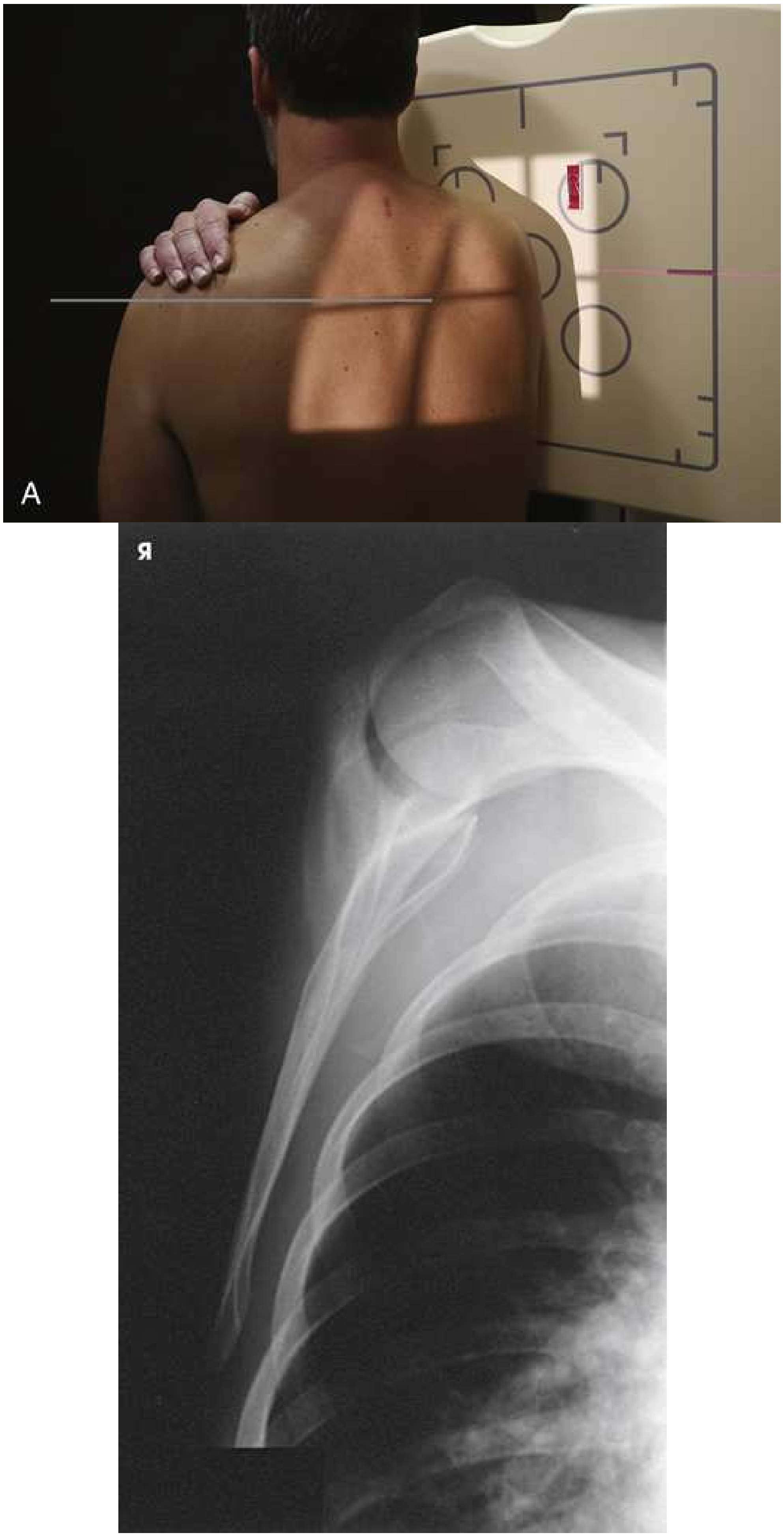


FIG. 6.73 (A) Lateral scapula, RAO position. Arm is positioned across upper chest, grasping opposite shoulder to demonstrate the scapular body. (B) Lateral scapula with arm across upper anterior thorax.

(A) The patient is standing in the upright position against the vertical grid. The arm of the patient is positioned across the upper chest by grasping the opposite shoulder. The side marker is in the collimated exposure field. The central ray is perpendicular to the midmedial border of the scapula. (B) The x-ray shows the lateral and medial scapular borders superimposed.

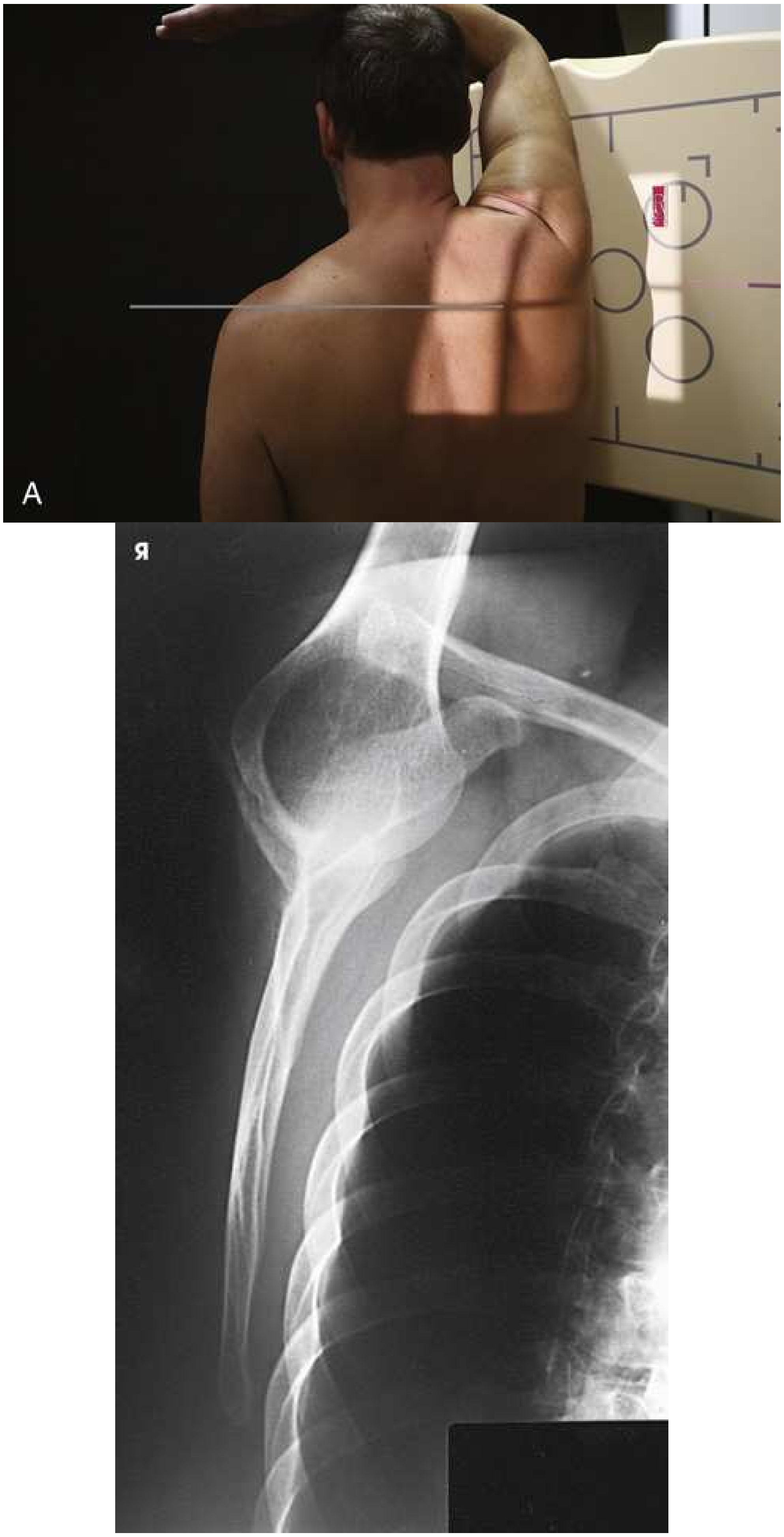


FIG. 6.74 (A) Lateral scapula, RAO position, Arm is positioned with forearm resting on forehead to demonstrate the scapular body. (B) Lateral scapula with arm extended above head.

(A) The patient is standing in the upright position against the vertical grid. The arm of the patient is extended upward and the forearm is resting on the head. (B) An x-ray shows the lateral and medial scapular borders superimposed. The borders are defined and the insides are grey.

AP Oblique Projection

RPO or LPO position

Image receptor + grid: Positioned by manufacturer or department protocol for proper anatomy display orientation; CR plate: 10 × 12 inches (24 × 30 cm) lengthwise.

Position of patient

- Place the patient in the supine or upright position.
- Use the upright position when the shoulder is painful unless contraindicated.

Position of part

- Align the body and center the affected scapula to the midline of the grid.
- For moderate AP oblique projection, ask the patient to extend the arm superiorly, flex the elbow, and place the supinated hand under the head, or have the patient extend the affected arm across the anterior chest.
- Have the patient turn away from the affected side enough to rotate the shoulder 15 to 25 degrees (Fig. 6.75).
- For a steeper oblique projection, ask the patient to extend the arm, rest the flexed elbow on the forehead, and rotate the body *away* from the affected side 25 to 35 degrees (Fig. 6.76).
- Grasp the lateral and medial borders of the scapula between the thumb and index finger of one hand and adjust the rotation of the body to project the scapula free of the rib cage.
- For a direct lateral projection of the scapula using this position, draw the arm across the chest, and adjust the body rotation to place the scapula perpendicular to the plane of the IR as previously described and shown in Figs. 6.71 through 6.74.
- *Shield gonads.*
- *Respiration:* Suspend.

Central ray

- Perpendicular to the lateral border of the rib cage at the midscapular area

Collimation

- Adjust radiation field to 12 inches (30 cm) in length on the collimator, 1.5 inches (3.8 cm) above the shoulder and 1 inch (2.5 cm) beyond the lateral shadow. Place side marker in the collimated exposure field.

Structures shown

An oblique image of the scapula, projected free or nearly free of rib superimposition (Figs. 6.77 and 6.78).

Evaluation Criteria

The following should be clearly seen:

- Evidence of proper collimation and presence of side marker placed clear of anatomy of interest
- Oblique scapula
- Lateral scapular border adjacent to the ribs
- Acromion and inferior angle
- Bony trabecular detail and surrounding soft tissues

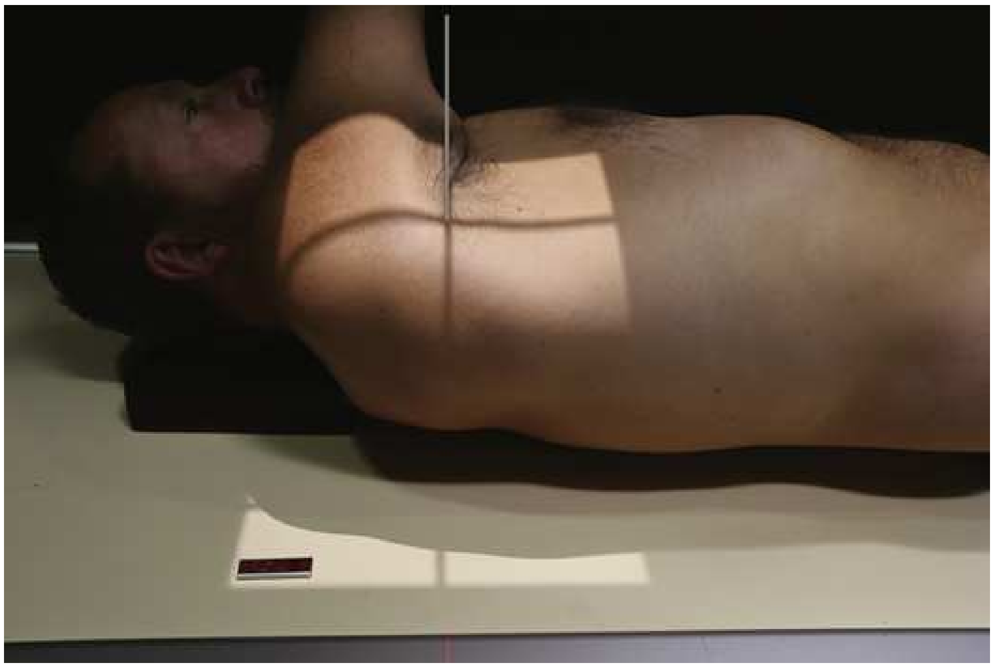


FIG. 6.75 AP oblique scapula, 20-degree body rotation.

The patient is in the supine position on the radiographic table. The patient's body is turned away from the affected side and the shoulder is rotated. The side marker is in the collimated exposure field. The central ray is perpendicular to the lateral border of the rib cage at the midscapular area.

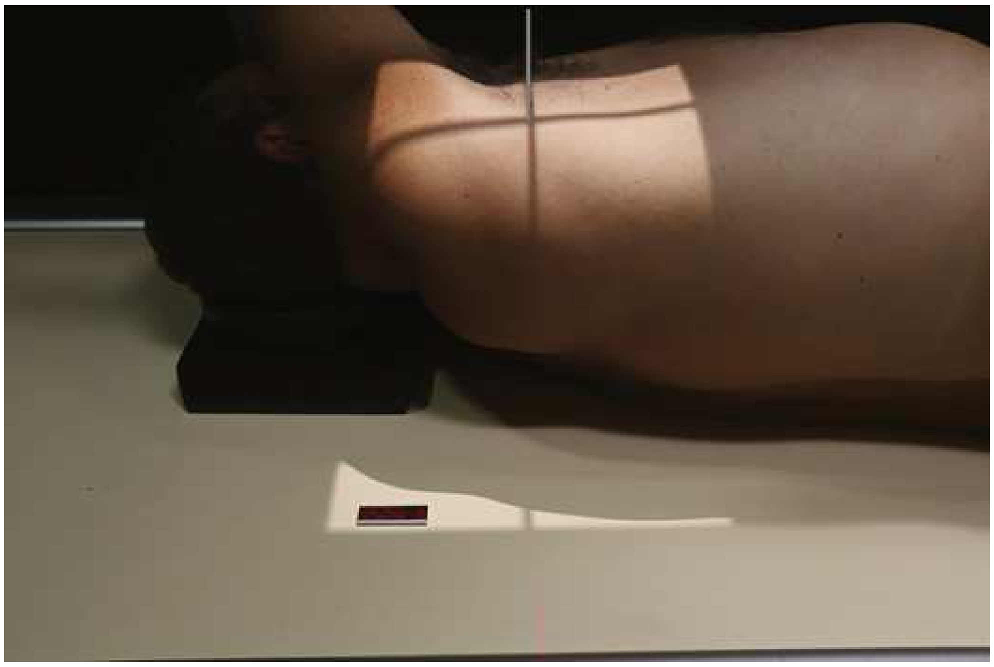


FIG. 6.76 AP oblique scapula, 35-degree body rotation.

The patient is in the supine position on the radiographic table. The patient's arm is extended and the elbow is flexed. The side marker is in the collimated exposure field. The central ray is perpendicular to the lateral border of the rib cage at the midscapular area.

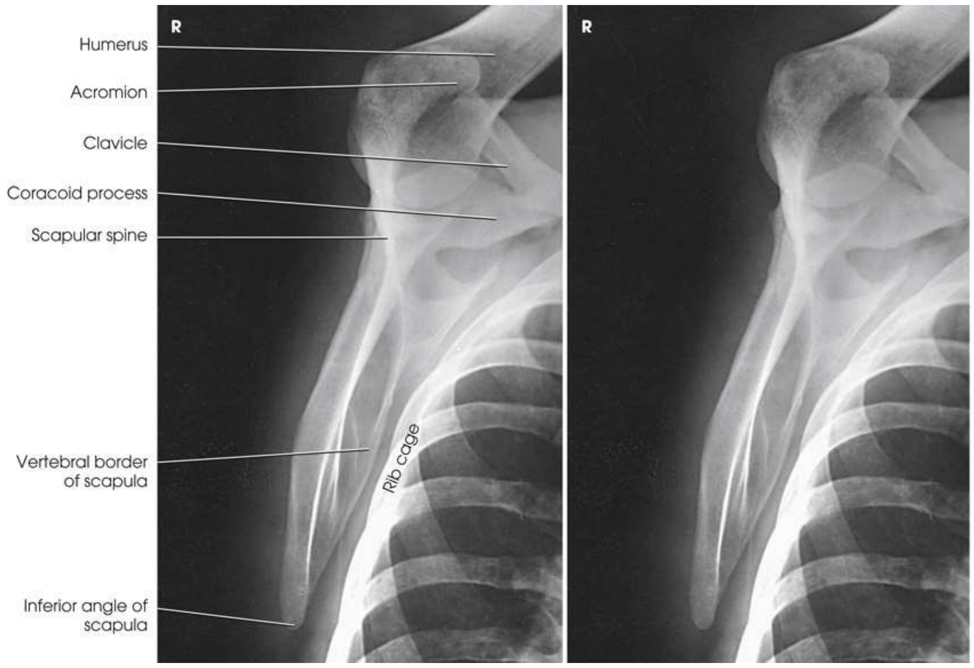


FIG. 6.77 AP oblique scapula, 15- to 25-degree body rotation.

Two x-ray views show the scapula free of first rib superimposition. The parts labeled in the x-ray on the left are as follows: humerus, rib cage, acromion, clavicle, coracoid process, scapular spine, vertebral border of the scapula, and inferior angle of the scapula.

FIG. 6.78 AP oblique scapula, 25- to 30-degree body rotation.

Coracoid Process

AP Axial Projection

Image receptor + grid: Positioned by manufacturer or department protocol for proper anatomy display orientation; CR plate: 10 × 12 inches (24 × 30 cm) crosswise

Position of patient

- Place the patient in the supine position with the arms along the sides of the body.

Position of part

- Adjust the position of the body to center the affected coracoid process to the midline of the grid.
- Position the IR so that the midpoint of the IR coincides with the angled CR.
- Adjust the shoulders to lie in the same horizontal plane.
- Abduct the arm of the affected side slightly, and supinate the hand, immobilizing it with a sandbag across the palm (Fig. 6.79).
- *Shield gonads.*
- *Respiration:* Suspend at the end of exhalation for a more uniform density.

Central ray

- Directed to enter the coracoid process at an angle of 15 to 45 degrees cephalad. Kwak et al. [18] recommended an angle of 30 degrees. The degree of angulation depends on the shape of the patient's back. Round-shouldered patients require *greater* angulation (Fig. 6.80).

Collimation

- Adjust radiation field to 8 × 10 inches (18 × 24 cm) on the collimator. Place side marker in the collimated exposure field.

Structures shown

The coracoid process in its entirety with some superimposition by the clavicle (Fig. 6.81).

Evaluation Criteria

The following should be clearly seen:

- Evidence of proper collimation and presence of side marker placed clear of anatomy of interest
- Coracoid process with minimal self-superimposition
- Clavicle slightly superimposing the coracoid process
- Bony trabecular detail and surrounding soft tissues

FIG. 6.79 AP axial coracoid process.

The patient is in the supine position on the radiographic table. The head is supported. The side marker is in the collimated exposure field. The central ray is directed to enter the coracoid process at an angle of 15 to 45 degrees cephalad.

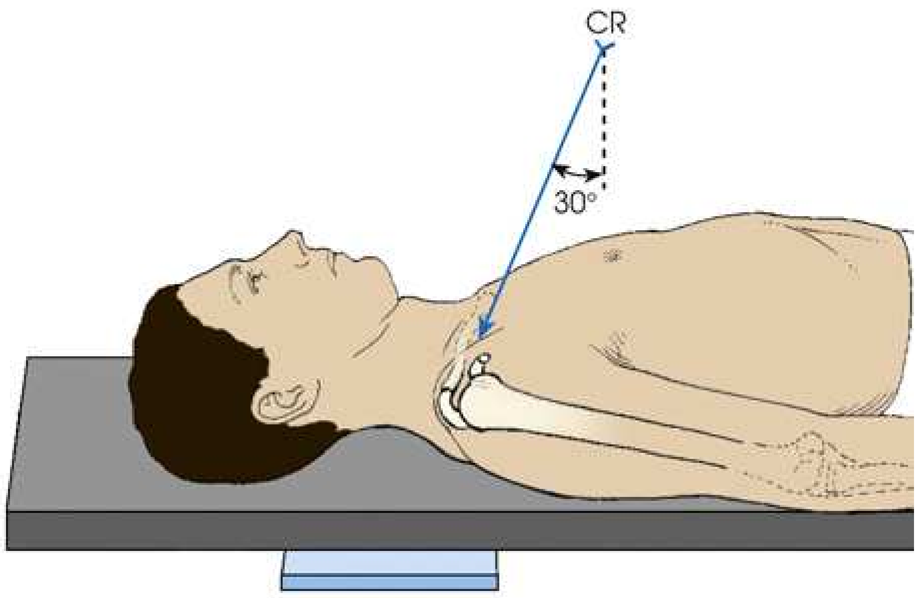


FIG. 6.80 AP axial coracoid process.

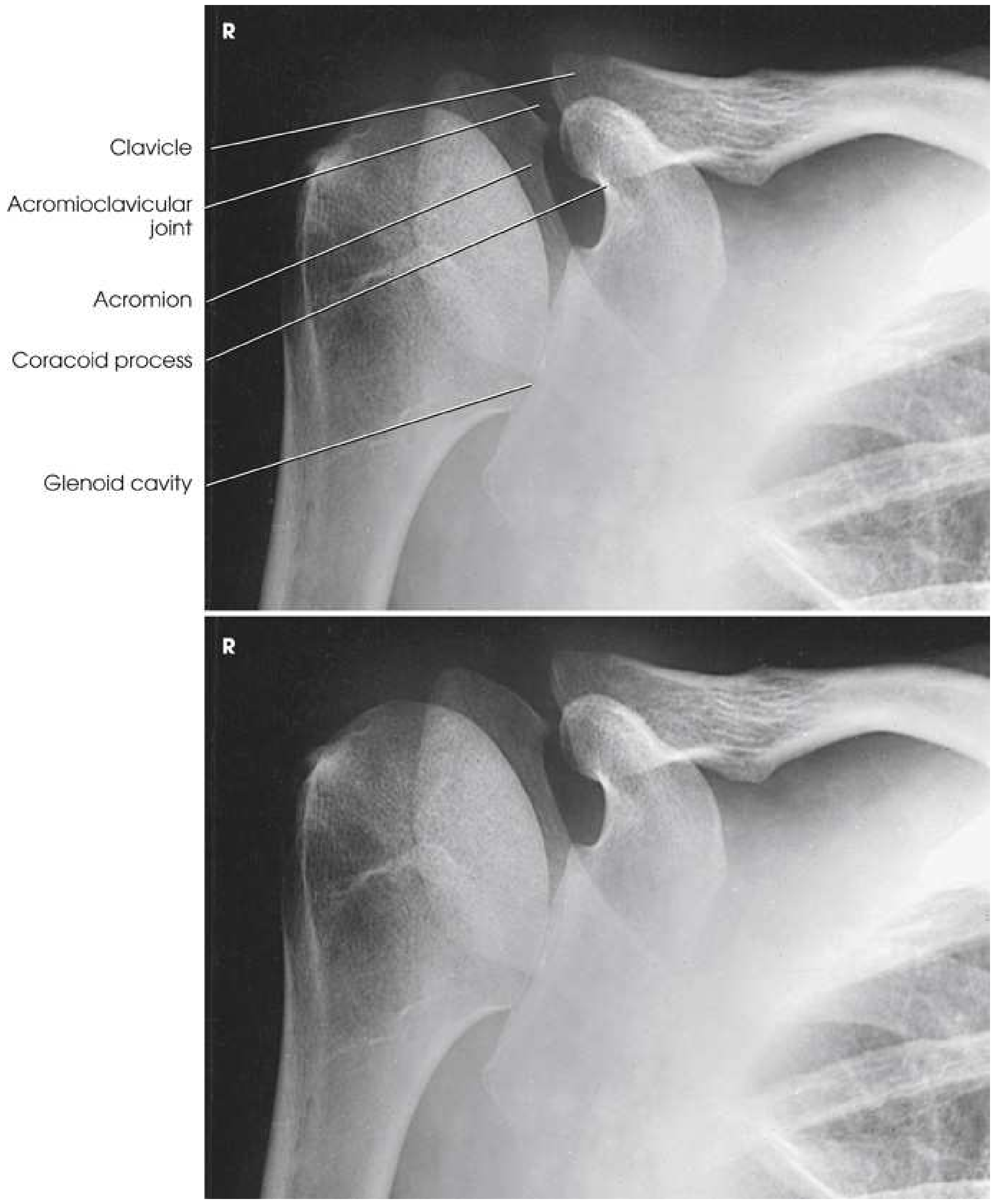


FIG. 6.81 AP axial coracoid process.

Two x-ray views show the coracoid process in its entirety with some superimposition by the clavicle. It appears smooth and the clavicular end appears dark. The parts labeled in the x-ray on the left are as follows: clavicle, acromioclavicular joint, acromion, coracoid process, and glenoid cavity.

FIG. 6.82 Tangential scapular spine.

The patient is in the supine position on the radiographic table. The body of the scapula is placed in a horizontal position. The side marker is in the collimated exposure field. The central ray is directed through the posterosuperior region of the shoulder at an angle of 45 degrees caudad.

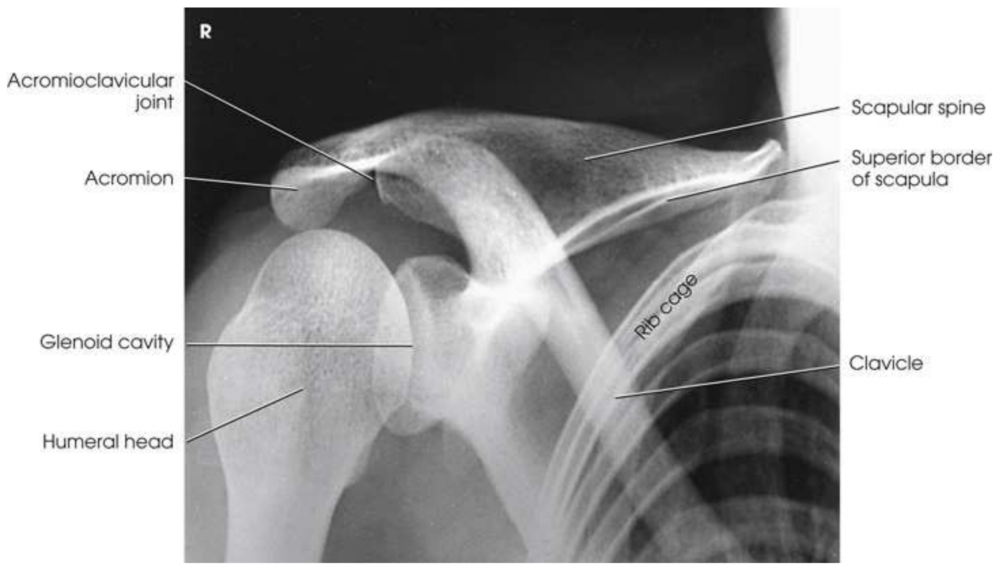


FIG. 6.83 Tangential scapular spine image with 45-degree central ray angulation.

An x-ray shows the spine of the scapula in profile and free of bony superimposition except for the lateral end of the clavicle. The parts labeled in the x-ray are marked clockwise as follows. humeral head, glenoid cavity, acromion, acromioclavicular joint, scapular spine, superior border of scapula, and clavicle.

FIG. 6.84 Tangential scapular spine image with 30-degree central ray angulation.

Scapular Spine

Tangential Projection

Laquerrière-Pierquin Method

Image receptor + grid: Positioned by manufacturer or department protocol for proper anatomy display orientation; CR plate: 10 × 12 inches (24 × 30 cm) crosswise.

Position of patient

- As described by Laquerrière and Pierquin, [19] place the patient in the supine position.

Position of part

- Center the shoulder to the midline of the grid.
- Adjust the patient's rotation to place the body of the scapula in a horizontal position. When this requires elevation of the opposite shoulder, support it on sandbags or radiolucent sponges.
- Turn the head away from the shoulder being examined, enough to prevent superimposition (Fig. 6.82).
- *Shield gonads.*
- *Respiration:* Suspend.

Central ray

- Directed through the posterosuperior region of the shoulder at an angle of 45 degrees caudad. A 35-degree angulation suffices for obese and round-shouldered patients.
- After adjusting the x-ray tube, position the IR so that it is centered to the CR.

Collimation

- Adjust radiation field to 10 × 10 inches (24 × 24 cm) on the collimator. Place side marker in the collimated exposure field.

Structures shown

The spine of the scapula in profile and free of bony superimposition except for the lateral end of the clavicle (see Figs. 6.83 and 6.84).

Evaluation Criteria

The following should be clearly seen:

- Evidence of proper collimation and presence of side marker placed clear of anatomy of interest
- Scapular spine superior to the scapular body
- Bony trabecular detail and surrounding soft tissues

NOTE: When the shoulder is too painful to tolerate the supine position, this projection can be obtained with the patient in the prone or upright position.

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[a] NOTE: These landmarks are recommended by Johnston et al.[1] as useful to identify the plane through the scapular body.

7: Lower Extremity

OUTLINE

Knee,
Intercondylar Fossa,
Patella,
Patella and Patellofemoral Joint,
Femur,
Long Bone Measurement,

Summary of Projections

Projections, Positions, and Methods					
Page	**Essential**	**Anatomy**	**Projection**	**Position**	**Method**
292		Toes	AP or AP axial		
294		Toes	PA		
295		Toes	AP oblique	Medial rotation	
296		Toes	Lateral (mediolateral or lateromedial)		
300		Sesamoids	Tangential		LEWIS, HOLLY
302		Foot	AP or AP axial		
306		Foot	AP oblique	Medial rotation	
308		Foot	AP oblique	Lateral rotation	
310		Foot	Lateral (mediolateral)		
312		Foot: *Longitudinal arch*	Lateral (lateromedial)	Standing	WEIGHT-BEARING
314		Feet	AP axial	Standing	WEIGHT-BEARING
315		Foot	AP axial	Standing	WEIGHT-BEARING COMPOSITE
317		Foot: *Congenital clubfoot*	AP		KITE
318		Foot: *Congenital clubfoot*	Lateral (mediolateral)		KITE
320		Foot: *Congenital clubfoot*	Axial (dorsoplantar)		KANDEL
321		Calcaneus	Axial (plantodorsal)		
322		Calcaneus	Axial (dorsoplantar)		
325		Calcaneus	Axial (dorsoplantar)	Standing	WEIGHT-BEARING
324		Calcaneus	Lateral (mediolateral)		
325		Calcaneus	Lateromedial oblique		WEIGHT-BEARING
326		Subtalar joint	Lateromedial oblique	Medial rotation foot	ISHERWOOD
327		Subtalar joint	AP axial oblique	Medial rotation ankle	ISHERWOOD
328		Subtalar joint	AP axial oblique	Lateral rotation ankle	ISHERWOOD
329		Ankle	AP		
330		Ankle	Lateral (mediolateral)		
332		Ankle	Lateral (lateromedial)		
333		Ankle	AP oblique	Medial rotation	
334		Ankle: *Mortise joint*	AP oblique	Medial rotation	
336		Ankle	AP oblique	Lateral rotation	
337		Ankle	AP		STRESS
338		Ankles	AP	Standing	WEIGHT-BEARING

Table Continued

Projections, Positions, and Methods					
Page	**Essential**	**Anatomy**	**Projection**	**Position**	**Method**
340		Leg	AP		
342		Leg	Lateral (mediolateral)		
344		Leg	AP oblique	Medial and lateral rotations	
346		Knee	AP		
348		Knee	PA		
350		Knee	Lateral (mediolateral)		
352		Knees	AP	Standing	WEIGHT-BEARING
353		Knees	PA	Standing flexion	ROSENBERG, WEIGHT-BEARING
354		Knee	AP oblique	Lateral rotation	
355		Knee	AP oblique	Medial rotation	
356		Intercondylar fossa	PA axial		HOLMBLAD
358		Intercondylar fossa	PA axial		CAMP-COVENTRY
360		Intercondylar fossa	AP axial		BÉCLÈRE
361		Patella	PA		
362		Patella	Lateral (mediolateral)		
363		Patella and patellofemoral joint	Tangential		HUGHSTON
364		Patella and patellofemoral joint	Tangential		MERCHANT
366		Patella and patellofemoral joint	Tangential		SETTEGAST
368		Femur	AP		
370		Femur	Lateral (mediolateral)		
372		Lower extremities: Long bone measurement	AP	Standing	WEIGHT-BEARING

The icons in the Essential column indicate projections frequently performed in the United States and Canada. Students should become competent in these projections.

AP, Anteroposterior; *PA,* posteroanterior.

Anatomy

The lower extremity and its girdle (considered in Chapter 8) are studied in four parts: (1) foot, (2) leg, (3) thigh, and (4) hip. The bones are composed, shaped, and placed so that they can carry the body in the upright position and transmit its weight to the ground with a minimal amount of stress to the individual parts.

Foot

The *foot* consists of 26 bones (Figs. 7.1 and 7.2):

- 14 phalanges (bones of the toes)
- 5 metatarsals (bones of the instep)
- 7 tarsals (bones of the ankle)

The bones of the foot are similar to the bones of the hand. Structural differences permit walking and support of the body's weight. For descriptive purposes, the foot is sometimes divided into the forefoot, midfoot, and hindfoot. The forefoot includes the metatarsals and toes. The midfoot includes five tarsals: cuneiforms, navicular, and cuboid bones. The hindfoot includes the talus and calcaneus. The bones of the foot are shaped and joined together to form a series of longitudinal and transverse arches. The longitudinal arch functions as a shock absorber to distribute the weight of the body in all directions, which permits smooth walking (see Fig. 7.2). The transverse arch runs from side to side and assists in supporting the longitudinal arch. The superior surface of the foot is termed the *dorsum* or *dorsal surface,* and the inferior, or posterior, aspect of the foot is termed the *plantar surface*.

Phalanges

Each foot has 14 *phalanges*: 2 in the great toe and 3 in each of the other toes. The phalanges of the great toe are termed *distal* and *proximal*. The phalanges of the other toes are termed *proximal, middle,* and *distal*. Each phalanx is composed of a body and two expanded articular ends: the proximal *base* and the distal *head*.

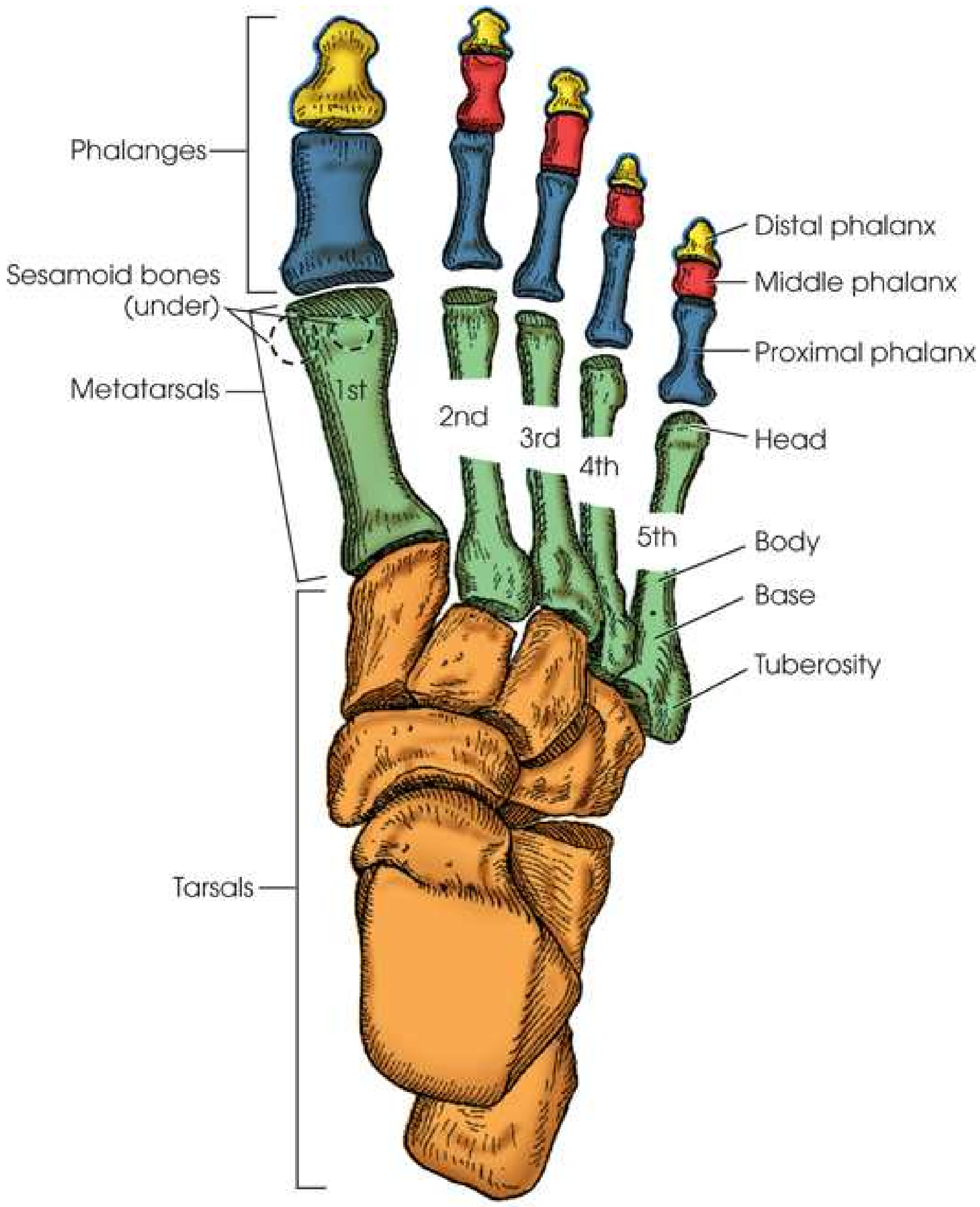

FIG. 7.1 Color-coded dorsal (superior) aspect of right foot. *Blue*, Proximal phalanges; *green*, metatarsals; *orange*, tarsals; *red*, middle phalanges; *yellow*, distal phalanges.

Diagram shows a dorsal aspect of the right foot consisting of 26 bones. The parts labeled from top to bottom on the left side are phalanges, sesamoid bones (under), metatarsals, tarsals. On the right side from top to bottom are distal phalanx, middle phalanx, proximal phalanx, head, body, base, and tuberosity.

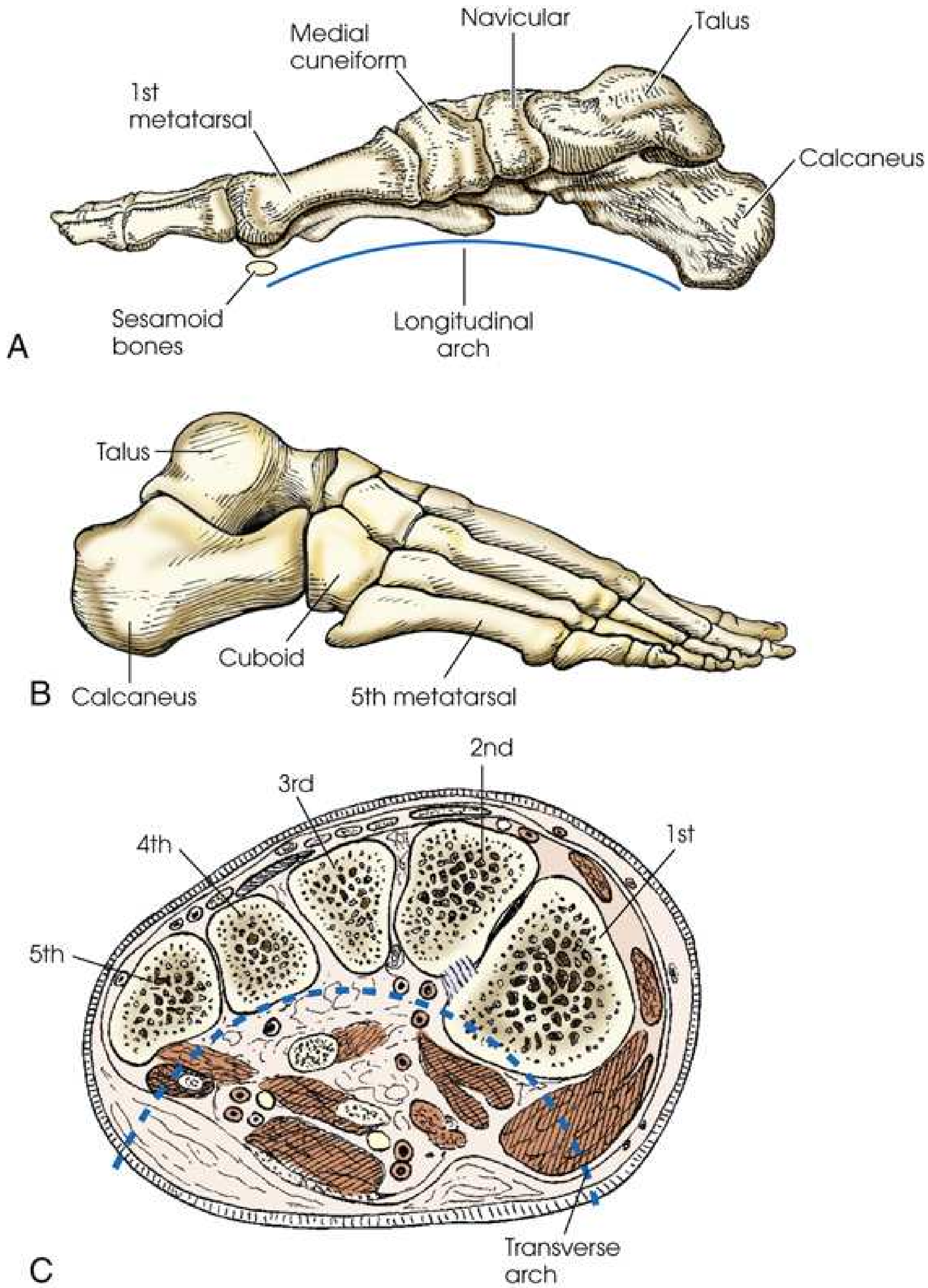

FIG. 7.2 Right foot. (A) Medial aspect. (B) Lateral aspect. (C) Coronal section near base of metatarsals. Transverse arch shown.

Diagram (A) shows the medial aspect of the foot. The parts labeled on the top from left to right: first metatarsal, medial cuneiform, navicular, talus, calcaneus. At the bottom: sesamoid bones, longitudinal arch. Diagram (B) shows the lateral aspect of the foot. The part labeled on the top is the talus. At the bottom: calcaneus, cuboid, fifth metatarsal. Diagram (C) shows the coronal section of the foot. The parts labeled on the top from right to left are first, second, third, fourth, and fifth metatarsals. The transverse arch is marked by a concave down dashed curve.

Metatarsals

The five *metatarsals* are numbered one to five beginning at the medial or great toe side of the foot. The metatarsals consist of a *body* and two articular ends. The expanded proximal end is called the *base,* and the small, rounded distal end is termed the *head*. The five heads form the "ball" of the foot. The first metatarsal is the shortest and thickest. The second metatarsal is the longest. The base of the fifth metatarsal contains a prominent *tuberosity,* which is a common site of fractures.

Tarsals

The proximal foot contains seven *tarsals* (see Fig. 7.3A):

- Calcaneus
- Talus
- Navicular
- Cuboid

• Medial cuneiform
• Intermediate cuneiform
• Lateral cuneiform

Beginning at the medial side of the foot, the cuneiforms are described as *medial, intermediate,* and *lateral*.

The *calcaneus* is the largest and strongest tarsal bone (Fig. 7.3B through D). Some texts refer to it as the *os calcis*. It projects posteriorly and medially at the distal part of the foot. The long axis of the calcaneus is directed inferiorly and forms an angle of approximately 30 degrees. The posterior and inferior portions of the calcaneus contain the posterior *tuberosity* for attachment of the Achilles tendon. Superiorly, three articular facets join with the talus. They are called the *anterior, middle,* and *posterior facets*. Between the middle and posterior talar articular facets is a groove —the calcaneal sulcus—which corresponds to a similar groove on the inferior surface of the talus. Collectively, these sulci constitute the *sinus tarsi*. The interosseous ligament passes through this sulcus. The medial aspect of the calcaneus extends outward as a shelf-like overhang and is termed the *sustentaculum tali*. The lateral surface of the calcaneus contains the *trochlea*.

The *talus,* irregular in form and occupying the superior-most position of the foot, is the second largest tarsal bone (see Figs. 7.1 through 7.3). The talus articulates with four bones: tibia, fibula, calcaneus, and navicular bone. The superior surface, the *trochlear surface,* articulates with the tibia and connects the foot to the leg. The head of the talus is directed anteriorly and has articular surfaces that join the navicular bone and calcaneus. On the inferior surface is a groove, the *sulcus tali,* which forms the roof of the sinus tarsi. The inferior surface also contains three facets that align with the facets on the superior surface of the calcaneus.

The *cuboid* bone lies on the lateral side of the foot between the calcaneus and the fourth and fifth metatarsals (see Fig. 7.3A). The *navicular* bone lies on the medial side of the foot between the talus and the three cuneiforms. The *cuneiforms* lie at the central and medial aspect of the foot between the navicular bone and the first, second, and third metatarsals. The *medial* cuneiform is the largest of the three cuneiform bones, and the *intermediate* cuneiform is the smallest.

The seven tarsals can be remembered using the following mnemonic:

Chubby	**C**alcaneus
Twisted	**T**alus
Never	**N**avicular
Could	**C**uboid
Cha	**C**uneiform—medial
Cha	**C**uneiform—intermediate
Cha	**C**uneiform—lateral

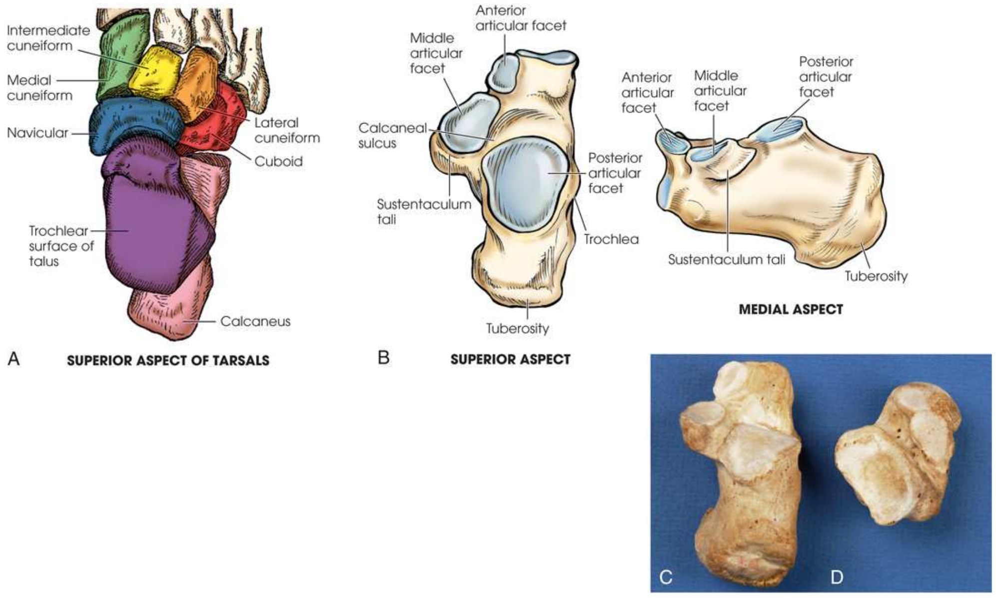

FIG. 7.3 (A) Color-coded tarsals. *Blue*, Navicular; *Green*, medial cuneiform; *pink*, calcaneus; *orange*, lateral cuneiform; *purple*, talus; *red*, cuboid; *yellow*, intermediate cuneiform. (B) Articular surfaces of right calcaneus. (C) Photograph of superior aspect of right calcaneus. Note three articular facet surfaces. (D) Photograph of the inferior aspect of talus. Note three articular surfaces that articulate with the superior calcaneus.

Diagram (A) shows the proximal foot containing seven tarsals. The parts labeled from top to bottom on the left are intermediate cuneiform, medial cuneiform, navicular, the trochlear surface of the talus. At right from top to bottom are lateral cuneiform, cuboid, the calcaneus. Diagram (B) shows at superior and the medial aspect of the foot. The parts labeled on the superior aspect are posterior articular facet, trochlea, sustentaculum tali, calcaneal sulcus, and middle articular facet, anterior articular facet, and tuberosity, medial aspect. The parts labeled on the medial aspect of the foot are the anterior articular facet, posterior articular facet, middle articular facet, sustentaculum tali, and tuberosity. Diagram (D) has two bones showing the inferior aspect of the talus.

Sesamoid Bones

Beneath the head of the first metatarsal are two small bones called *sesamoid* bones. They are detached from the foot and embedded within two tendons. These bones are seen on most adult foot radiographs. They are a common site of fractures and must be shown radiographically (see Fig. 7.2).

Leg

The leg has two bones: the *tibia* and the *fibula*. The tibia, the second largest bone in the body, is situated on the medial side of the leg and is a weight-bearing bone. Slightly posterior to the tibia on the lateral side of the leg is the fibula. The fibula does not bear any body weight.

Tibia

The *tibia* (Fig. 7.4) is the larger of the two bones of the leg and consists of one body and two expanded extremities. The proximal end of the tibia has two prominent processes: the *medial* and *lateral condyles*. The superior surfaces of the condyles form smooth facets for articulation with the condyles of the femur. These two flat-like superior surfaces are called the *tibial plateaus,* and they slope posteriorly about 10 to 20 degrees. Between the two articular surfaces is a sharp projection, the *intercondylar eminence,* which terminates in two peaklike processes called the *medial* and *lateral intercondylar tubercles*. The lateral condyle has a facet at its distal posterior surface for articulation with the *head* of the fibula. On the anterior surface of the tibia, just below the condyles, is a prominent process called the *tibial tuberosity,* to which the ligamentum patellae attach. Extending along the anterior surface of the tibial body, beginning at the tuberosity, is a sharp ridge called the *anterior crest*.

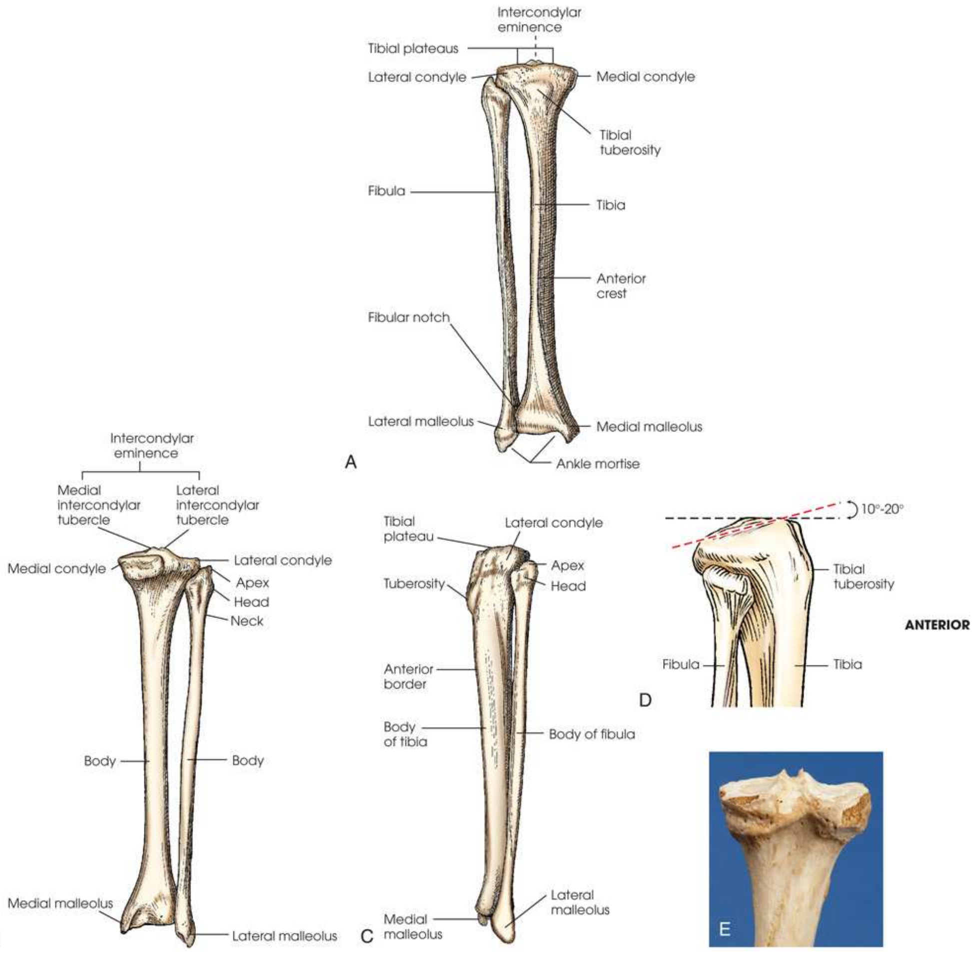

FIG. 7.4 Right tibia and fibula. (A) Anterior aspect. (B) Posterior aspect. (C) Lateral aspect. (D) Proximal end of tibia and fibula showing angle of the tibial plateau. (E) Photograph of superior and posterior aspects of the tibia.

Diagram (A) shows the anterior aspect of the right tibia and fibula. The parts labeled are intercondylar eminence, ankle mortise, tibial plateaus, lateral condyle, fibula, fibular notch, lateral malleolus, medial condyle, tibial tuberosity, tibia, anterior crest, and Medial malleolus. Diagram (B) shows the posterior aspect of the right tibia and fibula. The parts labeled are intercondylar eminence which are medial intercondylar tubercle and lateral intercondylar tubercle, medial condyle, body, medial malleolus, lateral condyle, apex, head, neck, body, and lateral malleolus. Diagram (C) shows the lateral aspect of the right tibia and fibula. The parts labeled are lateral condyle; at left from top to bottom: Tibial plateau, tuberosity, anterior border, the body of tibia, medial malleolus, apex, head, the body of fibula, and lateral malleolus. Diagram (D) shows the flat-like superior surfaces slope posteriorlyabout 10 to 20 degrees. The parts labeled are fibula, tibial tuberosity, and tibia. Diagram (E) shows the superior and posterior aspects of the tibia.

The distal end of the tibia (Fig. 7.5) is broad, and its medial surface is prolonged into a large process called the *medial malleolus*. Its anterolateral surface contains the *anterior tubercle,* which overlays the fibula. The lateral surface is flattened and contains the triangular *fibular notch* for articulation with the fibula. The surface under the distal tibia is smooth and shaped for articulation with the talus.

Fibula

The *fibula* is slender compared with its length and consists of one *body* and two articular extremities. The proximal end of the fibula is expanded into a *head,* which articulates with the lateral condyle of the tibia. At the lateroposterior aspect of the head is a conic projection called the *apex*. The enlarged distal end of the fibula is the *lateral malleolus*. The lateral malleolus is pyramidal and is marked by several depressions at its inferior and posterior surfaces. Viewed axially, the lateral malleolus lies approximately 15 to 20 degrees more posterior than the medial malleolus (see Fig. 7.5C).

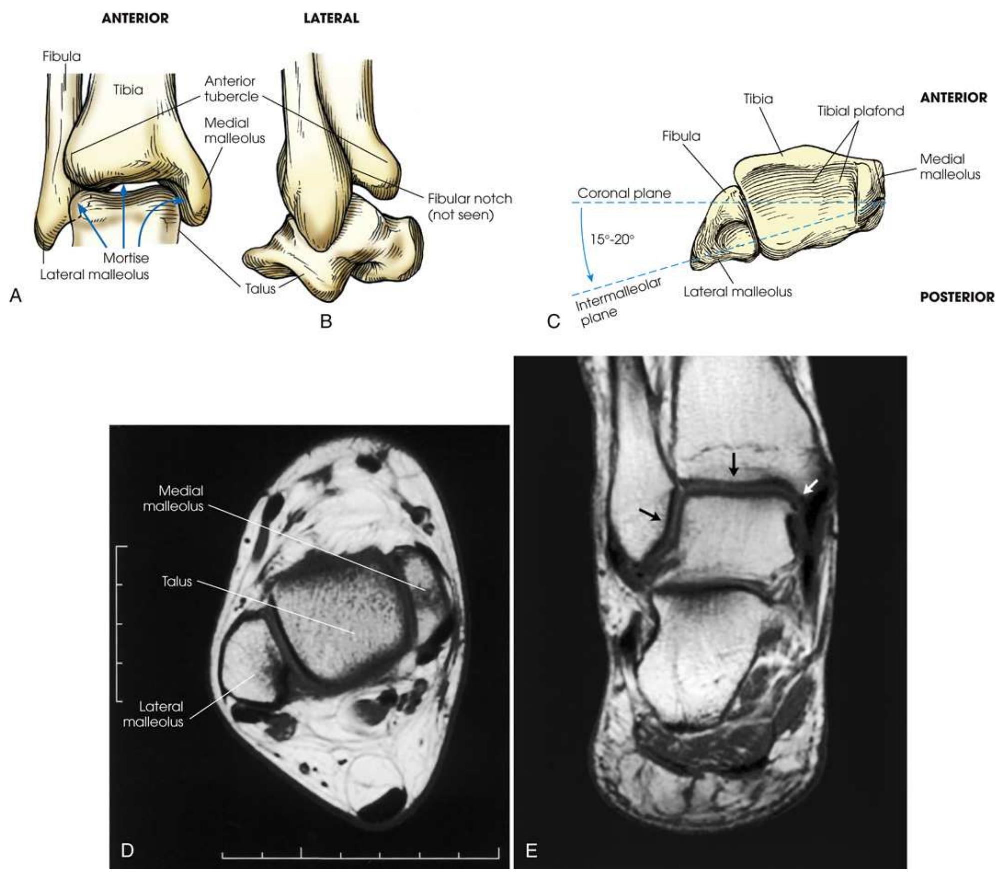

FIG. 7.5 (A) Right distal tibia and fibula in true anatomic position. Mortise joint and surrounding anatomy. Note slight overlap of anterior tubercle of tibia and superolateral talus over fibula. (B) Lateral aspect showing fibula positioned slightly posterior to tibia. (C) Inferior aspect. Note lateral malleolus lies more posterior than medial malleolus. (D) MRI axial plane of lateral and medial malleoli and talus. Lateral malleolus lies more posterior than medial malleolus. (E) MRI coronal plane of ankle clearly showing ankle mortise joint *(arrows)*.

Diagram (A) shows a broad distal end of the tibia. The medial part is prolonged into a large process called medial malleolus. The anterolateral surface overlays the fibula. Below it is the mortise lateral malleolus. Diagram (B) shows the fibula positioned slightly posterior to the tibia. The parts labeled are talus, fibular notch (not seen). Diagram (C) shows lateral malleolus lying 15 to 20 degrees more posterior than the medial malleolus. The parts labeled are lateral malleolus, intermalleolar plane, coronal plane, fibula, tibia, tibial plafond, and medial malleolus. (D) shows the M R I of the lateral and medial malleoli and talus. The parts labeled are as follows: medial malleolus, talus, and lateral malleolus. The talus in the middle is grainy. The medial malleolus is dark and grainy. The maleral malleolus is lighter. (E) shows the outline of the ankle mortise joint marked by two black and one white arrow.

Femur

The *femur* is the longest, strongest, and heaviest bone in the body (Figs. 7.6 and 7.7). This bone consists of one body and two articular extremities. The *body* is cylindric and slightly convex anteriorly, and slants medially 5 to 15 degrees (see Fig. 7.6A). The extent of medial inclination depends on the breadth of the pelvic girdle. When the femur is vertical, the medial condyle is lower than the lateral condyle (see Fig. 7.6C). About a 5- to 7-degree difference exists between the two condyles. Because of this difference, on lateral radiographs of the knee, the central ray is angled 5 to 7 degrees cephalad to "open" the joint space of the knee. The superior portion of the femur articulates with the acetabulum of the hip joint (considered with the pelvic girdle in Chapter 8).

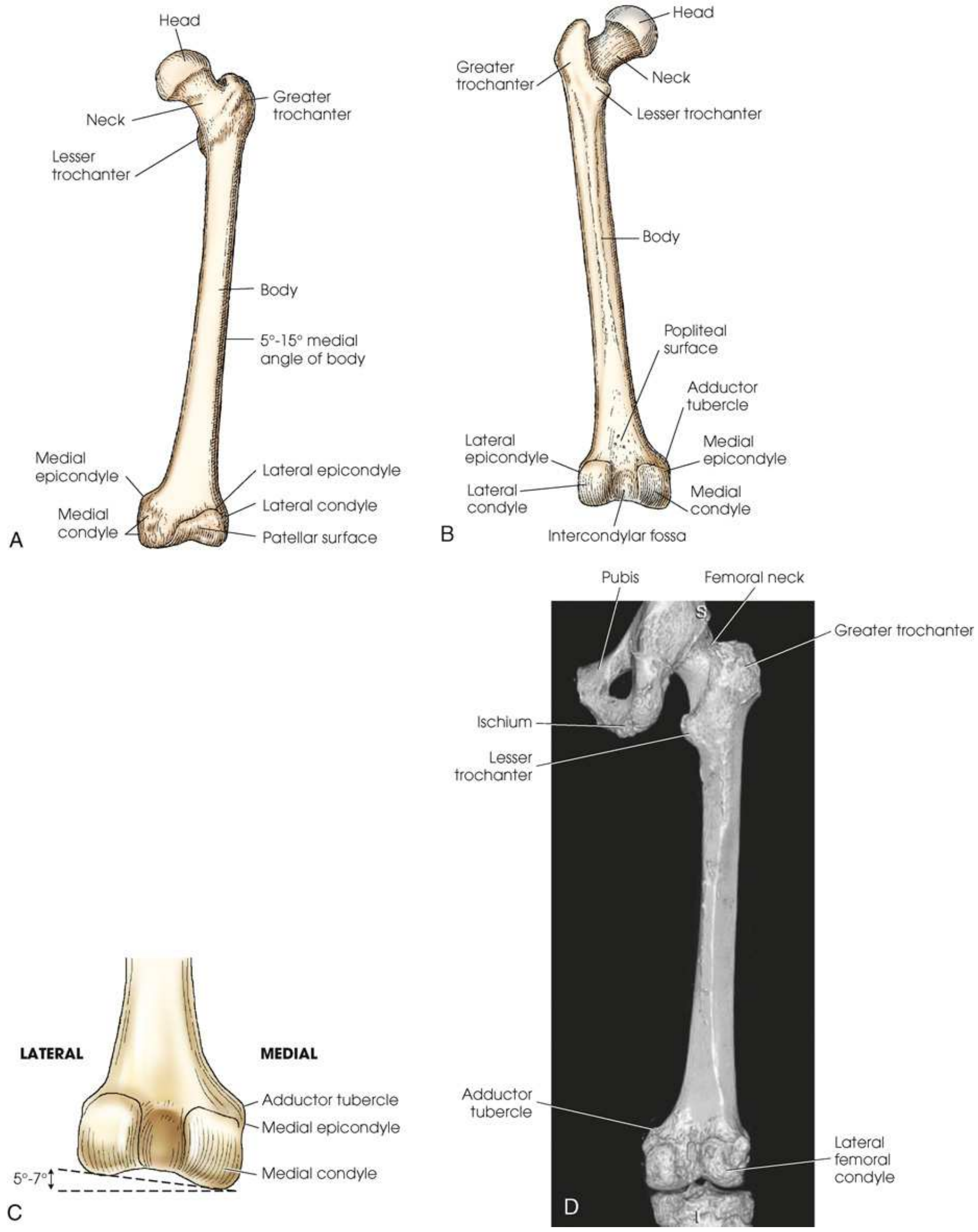

FIG. 7.6 (A) Anterior aspect of left femur. (B) Posterior aspect. (C) Distal end of posterior femur showing a 5- to 7-degree difference between medial and lateral condyle when the femur is vertical. (D) Three-dimensional CT scan showing posterior aspect and articulation with knee and hip.

Diagram (A) shows the femur. The body is cylindric and slightly convex anteriorly, and slants medially 5 to 15 degrees. The parts labeled are head, neck, lesser trochanter, medial epicondyle, medial condyle, greater trochanter, and body, 5 degrees to 15 degrees medial angle of the body, lateral epicondyle, lateral condyle, and patellar surface. Diagram (B) shows the posterior aspect of the femur. The parts labeled are greater trochanter, lateral epicondyle, lateral condyle, head, neck, lesser trochanter, body, popliteal surface, adductor tubercle, medial epicondyle, medial condyle, and intercondylar fossa. Diagram (C) shows about a 5 to7-degree difference between the two condyles. The parts labeled are adductor tubercle, medial epicondyle, and medial condyle. (D) shows a three-dimensional C T scan of the femur and its attachments. The parts labeled are pubis, ischium, lesser trochanter, adductor tubercle, femoral neck, greater trochanter, and lateral femoral condyle.

The distal end of the femur is broadened and has two large eminences: the larger *medial condyle* and the smaller *lateral condyle*. Anteriorly, the condyles are separated by the *patellar surface*: a shallow, triangular depression. Posteriorly, the condyles are separated by a deep depression called the *intercondylar fossa*. A slight prominence above and within the curve of each condyle forms the *medial* and *lateral epicondyles*. The medial condyle contains the *adductor tubercle,* which is located on the posterolateral aspect. The tubercle is a raised bony area that receives the tendon of the adductor muscle. This tubercle is important to identify on lateral knee radiographs because it assists in identifying overrotation or underrotation. The triangular area superior to the intercondylar fossa on the posterior femur is the *trochlear groove,* over which the popliteal blood vessels and nerves pass.

The posterior area of the knee, between the condyles, contains a sesamoid bone in 3% to 5% of people. This sesamoid is called the *fabella* and is seen only on the lateral projection of the knee.

Patella

The *patella,* or kneecap (Fig. 7.8), is the largest and most constant sesamoid bone in the body (see Chapter 2). The patella is a flat, triangular bone situated at the distal anterior surface of the femur. The patella develops in the tendon of the quadriceps femoris muscle between 3 and 5 years of age. The *apex,* or tip, is directed inferiorly, lies ½ inch (1.3 cm) above the joint space of the knee, and is attached to the tuberosity of the tibia by the patellar ligament. The superior border of the patella is called the *base.*

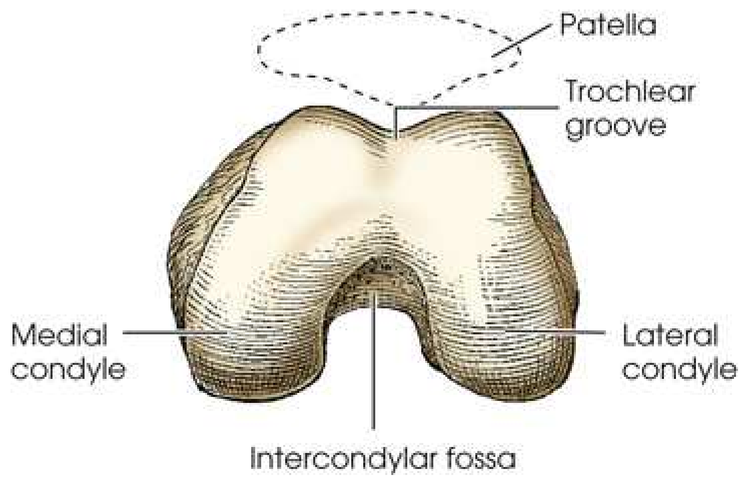

FIG. 7.7 Inferior aspect of left femur.

Diagram shows an inferior aspect of the left femur which is bean-shaped. The parts labeled are as follows: medial condyle, patella, or kneecap which is marked by a dashed circle, trochlear groove, lateral condyle, and intercondylar fossa.

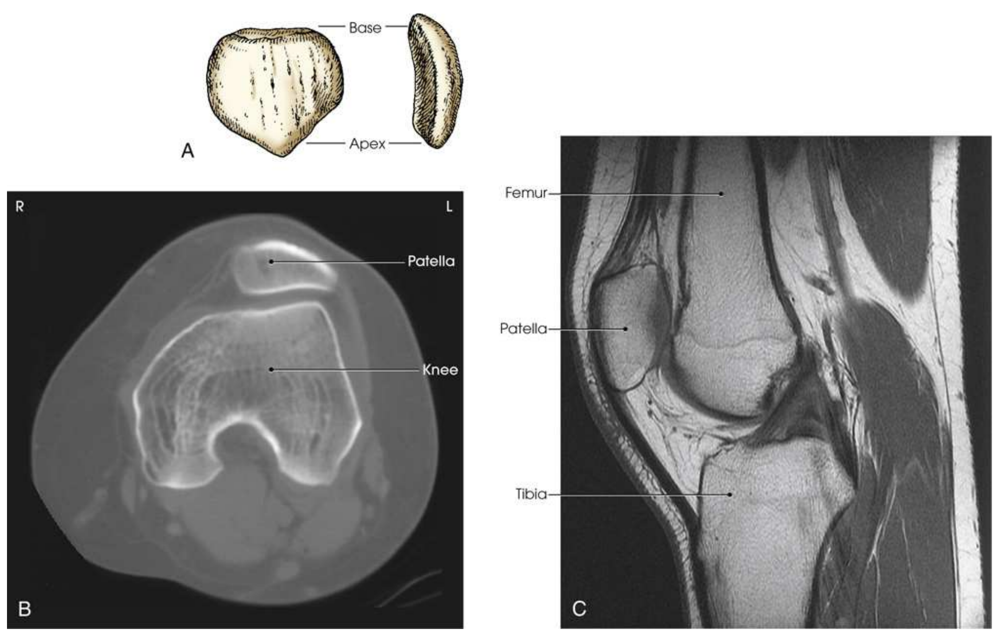

FIG. 7.8 (A) Anterior and lateral aspects of patella. (B) Axial CT scan of patella showing relationship to femur. (C) Sagittal MRI showing patellar relationship to femur and knee joint. The apex of the patella is ½ inch (1.3 cm) above the knee joint. B and C, Modified from Kelley LL, Petersen CM. *Sectional anatomy for imaging professionals,* ed 2, St Louis: Mosby; 2007.

Diagram (A) shows the heart-shaped anterior aspect and the posterior aspect is flat. The base and the apex are labeled on it. (B) shows the C T scan of the patella in the knee joint. The knee joint has an irregular bean shape and the patella is labeled above it. The outlines are defined. (C) shows the M R I of the patella. The parts are labeled femur, patella, and tibia. The patella is flat and triangular.

Knee Joint

The knee joint is one of the most complex joints in the human body. The femur, tibia, fibula, and patella are held together by a complex group of ligaments. These ligaments work together to provide stability for the knee joint. Although radiographers do not produce images of these ligaments, they need to have a basic understanding of their positions and interrelationships. Many patients with knee injuries do not have fractures, but they may have one or more torn ligaments, which can cause great pain and may alter the position of the bones. Fig. 7.9 shows the following important ligaments of the knee:

- Posterior cruciate ligament

• Anterior cruciate ligament
• Tibial collateral ligament
• Fibular collateral ligament

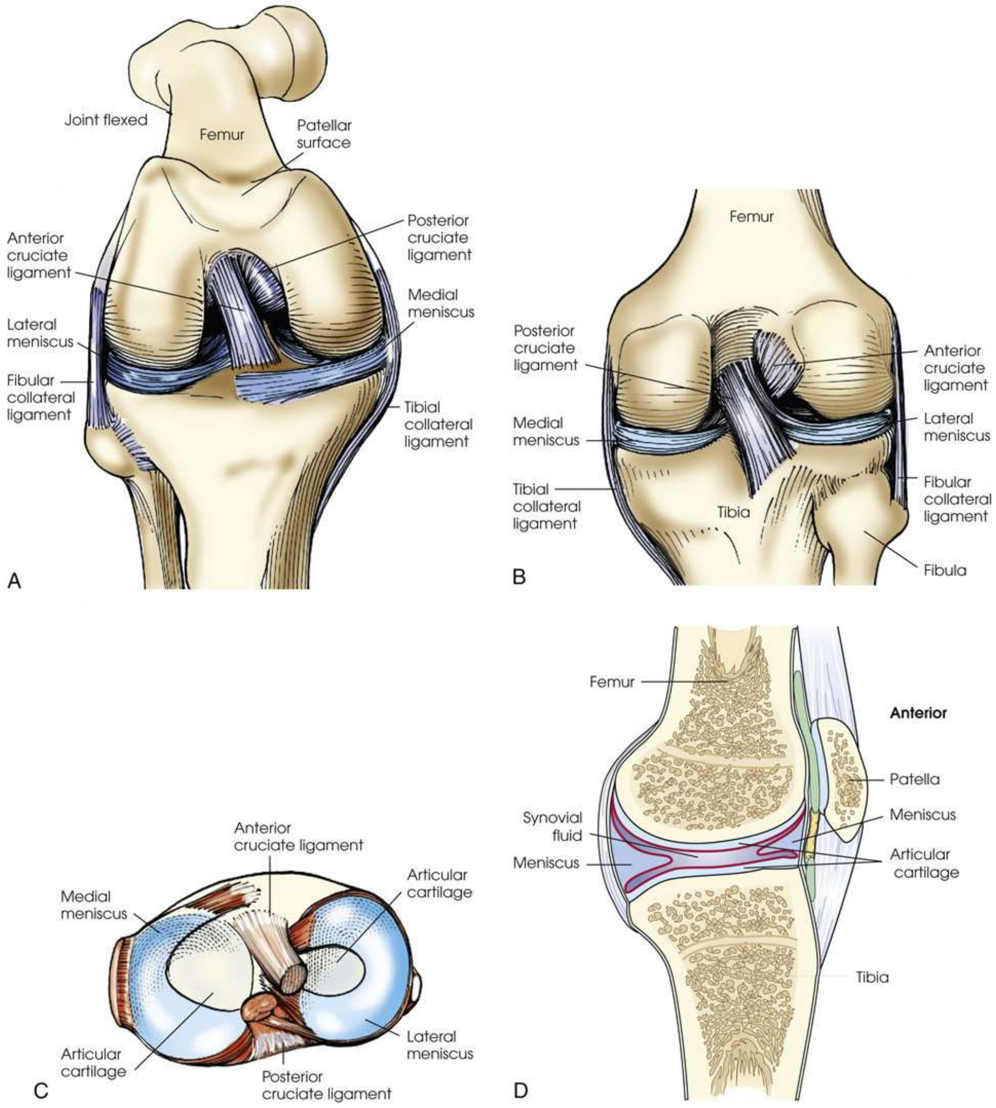

FIG. 7.9 Knee joint. (A) Anterior aspect with femur flexed. (B) Posterior aspect. (C) Superior surface of tibia. (D) Sagittal section.

Diagram (A) the femur, tibia, fibula, and patella are held together by a complex group of ligaments. The parts labeled are as follows: anterior cruciate ligament, lateral meniscus, fibular collateral ligament, patellar surface, posterior cruciate ligament, medial meniscus, tibial collateral ligament. Diagram (B) the femur, tibia, fibula, and patella are held together by a complex group of ligaments. The parts labeled are as follows: posterior cruciate ligament, medial meniscus, tibial collateral ligament, anterior cruciate ligament, lateral meniscus, fibular collateral ligament, and fibula. Diagram (C) shows the superior surface of the tibia. The parts labeled are as follows: posterior cruciate ligament, articular cartilage, medial meniscus, anterior cruciate ligament, articular cartilage, and lateral meniscus. Diagram (D) shows the sagittal section. The parts labeled are as follows: femur, synovial fluid, meniscus, patella, meniscus, articular cartilage, and tibia. Femur and tibia are grainy.

The knee joint contains two fibrocartilage disks called the *lateral meniscus* and *medial meniscus* (Fig. 7.10; also see Fig. 7.9). The circular menisci lie on the tibial plateaus. They are thick at the outer margin of the joint and taper off toward the center of the tibial plateau. The center of the tibial plateau contains cartilage that articulates directly with the condyles of the knee. The menisci provide stability for the knee and act as a shock absorber. The menisci are commonly torn during injury. A knee arthrogram or a magnetic resonance imaging (MRI) scan must be performed to visualize a meniscus tear.

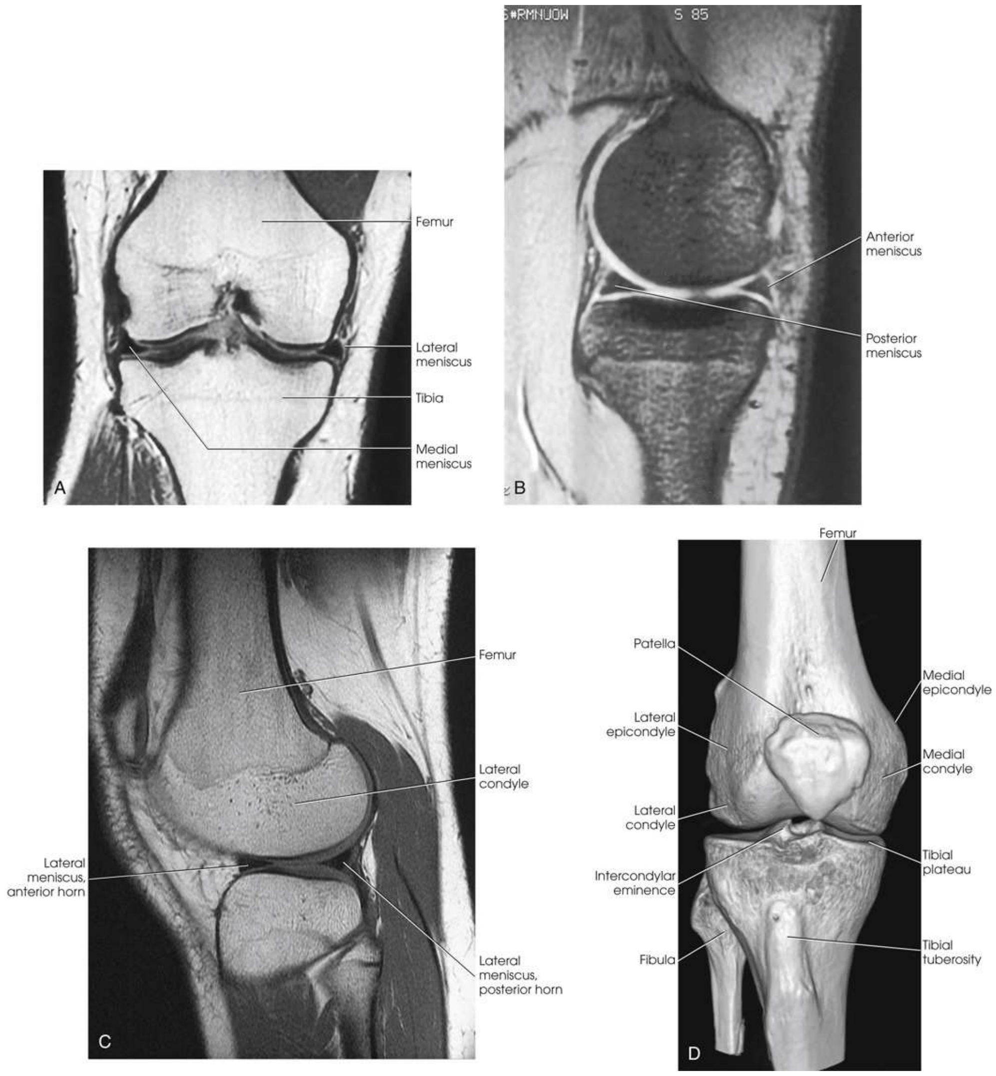

FIG. 7.10 (A) MRI coronal plane. (B) MRI sagittal plane. (C) MRI oblique plane. (D) Three-dimensional CT reformat of the knee joint.

(A) shows the M R I of the knee joint in the coronal plane. The parts labeled from top to bottom are as follows: femur, lateral meniscus, tibia, medial meniscus. The lateral meniscus appears dark. (B) shows the M R I of the knee joint in the sagittal plane. The parts labeled are as follows: anterior meniscus and posterior meniscus. They are thick at the outer margin of the joint and taper off toward the center of the tibial plateau. (C) shows the M R I of the knee joint in the oblique plane. The parts labeled are as follows: lateral meniscus anterior horn, femur, lateral condyle, and lateral meniscus posterior horn. (D) shows the three-dimensional C T of the knee joint. The parts labeled are as follows: femur, patella, lateral epicondyle, lateral condyle, intercondylar eminence, fibula, medial epicondyle, medial condyle, tibial plateau, and tibial tuberosity. The center of the tibial plateau contains cartilage that articulates directly with the condyles of the knee.

Lower Extremity Articulations

The joints of the lower extremity are summarized in Table 7.1 and shown in Figs. 7.11 and 7.12. Beginning at the distal end of the lower extremity, the articulations are as follows.

The *interphalangeal (IP) articulations,* between the phalanges, are *synovial hinges* that allow only flexion and extension. The joints between the distal and middle phalanges are the *distal interphalangeal (DIP) joints*. Articulations between the middle and proximal phalanges are the *proximal interphalangeal (PIP) joints*. With only two phalanges in the great toe, the joint is known simply as the *IP joint*.

TABLE 7.1

Joint	Structural classification		Movement
	Tissue	Type	
Interphalangeal	Synovial	Hinge	Freely movable
Metatarsophalangeal	Synovial	Ellipsoidal	Freely movable
Intermetatarsal	Synovial	Gliding	Freely movable
Tarsometatarsal	Synovial	Gliding	Freely movable
Calcaneocuboid	Synovial	Gliding	Freely movable
Cuneocuboid	Synovial	Gliding	Freely movable
Intercuneiform	Synovial	Gliding	Freely movable
Cuboidonavicular	Fibrous	Syndesmosis	Slightly movable
Naviculocuneiform	Synovial	Gliding	Freely movable
Subtalar			
Talocalcaneal	Synovial	Gliding	Freely movable
Talocalcaneonavicular	Synovial	Ball and socket	Freely movable
Ankle mortise			
Talofibular	Synovial	Hinge	Freely movable
Tibiotalar	Synovial	Hinge	Freely movable
Tibiofibular			
Proximal	Synovial	Gliding	Freely movable
Distal	Fibrous	Syndesmosis	Slightly movable
Knee			
Patellofemoral	Synovial	Gliding	Freely movable
Femorotibial	Synovial	Hinge modified	Freely movable

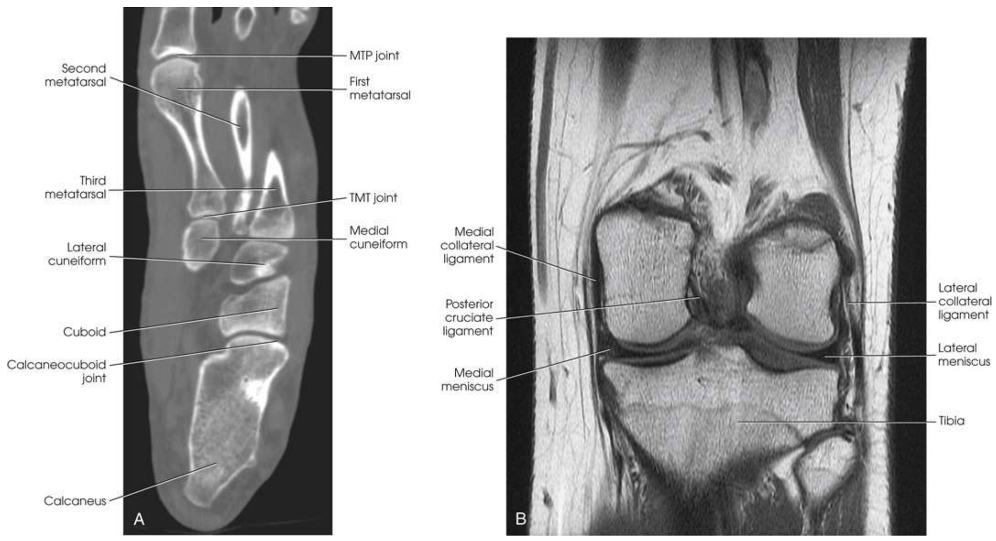

FIG. 7.11 (A) Axial CT scan of foot and calcaneus. (B) MRI coronal plane of the knee joint. Joint spaces are clearly shown.

(A) A C T scan shows the foot and calcaneus. The joints of the foot are outlined. The parts labeled are as follows: second metatarsal, third metatarsal, lateral cuneiform, cuboid, calcaneocuboid joint, calcaneus, M T P joint, first metatarsal, T M T joint, medial cuneiform. (B) shows the joint spaces in the knee joint. They are dark. The parts labeled are as follows: medial collateral ligament, posterior cruciate ligament, medial meniscus, lateral collateral ligament, lateral meniscus, and tibia.

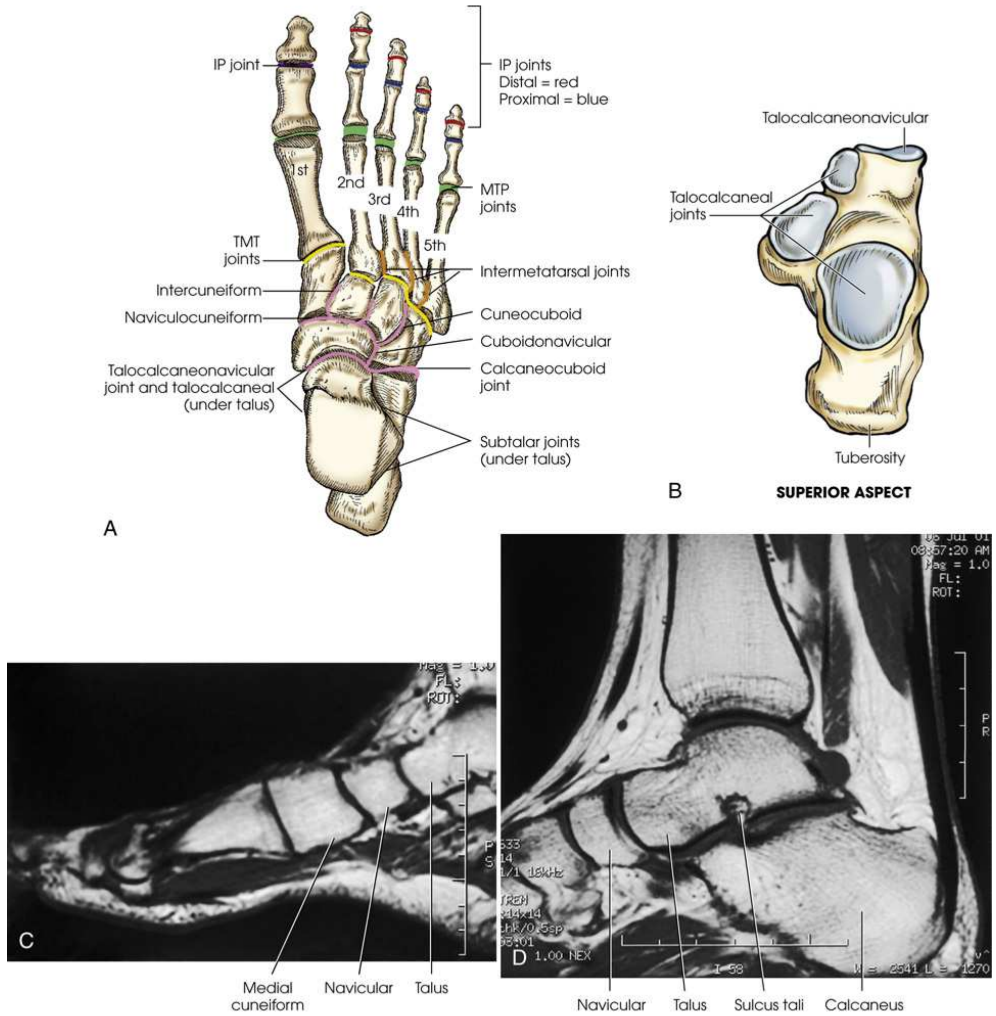

FIG. 7.12 (A) Color-coded joints of right foot. *Blue*, Proximal IP joints; *green*, MTP joints; *orange*, intermetatarsal joints; *pink*, intertarsal joints; *purple*, IP joint of 1st digit; *red*, distal IP joints; *yellow*, TMT joints. (B) Superior aspect of right calcaneus showing articular facets. (C) MRI sagittal plane of the anterior foot. (D) MRI sagittal plane of the posterior foot and ankle. Joint spaces and articular surfaces are clearly shown.

Diagram (A) shows the joints of the right foot. The parts labeled are as follows: I P joint, T M T joints, intercuneiform, naviculocuneiform, talocalcaneonavicular joint, talocalcaneal (under talus), I P joints, distal equals red, proximal equals blue, M T P joints, intermetatarsal joints, cuneocuboid, cuboidonavicular, calcaneocuboid joint, subtalar joints (under talus). Diagram (B) shows the articular facets. They are small circular structures. The parts labeled are as follows: talocalcaneonavicular, tuberosity, talocalcaneal joints. (C) shows the M R I of the anterior foot. The parts labeled are as follows: medial cuneiform, navicular, talus. They appear white. (D) shows the M R I of the foot and ankle. The parts labeled are as follows: navicular, talus, sulcus tali, and calcaneus. The sulcus tali appear small, circular, and dark.

The distal heads of the metatarsals articulate with the proximal ends of the phalanges at the *metatarsophalangeal* (MTP) articulations to form *synovial ellipsoidal* joints, which have movements of flexion, extension, and slight adduction and abduction. The proximal bases of the metatarsals articulate with one another (*intermetatarsal* articulations) and with the tarsals (*tarsometatarsal* [TMT] articulations) to form *synovial gliding* joints, which permit flexion, extension, adduction, and abduction movements.

The *intertarsal* articulations allow only slight gliding movements between the bones and are classified as *synovial gliding* or *synovial ball-and-socket* joints (see Table 7.1). The joint spaces are narrow and obliquely situated. When the joint surfaces of these bones are in question, it is necessary to angle the x-ray tube or adjust the foot to place the joint spaces parallel with the central ray.

The calcaneus supports the talus and articulates with it by an irregularly shaped, three-faceted joint surface, forming the *subtalar joint*. This joint is classified as a *synovial gliding* joint. Anteriorly, the calcaneus articulates with the cuboid at the calcaneocuboid joint. This joint is a synovial gliding joint. The talus rests on top of the calcaneus (see Fig. 7.12). It articulates with the navicular bone anteriorly, supports the tibia above, and articulates with the malleoli of the tibia and fibula at its sides.

Each of the three parts of the subtalar joint is formed by reciprocally shaped facets on the inferior surface of the talus and the superior surface of the calcaneus. Study of the superior and medial aspects of the calcaneus (see Fig. 7.3) helps the radiographer to understand better the problems involved in radiography of this joint.

The intertarsal articulations are:

- Calcaneocuboid
- Cuneocuboid

• Intercuneiform (two)
• Cuboidonavicular
• Naviculocuneiform
• Talocalcaneal
• Talocalcaneonavicular

The *ankle joint* is commonly called the *ankle mortise,* or *mortise joint*. It is formed by the articulations between the lateral malleolus of the fibula and the inferior surface and medial malleolus of the tibia (Fig. 7.13A). The mortise joint is often divided specifically into the *talofibular* and *tibiofibular* joints. These form a socket type of structure that articulates with the superior portion of the talus. The talus fits inside the mortise. The articulation is a synovial hinge type of joint. The primary action of the ankle joint consists of dorsiflexion (flexion) and plantar flexion (extension); however, in full plantar flexion, a small amount of rotation and abduction-adduction is permitted. The mortise joint also allows inversion and eversion of the foot. Other movements at the ankle largely depend on the gliding movements of the intertarsal joints, particularly the one between the talus and the calcaneus.

The fibula articulates with the tibia at its distal and proximal ends. The *distal tibiofibular* joint is a *fibrous syndesmosis* joint allowing slight movement. The head of the fibula articulates with the posteroinferior surface of the lateral condyle of the tibia, which forms the *proximal tibiofibular* joint: a *synovial gliding* joint (see Fig. 7.13A).

The patella articulates with the patellar surface of the femur and protects the front of the knee joint. This articulation is called the *patellofemoral joint;* when the knee is extended and relaxed, the patella is freely movable over the patellar surface of the femur. When the knee is flexed as a *synovial gliding* joint, the patella is locked in position in front of the patellar surface. The knee joint, or *femorotibial* joint, is the largest joint in the body. It is called a *synovial modified-hinge joint*. In addition to flexion and extension, the knee joint allows slight medial and lateral rotation in the flexed position. The joint is enclosed in an articular capsule and is held together by numerous ligaments (see Figs. 7.9 and 7.13B).

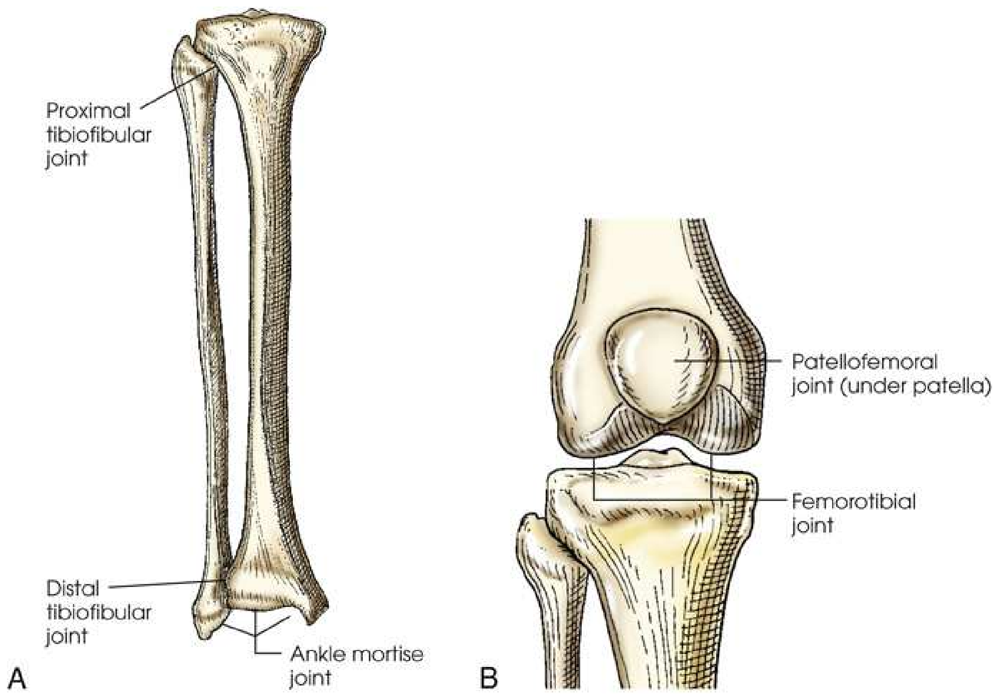

FIG. 7.13 (A) Joints of the right tibia and fibula. (B) Joints of the right knee.

Diagram (A) shows the right tibia and fibula. The parts labeled are as follows: ankle mortise joint, proximal tibiofibular joint, and distal tibiofibular joint. The head of the fibula articulates with the posteroinferior surface of the lateral condyle of the tibia, which forms the proximal tibiofibular joint. Diagram (B) shows the joints of the right knee. The parts labeled are the patellofemoral joint, and femorotibial joint. There is a gap between the two joints.

Summary of Anatomy

Foot

Phalanges
Metatarsals
Tarsals
Dorsum (dorsal surface)
Plantar surface

Phalanges (14)

Proximal phalanx
Middle phalanx
Distal phalanx
Body
Base
Head

Metatarsals (5)

First metatarsal
Second metatarsal
Third metatarsal
Fourth metatarsal
Fifth metatarsal
Body
Base
Head
Tuberosity (fifth)

Tarsals (7)

Calcaneus
Tuberosity
Anterior facet
Middle facet
Posterior facet
Calcaneal sulcus
Sinus tarsi
Sustentaculum tali
Trochlea
Talus
Trochlear surface
Sulcus tali
Posterior articular surface
Cuboid
Navicular
Medial cuneiform
Intermediate cuneiform
Lateral cuneiform

Others

Sesamoid bones

Leg

Tibia
Fibula

Tibia

Body
Medial condyle
Lateral condyle
Tibial plateau
Intercondylar eminence
Medial intercondylar
Tubercle
Lateral intercondylar
Tubercle
Tibial tuberosity
Anterior crest
Medial malleolus
Anterior tubercle
Fibular notch

Fibula

- Body
- Head
- Apex
- Lateral malleolus

Thigh

- Femur
- Body
- Medial condyle
- Lateral condyle
- Trochlear groove
- Intercondylar fossa
- Medial epicondyle
- Lateral epicondyle
- Adductor tubercle
- Popliteal surface
- Fabella

Patella

- Apex
- Base

Knee joint

- Posterior cruciate ligament
- Anterior cruciate ligament
- Tibial collateral ligament
- Fibular collateral ligament
- Lateral meniscus
- Medial meniscus

Articulations

- Interphalangeal
- Metatarsophalangeal
- Intermetatarsal
- Tarsometatarsal
- Intertarsal
- Subtalar
    - Talocalcaneonavicular
    - Talocalcaneal
- Calcaneocuboid
- Cuneocuboid
- Intercuneiform
- Cuboidonavicular
- Naviculocuneiform
- Ankle mortise
    - Talofibular
    - Tibiotalar
- Tibiofibular
    - Proximal
    - Distal
- Knee
    - Patellofemoral
    - Femorotibial

Abbreviations Used in Chapter 7

ASIS	Anterior superior iliac spine
DIP [a]	Distal interphalangeal
IP [a]	Interphalangeal
MTP	Metatarsophalangeal
PIP [a]	Proximal interphalangeal
TMT	Tarsometatarsal

[a] The same abbreviations are used for joints in the hand.
See Addendum A for a summary of all abbreviations used in Volume 1.

Summary of Pathology

Condition	Definition
Bone cyst	Fluid-filled cyst with a wall of fibrous tissue
Congenital clubfoot	Abnormal twisting of the foot, usually inward and downward
Dislocation	Displacement of a bone from the joint space
Fracture	Disruption in the continuity of bone
Pott	Avulsion fracture of the medial malleolus with loss of the ankle mortise
Jones	Avulsion fracture of the base of the fifth metatarsal
Gout	Hereditary form of arthritis in which uric acid is deposited in joints
Metastases	Transfer of a cancerous lesion from one area to another
Osgood–Schlatter disease	Incomplete separation or avulsion of the tibial tuberosity
Osteoarthritis or degenerative joint disease	Form of arthritis marked by progressive cartilage deterioration in synovial joints and vertebrae
Osteomalacia or rickets	Softening of the bones due to vitamin D deficiency
Osteomyelitis	Inflammation of bone due to a pyogenic infection
Osteopetrosis	Increased density of atypically soft bone
Osteoporosis	Loss of bone density
Paget disease	Chronic metabolic disease of bone marked by weakened, deformed, and thickened bone that fractures easily
Tumor	New tissue growth where cell proliferation is uncontrolled
Chondrosarcoma	Malignant tumor arising from cartilage cells
Enchondroma	Benign tumor consisting of cartilage
Ewing sarcoma	Malignant tumor of bone arising in medullary tissue
Osteochondroma or exostosis	Benign bone tumor projection with a cartilaginous cap
Osteoclastoma or giant cell tumor	Lucent lesion in the metaphysis, usually at the distal femur
Osteoid osteoma	Benign lesion of cortical bone
Osteosarcoma	Malignant, primary tumor of bone with bone or cartilage formation

Eponymous (named) pathologies are listed in nonpossessive form to conform to the *AMA manual of style: a guide to authors and editors*, ed 10, Oxford, 2009, Oxford University Press.

Sample Exposure Technique Chart Essential Projections

These techniques were accurate for the equipment used to produce each exposure. However, use caution when applying them in your department because “there is considerable variability in image receptor response owing to varying scatter sensitivity, the use of grids with different grid ratios, collimation, beam filtration, the choice of kilovoltage, source-to-image distance, and image receptor size.”[a]								
This chart was created in collaboration with Dennis Bowman, AS, RT(R), Clinical Instructor, Community Hospital of the Monterey Peninsula, Monterey, CA. http://digitalradiographysolutions.com/.								
Lower Extremity								
Part	cm	kVp[b]	SID[c]	Collimation	CR[d]		DR[e]	
					mAs	Dose (mGy)[f]	mAs	Dose (mGy)[f]
Toes—*all*[g]	1.5	63	40″	2″ × 6″ (5 × 15 cm)	2.0[h]	0.052	0.9[h]	0.023
Foot—*AP, oblique, lateral*[g]	5	70	40″	6″ × 11″ (15 × 28 cm)	2.5[h]	0.166	1.25[h]	0.082
Calcaneus—*axial*[g]	8	70	40″	4″ × 6″ (10 × 15 cm)	3.2[h]	0.201	1.8[h]	0.112
Calcaneus—*lateral*[g]	5	70	40″	4″ × 5″ (10 × 13 cm)	2.2[h]	0.130	1.1[h]	0.063
Ankle—*AP*[g]	11	70	40″	4″ × 9″ (10 × 23 cm)	3.2[h]	0.217	1.8[h]	0.121
Ankle—*lateral*[g]	7	70	40″	5″ × 9″ (13 × 23 cm)	2.2[h]	0.150	1.25[h]	0.084
Leg—*all*[i]	11	81	40″	6″ × 17″ (15 × 43 cm)	4.5[h]	0.468	2.0[h]	0.206
Leg—*all*[g]	12	70	40″	6″ × 17″ (15 × 43 cm)	3.6[h]	0.286	2.5[h]	0.199
Knee—*AP, oblique, lateral*[i]	12	85	40″	6″ × 11″ (15 × 28 cm)	5.0[h]	0.576	2.5[h]	0.283
Knee—*AP, oblique, lateral*[g]	13	70	40″	6″ × 11″ (15 × 28 cm)	5.0[h]	0.405	2.5[h]	0.202
Intercondylar fossa[g]	14	70	40″	6″ × 6″ (15 × 15 cm)	5.0[h]	0.398	2.5[h]	0.199
Patella—*PA*[i]	12	85	40″	6″ × 6″ (15 × 15 cm)	6.3[h]	0.698	3.2[h]	0.353
Patella—*lateral*[i]	12	85	40″	5″ × 5″ (13 × 13 cm)	2.8[h]	0.342	2.0[h]	0.190
Patella—*tangential*[g]	12	70	40″	5″ × 5″ (13 × 13 cm)	4.0[h]	0.259	2.0[h]	0.143
Femur—*AP, lateral*[i]	15	87.5	40″	8″ × 17″ (20 × 43 cm)	7.1[h]	0.949	3.6[h]	0.479
Femur—*proximal*[i]	19	87.5	40″	9″ × 17″ (23 × 43 cm)	14[h]	2.082	7.1[h]	1.052

[a] ACR-AAPM-SIMM Practice Parameter for Digital Radiography, revised 2017.

[b] kVp values are for a high-frequency generator.

[c] 40-inch minimum; 44 to 48 inches recommended to improve spatial resolution (mAs increase needed, but no increase in patient dose will result).

[d] AGFA CR MD 4.0 General IP, central ray (CR) 75.0 reader, 400 speed class, with 6:1 (178LPI) grid when needed.

[e] GE Definium 8000, with 13:1 grid when needed.

[f] All doses are skin entrance for average adult (160- to 200-pound male, 150- to 190-pound female) at part thickness indicated.

[g] Tabletop, nongrid.

[h] Small focal spot.

[i] Bucky/Grid.

Radiography

Toes

Radiation Protection

Protecting the patient from unnecessary radiation is a professional responsibility of the radiographer. In this chapter, the *Shield gonads* statement at the end of the *Position of part* sections indicates that the patient is to be protected from unnecessary radiation by using proper collimation and by placing lead shielding between the gonads and the radiation source, when requested by the patient or caregiver. See Chapter 1 for details.

Toes

AP or AP Axial Projections

Because of the natural curve of the toes, the IP joint spaces are not best shown on the AP projection. When demonstration of these joint spaces is not critical, an AP projection may be performed (Figs. 7.14 and 7.15). An AP axial projection is recommended to open the joint spaces and reduce foreshortening (Figs. 7.16 and 7.17).

Image receptor:

Positioned by manufacturer or department protocol for proper anatomy display orientation; CR plate: 10 × 12 inches (24 × 30 cm) lengthwise.

Position of patient

- Have the patient seated or placed supine on the radiographic table.

Position of part

- With the patient in the supine or seated position, flex the knees, separate the feet about 6 inches (15 cm), and touch the knees together for immobilization.

- Center the toes to the IR (see Figs. 7.14 and 7.16), or place a 15-degree foam wedge well under the foot and rest the toes near the elevated base of the wedge (Fig. 7.18).
- Adjust the IR with its midline parallel to the long axis of the foot, and center it to the third MTP joint.
- *Shield gonads.*

NOTE: Some institutions may show the entire foot, whereas others radiograph only the toe or toes of interest.

Central ray

- Perpendicular through the third MTP joint (see Fig. 7.14) when it is not critical to demonstrate the joint spaces. To open the joint spaces, direct the central ray 15 degrees posteriorly through the third MTP joint (see Fig. 7.16), or elevate the foot on a 15-degree foam wedge (Fig. 7.19).

Collimation

- Adjust the radiation field to 1 inch (2.5 cm) on all sides of the toes, including 1 inch (2.5 cm) proximal to the MTP joint. Place side marker in the collimated exposure field.

Structures shown

The 14 phalanges of the toes; the distal portions of the metatarsals; and, on the axial projections, the IP joints.

Evaluation Criteria

The following should be clearly seen:

- Evidence of proper collimation and the presence of a side marker placed clear of the anatomy of interest
- Entire toes, including distal ends of the metatarsals
- Toes separated from each other
- No rotation of phalanges; soft tissue width and midshaft concavity equal on both sides
- Open interphalangeal and metatarsophalangeal joint spaces on axial projections
- Bony trabecular detail and surrounding soft tissues

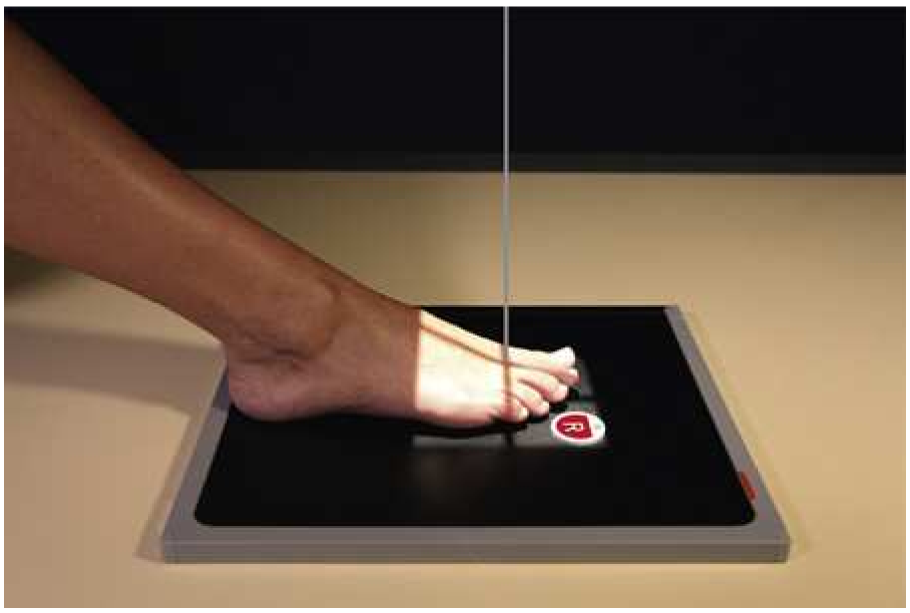

FIG. 7.14 AP toes, perpendicular CR.

The foot of the patient is placed on the image receptor and the toes are centered to the I R. The side marker is in the collimated exposure field. The central ray is perpendicular to the third M T P joint.

FIG. 7.15 AP toes, perpendicular CR.

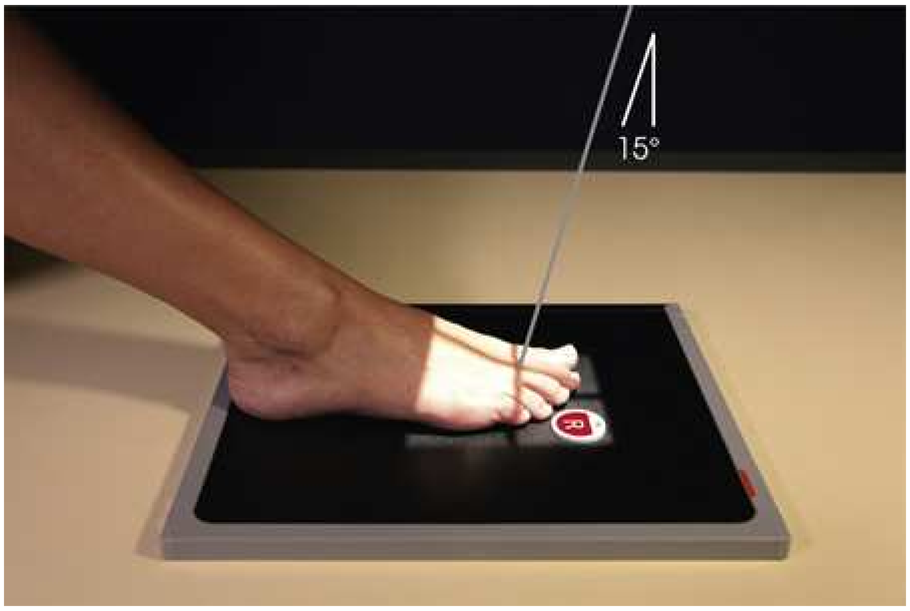

FIG. 7.16 AP axial toes, CR angulation of 15 degrees.

The foot of the patient is placed on the image receptor and the toes are centered to the I R. The side marker is in the collimated exposure field. The central ray is directed 15 degrees posteriorly through the third M T P joint.

FIG. 7.17 AP axial toes, CR angulation of 15 degrees.

An x-ray shows the 14 phalanges of the toes and the distal portions of the metatarsals. The parts labeled on the left from top to bottom are as follows: second D I P joint, second P I P joint, second M T P joint.

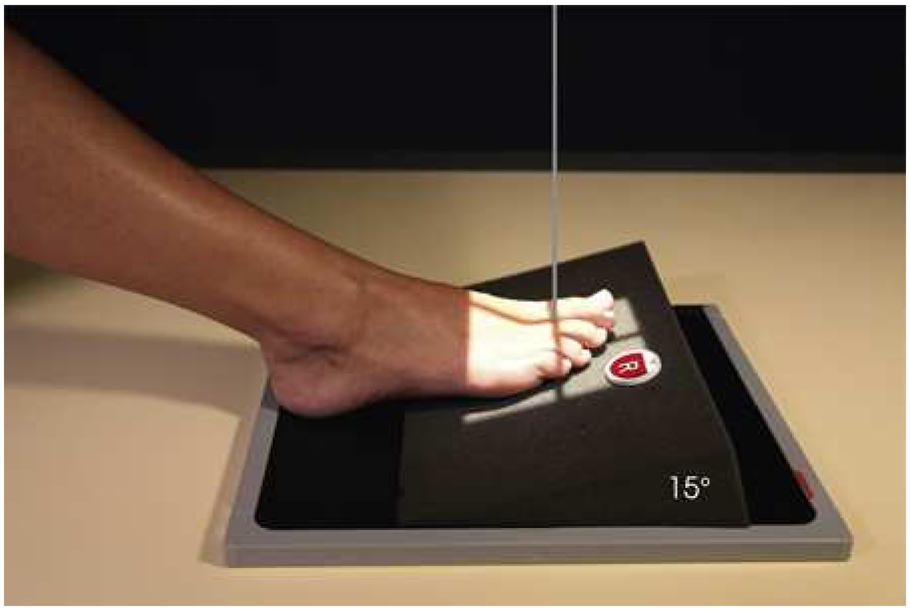

FIG. 7.18 AP axial, 15-degree foam wedge.

The foot of the patient is placed on the image receptor and the toes are centered to the I R. A 15-degree foam wedge is placed under the foot and the toes are rested near the elevated base of the wedge. The side marker is in the collimated exposure field. The central ray is directed 15 degrees posteriorly through the third M T P joint.

FIG. 7.19 AP axial, toes on 15-degree wedge.

PA Projection

Image receptor:

Positioned by manufacturer or department protocol for proper anatomy display orientation; CR plate: 10 × 12 inches (24 × 30 cm) lengthwise.

Position of patient

- Have the patient lie prone on the radiographic table because this position naturally turns the foot over so that the dorsal aspect is in contact with the IR.

Position of part

- Place the toes in the appropriate position by elevating them on one or two small sandbags and adjusting the support to place the toes horizontally.

Place the IR under the toes with the midline parallel with the long axis of the foot, and centered to the third MTP joint (Fig. 7.20).

Central ray

- Perpendicular to the midpoint of the IR entering the third MTP joint (see Fig. 7.20). The IP joint spaces are shown well because the natural divergence of the x-ray beam coincides closely with the position of the toes (Fig. 7.21).

Collimation

- Adjust the radiation field to 1 inch (2.5 cm) on all sides of the toes, including 1 inch (2.5 cm) proximal to the MTP joint. Place side marker in the collimated exposure field.

Structures shown

The 14 phalanges of the toes, the IP joints, and the distal portions of the metatarsals.

Evaluation Criteria

The following should be clearly seen:

- Evidence of proper collimation and the presence of a side marker placed clear of the anatomy of interest
- Entire toes, including distal ends of the metatarsals
- Toes separated from each other
- No rotation of phalanges; soft tissue width and midshaft concavity equal on both sides
- Open interphalangeal and metatarsophalangeal joint spaces
- Bony trabecular detail and surrounding soft tissues

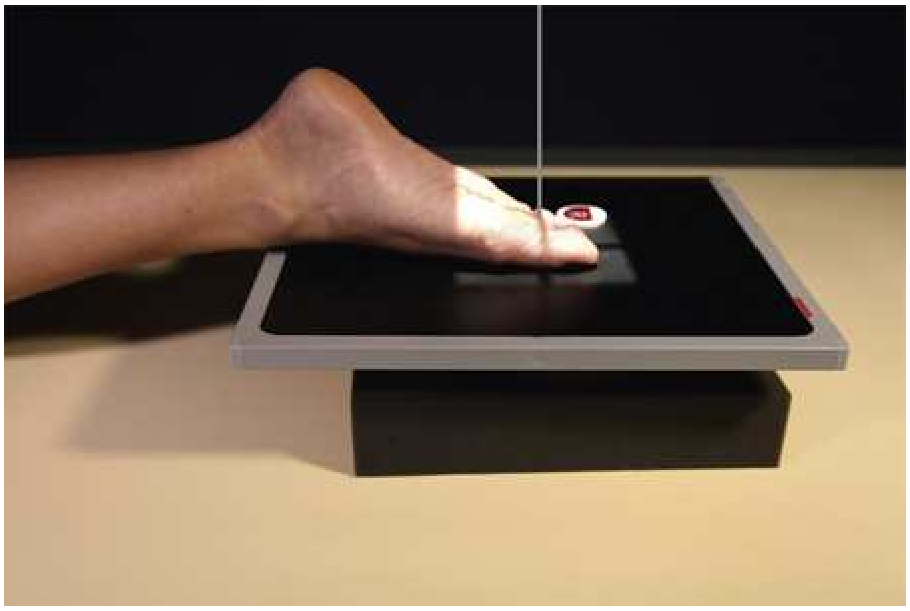

FIG. 7.20 PA toes.

A patient's dorsal aspect of the foot on the image receptor is placed on top of a box. The midline of the I R is parallel to the long axis of the foot. The side marker is in the collimated exposure field. The central ray is perpendicular to the midpoint of the I R entering the third M T P joint.

FIG. 7.21 PA toes.

An x-ray shows the 14 phalanges of the toes, the I P joints, and the distal portions of the metatarsals. The parts labeled at left from top to bottom are phalanges, sesamoids, metatarsals. At right from top to bottom: distal I P joint, distal phalanx, middle phalanx, proximal I P joint, proximal phalanx, M T P joint.

AP Oblique Projection

Medial rotation

Image receptor:

Positioned by manufacturer or department protocol for proper anatomy display orientation; CR plate: 10 × 12 inches (24 ×30 cm) lengthwise.

Position of patient

- Place the patient in the supine or seated position on the radiographic table.
- Flex the knee of the affected side enough to have the sole of the foot resting firmly on the table.

Position of part

- Position the IR under the toes.

- Medially rotate the lower leg and foot and adjust the plantar surface of the foot to form a 30- to 45-degree angle from the plane of the IR (Fig. 7.22).
- Center the toes to the IR.
- *Shield gonads.*

Central ray

- Perpendicular and entering the third MTP joint.

Collimation

- Adjust the radiation field to 1 inch (2.5 cm) on all sides of the toes, including 1 inch (2.5 cm) proximal to the MTP joint. Place side marker in the collimated exposure field.

NOTE: Oblique projections of individual toes may be obtained by centering the affected toe to the portion of the IR being used and collimating closely. The foot may be placed in a medial oblique position for the first and second toes and in a lateral oblique position for the fourth and fifth toes. Either oblique position is adequate for the third (middle) toe.

Structures shown

An AP oblique projection of the phalanges shows the toes and the distal portion of the metatarsals rotated medially (Fig. 7.23).

Evaluation Criteria

The following should be clearly seen:

- Evidence of proper collimation and the presence of a side marker placed clear of the anatomy of interest
- Entire toes, including distal ends of the metatarsals
- Toes separated from each other
- Proper rotation of toes, as demonstrated by more soft tissue width and more midshaft concavity on elevated side
- Open interphalangeal and second through fifth metatarsophalangeal joint spaces
- First MTP joint (not always opened)
- Bony trabecular detail and surrounding soft tissues

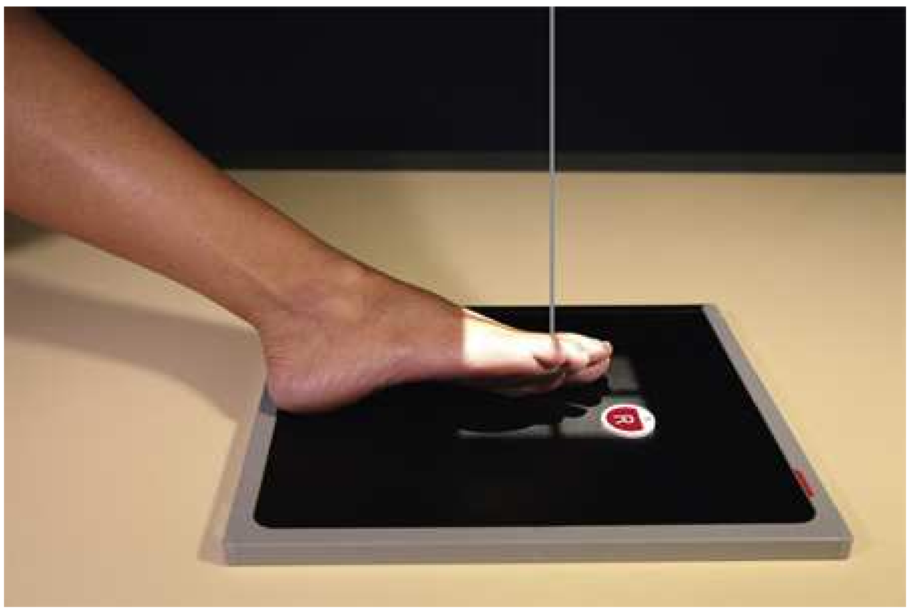

FIG. 7.22 AP oblique toes, medial rotation.

The patient's lower leg and the foot are medially rotated and the plantar surface of the foot is adjusted to form a 30 to 45-degree angle from the plane of the I R. The side marker is in the collimated exposure field. The central ray is perpendicular and enters the third M T P joint.

FIG. 7.23 AP oblique toes.

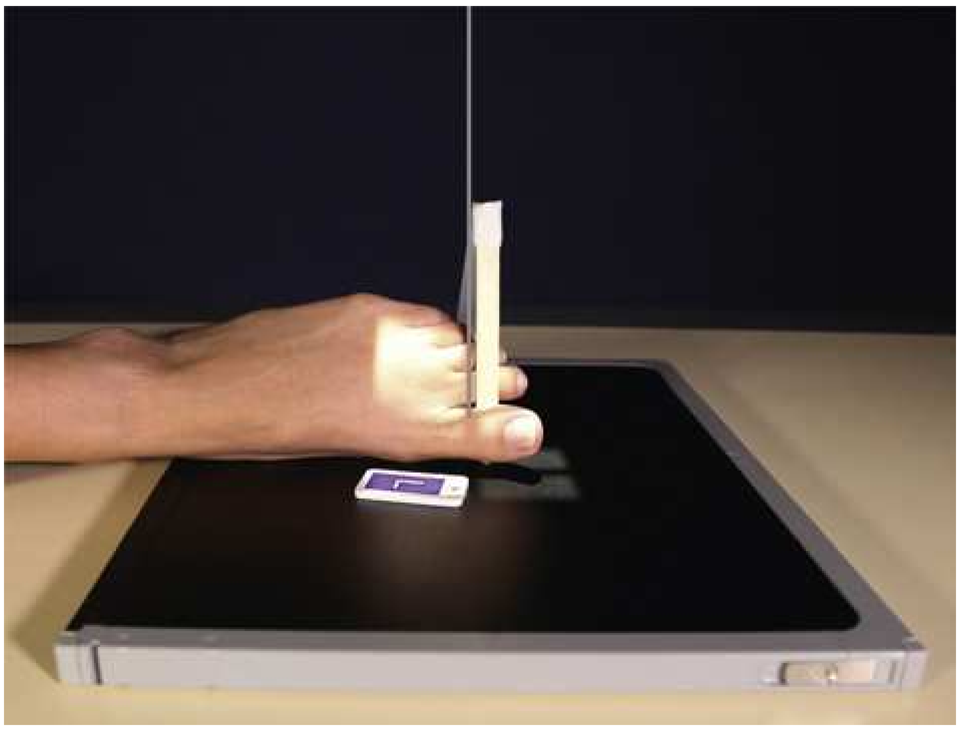

FIG. 7.24 Lateral great toe.

The patient's medial side of the foot is on the image receptor and the toe is in true lateral position. The toe is separated using two taped tongue blades. The side marker is in the collimated exposure field. The central ray is perpendicular to the plane of the IR entering the I P joint of the great toe.

Lateral Projections

Mediolateral or lateromedial

Image receptor:

Positioned by manufacturer or department protocol for proper anatomy display orientation; CR plate: 10 × 12 inches (24 × 30 cm) lengthwise.

Position of patient

- Have the patient lie in the lateral recumbent position.

- Support the affected extremity on sandbags and adjust it in a comfortable position.
- To prevent superimposition, tape the toes above the one being examined into a flexed position; a 4 × 4-inch gauze pad also may be used to separate the toes.

NOTE: Manipulate toes only if no deformity is apparent.

FIG. 7.25 Lateral second toe.

The patient's medial side of the foot is on the image receptor and the toe is in true lateral position. The toes are separated using two taped tongue blades from the lateral second toe. The side marker is in the collimated exposure field. The central ray is perpendicular to the plane of the IR entering the I P joint of the great toe.

FIG. 7.26 Lateral third toe.

The patient's lateral side of the foot is on the image receptor. The elevated heel is supported using a sandbag. The toes are separated using two taped tongue blades from the lateral third toe. The side marker is in the collimated exposure field. The central ray is perpendicular to the plane of the IR entering the I P joint of the great toe.

Position of part

Great toe, second toe

- Place the patient on the *unaffected* side for these two toes.
- Place an IR under the medial side of the foot and center it to the affected toe.
- Grasp the patient's extremity by the heel and knee and adjust its position to place the toe in a true lateral position (plane through MTP joints will be perpendicular to IR).
- Adjust the long axis of the IR so that it is parallel with the long axis of the toe (Figs. 7.24 and 7.25).

Third, fourth, fifth toes

- Place the patient on the *affected* side for these three toes.
- Place an IR under the lateral side of the foot and center it to the toes.
- Grasp patient's extremity by heel and knee and adjust its position to place the toes in a true lateral position (plane through MTP joints is perpendicular to IR).
- Adjust the long axis of the IR so that it is parallel with the long axis of the toe.
- Support the elevated heel on a sandbag or sponge for immobilization (Figs. 7.26 through 7.28).
- *Shield gonads.*

FIG. 7.27 Lateral fourth toe.

The patient's lateral side of the foot is on the image receptor. The elevated heel is supported using a sandbag. The toes are separated using two taped tongue blades from the lateral fourth toe. The side marker is in the collimated exposure field. The central ray is perpendicular to the plane of the IR entering the I P joint of the great toe.

FIG. 7.28 Lateral fifth toe.

The patient's lateral side of the foot is on the image receptor. The elevated heel is supported using a sandbag. The toes are separated using two taped tongue blades from the lateral fifth toe. The side marker is in the collimated exposure field. The central ray is perpendicular to the plane of the IR entering the I P joint of the fifth toe.

Central ray

- Perpendicular to the plane of the IR, entering the IP joint of the great toe or the proximal IP joint of the lesser toes.

Collimation

- Adjust the radiation field to 1 inch (2.5 cm) on all sides of the toes, including 1 inch (2.5 cm) proximal to the MTP joint. Place side marker in the collimated exposure field.

Structures shown

Lateral projection of the phalanges of the toe and the IP articulations projected free of the other toes (Figs. 7.29 through 7.33).

FIG. 7.29 Lateral great toe.

FIG. 7.30 (A) Lateral second toe. (B) Lateral second toe showing the MTP joint *(arrow)*.

(A) An x-ray shows the phalanges of the second toe. The phalanges have concave surfaces. The parts labeled are the second D I P joint, second P I P joint. (B) shows the phalanges of the second toe with the M T P joint. It is marked by a black arrow.

Evaluation Criteria

The following should be clearly seen:

- Evidence of proper collimation and the presence of a side marker placed clear of the anatomy of interest
- Entire toe, without superimposition of adjacent toes; when superimposition cannot be avoided, the proximal phalanx must be shown
- Toe(s) in a true lateral position
    - Toenail in profile, if visualized and normal
    - Concave, plantar surfaces of the phalanges
    - No rotation of the phalanges

- Open interphalangeal joint spaces; the metatarsophalangeal joints are overlapped but may be seen in some patients
- Bony trabecular detail and surrounding soft tissues

FIG. 7.31 Lateral third toe.

FIG. 7.32 Lateral fourth toe.

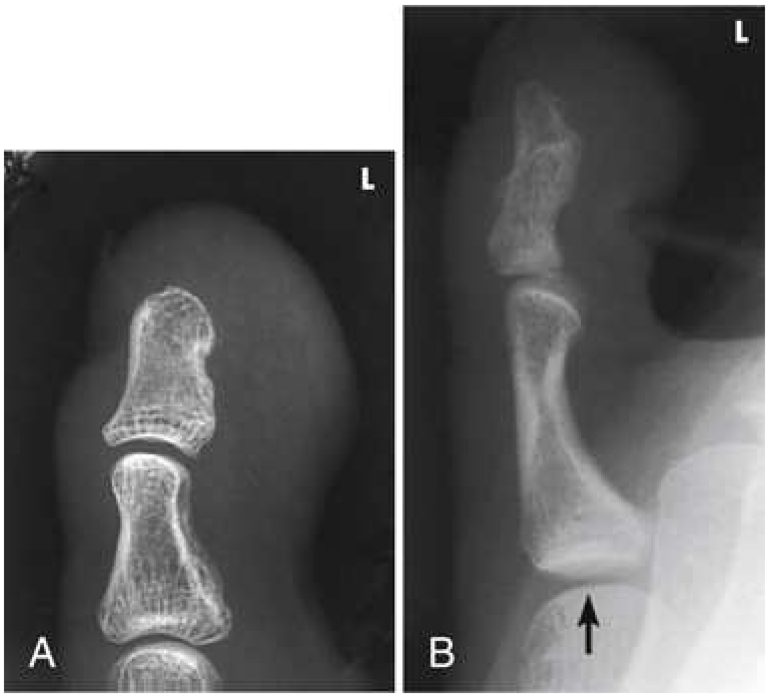

FIG. 7.33 (A) Lateral fifth toe. (B) Lateral fifth toe showing the MTP joint *(arrow)*. Note that the distal IP joint is fused.

Sesamoids

Tangential Projection

Lewis [1] and Holly [2] Methods

Image receptor:
Positioned by manufacturer or department protocol for proper anatomy display orientation; CR plate: 10 × 12 inches (24 × 30 cm) lengthwise.

Position of patient

- Place the patient in the prone position for the Lewis method and in a sitting position for the Holly method.
- Elevate the ankle of the affected side on sandbags for stability, if needed. A folded towel may be placed under the knee for comfort.

Position of part

- Rest the great toe on the table in a position of dorsiflexion and adjust it to place the ball of the foot perpendicular to the horizontal plane.
- Center the IR to the second metatarsal (Fig. 7.34).
- *Shield gonads.*

Central ray

- Perpendicular and tangential to the first MTP joint.

Collimation

- Adjust the radiation field to 3 × 3 inches (7.6 × 7.6 cm). Place side marker in the collimated exposure field.

Structures shown
Tangential projection of the metatarsal head in profile and the sesamoids (Fig. 7.35).

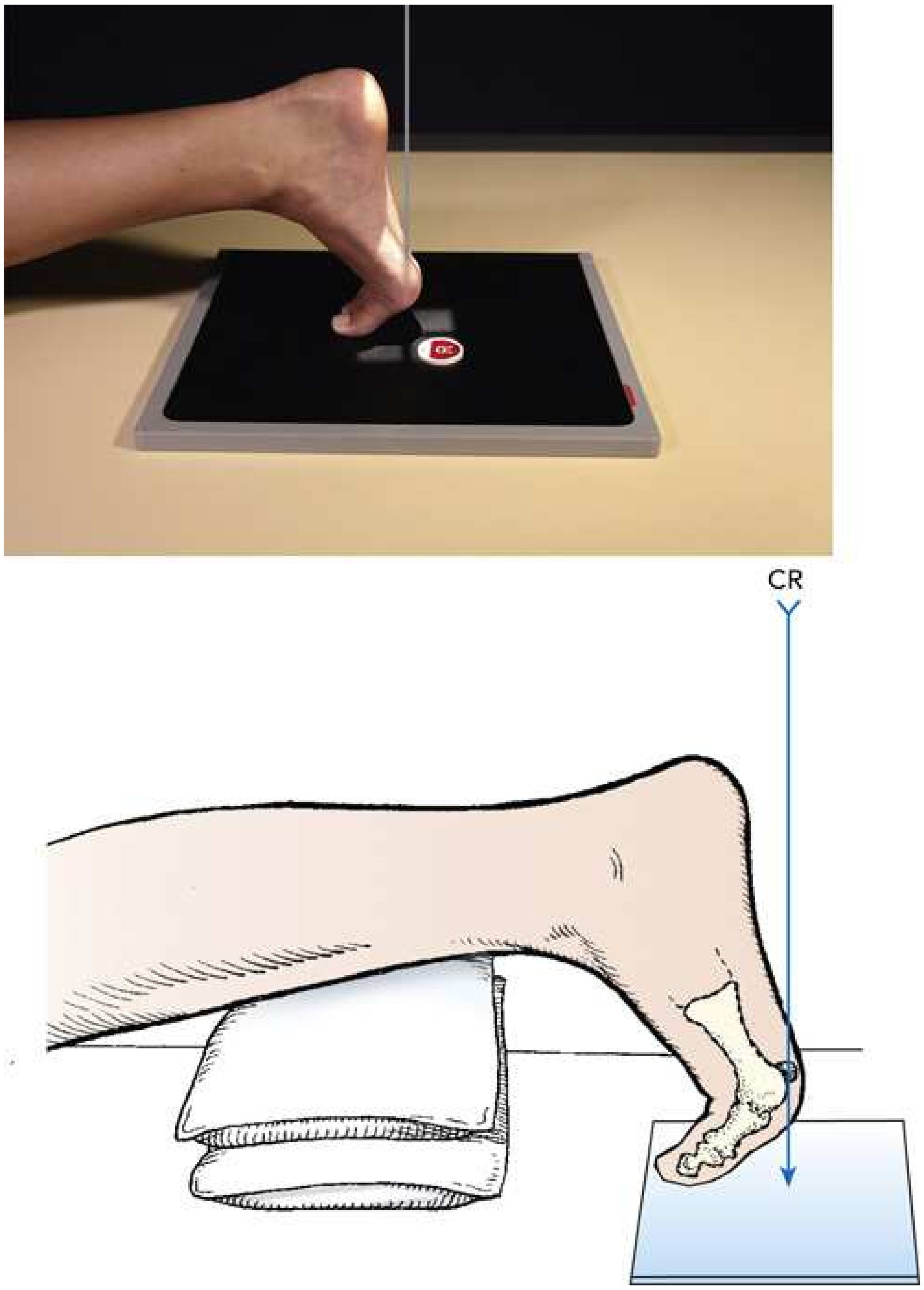

FIG. 7.34 Tangential sesamoids: Lewis method.

The patient's great toe is resting on the image receptor in a position of dorsiflexion. The side marker is in the collimated exposure field. The central ray is perpendicular and tangential to the first M T P joint. Diagram at the bottom shows a patient's great toe is resting on the image receptor in a position of dorsiflexion. A folded towel is placed under the knee. The central ray is perpendicular and tangential to the first M T P joint.

FIG. 7.35 Tangential sesamoids: Lewis method with toes against the IR.

Evaluation Criteria

The following should be clearly seen:

- Evidence of proper collimation and the presence of a side marker placed clear of the anatomy of interest
- Sesamoids free of any portion of the first metatarsal
- Metatarsal heads
- Bony trabecular detail and surrounding soft tissues

NOTE: Holly [2] described a position that he believed was more comfortable for the patient. With the patient seated on the table, the foot is adjusted so that the medial border is vertical, and the plantar surface is at an angle of 75 degrees with the plane of the IR. The patient holds the toes in a flexed position with a strip of gauze bandage. The *central ray* is directed perpendicular to the head of the first metatarsal bone (Figs. 7.36 through 7.38).

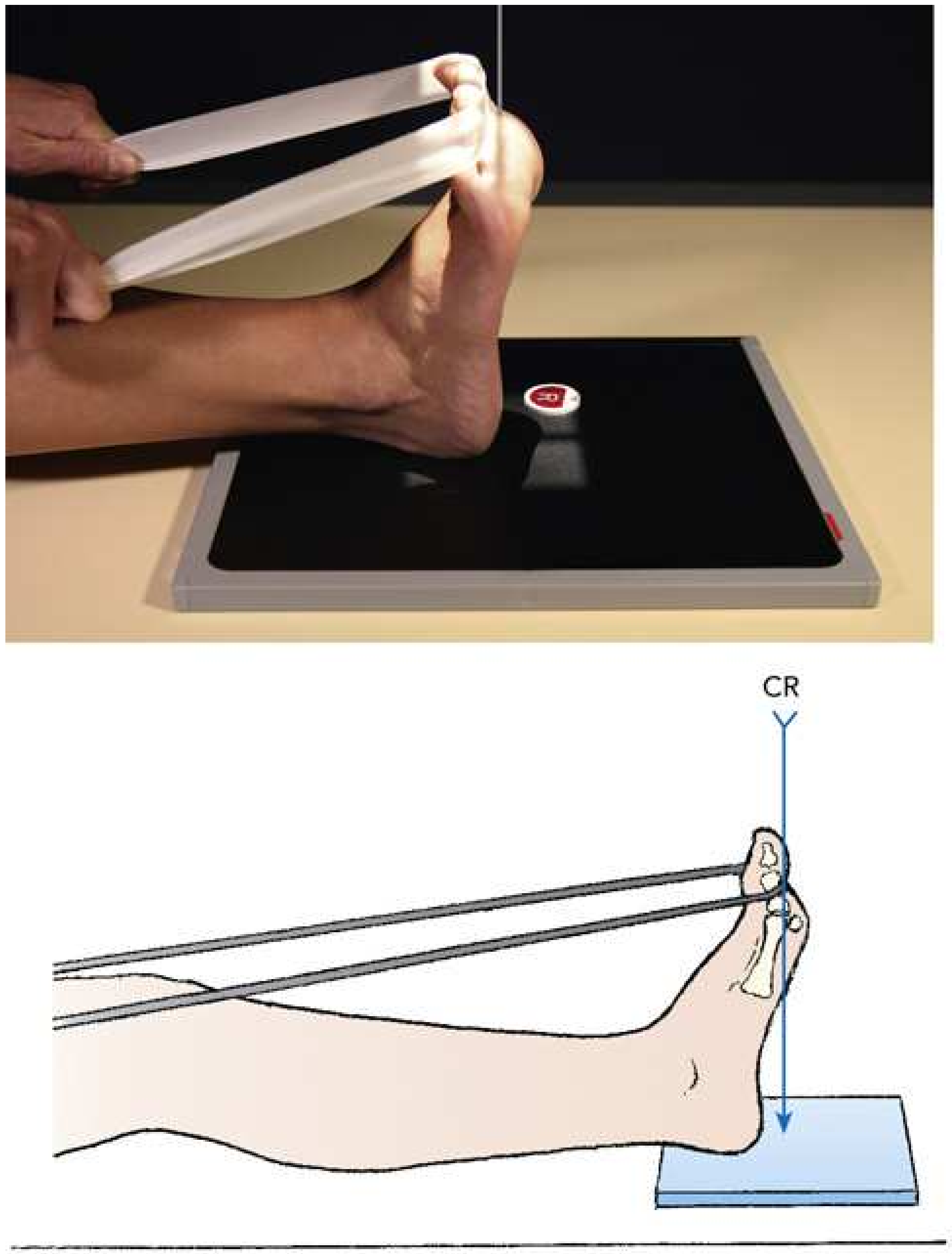

FIG. 7.36 Tangential sesamoids: Holly method.

A patient in a sitting position is holding the toes by flexible strip or gauze. The heel of the foot firmly rests on the image receptor. The side marker is in the collimated exposure field. The central ray is directed perpendicular to the head of the first metatarsal bone. A diagram below shows a patient in a sitting position is holding the toes by flexible strip or gauze. The heel of the foot firmly rests on the image receptor. The central ray is directed perpendicular to the head of the first metatarsal bone which is highlighted.

FIG. 7.37 Tangential sesamoids: Holly method with heel against the IR.

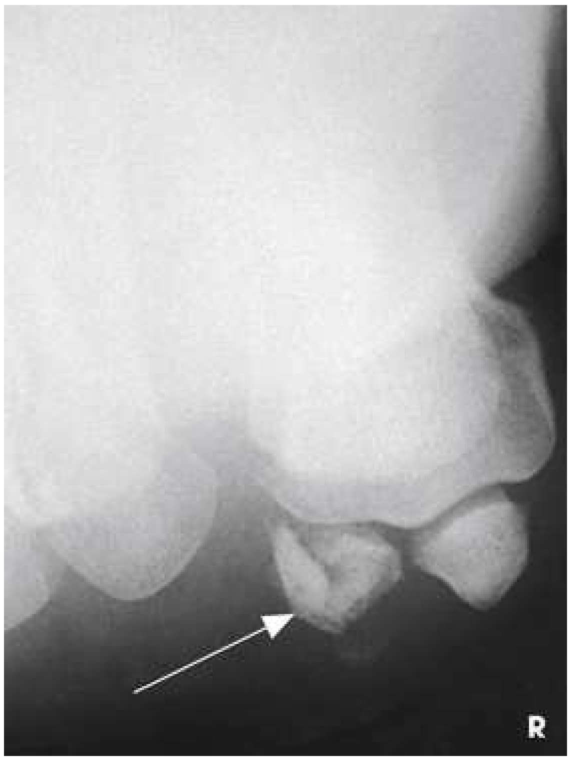

FIG. 7.38 Sesamoid with fracture *(arrow)*.

Foot

AP or AP Axial Projection

Radiographs may be obtained by directing the central ray perpendicular to the plane of the IR or by angling the central ray 10 degrees posteriorly (toward the heel). When a 10-degree posterior angle is used, the central ray is perpendicular to the metatarsals, reducing foreshortening. The TMT joint spaces of the midfoot are also better shown (Figs. 7.39 and 7.40).

Image receptor:

Positioned by manufacturer or department protocol for proper anatomy display orientation; CR plate: 10 × 12 inches (24 × 30 cm) lengthwise.

Position of patient

• Place the patient in the supine or seated position.
• Flex the knee of the affected side enough to rest the sole of the foot firmly on the radiographic table.

FIG. 7.39 AP axial foot with posterior angulation of 10 degrees.

A patient is in a sitting position and is resting the plantar surface of the foot on the image receptor. The side marker is in the collimated exposure field. The central ray is directed 10 degrees toward the heel entering the base of the third metatarsal.

FIG. 7.40 AP axial foot with posterior angulation of 10 degrees.

An x-ray shows the toes to tarsals. There is open joint space between medial and intermediate cuneiforms. The parts labeled are as follows: M T P joint, T M T joint, cuneiforms, navicular, phalanges, metatarsals, cuboid, and tarsals.

Position of part

- Position the IR under the patient's foot, center it to the base of the third metatarsal, and align the IR long axis parallel with the long axis of the foot.
- Hold the leg in the vertical position by having the patient flex the opposite knee and lean it against the knee of the affected side.
- In this foot position, the entire plantar surface rests on the IR; it may be necessary to take precautions against the IR slipping by placing a sandbag on the table against the IR adjacent to the toes.
- Ensure that no rotation of the foot occurs.
- *Shield gonads.*

Central ray

- Directed one of two ways: (1) 10 degrees toward the heel entering the base of the third metatarsal (see Fig. 7.39), or (2) perpendicular to the IR and entering the base of the third metatarsal (Fig. 7.41). Palpating the prominent base of the fifth metatarsal assists in finding the third metatarsal. The third metatarsal base is in the midline, approximately 1 inch anterior (toward the toes) (Fig. 7.42).

Collimation

- Adjust the radiation field to 1 inch (2.5 cm) on the sides and 1 inch (2.5 cm) beyond the calcaneus and distal tip of the toes. Place side marker in the collimated exposure field.

FIG. 7.41 AP foot with perpendicular CR.

A patient is in a sitting position and is resting the plantar surface of the foot on the image receptor. The side marker is in the collimated exposure field. The central ray is perpendicular to the IR and enters the base of the third metatarsal.

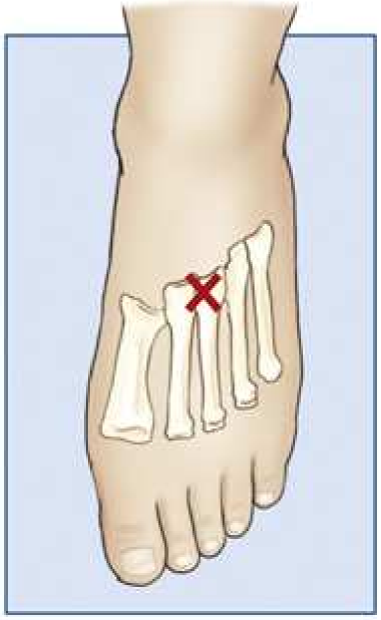

FIG. 7.42 Front view of foot in position showing CR entrance point.

Compensating Filter

This projection can be improved with the use of a wedge-type compensating filter because of the difference in thickness between the toe area and the much thicker tarsal area (see Fig. 7.44).

Structures shown

AP (dorsoplantar) projection of the tarsals anterior to the talus, metatarsals, and phalanges (Figs. 7.43 through 7.45). This projection is used for localizing foreign bodies, determining the locations of fragments in fractures of the metatarsals and anterior tarsals, and performing general surveys of the bones of the foot.

FIG. 7.43 AP foot with perpendicular CR.

FIG. 7.44 AP foot with Ferlic compensating filter. Note how tarsal bones are better visualized.

Evaluation Criteria

The following should be clearly seen:

- Evidence of proper collimation and the presence of a side marker placed clear of the anatomy of interest
- Anatomy from toes to tarsals; may include portions of talus and calcaneus
- No rotation of the foot, as demonstrated by equal amounts of space between the second through fourth metatarsals

- Overlap of the second through fifth metatarsal bases
- Axial projection resulting in improved demonstration of interphalangeal, metatarsophalangeal, and tarsometatarsal joint spaces
- Open joint space between medial and intermediate cuneiforms
- Bony trabecular detail and surrounding soft tissues

FIG. 7.45 (A) AP foot of a 6-year-old patient. Note epiphyseal lines *(arrows)*. (B) AP foot showing well-penetrated tarsal bones.

(A) An x-ray shows the tarsals anterior to the talus, metatarsals, and phalanges. The epiphyseal lines above and below the metatarsals are marked by a white arrow. (b) An x-ray shows the tarsals anterior to the talus, metatarsals, and phalanges. The tarsal bones are evident.

A que Projection

Medial rotation

Image receptor:

Positioned by manufacturer or department protocol for proper anatomy display orientation; CR plate: 10 × 12 inches (24 × 30 cm) lengthwise.

NOTE: The medial oblique is preferred over the lateral oblique because the plane through the metatarsals is more parallel to the IR, and it opens better the lateral side joints of the midfoot and hindfoot.

Position of patient

- Place the patient in the supine or seated position.
- Flex the knee of the affected side enough to firmly rest the plantar surface of the foot on the radiographic table.

Position of part

- Place the IR under the patient's foot, parallel with its long axis, and center it to the midline of the foot at the level of the base of the third metatarsal.
- Rotate the patient's leg medially until the plantar surface of the foot forms an angle of 30 degrees to the plane of the IR (Fig. 7.46). If the angle of the foot is increased by more than 30 degrees, the lateral cuneiform tends to be thrown over the other cuneiforms. [3]
- *Shield gonads.*

Central ray

- Perpendicular to the base of the third metatarsal.

Collimation

- Adjust the radiation field to 1 inch (2.5 cm) on all sides and 1 inch (2.5 cm) beyond the calcaneus and distal tip of the toes. Place side marker in the collimated exposure field.

Compensating Filter

This projection can be improved with the use of a wedge-type compensating filter because of the difference in thickness between the toe area and the much thicker tarsal area.

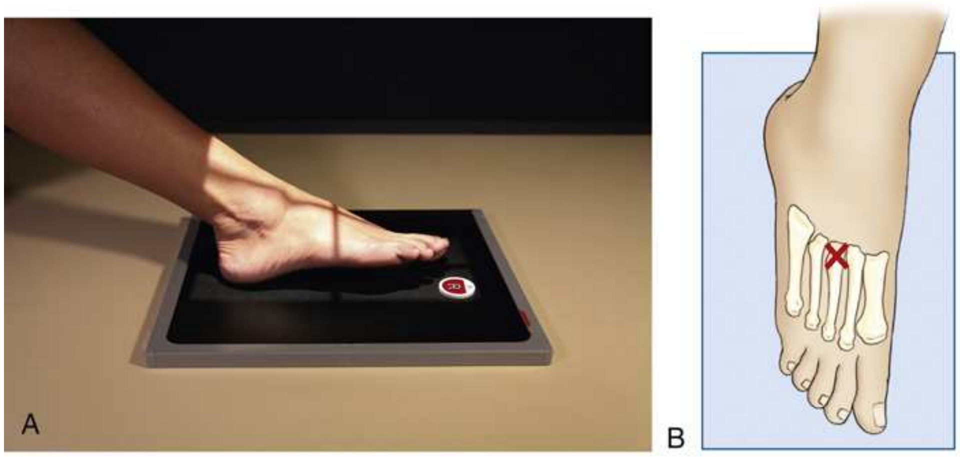

FIG. 7.46 (A) AP oblique foot, medial rotation. (B) Front view of oblique foot in position showing CR entrance point.

A patient is in a sitting position and is resting the plantar surface of the foot on the image receptor. The side marker is in the collimated exposure field. The central ray is perpendicular to the base of the third metatarsal. (B) shows the front view of the foot marked as x on the base of the third metatarsal.

Structures shown

The joint spaces between the following: the cuboid and the calcaneus; the cuboid and the fourth and fifth metatarsals; the cuboid and the lateral cuneiform; and the talus and the navicular bone. The cuboid is shown in profile. The sinus tarsi is also well shown (Fig. 7.47A).

Evaluation Criteria

The following should be clearly seen:

- Evidence of proper collimation and the presence of a side marker placed clear of the anatomy of interest
- Entire foot, from toes to heel
- Proper rotation of foot
  - Third through fifth metatarsals free of superimposition
  - Bases of the first and second metatarsals superimposed on medial and intermediate cuneiforms
  - Navicular, lateral cuneiform, and cuboid with less superimposition than in the AP projection
- Tuberosity of the fifth metatarsal
- Lateral tarsometatarsal and intertarsal joints
- Sinus tarsi
- Bony trabecular detail and surrounding soft tissues

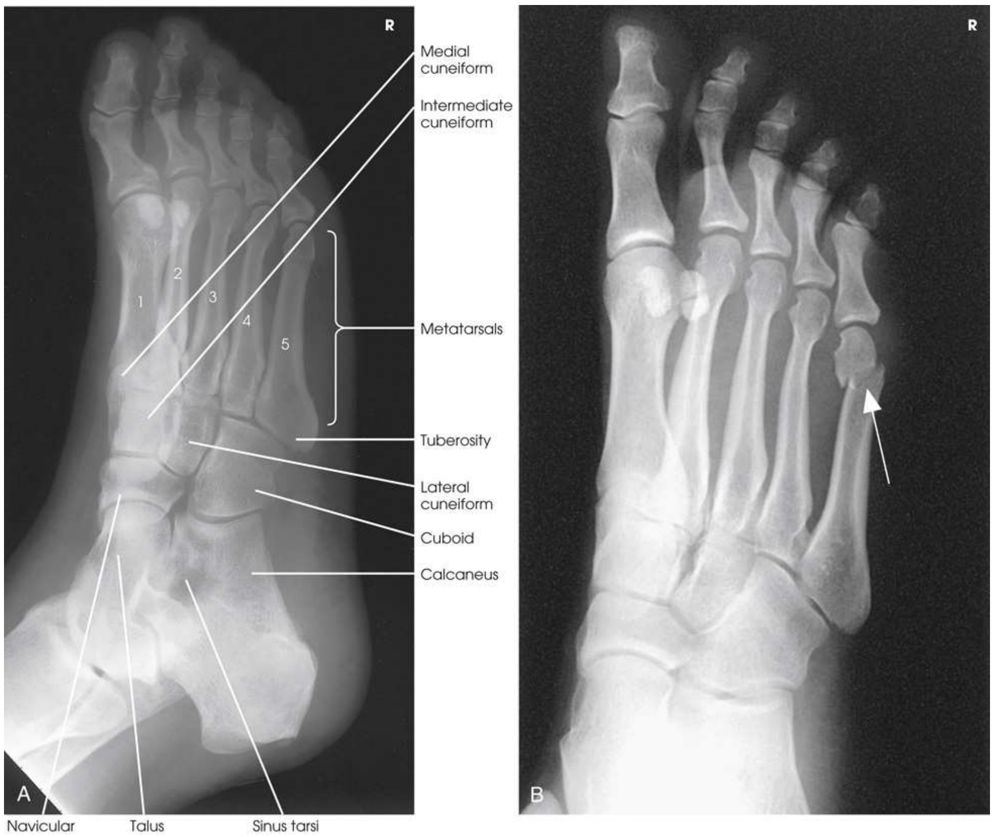

FIG. 7.47 (A) AP oblique projection foot, medial rotation. (B) Fracture of distal aspect of fifth metatarsal *(arrow)*. Calcaneus was not included, and technique was adjusted to visualize distal foot better.

(B) An x-ray shows the entire foot from toes to heel and the joint spaces. The parts labeled are as follows: navicular, talus, sinus tarsi, medial cuneiform, intermediate cuneiform, metatarsals, tuberosity, lateral cuneiform, cuboid, and calcaneus. (B) An x-ray shows the fracture of the distal aspect of the fifth metatarsal. It is marked with an arrow.

AP Oblique Projection

Lateral rotation

Image receptor:

Positioned by manufacturer or department protocol for proper anatomy display orientation; CR plate: 10 × 12 inch (24 × 30 cm) lengthwise.

Position of patient

- Place the patient in the supine position.
- Flex the knee of the affected side enough for the plantar surface of the foot to rest firmly on the radiographic table.

Position of part

- Place the IR under the patient's foot, parallel with its long axis, and center it to the midline of the foot at the level of the base of the third metatarsal.
- Rotate the leg laterally until the plantar surface of the foot forms an angle of 30 degrees to the IR.
- Support the elevated side of the foot on a 30-degree foam wedge to ensure consistent results (Fig. 7.48).
- *Shield gonads.*

Central ray

- Perpendicular to the base of the third metatarsal.

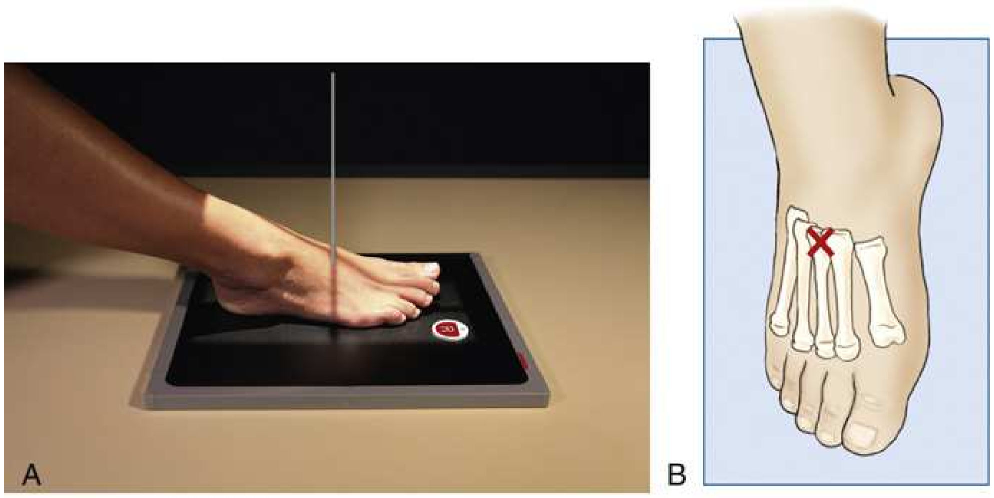

FIG. 7.48 (A) AP oblique foot, lateral rotation. (B) Front view of oblique foot in position showing CR entrance point.

A patient is in a sitting position and is resting the plantar surface of the foot on the image receptor. The side marker is in the collimated exposure field. The central ray is perpendicular to the base of the third metatarsal. (B) shows the front view of the foot marked as x on the base of the third metatarsal.

Collimation

- Adjust the radiation field to 1 inch (2.5 cm) on all sides and 1 inch (2.5 cm) beyond the calcaneus and distal tip of the toes. Place a side marker in the collimated exposure field.

Structures shown

The joint spaces between the first and second metatarsals and between the medial and intermediate cuneiforms (Fig. 7.49).

Evaluation Criteria

The following should be clearly seen:

- Evidence of proper collimation and the presence of a side marker placed clear of the anatomy of interest
- Anatomy from toes to tarsals; may include portions of talus and calcaneus
- Proper rotation of foot
  - First and second metatarsal bases free of superimposition
  - Minimal superimposition between medial and intermediate cuneiforms
  - Navicular seen with less foreshortening than in the medial rotation AP oblique projection
- Bony trabecular detail and surrounding soft tissues

FIG. 7.49 AP oblique foot.

(A) An x-ray shows the joint spaces between the first and second metatarsals and between the medial and intermediate cuneiforms. The parts labeled are as follows: talus, calcaneus, medial cuneiform, intermediate cuneiform, navicular, cuboid. The phalanges appear darker than the metatarsals and the tarsals. (B) An x-ray shows the joint spaces between the first and second metatarsals and between the medial and intermediate cuneiforms. Two sesamoid circles are below the metatarsal head.

Lateral Projection

Mediolateral

The lateral (mediolateral) projection is routinely used in most radiology departments because it is the most comfortable position for the patient to assume.

Image receptor:

Positioned by manufacturer or department protocol for proper anatomy display orientation; CR plate: 10 × 12 inches (24 × 30 cm) lengthwise.

Position of patient

- Have the patient lie on the radiographic table and turn toward the affected side until the leg and the foot are lateral.
- Place the opposite leg behind the affected leg.

Position of part

- Elevate the patient's knee enough to place the patella perpendicular to the horizontal plane and adjust a sandbag support under the knee. The heel should not touch the IR, and the medial surface of the foot should be parallel with the plane of the IR.
- Adjust the foot to place the plantar surface of the forefoot perpendicular to the IR (Fig. 7.50).
- Center the IR to the midfoot and align the IR long axis parallel with the long axis of the foot.
- Dorsiflex the foot to form a 90-degree angle with the lower leg.
- *Shield gonads.*

Central ray

- Perpendicular to the base of the third metatarsal.

Collimation

- Adjust the radiation field to 1 inch (2.5 cm) on all sides of the shadow of the foot and including the medial malleolus. Place a side marker in the collimated exposure field.

Structures shown

The entire foot in profile, the ankle joint, and the distal ends of the tibia and fibula (Figs. 7.51 and 7.52).

Evaluation Criteria

The following should be clearly seen:

- Evidence of proper collimation and the presence of a side marker placed clear of the anatomy of interest
- Entire foot and distal leg
- Superimposed plantar surfaces of the metatarsal heads
- Fibula overlapping the posterior portion of the tibia
- Tibiotalar joint
- Bony trabecular detail and surrounding soft tissues

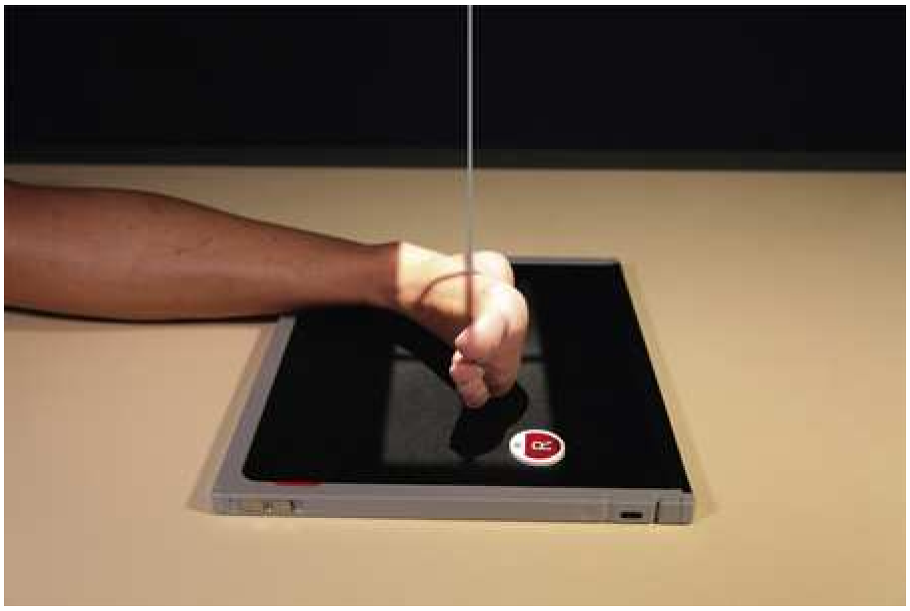

FIG. 7.50 Lateral foot.

A patient's lateral foot is placed on the image receptor. The plantar surface of the forefoot is perpendicular to the I R. The side marker is in the collimated exposure field. The central ray is perpendicular to the base of the third metatarsal.

FIG. 7.51 Lateral (mediolateral) foot with anatomy identified.

An x-ray shows the ankle joint, and the distal ends of the tibia and fibula. The parts labeled are as follows: tarsals, metatarsals, phalanges, fibula, tibia, tibiotalar joint, navicular, sinus tarsi, talus, and calcaneus. The fibula and the calcaneus appear grainy.

FIG. 7.52 Lateral (mediolateral foot) with foot not dorsiflexed completely.

Longitudinal Arch

Lateral Projection

Lateromedial

Weight-Bearing Method

Standing

Image receptor:

Positioned by manufacturer or department protocol for proper anatomy display orientation; CR plate: 10 × 12 inches (24 × 30 cm) lengthwise.

Position of patient

- Place the patient in the upright position, preferably on a low riser that has an IR groove. If such a riser is unavailable, use blocks to elevate the feet to the level of the x-ray tube (Figs. 7.53 and 7.54).
- If needed, use a mobile unit to allow the x-ray tube to reach the floor level.

Position of part

- Place the IR in the IR groove of the stool or between blocks.
- Have the patient stand in a natural position, one foot on each side IR, with the weight of the body equally distributed on the feet.
- Adjust the IR so that it is centered to the base of the third metatarsal, and place the medial surface of the foot against the IR.
- After the exposure, repeat the above steps to image the opposite foot.
- *Shield gonads.*

Central ray

- Perpendicular to a point just above the base of the third metatarsal.

Collimation

- Adjust the radiation field to 1 inch (2.5 cm) on all sides of the shadow of the foot including 1 inch (2.5 cm) above the medial malleolus. Place a side marker in the collimated exposure field.

Structures shown

A lateromedial projection of the bones of the foot with weight bearing. The projection is used to show the structural status of the longitudinal arch. The right and left sides are examined for comparison (Figs. 7.55 and 7.56).

Evaluation Criteria

The following should be clearly seen:

- Evidence of proper collimation and the presence of a side marker placed clear of the anatomy of interest
- Entire foot and distal leg
- Superimposed plantar surfaces of the metatarsal heads

- Fibula overlapping the posterior portion of the tibia
- Tibiotalar joint
- Bony trabecular detail and surrounding soft tissues

FIG. 7.53 Weight-bearing lateral foot.

A patient is standing straight on a block with one foot on each side of the I R that is placed in the groove of the block. The side marker is in the collimated exposure field. The central ray is perpendicular to a point just above the base of the third metatarsal.

FIG. 7.54 Weight-bearing lateral foot.

A patient is standing turned to the right on a block with one foot on each side of the I R that is placed in the groove of the block. The side marker is in the collimated exposure field. The central ray is perpendicular to a point just above the base of the third metatarsal.

FIG. 7.55 Weight-bearing lateral foot showing centimeter measuring scale built into standing platform.

FIG. 7.56 Weight-bearing lateral foot.

Feet

AP Axial Projection

Weight-Bearing Method

Standing

Image receptor:

Positioned by manufacturer or department protocol for proper anatomy display orientation; CR plate: 10 ×12 inches (24 × 30 cm) crosswise.

SID:

48 inches (122 cm). This SID is used to reduce magnification and improve spatial resolution in the image.

Position of patient

- Place the patient in the standing-upright position.

Position of part

- Place the IR on the floor and have the patient stand on the IR with the feet centered on each side.
- Pull the patient's pant legs up to the knee level, if necessary.
- Ensure that right and left markers and an upright marker are placed on the IR.

• Ensure that the patient's weight is distributed equally on each foot (Fig. 7.57).
• The patient may hold the x-ray tube crane for stability.
• *Shield gonads.*

Central ray

• Angled 10 degrees toward the heel is optimal. A minimum of 15 degrees is usually necessary to have enough room to position the tube and allow the patient to stand. The central ray is positioned between the feet and at the level of the base of the third metatarsal.

Collimation

• Adjust the radiation field to 1 inch (2.5 cm) on all sides and 1 inch (2.5 cm) beyond the calcaneus and distal tip of the toes. Place a side marker in the collimated exposure field.

Structures shown

A weight-bearing AP axial projection of both feet, permitting accurate evaluation and comparison of the tarsals and metatarsals (Fig. 7.58).

Evaluation Criteria

The following should be clearly seen:

- Evidence of proper collimation and the presence of a side marker placed clear of the anatomy of interest
- Both feet centered on one image
- Anatomy from toes to tarsals; may include portions of talus and calcaneus
- Correct right and left marker placement and a weight-bearing marker
- Bony trabecular detail and surrounding soft tissues

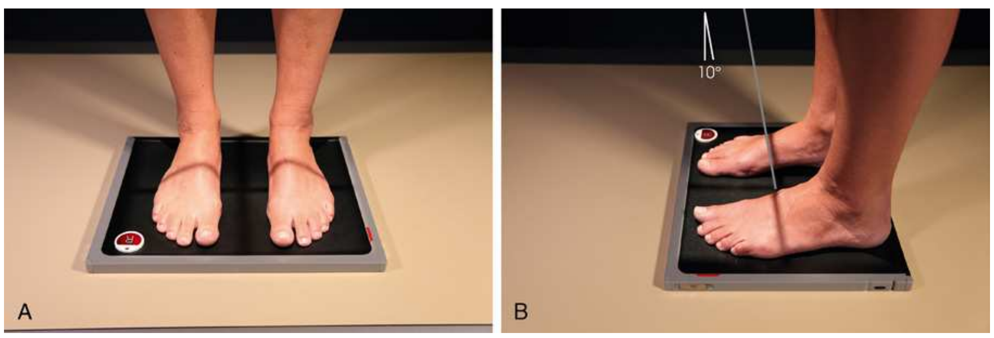

FIG. 7.57 Weight-bearing AP both feet, standing. (A) Correct position of both feet on the IR. (B) Lateral perspective of same projection shows position of feet on the IR and CR.

(A) A patient is standing straight on the image receptor with feet centered on each side. The side marker is in the collimated exposure field. (B) A patient is standing turned to the right on the image receptor with feet centered on each side. The side marker is in the collimated exposure field. The central ray is angled 10 degrees toward the heel is optimal.

FIG. 7.58 Weight-bearing AP both feet, standing.

Foot

AP Axial Projection

Weight-Bearing Composite Method

Standing

Image receptor:

Positioned by manufacturer or department protocol for proper anatomy display orientation; CR plate: 10 × 12 inches (24 × 30 cm) lengthwise.

Position of patient

- Place the patient in the standing-upright position. The patient should stand at a comfortable height on a low stool or on the floor.

Position of part

- With the patient standing upright, adjust the IR under the foot and center its midline to the long axis of the foot.
- To prevent superimposition of the leg shadow on that of the ankle joint, have the patient place the opposite foot one step backward for the exposure of the forefoot and one step forward for the exposure of the hindfoot or calcaneus.
- *Shield gonads.*

Central ray

- To use the masking effect of the leg, direct the central ray along the plane of alignment of the foot in both exposures.
- With the tube in front of the patient and adjusted for a posterior angulation of 15 degrees, center the central ray to the base of the third metatarsal for the first exposure (Figs. 7.59 and 7.60).
- Caution the patient to carefully maintain the position of the affected foot and to place the opposite foot one step forward in preparation for the second exposure.
- Move the tube behind the patient, adjust it for an anterior angulation of 25 degrees, and direct the central ray to the posterior surface of the ankle. The central ray emerges on the plantar surface at the level of the lateral malleolus (Figs. 7.61 and 7.62). An increase in technical factors is recommended for this exposure.

FIG. 7.59 Composite AP axial foot, posterior angulation of 15 degrees.

A patient is in a standing position and the foot is placed on the image receptor. The other foot is placed one step backward. The midline of the I R is centered to the long axis of the foot. The side marker is in the collimated exposure field. The central ray is angled 15 degrees to the base of the third metatarsal.

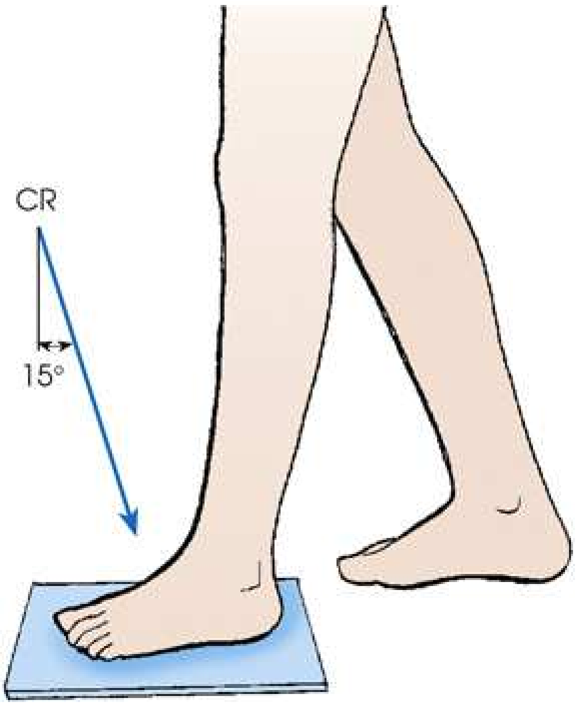

FIG. 7.60 Composite AP axial foot, posterior angulation of 15 degrees.

A patient is in a standing position and the foot is placed on the image receptor. The other foot is placed one step backward. The midline of the I R is centered to the long axis of the foot. The side marker is in the collimated exposure field. The central ray is angled 15 degrees to the base of the third metatarsal.

FIG. 7.61 Composite AP axial foot, anterior angulation of 25 degrees.

A patient is in a standing position and the foot is placed on the image receptor. The other foot is placed one step forward. The midline of the I R is centered to the long axis of the foot. The side marker is in the collimated exposure field. The central ray is angled 25 degrees to the posterior surface of the ankle.

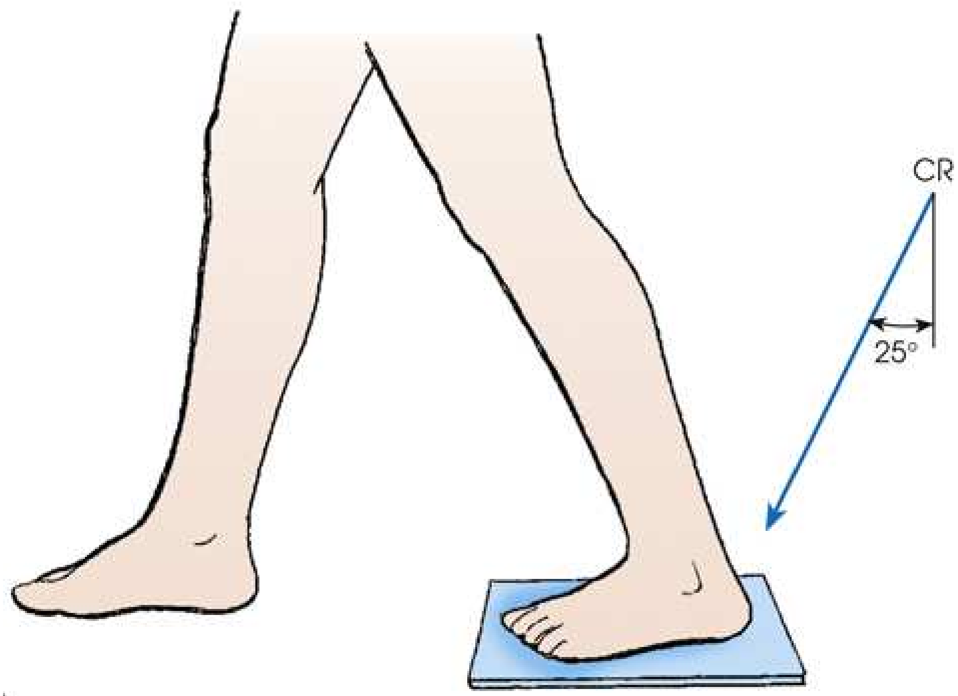

FIG. 7.62 Composite AP axial foot, anterior angulation of 25 degrees.

A patient is in a standing position and the foot is placed on the image receptor. The other foot is placed one step forward. The midline of the I R is centered to the long axis of the foot. The side marker is in the collimated exposure field. The central ray is angled 25 degrees to the posterior surface of the ankle.

Collimation

- Adjust the radiation field to 1 inch (2.5 cm) on all sides and 1 inch (2.5 cm) beyond the calcaneus and distal tip of the toes. Place a side marker in the collimated exposure field.

Structures shown

A weight-bearing AP axial projection of all bones of the foot. The full outline of the foot is projected free of the leg (Fig. 7.63).

Evaluation Criteria

The following should be clearly seen:

- Evidence of proper collimation and the presence of a side marker placed clear of the anatomy of interest
- Entire foot, from toes to heel
- Shadow of leg not overlapping the tarsals
- Foot not rotated
- Bony trabecular detail and surrounding soft tissues

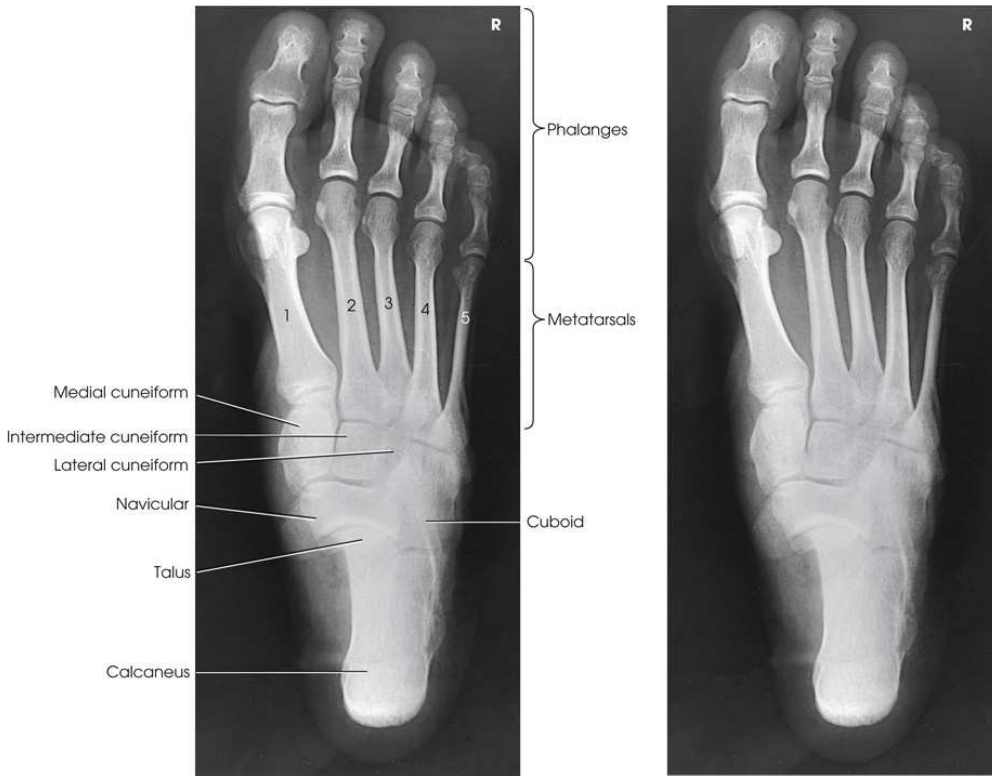

FIG. 7.63 Composite AP axial foot.

Two x-ray views show the full outline with all bones of the foot. The parts labeled on the x-ray in the left are as follows: medial cuneiform, intermediate cuneiform, lateral cuneiform, navicular, talus, calcaneus, phalanges, metatarsals, and cuboid.

Congenital Clubfoot

AP Projection

Kite Method

The typical clubfoot, or *talipes equinovarus,* shows three deviations from the normal alignment of the foot in relation to the weight-bearing axis of the leg. These deviations are plantar flexion and inversion of the calcaneus (equinus), medial displacement of the forefoot (adduction), and elevation of the medial border of the foot (supination). The typical clubfoot has numerous variations. Each of the typical abnormalities just described has varying degrees of deformity.

The classic Kite method [4, 5]—exactly placed AP and lateral projections—for radiography of the clubfoot is used to show the anatomy of the foot and the bones or ossification centers of the tarsals and their relation to one another. *A primary objective makes it essential that no attempt be made to change the abnormal alignment of the foot when placing it on the IR*. Davis and Hatt [6] stated that even slight rotation of the foot can result in marked alteration in the radiographically projected relation of the ossification centers.

The AP projection shows the degree of adduction of the forefoot and the degree of inversion of the calcaneus.

Image receptor:

Positioned by manufacturer or department protocol for proper anatomy display orientation; CR plate: 10 × 12 inches (24 × 30 cm) lengthwise.

Position of patient

- Place the infant in the supine position, with the hips and knees flexed to permit the foot to rest flat on the IR. Elevate the body on firm pillows to knee height to simplify gonad shielding and leg adjustment.

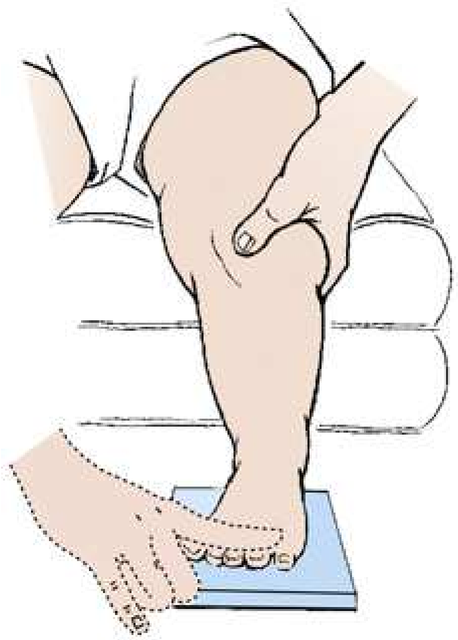

FIG. 7.64 AP foot to show clubfoot deformity.

Position of part

- Rest the feet flat on the IR with the ankles extended slightly to prevent superimposition of the leg shadow.
- Hold the infant's knees together or in such a way that the legs are exactly vertical (i.e., so that they do not lean medially or laterally).
- Using a lead glove, hold the infant's toes. When the adduction deformity is too great to permit correct placement of the legs and feet for bilateral images without overlap of the feet, each foot must be examined separately (Figs. 7.64 and 7.65).
- *Shield gonads.*

Central ray

- Perpendicular to the tarsals, midway between the tarsal areas for a bilateral projection.
- An approximately 15-degree posterior angle is generally required for the central ray to be perpendicular to the tarsals.
- Kite[4,5] stressed the importance of directing the central ray vertically for the purpose of projecting the true relationship of the bones and ossification centers.

FIG. 7.65 AP projection showing nearly 90-degree adduction of forefoot.

Congenital Clubfoot

Lateral Projection

Mediolateral

Kite Method

The Kite method lateral radiograph shows the anterior talar subluxation and the degree of plantar flexion (equinus).

Position of patient

- Place the infant on his or her side in as near the lateral position as possible.
- Flex the uppermost extremity, draw it forward, and hold it in place.

Position of part

- After adjusting the IR under the foot, place a support that has the same thickness as the IR under the infant's knee to prevent angulation of the foot and to ensure a lateral foot position.
- Hold the infant's toes in position with tape or a protected hand (Figs. 7.66 through 7.70).
- *Shield gonads.*

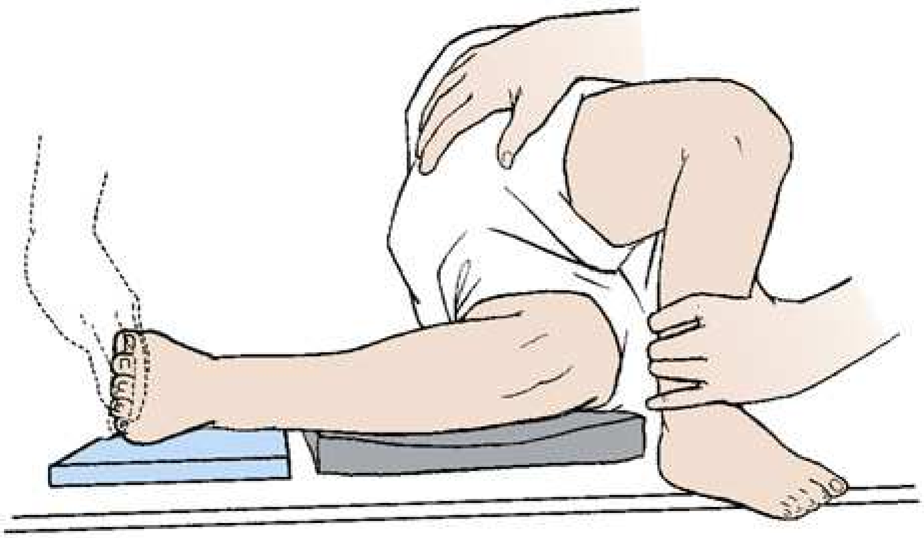

FIG. 7.66 Lateral foot.

A hand is placing the infant in a lateral position by flexing the uppermost extremity and holding it in place. The I R is placed under the infant's foot, and a hand wearing lead gloves is holding the toes of the infant. A support is placed under the infant's knee.

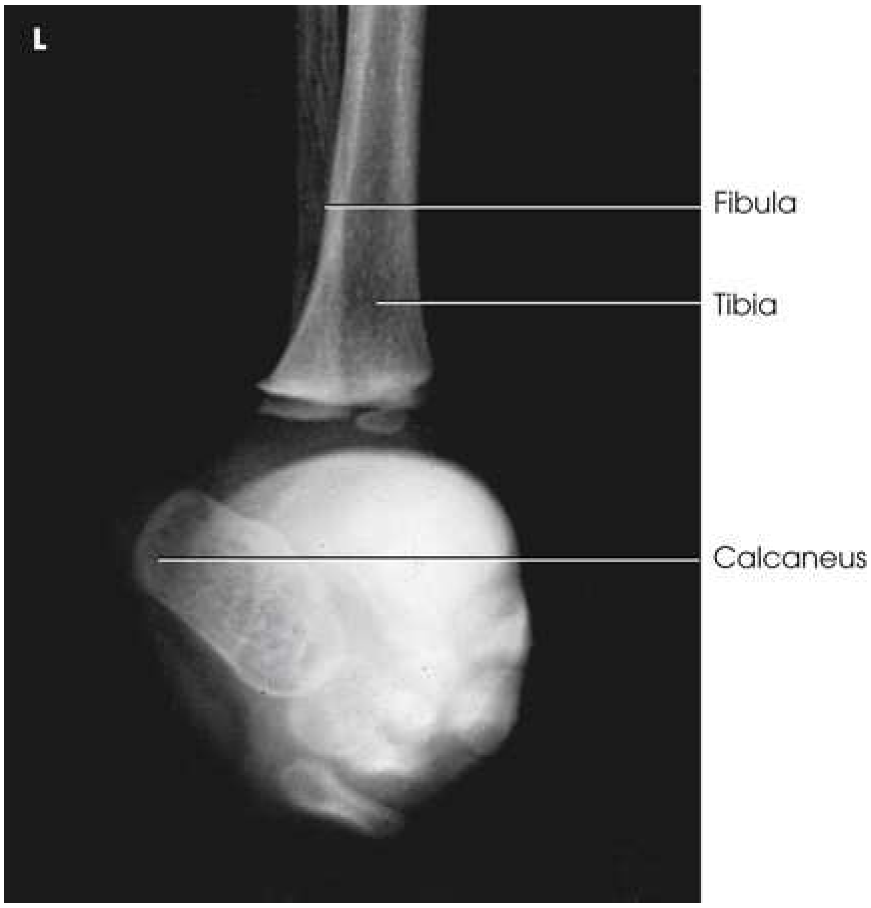

FIG. 7.67 Lateral foot projection showing pitch of calcaneus. Other tarsals are obscured by adducted forefoot.

An x-ray shows the pitch of the calcaneus. The fibula in lateral projection overlapping the posterior half of the tibia. The parts labeled on the diagram are as follows: fibula, tibia, and calcaneus. Calcaneus is shaped like a rectangle.

FIG. 7.68 Nonroutine 45-degree medial rotation showing extent of talipes equinovarus.

Central ray

- Perpendicular to the midtarsal area.

Evaluation Criteria

The following should be clearly seen:

- Evidence of proper collimation and the presence of a side marker placed clear of the anatomy of interest
- No medial or lateral angulation of the leg
- Fibula in lateral projection overlapping the posterior half of the tibia
- The need for a repeat examination if slight variations in rotation are seen in either image compared with previous radiographs
- Talus, calcaneus, and metatarsals to allow assessment of alignment variations
- Bony trabecular detail and surrounding soft tissues

NOTE: Freiberger et al. [7] recommended that dorsiflexion of an infant's foot could be obtained by pressing a small plywood board against the sole of the foot. An older child or adult is placed in the upright position for a horizontal projection. With the upright position, the patient leans the leg forward to dorsiflex the foot.

NOTE: Conway and Cowell [8] recommended tomography to show coalition at the middle facet and particularly the hidden coalition involving the anterior facet.

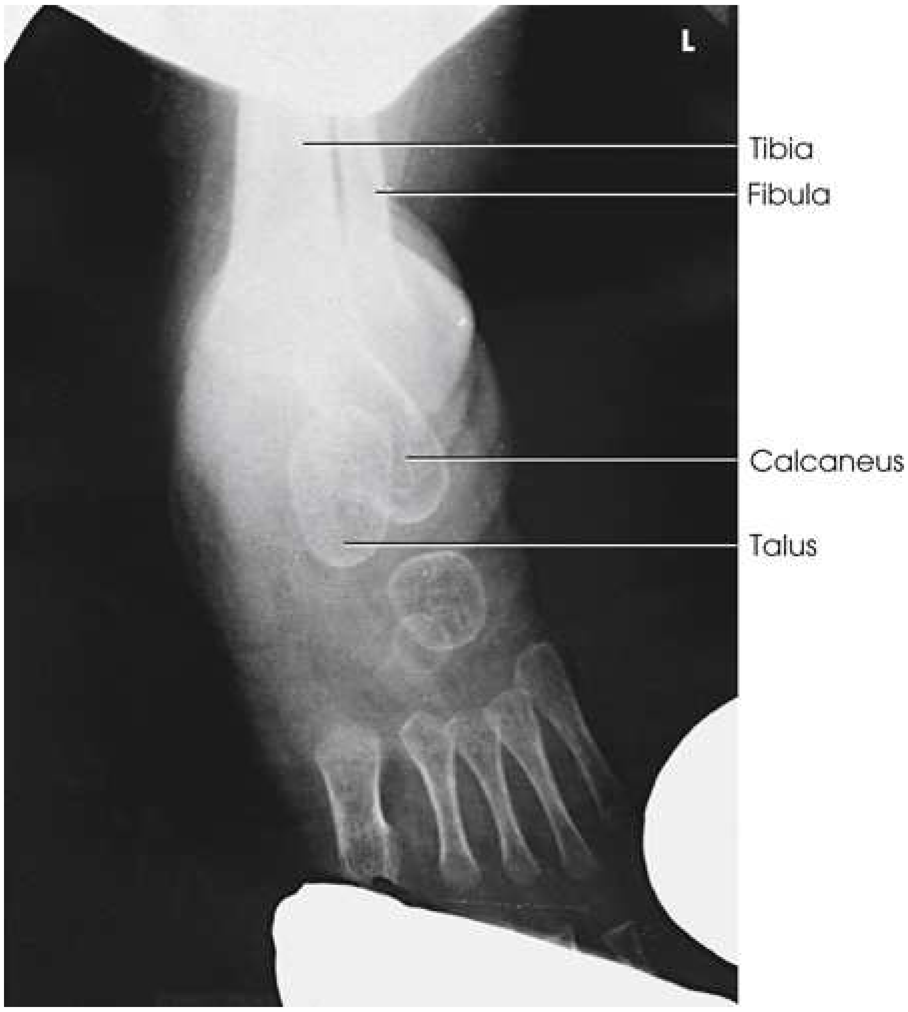

FIG. 7.69 AP projection after treatment (same patient as in Fig. 7.68).

An x-ray shows the infant's entire left foot. The calcaneus and the talus overlap each other. The tibia and the fibula appear radiopaque. The parts labeled are as follows: tibia, fibula, calcaneus, and talus.

FIG. 7.70 Lateral projection after treatment (same patient as in Fig. 7.67).

Congenital Clubfoot

Axial Projection

Dorsoplantar

Kandel Method

Kandel [9] recommended the inclusion of a dorsoplantar axial projection in the examination of the patient with a clubfoot (Fig. 7.71).

For this method, the infant is held in a vertical or a bending-forward position. The plantar surface of the foot should rest on the IR, although a moderate elevation of the heel is acceptable when the equinus deformity is well marked. The central ray is directed 40 degrees anteriorly through the lower leg, as for the usual dorsoplantar projection of the calcaneus (Fig. 7.72).

Freiberger et al. [7] stated that sustentaculum talar joint fusion cannot be assumed on one projection because the central ray may not have been parallel with the articular surfaces. They recommended that three radiographs be obtained with varying central ray angulations (35, 45, and 55 degrees).

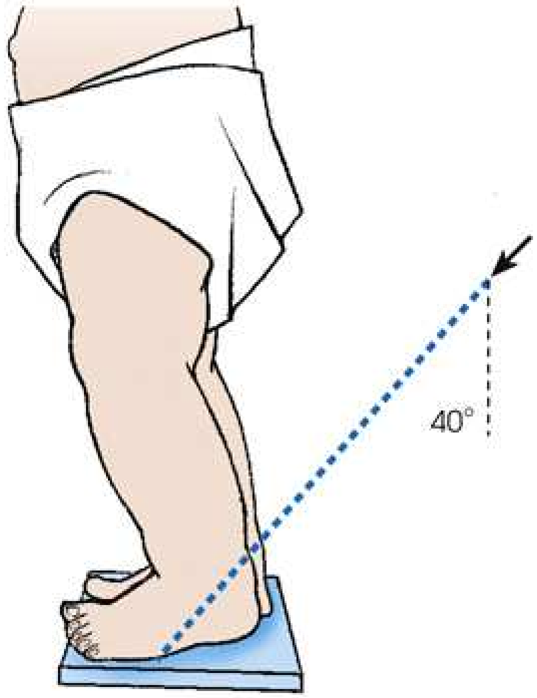

FIG. 7.71 Axial foot (dorsoplantar): Kandel method.

FIG. 7.72 Axial foot (dorsoplantar): Kandel method.

Calcaneus

Axial Projection

Plantodorsal

Image receptor:

Positioned by manufacturer or department protocol for proper anatomy display orientation; CR plate: 10 × 12 inches (24 × 30 cm) lengthwise.

Position of patient

- Place the patient in the supine or seated position with the legs fully extended.

Position of part

- Place the IR under the patient's ankle, centered to the midline of the ankle (Figs. 7.73 and 7.74).
- Place a long strip of gauze around the ball of the foot. Have the patient grasp the gauze to hold the ankle in right-angle dorsiflexion.
- If the patient's ankles cannot be flexed enough to place the plantar surface of the foot perpendicular to the IR, elevate the leg on sandbags to obtain the correct position.
- *Shield gonads.*

Central ray

- Directed to the midpoint of the IR at a cephalic angle (entering the plantar surface and toward the heel) of 40 degrees to the long axis of the foot. The central ray enters near the base of the third metatarsal.

Collimation

- Adjust the radiation field to 1 inch (2.5 cm) on three sides of the shadow of the calcaneus and to include the fifth metatarsal base. Place side marker in the collimated exposure field.

Compensating Filter

This projection can be improved significantly with the use of a compensating filter because of the increased thickness of the midportion of the foot.

Structures shown

An axial projection of the calcaneus, talocalcaneal joint, and the sustentaculum tali in profile. (Fig. 7.75).

Evaluation Criteria

The following should be clearly seen:

- Evidence of proper collimation and the presence of a side marker placed clear of the anatomy of interest
- Calcaneus and talocalcaneal joint
- No rotation of the calcaneus
  - Sustentaculum tali in profile on the medial side
  - The first or fifth metatarsals not visible on either side
- Bony trabecular detail and surrounding soft tissues

FIG. 7.73 Axial (plantodorsal) calcaneus.

A patient is in a sitting position and is holding the toes by flexible strip or gauze. The heel of the foot firmly rests on the image receptor. The side marker is in the collimated exposure field. The central ray is directed to the midpoint of the IR at a cephalic angle of 40 degrees to the long axis of the foot.

FIG. 7.74 Axial (plantodorsal) calcaneus. Note that anterior calcaneus is not penetrated.

FIG. 7.75 Axial (plantodorsal) calcaneus. Image made using Ferlic swimmer's filter. Note penetration of anterior calcaneus and metatarsal joint spaces.

Axial Projection

Dorsoplantar

Image receptor:

Positioned by manufacturer or department protocol for proper anatomy display orientation; CR plate: 10 × 12 inches (24 × 30 cm) lengthwise.

Position of patient

- Place the patient in the prone position.

Position of part

- Elevate the patient's ankle on sandbags.
- Adjust the height and position of the sandbags under the ankle in such a way that the patient can dorsiflex the ankle enough to place the long axis of the foot perpendicular to the tabletop.
- Place the IR against the plantar surface of the foot and support it in position with sandbags or a portable IR holder (Figs. 7.76 and 7.77).
- *Shield gonads.*

Central ray

- Directed to the midpoint of the IR at a caudal angle (enters posterior surface and toward the heel) of 40 degrees to the long axis of the foot. The central ray enters the dorsal surface of the ankle joint.

Collimation

- Adjust the radiation field to 1 inch (2.5 cm) on three sides of the shadow of the calcaneus and to include the fifth metatarsal base. Place side marker in the collimated exposure field.

Compensating Filter

This projection can be improved significantly with the use of a compensating filter because of increased thickness of the midportion of the foot.

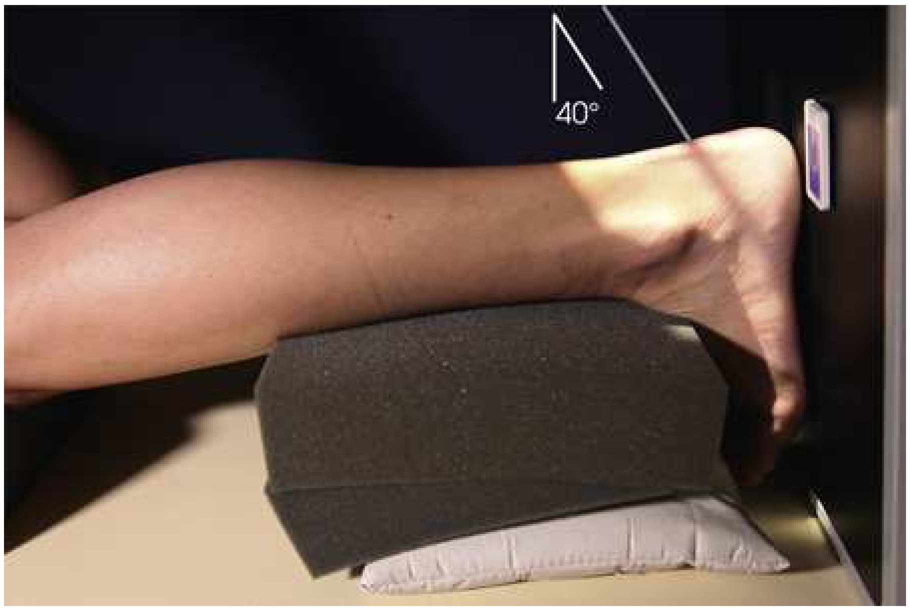

FIG. 7.76 Axial (dorsoplantar) calcaneus.

A patient is in the prone position with ankles supported by a foam. The foot rests on the image receptor at the vertical position. The side marker is in the collimated exposure field. The central ray is directed to the midpoint of the IR at a cephalic angle of 40 degrees to the long axis of the foot.

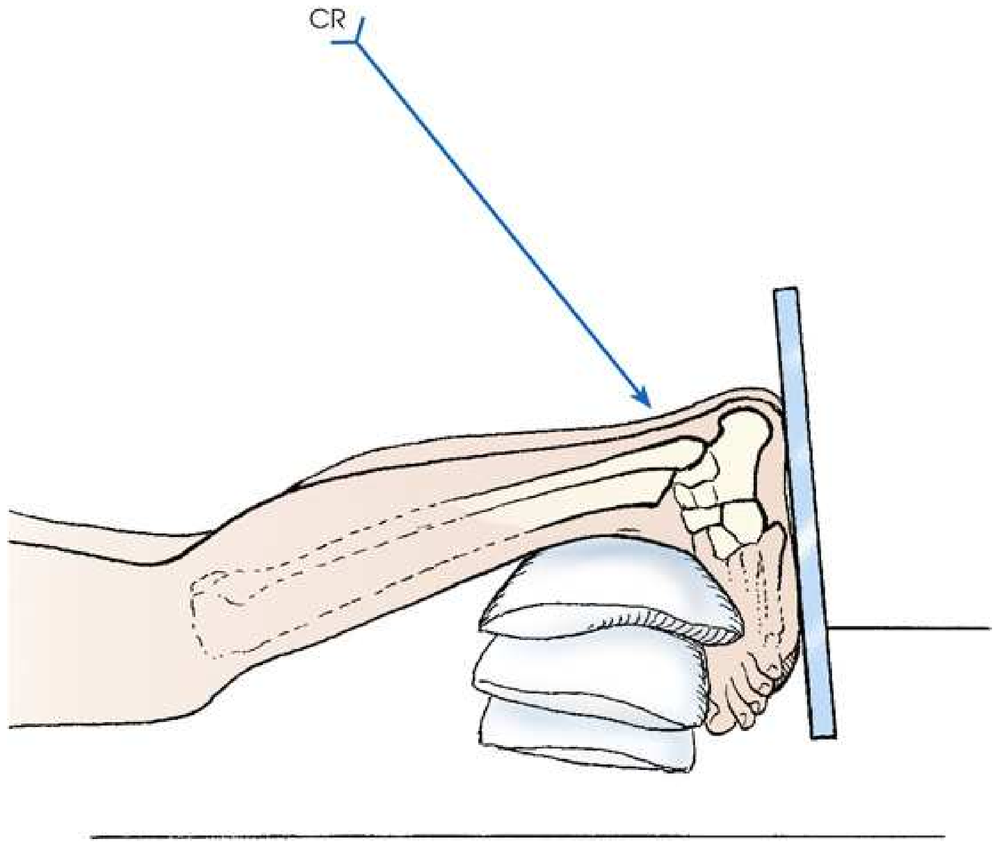

FIG. 7.77 Axial (dorsoplantar) calcaneus.

A patient is in the prone position with ankles supported by few pillows. The foot rests on the image receptor at the vertical position. The side marker is in the collimated exposure field. The central ray is directed to the midpoint of the IR at a cephalic angle of 40 degrees to the long axis of the foot.

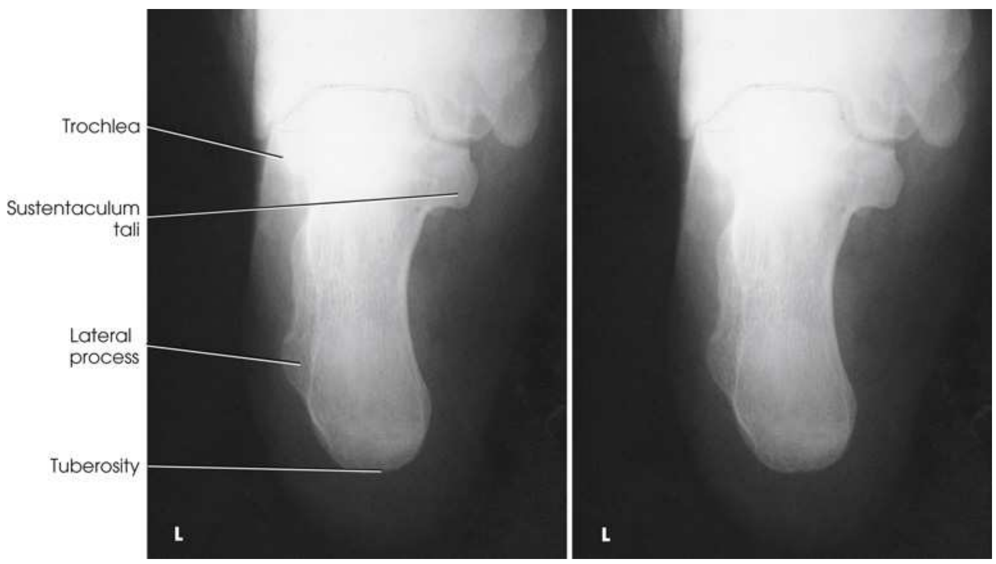

FIG. 7.78 Axial (dorsoplantar) calcaneus.

Two x-ray shows the calcaneus and the talocalcaneal joint. The parts labeled in the x-ray on the left are as follows: trochlea, sustentaculum tali, lateral process, and tuberosity. Trochlea and the part above the trochlea appear radiopaque. The lateral process is a small projection on the left.

Structures shown

An axial projection of the calcaneus and the talocalcaneal joint (Fig. 7.78). Computed tomography (CT) is often used to show this anatomy (Fig. 7.79).

Evaluation Criteria

The following should be clearly seen:

- Evidence of proper collimation and the presence of a side marker placed clear of the anatomy of interest
- Calcaneus and the talocalcaneal joint
- No rotation of the calcaneus
    - Sustentaculum tali in profile on the medial side
    - The first or fifth metatarsals not visible on either side
- Bony trabecular detail and surrounding soft tissues

Weight-Bearing Coalition (Harris-Beath) Method

This weight-bearing method, first described by Lilienfeld [10] (cit. Holzknecht), has come into use to show calcaneotalar coalition. [11–13] For this reason, it has been called the *coalition position*. It may also be called the Harris–Beath method. [11] It is more commonly used in podiatry.

Position of patient

- Place the patient in the standing-upright position.

Position of part

- Center the IR to the long axis of the calcaneus, with the posterior surface of the heel at the edge of the IR.
- To prevent superimposition of the leg shadow, have the patient place the opposite foot one step forward (Fig. 7.80).

Central ray

- Angled 45 degrees anteriorly and directed through the posterior surface of the flexed ankle to a point on the plantar surface at the level of the base of the fifth metatarsal.

FIG. 7.79 CT images of calcaneal fracture with three-dimensional reconstruction. Conventional x-ray shows most fractures; however, complex regions, such as calcaneal-talar area, are best shown on CT. Note how bone *(arrows)* shows extent of fracture. From Jackson SA, Thomas RM. *Cross- imaging made easy,* New York: Churchill Livingstone; 2004.

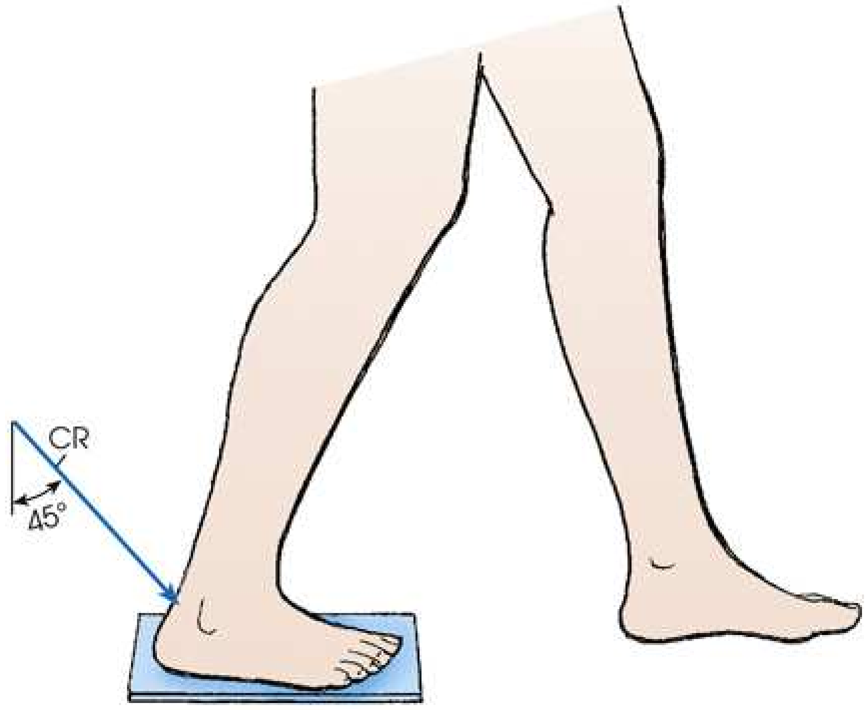

FIG. 7.80 Weight-bearing coalition method.

A patient in a standing position is placing one foot on the image receptor and the other foot is placed a step forward. The central ray is angled 45 degrees anteriorly and directed through the posterior surface of the flexed ankle.

Lateral Projection

Mediolateral

Image receptor:

Positioned by manufacturer or department protocol for proper anatomy display orientation; CR plate: 10 × 12 inches (24 × 30 cm) lengthwise.

Position of patient

- Have the supine patient turn toward the affected side until the leg is approximately lateral. A support may be placed under the knee.

Position of part

- Adjust the calcaneus as for a lateral foot and to the center of the IR.
- Adjust the IR so that the long axis is parallel with the plantar surface of the heel (Fig. 7.81).
- *Shield gonads.*

Central ray

- Perpendicular to the calcaneus. Center about 1 inch (2.5 cm) distal to the medial malleolus. This places the central ray at the subtalar joint.

Collimation

- Adjust the radiation field to 1 inch (2.5 cm) beyond the posterior and inferior shadow of the heel. Include the medial malleolus and the base of the fifth metatarsal. Place side marker in the collimated exposure field.

Structures shown

The ankle joint and the calcaneus in lateral profile (Fig. 7.82).

Evaluation Criteria

The following should be clearly seen:

- Evidence of proper collimation and presence of side marker placed clear of anatomy of interest

- Entire calcaneus, including ankle joint and adjacent tarsals
- No rotation of the calcaneus
  - Tuberosity in profile
  - Sinus tarsi open
  - Calcaneocuboid and talonavicular joints open
- Bony trabecular detail and surrounding soft tissues

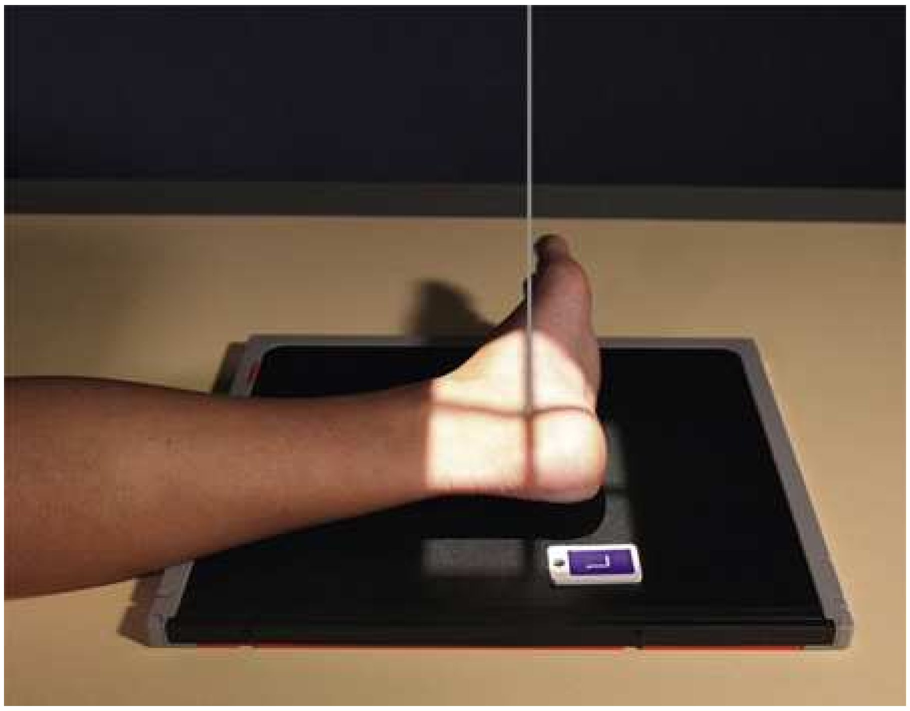

FIG. 7.81 Lateral calcaneus.

A patient in a supine position is placing the plantar surface of the forefoot perpendicular to the image receptor. The lateral surface of the foot is resting on the I R. The side marker is in the collimated exposure field. The central ray is perpendicular to the calcaneus.

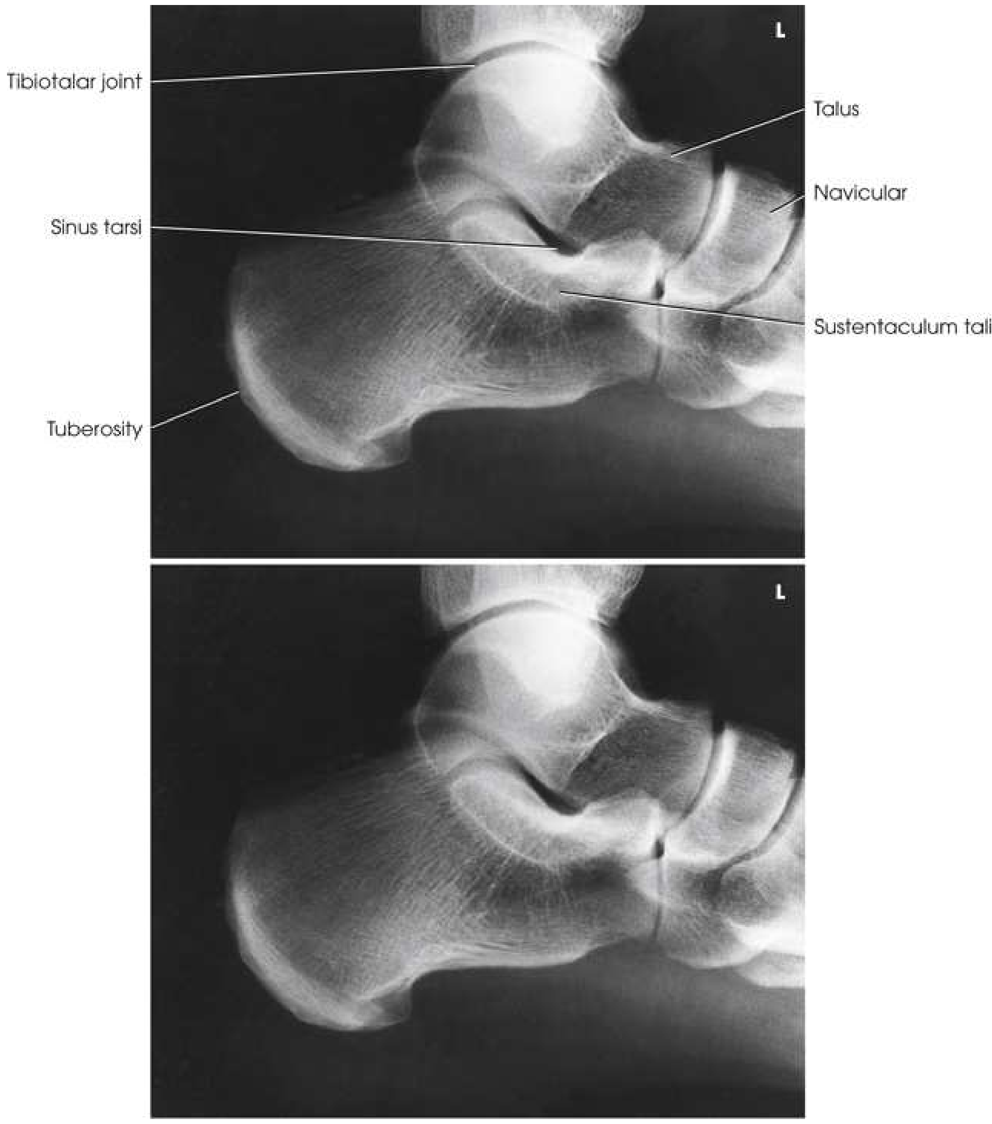

FIG. 7.82 Lateral calcaneus.

Two x-ray shows the ankle joint and the calcaneus. The tuberosity is shaped like an irregular rectangle. The parts labeled on the x-ray are as follows: tibiotalar joint, sinus tarsi, tuberosity, talus, navicular, sustentaculum tali.

Lateromedial Oblique Projection

Weight-Bearing Method

Image receptor:

Positioned by manufacturer or department protocol for proper anatomy display orientation; CR plate: 10 × 12 inches (24 × 30 cm) lengthwise.

Position of patient

- Have the patient stand with the affected heel centered toward the lateral border of the IR (Fig. 7.83).
- A mobile radiographic unit may assist in this examination.

Position of part

- Adjust the patient's leg to ensure that it is exactly perpendicular.
- Center the calcaneus so that it is projected to the center of the IR.
- Center the lateral malleolus to the midline axis of the IR.
- *Shield gonads.*

Central ray

- Directed medially at a caudal angle of 45 degrees to enter the lateral malleolus.

Collimation

• Adjust the radiation field to 1 inch (2.5 cm) beyond the posterior and inferior shadow of the heel. Include the lateral malleolus and the metatarsal bases. Place a side marker in the collimated exposure field.

Structures shown

The calcaneal tuberosity and is useful in diagnosing stress fractures of the calcaneus or tuberosity (Fig. 7.84).

Evaluation Criteria

The following should be clearly seen:

- Evidence of proper collimation and the presence of a side marker placed clear of the anatomy of interest
- Calcaneal tuberosity
- Sinus tarsi
- Cuboid, lateral cuneiform, and proximal metatarsals
- Bony trabecular detail and surrounding soft tissues

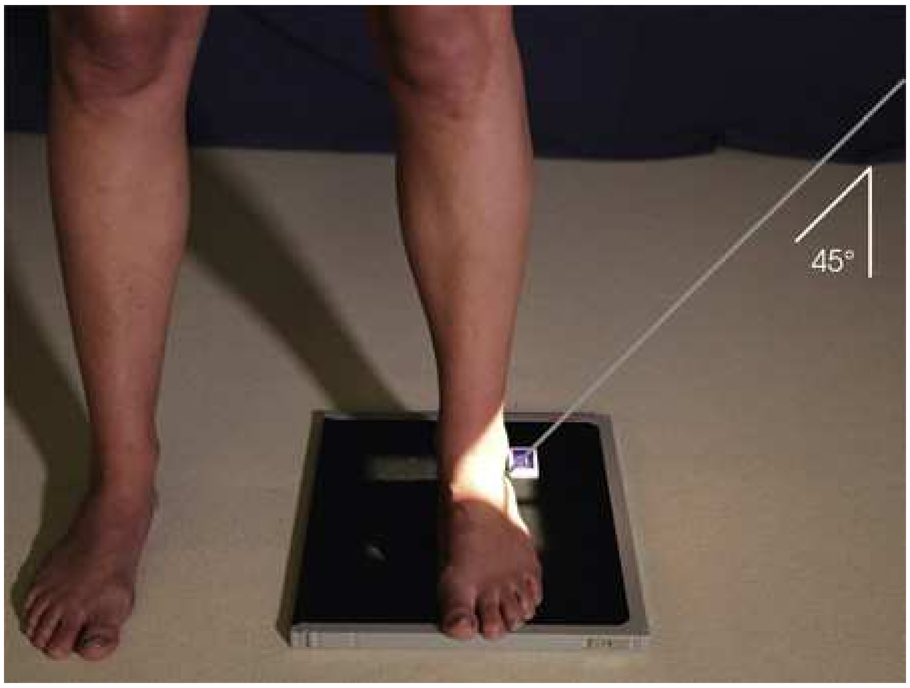

FIG. 7.83 Weight-bearing lateromedial oblique calcaneus.

A patient is standing straight with his heel centered toward the lateral border of the image receptor. The side marker is in the collimated exposure field. The central ray is directed medially at a caudal angle of 45 degrees to enter the lateral malleolus.

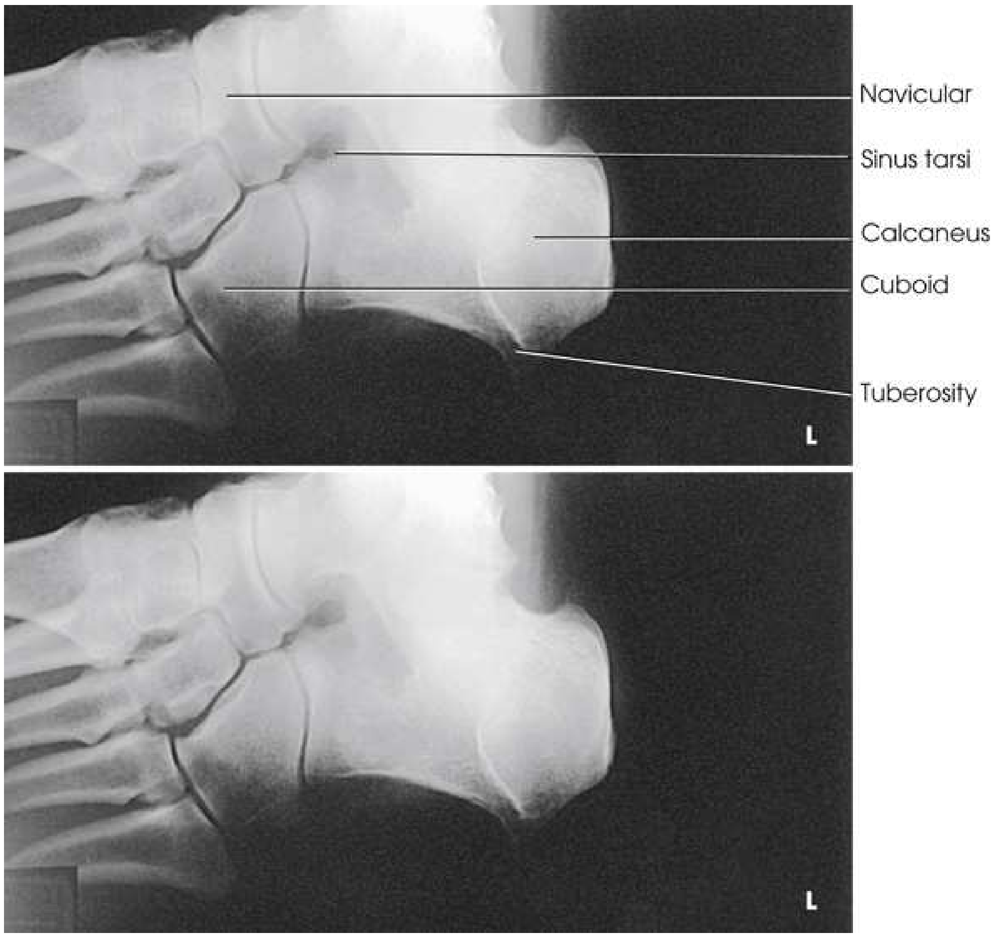

FIG. 7.84 Weight-bearing lateromedial oblique calcaneus.

Subtalar Joint

Lateromedial Oblique Projection

Isherwood Method

Medial rotation foot

Isherwood [14] devised a method for each of the three separate articulations of the subtalar joint: (1) a *medial rotation foot* position to show the anterior talar articulation, (2) a *medial rotation ankle* position to show the middle talar articulation, and (3) a *lateral rotation ankle* position to show the posterior talar articulation. Feist and Mankin [15] later described a similar position.

Image receptor:

Positioned by manufacturer or department protocol for proper anatomy display orientation; CR plate: 10 × 12 inches (24 × 30 cm) lengthwise.

Position of patient

- Place the patient in a semisupine or seated position, turned away from the side being examined.
- Ask the patient to flex the knee enough to place the ankle joint in nearly right-angle flexion and then to lean the leg and foot medially.

Position of part

- With the medial border of the foot resting on the IR, place a 45-degree foam wedge under the elevated leg.
- Adjust the leg so that its long axis is in the same plane as the central ray.
- Adjust the foot to be at a right angle.
- Place a support under the knee (Fig. 7.85).
- *Shield gonads.*

Central ray

- Perpendicular to a point 1 inch (2.5 cm) distal and 1 inch (2.5 cm) anterior to the lateral malleolus.

Collimation

- Adjust the radiation field to 1 inch (2.5 cm) beyond the posterior and inferior shadow of the heel. Include the lateral malleolus and the metatarsal bases. Place a side marker in the collimated exposure field.

Structures shown

The anterior subtalar articulation and an oblique projection of the tarsals (Fig. 7.86). The Feist-Mankin method produces a similar image representation.

Evaluation Criteria

The following should be clearly seen:

- Evidence of proper collimation and the presence of a side marker placed clear of the anatomy of interest
- Anterior talar articular surface
- Bony trabecular detail and surrounding soft tissues

FIG. 7.85 Lateromedial oblique subtalar joint, medial rotation: Isherwood method.

A patient is in a semisupine position with the knee flexed and the ankle joint is placed in a right angle flexion. The medial border of the foot resting on the image receptor. A 45-degree foam wedge is placed under the elevated leg. The side marker is in the collimated exposure field. The central ray is perpendicular and anterior to the lateral malleolus.

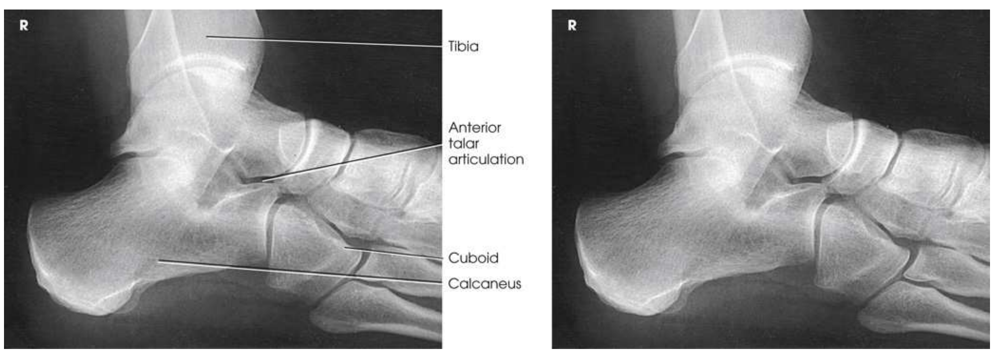

FIG. 7.86 Lateromedial oblique subtalar joint showing anterior articulation: Isherwood method.

Two x-ray views show the anterior subtalar articulation and the tarsals. The parts labeled in the x-ray on the left are as follows: tibia, anterior talar articulation, cuboid, the calcaneus. It appears grainy.

AP Axial Oblique Projection

Isherwood Method

Medial rotation ankle

Image receptor:

Positioned by manufacturer or department protocol for proper anatomy display orientation; CR plate: 10 × 12 inches (24 × 30 cm) lengthwise.

Position of patient

- Have the patient assume a seated position on the radiographic table and turn with body weight resting on the flexed hip and thigh of the unaffected side.
- If a semilateral recumbent position is more comfortable, adjust the patient accordingly.

Position of part

- Ask the patient to rotate the leg and foot medially enough to rest the side of the foot and affected ankle on an optional 30-degree foam wedge (Fig. 7.87).
- Place a support under the knee. If the patient is recumbent, place another support under the greater trochanter.
- Dorsiflex the foot, then invert it, if possible, and have the patient maintain the position by pulling on a strip of 2- or 3-inch (5- to 7.6-cm) bandage looped around the ball of the foot.
- *Shield gonads.*

Central ray

- Directed to a point 1 inch (2.5 cm) distal and 1 inch (2.5 cm) anterior to the lateral malleolus at an angle of 10 degrees cephalad.

Collimation

- Adjust the radiation field to 1 inch (2.5 cm) beyond the posterior and inferior shadow of the heel. Include the lateral malleolus and the metatarsal bases. Place a side marker in the collimated exposure field.

Structures shown

The middle articulation of the subtalar joint and an "end-on" projection of the sinus tarsi (Fig. 7.88).

Evaluation Criteria

The following should be clearly seen:

- Evidence of proper collimation and the presence of a side marker placed clear of the anatomy of interest
- Middle (subtalar) articulation
- Open sinus tarsi
- Bony trabecular detail and surrounding soft tissues

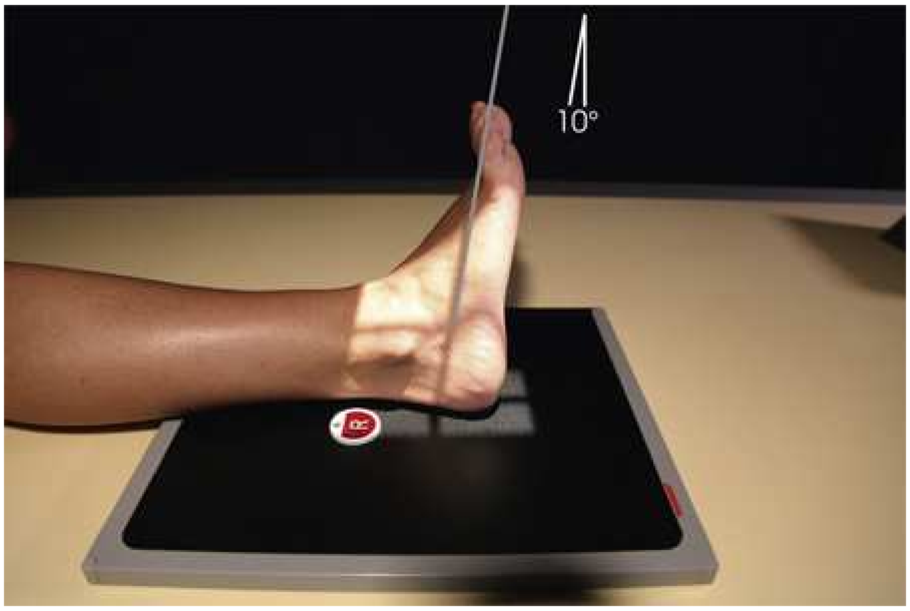

FIG. 7.87 AP axial oblique subtalar joint, medial rotation: Isherwood method.

A foot of the patient in a seated position is rotated and the medial side of the ankle is resting on the image receptor. The side marker is in the collimated exposure field. The central ray is directed to the lateral malleolus at an angle of 10 degrees cephalad.

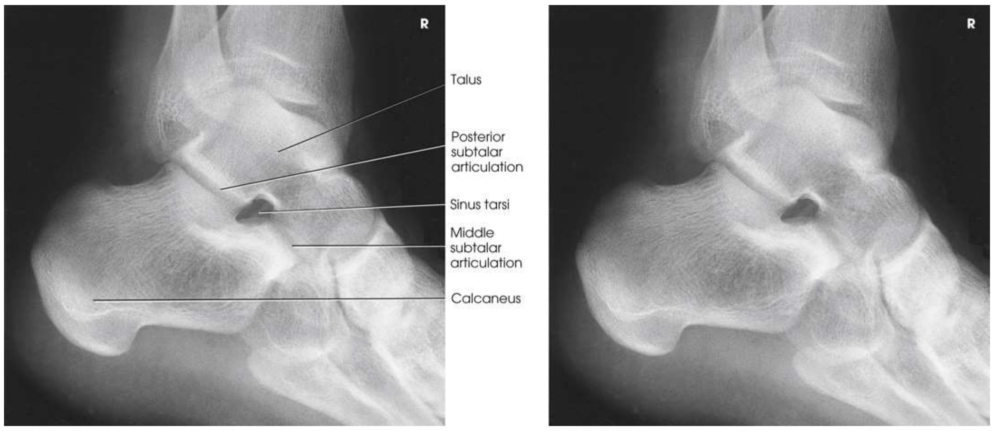

FIG. 7.88 AP axial oblique subtalar joint: Isherwood method.

Two x-ray shows the middle articulation of the subtalar joint and the projection of the sinus tarsi. The sinus tarsi appear dark. The parts labeled in the x-ray on the left are as follows: talus, posterior subtalar articulation, sinus tarsi, middle subtalar articulation, and calcaneus.

AP Axial Oblique Projection

Isherwood Method

Lateral rotation ankle

Image receptor:

Positioned by manufacturer or department protocol for proper anatomy display orientation; CR plate: 10 × 12 inches (24 × 30 cm) lengthwise.

Position of patient

- Place the patient in the supine or seated position.

Position of part

- Ask the patient to rotate the leg and foot laterally until the side of the foot and ankle rests against an optional 30-degree foam wedge.
- Dorsiflex the foot, evert it if possible, and have the patient maintain the position by pulling on a broad bandage looped around the ball of the foot (Fig. 7.89).
- *Shield gonads.*

Central ray

- Directed to a point 1 inch (2.5 cm) distal to the medial malleolus at an angle of 10 degrees cephalad.

Collimation

- Adjust the radiation field to 1 inch (2.5 cm) beyond the posterior and inferior shadow of the heel. Include the lateral malleolus and the metatarsal bases. Place a side marker in the collimated exposure field.

Structures shown

The posterior articulation of the subtalar joint in profile (Fig. 7.90).

Evaluation Criteria

The following should be clearly seen:

- Evidence of proper collimation and presence of side marker placed clear of anatomy of interest
- Posterior subtalar articulation
- Bony trabecular detail and surrounding soft tissues

FIG. 7.89 AP axial oblique subtalar joint, lateral rotation: Isherwood method.

A foot of the patient in a seated position is rotated and the medial side of the ankle is resting on the image receptor. The side marker is in the collimated exposure field. The central ray is directed to the lateral malleolus at an angle of 10 degrees distal to the medial malleolus at an angle of 10 degrees cephalad.

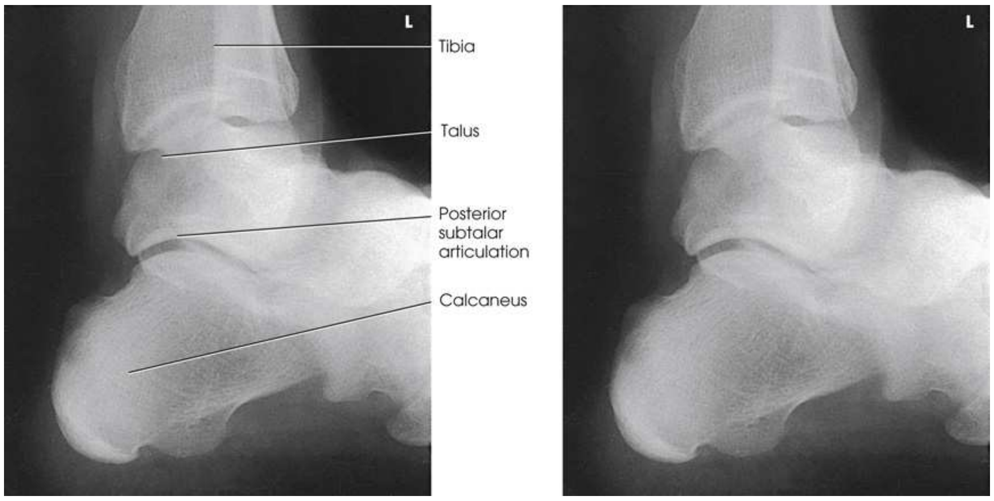

FIG. 7.90 AP oblique subtalar joint: Isherwood method.

Two x-ray shows the posterior articulation of the subtalar joint. It appears grainy. The parts labeled in the x-ray on the left are as follows: tibia, talus, posterior subtalar articulation, and calcaneus.

Ankle

AP Projection

Image receptor:

Positioned by manufacturer or department protocol for proper anatomy display orientation; CR plate: 10 × 12 inches (24 × 30 cm) lengthwise.

Position of patient

- Place the patient in the supine or seated position with the affected extremity fully extended.

Position of part

- Adjust the ankle joint in the anatomic position (foot pointing straight up) to obtain a true AP projection. Flex the ankle and foot enough to place the long axis of the foot in the vertical position (Fig. 7.91).
- Ball and Egbert [16] stated that the appearance of the ankle mortise is not appreciably altered by moderate plantar flexion or dorsiflexion as long as the leg is not rotated either laterally or medially.
- *Shield gonads.*

Central ray

- Perpendicular through the ankle joint at a point midway between the malleoli.

Collimation

- Adjust the radiation field to 1 inch (2.5 cm) on the sides of the ankle and 8 inches (18 cm) lengthwise to include the heel. Place a side marker in the collimated exposure field.

Structures shown

AP projection of the ankle joint, the distal ends of the tibia and fibula, and the proximal portion of the talus.

NOTE: The inferior tibiofibular articulation and the talofibular articulation are not "open" or shown in profile in the true AP projection. This is a positive sign for the radiologist because it indicates that the patient has no ruptured ligaments or other types of separations. For this reason, it is important that the position of the ankle be anatomically "true" for the AP projection shown (Fig. 7.92).

Evaluation Criteria

The following should be clearly seen:

- Evidence of proper collimation and the presence of a side marker placed clear of the anatomy of interest
- Ankle joint centered to exposure area
- Medial and lateral malleoli
- Talus
- No rotation of the ankle
  - Normal overlapping of the tibiofibular articulation with the anterior tubercle slightly superimposed over the fibula
  - Talus slightly overlapping the distal fibula
  - No overlapping of the medial talomalleolar articulation
- Tibiotalar joint space
- Bony trabecular detail and surrounding soft tissues

FIG. 7.91 AP ankle.

The patient lying in the supine position with the foot pointing straight up on the image receptor. The long axis of the foot is in the vertical position. The side marker is in the collimated exposure field. The central ray is directed perpendicular through the ankle joint at a point midway between the malleoli.

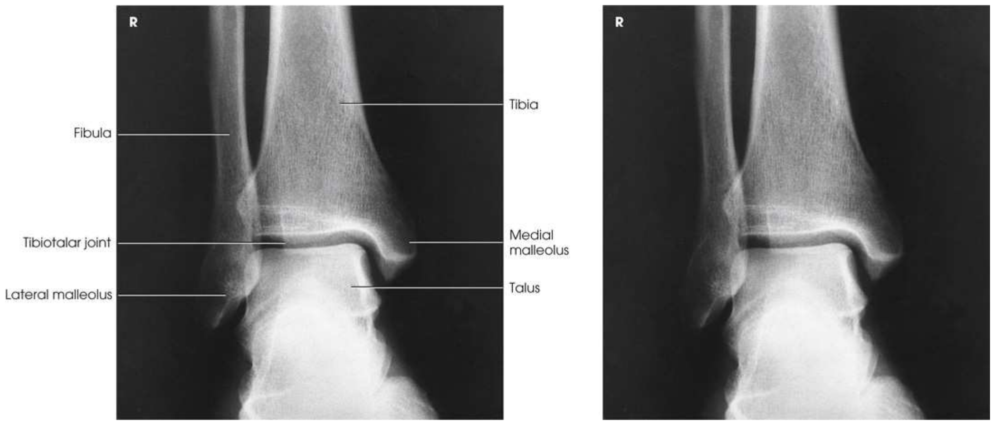

FIG. 7.92 AP ankle.

Two x-ray shows the ankle joint, the distal ends of the tibia and fibula, and the proximal portion of the talus. The ankle joint is centered on the exposure area. The parts labeled in the x-ray on the left are as follows: fibula, tibiotalar joint, lateral malleolus, tibia, medial malleolus, and talus.

Lateral Projection

Mediolateral

Image receptor:

Positioned by manufacturer or department protocol for proper anatomy display orientation; CR plate: 10 × 12 inches (24 × 30 cm) lengthwise.

Position of patient

- Have the supine patient turn toward the affected side until the ankle is lateral (Fig. 7.93).

Position of part

- Place the long axis of the IR parallel with the long axis of the patient's leg, and center it to the ankle joint.
- Ensure that the lateral surface of the foot is in contact with the IR.
- Dorsiflex the foot and adjust it in the lateral position. Dorsiflexion is required to prevent lateral rotation of the ankle.
- *Shield gonads.*

Central ray

- Perpendicular to the ankle joint, entering the medial malleolus.

Collimation

- Adjust the radiation field to 1 inch (2.5 cm) on the sides of the ankle and 8 inches (18 cm) lengthwise. Include the heel and the fifth metatarsal base. Place a side marker in the collimated exposure field.

Structures shown

The resulting image shows a true lateral projection of the lower third of the tibia and fibula; the ankle joint; and the tarsals, including the base of the fifth metatarsal (Figs. 7.94 and 7.95).

Evaluation Criteria

The following should be clearly seen:

- Evidence of proper collimation and the presence of a side marker placed clear of the anatomy of interest
- Ankle joint centered to exposure area
- Distal tibia and fibula, talus, calcaneus, and adjacent tarsals
- Ankle in true lateral position
  - Tibiotalar joint well visualized, with the medial and lateral talar domes superimposed
  - Fibula over the posterior half of the tibia
- Fifth metatarsal base and tuberosity should be seen to check for Jones fracture
- Bony trabecular detail and surrounding soft tissues

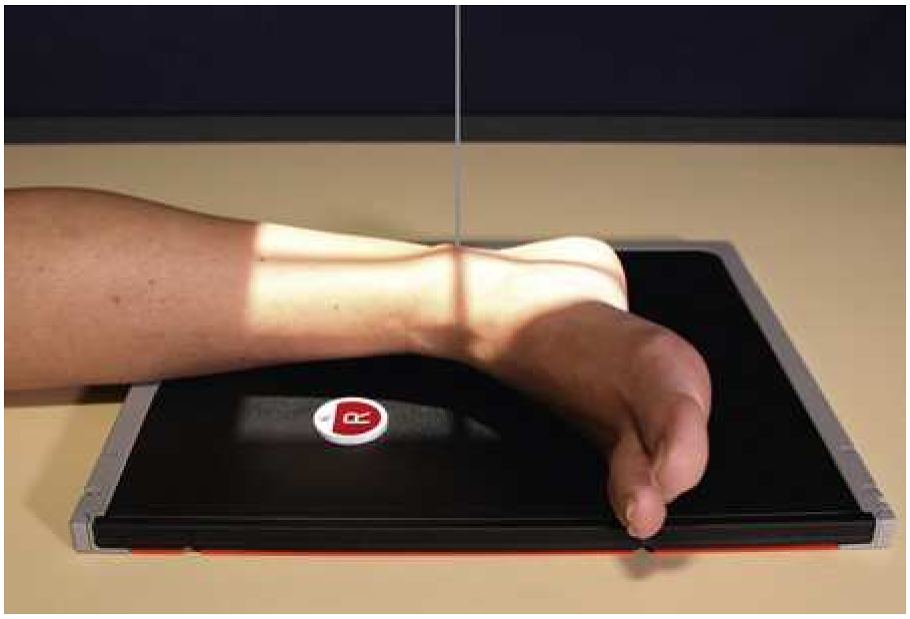

FIG. 7.93 Lateral ankle, mediolateral.

The patient lying in a supine position turned towards the affected area is resting the lateral surface of the foot on the image receptor. The side marker is in the collimated exposure field. The central ray is directed perpendicular through the ankle joint at a point midway between the malleoli.

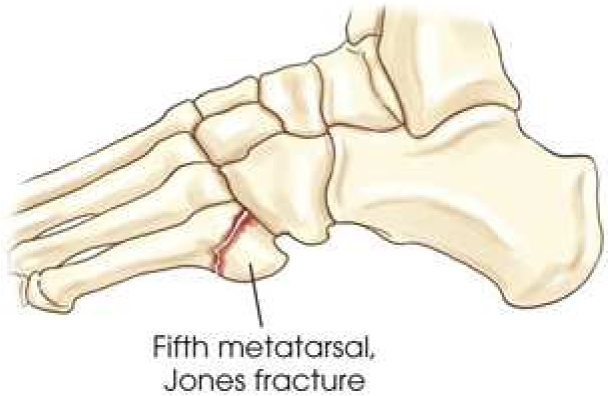

FIG. 7.94 Bones shown on lateral ankle. Inclusion of base of fifth metatarsal on lateral ankle projection can reveal Jones fracture if present.

FIG. 7.95 (A) and (B) Lateral ankle, mediolateral. Base of fifth metatarsal is seen *(arrow)*. (C) Lateral ankle of an 8-year-old child. Note tibial epiphysis *(arrow)*.

(A) An x-ray shows the lower third of the tibia and fibula, the ankle joint, and the tarsals. The parts labeled are as follows: tibia, fibula, tibiotalar joint, talus, the navicular, cuboid, and calcaneus. (B) An x-ray shows the base of the fifth metatarsal at the bottom. It is marked by a white arrow. (C) shows the ankle. It appears hazy. The tibial epiphysis is marked by a white arrow.

Lateral Projection

Lateromedial

The lateral projection of the ankle joint can be made with the medial side of the ankle in contact with the IR. Exact positioning of the ankle is more easily and more consistently obtained when the extremity is rested on its comparatively flat medial surface. However, this position is more difficult for patients than the more commonly performed mediolateral projection. For this reason, it is more commonly performed either upright or as a cross-table lateral.

Image receptor:

Positioned by manufacturer or department protocol for proper anatomy display orientation; CR plate: 10 × 12 inches (24 × 30 cm) lengthwise.

Position of patient

- Have the supine patient turn away from the affected side until the extended leg is placed laterally.

Position of part

- Center the IR to the ankle joint and adjust the IR so that its long axis is parallel with the long axis of the leg.
- Adjust the foot in the lateral position.
- Have the patient turn anteriorly or posteriorly as required to place the patella perpendicular to the horizontal plane (Fig. 7.96A). This projection also can be performed as a cross table lateral with the patient supine (Fig. 7.96B).
- If necessary, place a support under the patient's knee.
- *Shield gonads.*

Central ray

- Perpendicular through the ankle joint, entering ½ inch (1.3 cm) superior to the lateral malleolus.

Collimation

- Adjust the radiation field to 1 inch (2.5 cm) on the sides of the ankle and 8 inches (18 cm) lengthwise. Include the heel and the fifth metatarsal base. Place a side marker in the collimated exposure field.

Structures shown

A lateral projection of the lower third of the tibia and fibula, the ankle joint, and the tarsals (Fig. 7.97).

Evaluation Criteria

The following should be clearly seen:

- Evidence of proper collimation and presence of side marker placed clear of anatomy of interest
- Ankle joint centered to exposure area
- Distal tibia and fibula, talus, and adjacent tarsals
- Ankle in true lateral position
  - Tibiotalar joint well visualized, with the medial and lateral talar domes superimposed
  - Fibula over the posterior half of the tibia
- Bony trabecular detail and surrounding soft tissues

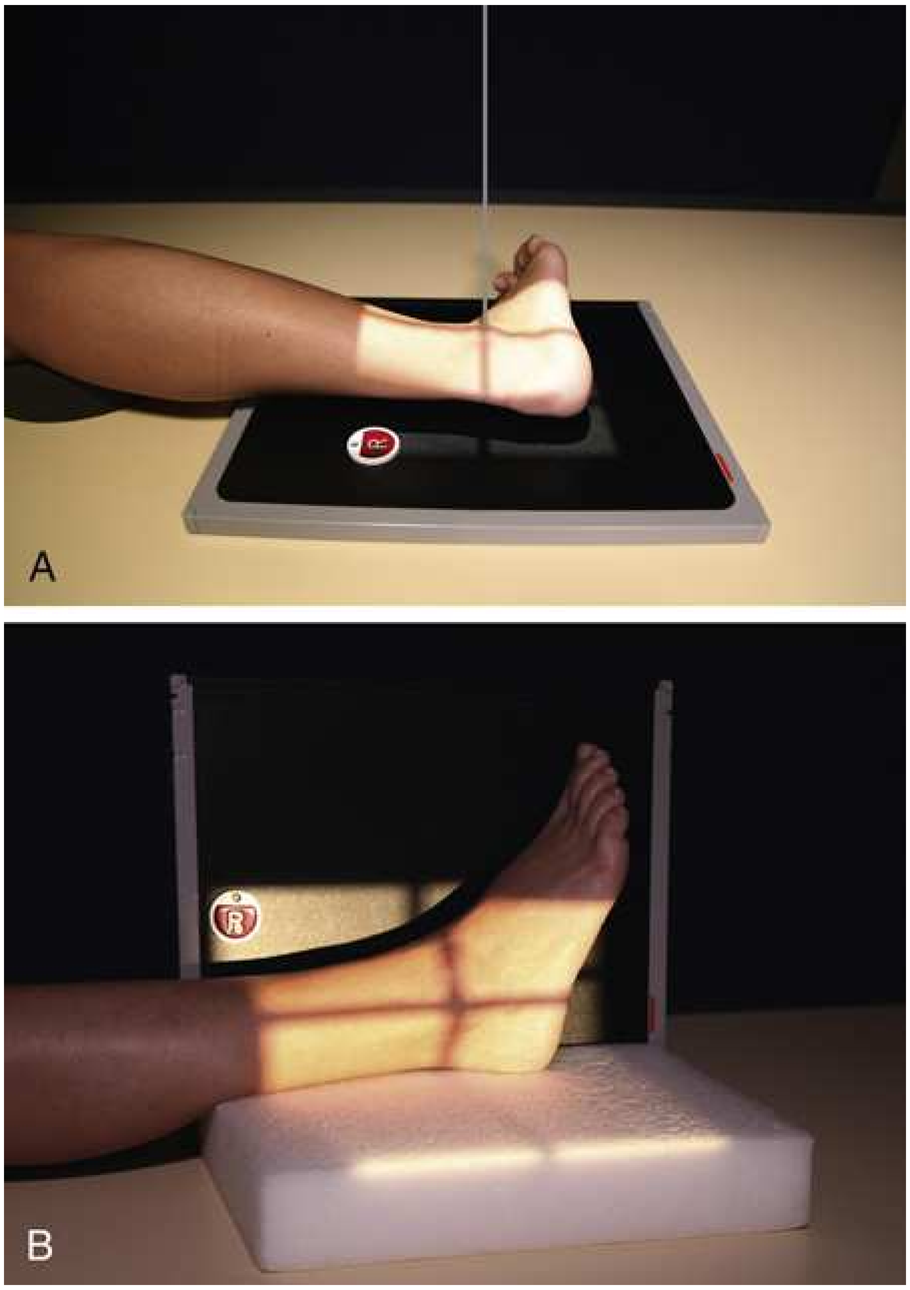

FIG. 7.96 Lateral ankle, lateromedial. (A) Positioned on tabletop. (B) Positioned as a cross-table lateral.

(A) A patient is lying in the supine position turning anteriorly with the lateral foot resting on the image receptor. The side marker is in the collimated exposure field. The central ray is directed perpendicular through the ankle joint superior to the lateral malleolus. (B) A patient lies in the position where leg and foot are against the image receptor. The plantar surface of the forefoot is kept perpendicular to the I R. The side marker is in the collimated exposure field. The central ray is directed perpendicular through the ankle joint superior to the lateral malleolus.

FIG. 7.97 Lateral ankle, lateromedial.

AP Oblique Projection

Medial rotation

Image receptor:

Positioned by manufacturer or department protocol for proper anatomy display orientation; CR plate: 10 × 12 inches (24 × 30 cm) lengthwise.

Position of patient

- Place the patient in the supine or seated position with the affected extremity fully extended.

Position of part

- Center the IR to the ankle joint midway between the malleoli and adjust the IR so that its long axis is parallel with the long axis of the leg.
- Dorsiflex the foot enough to place the ankle at nearly right-angle flexion (Fig. 7.98). The ankle may be immobilized with sandbags placed against the sole of the foot or by having the patient hold the ends of a strip of bandage looped around the ball of the foot.
- Rotate the patient's entire *leg* for all oblique projections of the ankle by grasping the lower femur area with one hand and the foot with the other (see Fig. 7.98). Because the knee is a hinge joint, rotation of the leg can come only from the hip joint. Internally rotate the entire leg and foot together until the 45-degree oblique position is achieved (Fig. 7.99).
- The foot can be placed against a foam wedge for support.
- *Shield gonads.*

Central ray

- Perpendicular to the ankle joint, entering midway between the malleoli.

Collimation

- Adjust the radiation field to 1 inch (2.5 cm) on the sides of the ankle and 8 inches (18 cm) lengthwise to include the heel. Place a side marker in the collimated exposure field.

Structures shown

The 45-degree medial oblique projection shows the distal ends of the tibia and fibula, parts of which are often superimposed over the talus. The tibiofibular articulation also should be shown (Fig. 7.100).

Evaluation Criteria

The following should be clearly seen:

- Evidence of proper collimation and the presence of a side marker placed clear of the anatomy of interest
- Ankle joint centered to exposure area
- Distal tibia, fibula, and talus
- Proper 45-degree rotation of ankle
  - Tibiofibular articulation open
  - Distal tibia and fibula overlap some of the talus
- Bony trabecular detail and surrounding soft tissues

FIG. 7.98 Radiographer properly positioning the leg for an oblique projection of the ankle joint. Note the action of the left hand *(arrow)* in turning the leg medially. Proper positioning requires turning the leg but not the foot.

The radiographer is positioning the leg of a patient by grasping the lower femur area with one hand and the foot with the other hand. The hand holding the femur is marked by a black arrow. A support is placed under the ankle.

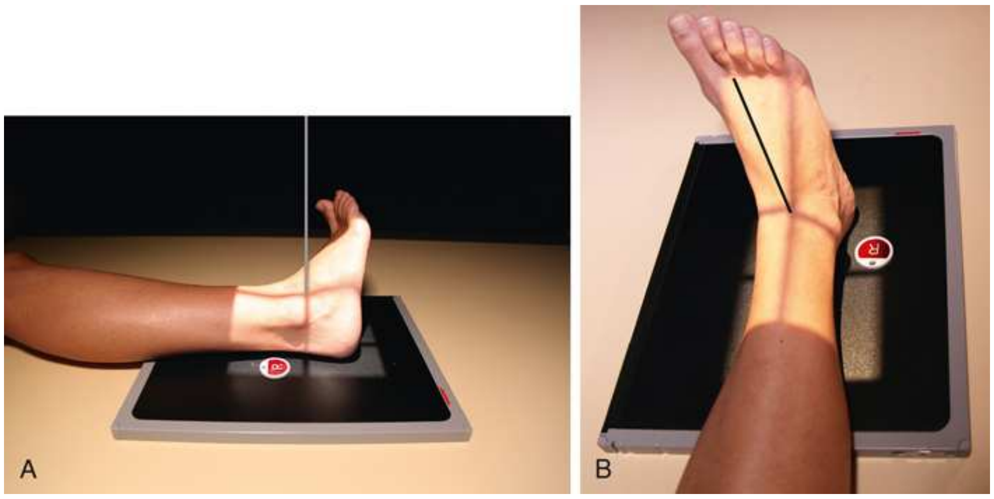

FIG. 7.99 (A) and (B) AP oblique ankle, 45-degree medial rotation.

(A) A patient's leg is internally rotated and the internally rotated foot is placed on the image receptor. The side marker is in the collimated exposure field. The central ray is directed perpendicular to the ankle joint, entering midway between the malleoli. (B) The front view shows a patient's leg internally rotated and the internally rotated foot is placed on the image receptor. The side marker is in the collimated exposure field. The central ray is directed perpendicular to the ankle joint, entering midway between the malleoli

FIG. 7.100 AP oblique ankle, 45-degree medial rotation.

Mortise Joint [17]

AP Oblique

Medial rotation

Image receptor:

Positioned by manufacturer or department protocol for proper anatomy display orientation; CR plate: 10 × 12 inches (24 × 30 cm) lengthwise.

Position of patient

- Place the patient in the supine or seated position.

Position of part

- Center the patient's ankle joint to the IR.
- Grasp the distal femur area with one hand and the foot with the other. Assist the patient by internally rotating the *entire leg* and *foot* together 15 to 20 degrees until the intermalleolar plane is parallel with the IR (Fig. 7.101).
- The plantar surface of the foot should be placed at a right angle to the leg.
- *Shield gonads.*

Central ray

- Perpendicular, entering the ankle joint midway between the malleoli.

Collimation

- Adjust the radiation field to 1 inch (2.5 cm) on the sides of the ankle and 8 inches (18 cm) lengthwise to include the heel. Place a side marker in the collimated exposure field.

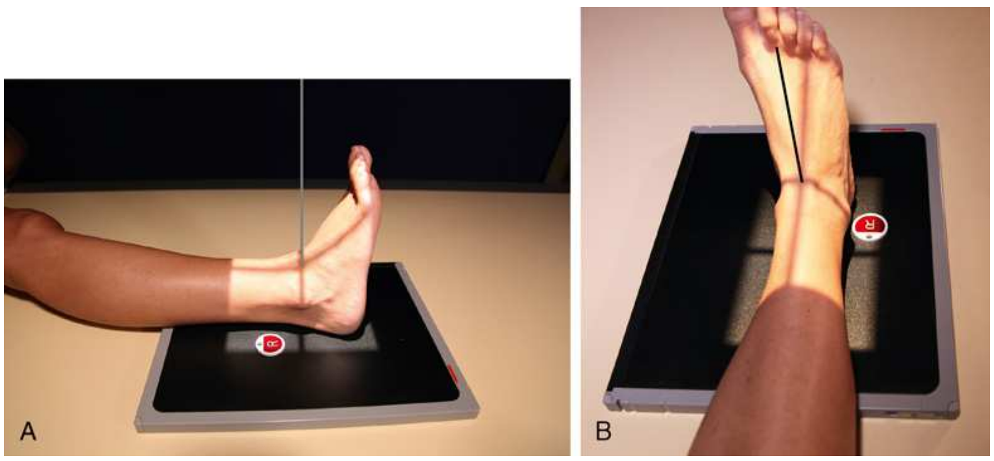

FIG. 7.101 (A) and (B) AP oblique ankle, 15- to 20-degree medial rotation to show ankle mortise joint.

(A) A patient's leg and foot are internally rotated and the plantar surface of the foot is placed at a right angle to the leg. The side marker is in the collimated exposure field. The central ray is directed perpendicular entering the ankle joint midway between the malleoli. (B) The front view shows a patient's leg internally rotated and the plantar surface of the foot is placed at a right angle to the leg. The side marker is in the collimated exposure field. The central ray is directed perpendicular entering the ankle joint midway between the malleoli.

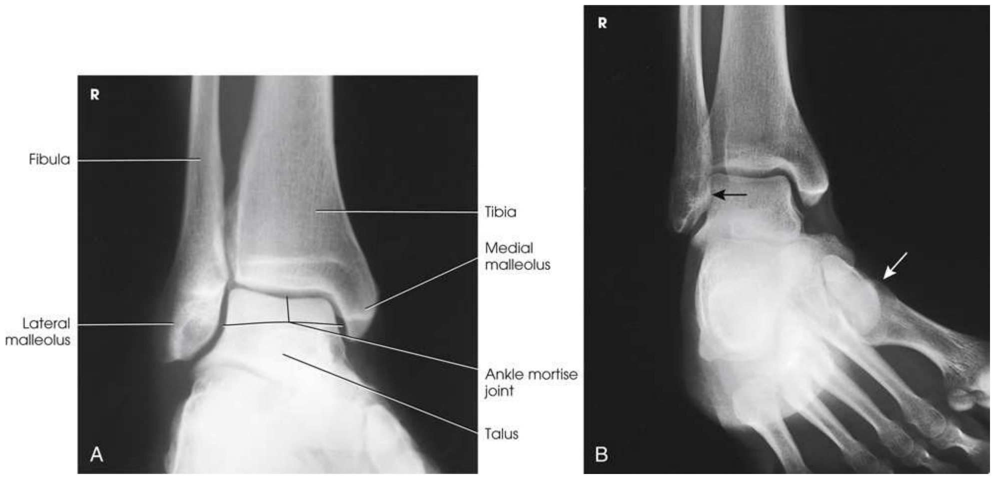

FIG. 7.102 AP oblique ankle, 15- to 20-degree medial rotation to show ankle mortise joint. (A) Properly positioned leg to show mortise joint. (B) Poorly positioned leg; radiograph had to be repeated. The foot was turned medially *(white arrow)*, but the leg was not. Lateral mortise is closed *(black arrow)* because the "leg" was not medially rotated.

(A) An x-ray shows the three sides of the mortise joint. The parts labeled are as follows: fibula, lateral malleolus, tibia, medial malleolus, ankle mortise joint, and talus. (B) An x-ray shows a medially turned foot. The white arrow points at the tarsals and the black arrow points at the tibia.

Structures shown

The entire ankle mortise joint in profile. The three sides of the mortise joint should be visualized (Figs. 7.102 and 7.103).

Evaluation Criteria

The following should be clearly seen:

- Evidence of proper collimation and the presence of a side marker placed clear of the anatomy of interest
- Entire ankle mortise joint centered to exposure area
- Distal tibia, fibula, and talus
- Proper 15- to 20-degree rotation of ankle
    - Talofibular articulation open
    - Tibiotalar articulation open
    - No overlap of the anterior tubercle of the tibia and the superolateral portion of the talus with the fibula
- Bony trabecular detail and surrounding soft tissues

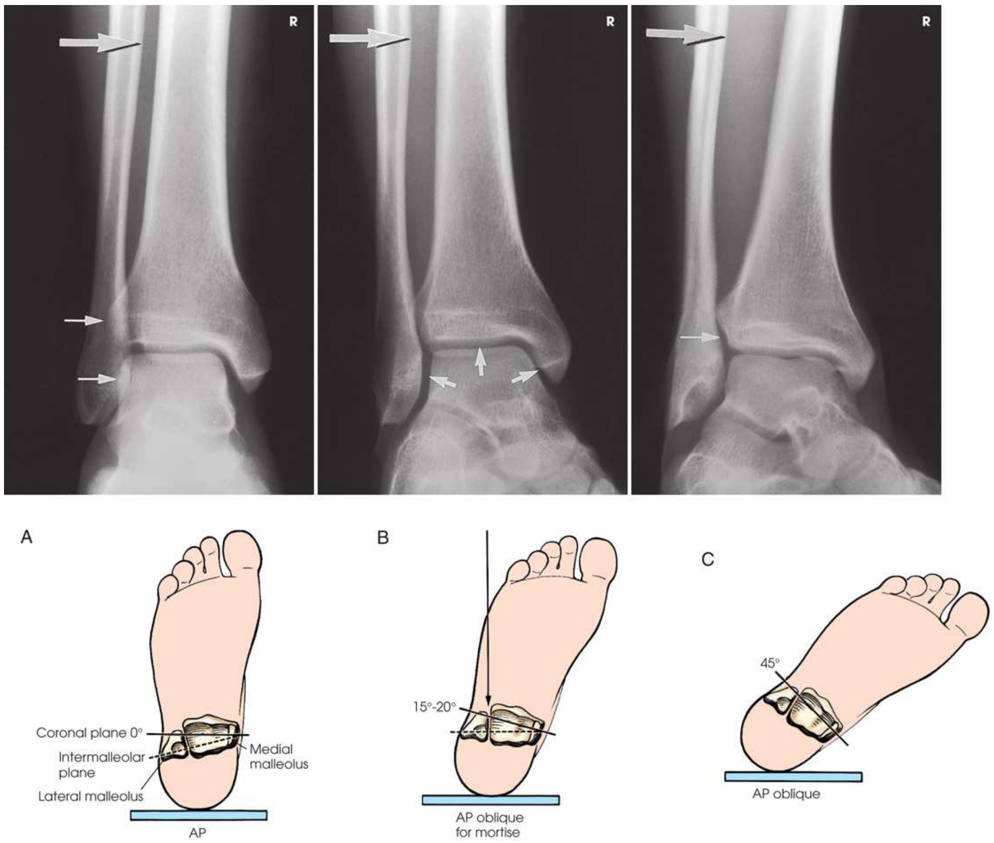

FIG. 7.103 Axial drawing of inferior surface of the tibia and fibula at the ankle joint along with matching radiographs. (A) AP ankle position with no rotation of the leg and foot. Drawing shows lateral malleolus positioned posteriorly when leg is in true anatomic position. Radiograph shows normal overlap of anterior tubercle and superolateral talus over fibula *(arrows)*. (B) AP oblique ankle, 15- to 20-degree medial rotation to show ankle mortise. Drawing shows both malleoli parallel with IR. Radiograph clearly shows all three aspects of the mortise joint *(arrows)*. (C) AP oblique ankle, 45-degree medial rotation. Radiograph shows the tibiofibular joint *(arrow)* and the entire distal fibula in profile. *Larger upper arrow* shows wider space created between tibia and fibula as the leg is turned medially for two AP oblique projections. This space should be observed when ankle radiographs are checked for proper positioning.

(A) shows an x-ray view of the three sides of the mortise joint. The anterior tubercle and superolateral talus over the fibula are pointed by three white arrows. Larger upper arrow points at the space created between the tibia and fibula. A diagram below shows the foot resting on the image receptor. The parts of the tibia and the fibula at the ankle joint are marked as follows: intermalleolar plane, lateral malleolus, and medial malleolus. The coronal plane is marked as 0 degrees. (B) shows an x-ray view of the three sides of the mortise joint. All three aspects of the mortise joint are pointed using three white arrows. Larger upper arrow points at the space created between the tibia and fibula. The space is wider than (A). A diagram below shows the oblique ankle resting on the image receptor in 15 to 20-degree medial rotation. The central ray is directed perpendicular entering the ankle joint midway between the malleoli. (C) shows an x-ray view of the entire distal fibula. The tibiofibular joint is pointed by a white arrow. Larger upper arrow points at the space created between the tibia and fibula. The space is wider than (B). A diagram below shows the oblique ankle resting on the image receptor in a 45-degree medial rotation.

AP Oblique Projection

Lateral rotation

Image receptor:

Positioned by manufacturer or department protocol for proper anatomy display orientation; CR plate: 10 × 12 inches (24 × 30 cm) lengthwise.

Position of patient

- Seat the patient on the radiographic table with the affected leg extended.

Position of part

- Place the plantar surface of the patient's foot in the vertical position, and laterally rotate the *leg* and *foot* 45 degrees.
- Rest the foot against a foam wedge for support and center the ankle joint to the IR (Fig. 7.104).
- *Shield gonads.*

Central ray

- Perpendicular, entering the ankle joint midway between the malleoli.

Collimation

- Adjust the radiation field to 1 inch (2.5 cm) on the sides of the ankle and 8 inches (18 cm) lengthwise to include the heel. Place side marker in the collimated exposure field.

Structures shown

The lateral rotation oblique projection is useful in determining fractures and showing the superior aspect of the calcaneus (Fig. 7.105).

Evaluation Criteria

The following should be clearly seen:

- Evidence of proper collimation and the presence of a side marker placed clear of the anatomy of interest
- Distal tibia, fibula, and talus
- Tibiotalar joint
- Calcaneal sulcus (superior portion of calcaneus)
- Bony trabecular detail and surrounding soft tissues

FIG. 7.104 AP oblique ankle, lateral rotation.

A patient's leg and foot are rotated and the plantar surface of the patient's foot is in the vertical position. The ankle joint is centered on the image receptor. The side marker is in the collimated exposure field. The central ray is directed perpendicular entering the ankle joint midway between the malleoli.

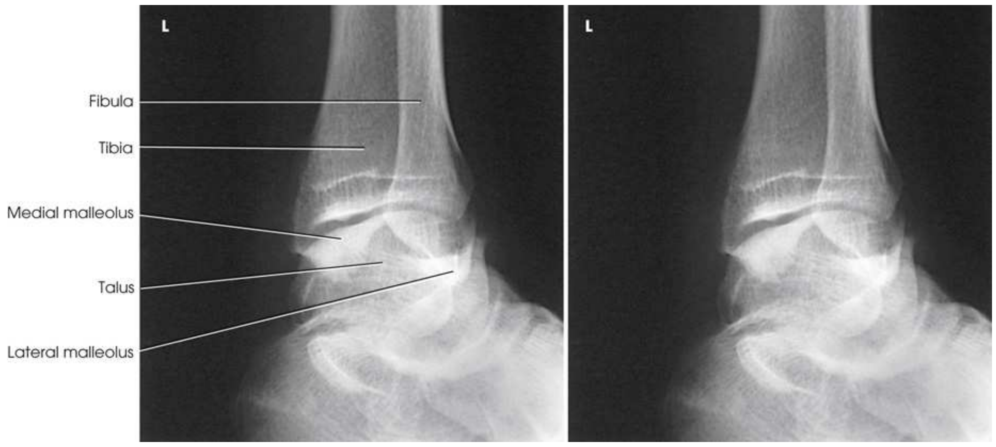

FIG. 7.105 AP oblique ankle, lateral rotation.

Two x-ray shows the superior aspect of the calcaneus. The parts are labeled in the x-ray on the left are fibula, tibia, medial malleolus, talus, and lateral malleolus. The lateral malleolus appears radiopaque. The other part appears grainy.

AP Projection

Stress Method

Stress studies of the ankle joint usually are obtained after an inversion or eversion injury to verify the presence of a ligamentous tear. Rupture of a ligament is shown by widening of the joint space on the side of the injury when, without moving or rotating the lower leg from the supine position, the foot is forcibly turned toward the opposite side.

When the injury is recent and the ankle is acutely sensitive to movement, the orthopedic surgeon may inject a local anesthetic into the sinus tarsi before performing the examination. The physician adjusts the foot when it must be turned into extreme stress and holds or straps it in position for the exposure. The patient usually can hold the foot in the stress position when the injury is not too painful or after he or she has received a local anesthetic by asymmetrically pulling on a strip of bandage looped around the ball of the foot (Figs. 7.106 through 7.108).

FIG. 7.106 AP ankle in neutral position. The use of lead glove and stress of the joint are required to obtain inversion and eversion radiographs (see Fig. 7.108).

A patient in a sitting position is pulling on a strip of bandage looped around the ball of the foot. The heel of the foot firmly rests on the image receptor. The side marker is in the collimated exposure field. The central ray is perpendicular to the center of the I R.

FIG. 7.107 AP ankle, neutral position.

FIG. 7.108 (A) Eversion stress. No damage to medial ligament is indicated. (B) Inversion stress. Change in joint and rupture of lateral ligament *(arrow)* are seen.

AP Projection

Weight-Bearing Method

Standing

This projection is performed to identify ankle joint space narrowing with weight-bearing.

Image receptor:

Positioned by manufacturer or department protocol for proper anatomy display orientation; CR plate: 10 × 12 inches (24 × 30 cm) crosswise.

Position of patient

- Place the patient in the upright position, preferably on a low platform that has an IR groove. If such a platform is unavailable, use blocks to elevate the feet to the level of the x-ray tube (Fig. 7.109).

• Ensure that the patient has proper support. Never stand the patient on the radiographic table.

Position of part

• Place the IR in the groove of the platform or between blocks.
• Have the patient stand with heels pushed back against the IR and toes pointing straight ahead toward the x-ray tube.
• *Shield gonads.*

FIG. 7.109 AP weight-bearing ankles.

Central ray

• Perpendicular to the center of the IR.

TECHNICAL NOTE: If needed, use a mobile unit to allow the x-ray tube to reach the floor level.

Collimation

• Adjust the radiation field to 1 inch (2.5 cm) outside the shadows of the feet but not beyond the IR borders, and 8 inches (18 cm) vertically to include the heel. Place a side marker in the collimated exposure field.

Structures shown

An AP projection of both ankle joints and the relationship of the distal tibia and fibula with weight bearing. It also shows side-to-side comparison of the joint (Fig. 7.110).

Evaluation Criteria

The following should be clearly seen:

- Evidence of proper collimation and the presence of a side marker placed clear of the anatomy of interest
- Both ankles centered on the image
- Medial mortise open
- Distal tibia and talus partially superimpose distal fibula
- Lateral mortise closed
- Bony trabecular detail and surrounding soft tissues

FIG. 7.110 AP weight-bearing ankles.

Leg

AP Projection

For this projection and the lateral and oblique projections described in the following sections, the long axis of the IR is placed parallel with the long axis of the leg and centered to the midshaft. Unless the leg is unusually long, the IR extends beyond the knee and ankle joints enough to prevent their being projected off the IR by divergence of the x-ray beam. The IR must extend 1 to 1½ inches (2.5 to 3.8 cm) beyond the joints. When the leg is too long for these allowances, and the site of the lesion is unknown, two images should always be made. In these instances, the leg is imaged to include one joint, and a separate projection of the other joint is performed. Diagonal use of a 14 × 17-inch (35 × 43-cm) IR is also an option if the leg is too long to fit lengthwise, and if such use is permitted by the facility. The use of a 48-inch (122-cm) SID reduces the divergence of the x-ray beam, and more of the body part is included.

Image receptor:

Positioned by manufacturer or department protocol for proper anatomy display orientation; CR plate: 14 × 17 inches (35 × 43 cm) lengthwise or diagonal.

Position of patient

- Place the patient in the supine position.

Position of part

- Adjust the patient's body so that the pelvis is not rotated.
- Adjust the leg so that the femoral condyles are parallel with the IR and the foot is vertical (Fig. 7.111).
- Flex the ankle until the foot is in the vertical position.
- If necessary, place a sandbag against the plantar surface of the foot to immobilize it in the correct position.
- *Shield gonads.*

Central ray

- Perpendicular to the center of the leg.

Collimation

- Adjust the radiation field to 1 inch (2.5 cm) on the sides and 1½ inches (3.8 cm) beyond the ankle and knee joints. Place a side marker in the collimated exposure field.

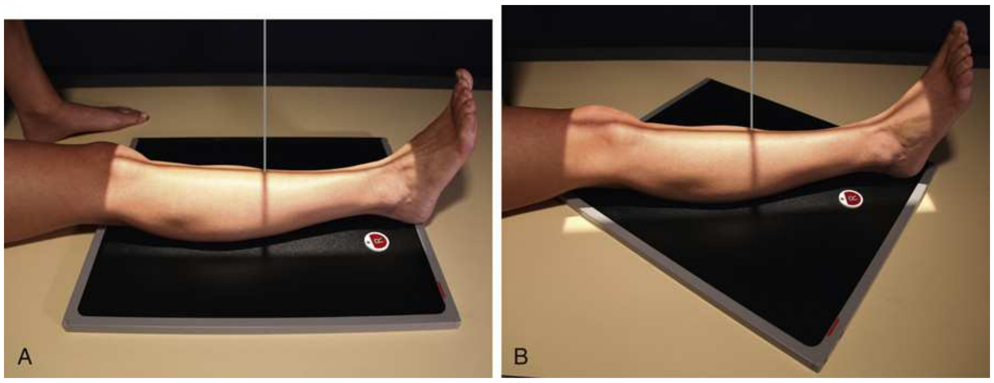

FIG. 7.111 AP tibia and fibula. (A) Performed lengthwise on IR. (B) Performed diagonal on the IR.

(A) A patient is in a supine position. The femoral condyles are parallel with the image receptor. The ankle is flexed and the foot is in the vertical position. The side marker is in the collimated exposure field. The central ray is perpendicular to the center of the leg. (B) A patient is in a supine position. The femoral condyles are parallel with the image receptor. The ankle is flexed. The foot is in the vertical position on the image receptor placed diagonally. The side marker is in the collimated exposure field. The central ray is perpendicular to the center of the leg.

Structures shown

The tibia, fibula, and adjacent joints (Fig. 7.112).

Evaluation Criteria

The following should be clearly seen:

- Evidence of proper collimation and the presence of a side marker placed clear of the anatomy of interest
- Ankle and knee joints on one or more images
- Entire leg without rotation
  - Proximal and distal articulations of the tibia and fibula moderately overlapped
  - Fibular midshaft free of tibial superimposition
- Bony trabecular detail and surrounding soft tissues

FIG. 7.112 (A) AP tibia and fibula. Long leg length prevented showing entire leg. A separate knee projection had to be performed on this patient. (B) Short leg length allowed the entire leg to be shown. A spiral fracture of distal tibia with accompanying spiral fracture of proximal fibula *(arrows)* is seen. This radiograph shows the importance of including the entire length of a long bone in trauma cases. (C) AP tibia and fibula on a 4-year-old with neurofibromatosis.

(A) An x-ray shows the tibia, fibula, and adjacent joints. The parts labeled are as follows: fibula, tibia, medial malleolus, and lateral malleolus. (B) An x-ray shows the spiral fracture of the distal tibia and the spiral fracture of the proximal fibula. It is marked by two white arrows. (C) An x-ray shows the tibia and fibula bent outwards to the left.

Lateral Projection

Mediolateral

Image receptor:

Positioned by manufacturer or department protocol for proper anatomy display orientation; CR plate: 14 × 17 inches (35 × 43 cm) lengthwise or diagonal.

Position of patient

- Place the patient in the supine position.

Position of part

- Turn the patient toward the affected side with the leg on the IR.
- Adjust the rotation of the body to place the patella perpendicular to the IR and ensure that a line drawn through the femoral condyles is also perpendicular (Fig. 7.113).
- Place sandbag supports where needed for the patient's comfort and to stabilize the body position (Fig. 7.113A).
- The knee may be flexed, if necessary, to ensure a true lateral position.
- The projection may be done with IR diagonal to include the ankle and knee joints or two projections are made—one of the leg to include a joint, and one to include the other joint.

Alternative method

- When the patient cannot be turned from the supine position, the lateromedial lateral projection may be taken cross-table using a horizontal central ray.
- Lift the leg high enough for an assistant to slide a rigid support under the patient's leg.

- The IR may be placed between the legs, and the central ray may be directed from the lateral side.
- *Shield gonads.*

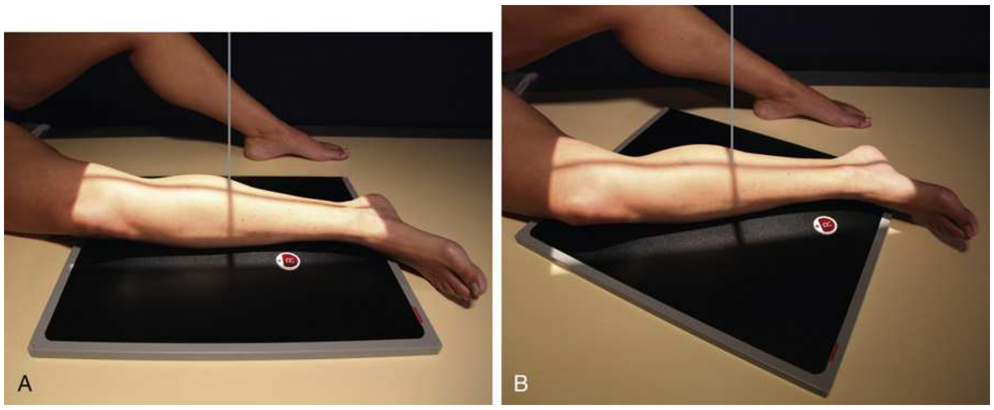

FIG. 7.113 Lateral tibia and fibula. (A) Performed lengthwise on the IR. (B) Performed diagonal on the IR.

(A) A patient is in the supine position. The knee is flexed and the patella is placed perpendicular to the image receptor. The side marker is in the collimated exposure field. The central ray is perpendicular to the midpoint of the leg. (B) A patient is in the supine position. The knee is flexed and the patella is placed perpendicular to the image receptor placed diagonally. The side marker is in the collimated exposure field. The central ray is perpendicular to the midpoint of the leg.

Central ray

- Perpendicular to the midpoint of the leg.

Collimation

- Adjust the radiation field to 1 inch (2.5 cm) on the sides and 1½ inches (3.8 cm) beyond the ankle and knee joints. Place side marker in the collimated exposure field.

Structures shown

The tibia, fibula, and adjacent joints (Fig. 7.114).

Evaluation Criteria

The following should be clearly seen:

- Evidence of proper collimation and the presence of a side marker placed clear of the anatomy of interest
- Ankle and knee joints on one or more images
- Entire leg in true lateral position
  - Distal fibula superimposed by the posterior half of the tibia
  - Slight overlap of the tibia on the proximal fibular head
  - Moderate separation of the tibial and fibular bodies or shafts (except at their articular ends)
- Possibly reduced superimposition of femoral condyles because of divergence of the beam
- Bony trabecular detail and surrounding soft tissues

FIG. 7.114 (A) and (B) Lateral tibia and fibula. (C) Lateral postreduction tibia and fibula showing the fixation device. The leg was too long to fit on one image.

(A) An x-ray shows the tibia, fibula, and adjacent joints. There is a slight overlap of the tibia on the proximal fibular head. The parts labeled are as follows: patella, femoral condyles, tibia, fibula, and medial malleolus. (B) An x-ray shows the tibia, fibula, and adjacent joints. The patella appears radiopaque. (B) An x-ray shows the tibia, fibula with three screws.

AP Oblique Projection

Medial and lateral rotations

Image receptor:

Positioned by manufacturer or department protocol for proper anatomy display orientation; CR plate: 14 × 17 inches (35 × 43 cm) lengthwise or diagonal.

Position of patient

- Place the patient in the supine position on the radiographic table.

Position of part

- Perform oblique projections of the leg by alternately rotating the extremity 45 degrees medially (Fig. 7.115) or laterally (Fig. 7.116). For the medial rotation, ensure that the *leg* is turned inward, not just the foot.
- For the medial oblique projection, elevate the affected hip enough to rest the medial side of the foot and ankle against a 45-degree foam wedge, and place a support under the greater trochanter.
- *Shield gonads.*

Central ray

- Perpendicular to the midpoint of the IR.

FIG. 7.115 AP oblique leg, medial rotation.

A patient is in the supine position and the leg is rotated medially. The medially rotated leg is placed on the image receptor. The side marker is in the collimated exposure field. The central ray is perpendicular to the midpoint of the I R.

FIG. 7.116 AP oblique leg, lateral rotation.

A patient is in the supine position. The leg is rotated laterally and turned inward. The laterally rotated leg is placed on the image receptor. The side marker is in the collimated exposure field. The central ray is perpendicular to the midpoint of the I R.

Collimation

- Adjust the radiation field to 1 inch (2.5 cm) on the sides and 1½ inches (3.8 cm) beyond the ankle and knee joints. Place a side marker in the collimated exposure field.

Structures shown

A 45-degree oblique projection of the bones and soft tissues of the leg and one or both of the adjacent joints (Figs. 7.117 and 7.118).

Evaluation Criteria

The following should be clearly seen:

- Evidence of proper collimation and the presence of a side marker placed clear of the anatomy of interest
- Ankle and knee joints on one or more images

- Bony trabecular detail and surrounding soft tissues

Medial rotation

- Proper rotation of leg
  - Proximal and distal tibiofibular articulations
  - Maximum interosseous space between the tibia and fibula

Lateral rotation

- Proper rotation of leg
  - Fibula superimposed by lateral portion of tibia

FIG. 7.117 AP oblique leg, medial rotation, showing the fixation device.

FIG. 7.118 AP oblique leg, lateral rotation, with the fixation device in place.

Knee

AP Projection

Radiographs of the knee may be taken with or without the use of a grid, although a grid is most often used. Factors to consider in reaching a decision are the size of the patient's knee and the preference of the radiographer and physician.

Image receptor + grid:

Positioned by manufacturer or department protocol for proper anatomy display orientation; CR plate: 10 × 12 inches (24 × 30 cm) lengthwise.

Position of patient

- Place the patient in the supine position and adjust the body so that the pelvis is not rotated.

Position of part

- With the IR under the patient's knee, flex the joint slightly, locate the apex of the patella, and as the patient extends the knee, center the IR about ½ inch (1.3 cm) below the patellar apex. This centers the IR to the joint space.
- Adjust the patient's leg by placing the femoral epicondyles parallel with the IR for a true AP projection (Fig. 7.119). The patella lies slightly off center to the medial side. If the knee cannot be fully extended, a curved IR may be used.

• *Shield gonads.*

Central ray

• Directed to a point ½ inch (1.3 cm) inferior to the patellar apex.
• Variable, depending on the measurement between the anterior superior iliac spine (ASIS) and the tabletop (Fig. 7.120), as follows: [18]

<19 cm	3–5 degrees *caudad* (thin pelvis)
19–24 cm	0 degrees
>24 cm	3–5 degrees *cephalad* (large pelvis)

Collimation

• Adjust the radiation field to 8 × 10 inches (18 × 24 cm) on the collimator. Adjust to 1 inch (2.5 cm) beyond the sides. Place side marker in the collimated exposure field.

Structures shown

An AP projection of the knee structures (Fig. 7.121).

Evaluation Criteria

The following should be clearly seen:

- Evidence of proper collimation and the presence of a side marker placed clear of the anatomy of interest
- Knee fully extended if patient's condition permits
- Entire knee without rotation
  - Femoral condyles symmetric and tibia intercondylar eminence centered
  - Slight superimposition of the fibular head if the tibia is normal
  - Patella completely superimposed on the femur
  - Open femorotibial joint space, with interspaces of equal width on both sides if the knee is normal
  - Bony trabecular detail and surrounding soft tissues

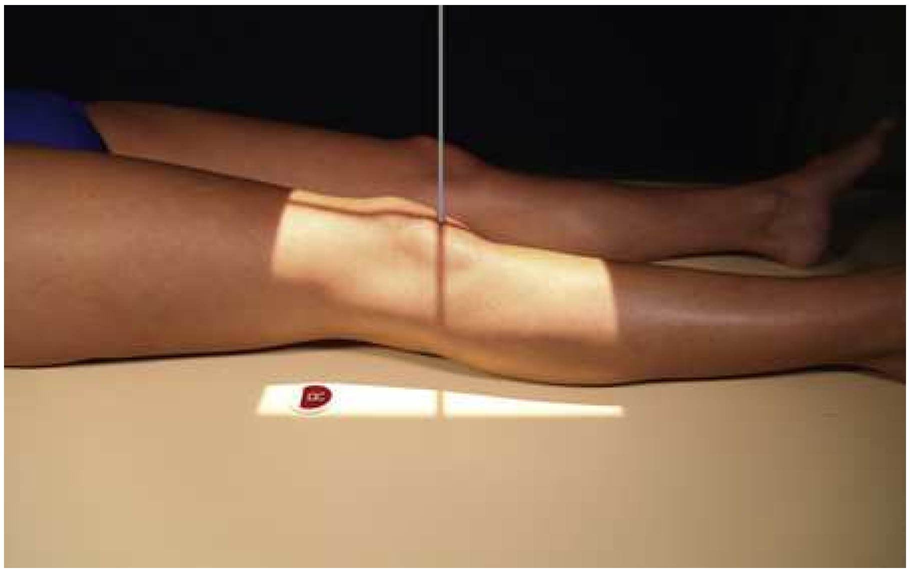

FIG. 7.119 AP knee.

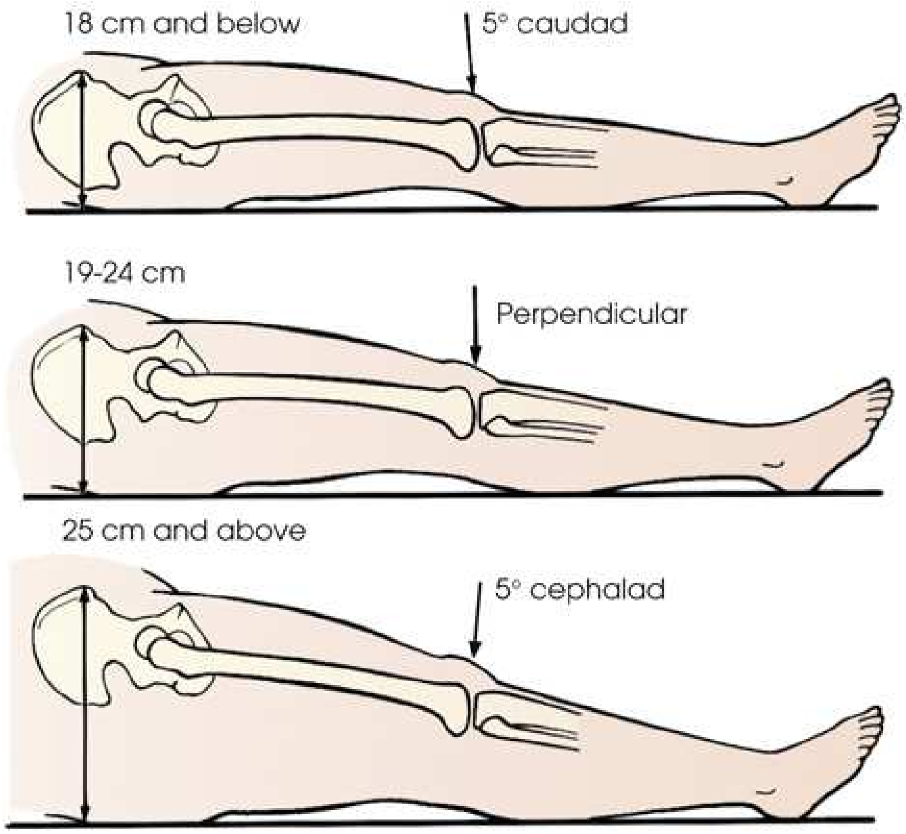

FIG. 7.120 Pelvic thickness and CR angles for AP knee radiographs. Modified from Martensen KM. Alternate AP knee method assures open joint space. *Radiol Technol.* 1992;64:19.

The first diagram shows a patient's leg extended in the supine position. The central ray is directed 18 centimeters and below in the thigh and 5 degrees caudad on the patella. The second diagram shows a patient's leg extended in the supine position. The central ray is directed 19 to 24 centimeters in the thigh and perpendicular to the patella. The third diagram shows a patient's leg extended in the supine position. The central ray is directed 25 centimeters and above in the thigh and 5 degrees cephalad on the patella.

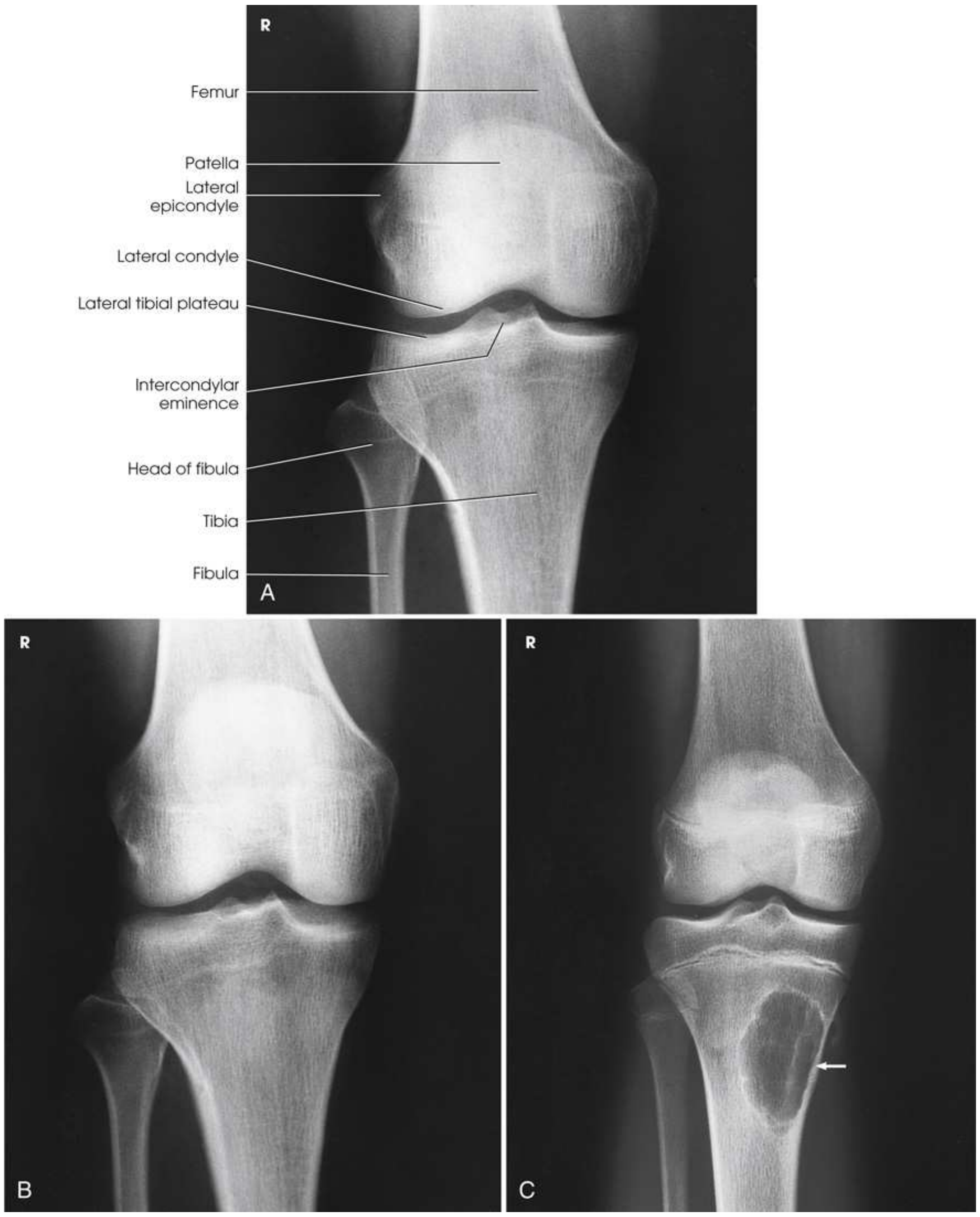

FIG. 7.121 (A) AP knee with CR angled 5 degrees cephalad. Patient's ASIS-to-tabletop distance was greater than 25 cm. (B) Same patient as in (A) with the CR perpendicular. Note that joint space is not opened as well. (C) AP knee on a 15-year-old. *Arrow* is pointing to a benign lesion in the tibia.

(A) An x-ray shows the knee structures. The parts labeled are as follows: femur, patella, lateral epicondyle, lateral condyle, lateral tibial plateau, intercondylar eminence, head of the fibula, tibia, and fibula. (B) An x-ray shows the knee structures. The patella is round and appears faded. (C) An x-ray shows the knee structures. An arrow points to a circular dark region in the tibia.

PA Projection

Image receptor + grid:

Positioned by manufacturer or department protocol for proper anatomy display orientation; CR plate: 10 × 12 inches (24 × 30 cm) lengthwise.

Position of patient

- Place the patient in the prone position with toes resting on the radiographic table, or place sandbags under the ankle for support.

Position of part

- Center a point ½ inch (1.3 cm) below the patellar apex to the center of the IR, and adjust the patient's leg so that the femoral epicondyles are parallel with the tabletop. Because the knee is balanced on the medial side of the obliquely located patella, care must be used in adjusting the knee (Fig. 7.122).
- *Shield gonads.*

Central ray

• Directed at an angle of 5 to 7 degrees caudad to exit a point ½ inch (1.3 cm) inferior to the patellar apex. Because the tibia and fibula are slightly inclined, the central ray is parallel with the tibial plateau. A perpendicular CR may be needed for patients with large thighs or when the foot is dorsiflexed.

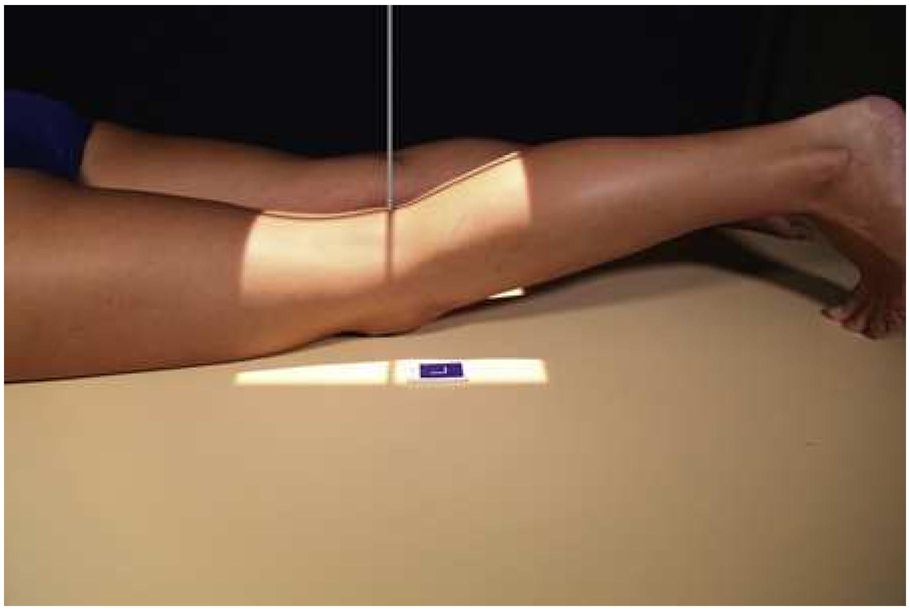

FIG. 7.122 PA knee.

A patient is lying in the prone position with toes resting on the image receptor. The knee is balanced on the medial side of the obliquely placed patella. The side marker is in the collimated exposure field. The central ray is directed at an angle of 5 to 7 degrees caudad.

Collimation

• Adjust the radiation field to 8 × 10 inches (18 × 24 cm) on the collimator. Adjust to 1 inch (2.5 cm) beyond the sides. Place side marker in the collimated exposure field.

Structures shown

A PA projection of the knee (Fig. 7.123).

Evaluation Criteria

The following should be clearly seen:

- Evidence of proper collimation and the presence of a side marker placed clear of the anatomy of interest
- Open the femorotibial joint space with interspaces of equal width on both sides if the knee is normal
- Knee fully extended if the patient's condition permits
- No rotation of the femur if the tibia is normal
- Slight superimposition of the fibular head with the tibia
- Bony trabecular detail and surrounding soft tissues

FIG. 7.123 PA knee.

An x-ray shows the knee joint with open femorotibial joint space with interspaces of equal width on both sides. The joint space appears dark. The parts labeled are as follows: femur, tibial plateau, tibia, and fibula.

Lateral Projection

Mediolateral

Image receptor + grid:

Positioned by manufacturer or department protocol for proper anatomy display orientation; CR plate: 10 × 12 inches (24 × 30 cm) lengthwise.

Position of patient

- Ask the patient to turn onto the affected side. Ensure that the pelvis is not rotated.
- For a standard lateral projection, have the patient bring the affected knee forward and extend the other extremity behind it (Fig. 7.124). The other extremity may also be placed in front of the affected knee on a support block.

Position of part

- Flexion of 20 to 30 degrees is usually preferred because this position relaxes the muscles and shows the maximum volume of the joint cavity. [19]
- To prevent fragment separation in new or unhealed patellar fractures, the knee should not be flexed more than 10 degrees.

- Place a support under the ankle.
- Grasp the epicondyles and adjust them so that they are perpendicular to the IR (condyles superimposed). The patella is perpendicular to the plane of the IR (Fig. 7.125).
- *Shield gonads.*

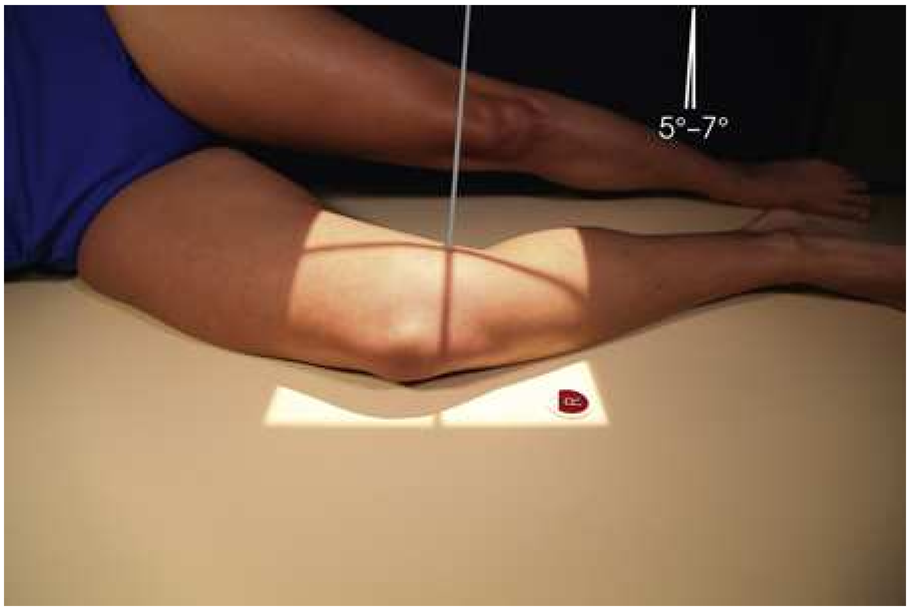

FIG. 7.124 Lateral knee showing a 5-degree cephalad angulation of CR.

A patient is lying on the side. One knee is brought forward and the other knee is extended behind it. The side marker is in the collimated exposure field. The central ray is directed at an angle of 5 to 7 degrees cephalad.

FIG. 7.125 (A) Improperly positioned lateral knee. Note that condyles are not superimposed *(black arrows)*, and the patella is a closed joint *(white arrow)*. (B) Same patient as in (A) after correct positioning. The condyles are superimposed, and the patellofemoral joint is open.

(A) An x-ray image of the distal end of the femur, patella, knee joint, proximal ends of the tibia and fibula. Two black arrows point at the condyles and a white arrow points at the patella. The patella appears closed. (B) An x-ray image of the distal end of the femur, patella, knee joint, proximal ends of the tibia and fibula, and the other soft tissues. There is a gap between the femur and the patella.

Central ray

- Directed to the knee joint 1 inch (2.5 cm) distal to the medial epicondyle at an angle of 5 to 7 degrees cephalad. This slight angulation of the central ray prevents the joint space from being obscured by the magnified image of the medial femoral condyle. In addition, in the lateral recumbent position, the medial condyle is slightly inferior to the lateral condyle.
- Center the IR to the central ray.

Collimation

- Adjust the radiation field to 8 × 10 inches (18 × 24 cm) on the collimator. Adjust to 1 inch (2.5 cm) anterior to the patella and 1 inch (2.5 cm) beyond the posterior shadow. Place side marker in the collimated exposure field.

Structures shown

A lateral image of the distal end of the femur, patella, knee joint, proximal ends of the tibia and fibula, and adjacent soft tissue (Fig. 7.126).

Evaluation Criteria

The following should be clearly seen:

- Evidence of proper collimation and the presence of a side marker placed clear of the anatomy of interest
- Knee flexed 20 to 30 degrees in true lateral position as demonstrated by femoral condyles superimposed (locate the more magnified medial condyle)
  - Anterior surface of medial condyle closer to patella results from over-rotation toward the image receptor (IR).
  - Anterior surface of medial condyle farther from patella results from under-rotation away from the IR.
  - Inferior surface of medial condyle caudal to lateral condyle results from insufficient cephalad central ray (CR) angle.
  - Inferior surface of lateral condyle caudal to medial condyle results from too much cephalad CR angle.
- Fibular head and tibia slightly superimposed (overrotation causes less superimposition, and under-rotation causes more superimposition)
- Patella in a lateral profile
- Open patellofemoral joint space
- Open joint space between femoral condyles and tibia
- Bony trabecular detail and surrounding soft tissues

FIG. 7.126 (A) Lateral knee. (B) Lateral knee showing severe arthritis.

(A) An x-ray shows the distal end of the femur, patella, knee joint, proximal ends of the tibia and fibula and the other soft tissues. There is a gap between the femur and the patella. The parts labeled are as follows: femur, femoral condyles, patella, tibial plateau, tibia, fibula. (B) shows deterioration in the knee joint. It appears hazy.

Knees

AP Projection

Weight-Bearing Method

Standing

Leach et al. [20] recommended that a bilateral weight-bearing AP projection be routinely included in radiographic examination of arthritic knees. They found that a weight-bearing study often reveals narrowing of a joint space that appears normal on a non–weight-bearing study.

Image receptor + grid:

Positioned by manufacturer or department protocol for proper anatomy display orientation; CR plate: 14 × 17 inches (35 × 43 cm) crosswise for bilateral image.

Position of patient

- Place the patient in the upright position with the back toward a vertical grid device.

Position of part

- Adjust the patient's position to center the knees to the IR.
- Place the toes straight ahead, with the feet separated enough for good balance.
- Ask the patient to stand straight with knees fully extended and weight equally distributed on the feet.
- Center the IR ½ inch (1.3 cm) below the apices of the patellae (Fig. 7.127).
- *Shield gonads.*

Central ray

- Horizontal and perpendicular to the center of the IR, entering at a point ½ inch (1.3 cm) below the apices of the patellae.

Collimation

- Adjust the radiation field to 14 × 17 inches (35 × 43 cm) on the collimator. Adjust to 1 inch (2.5 cm) beyond the sides. Place a side marker in the collimated exposure field.

Structures shown

The joint spaces of the knees. Varus and valgus deformities can also be evaluated with this procedure (Fig. 7.128).

Evaluation Criteria

The following should be clearly seen:

- Evidence of proper collimation and the presence of a side marker placed clear of the anatomy of interest
- Both knees without rotation
- Knee joint spaces centered to the exposure area
- Bony trabecular detail and surrounding soft tissues

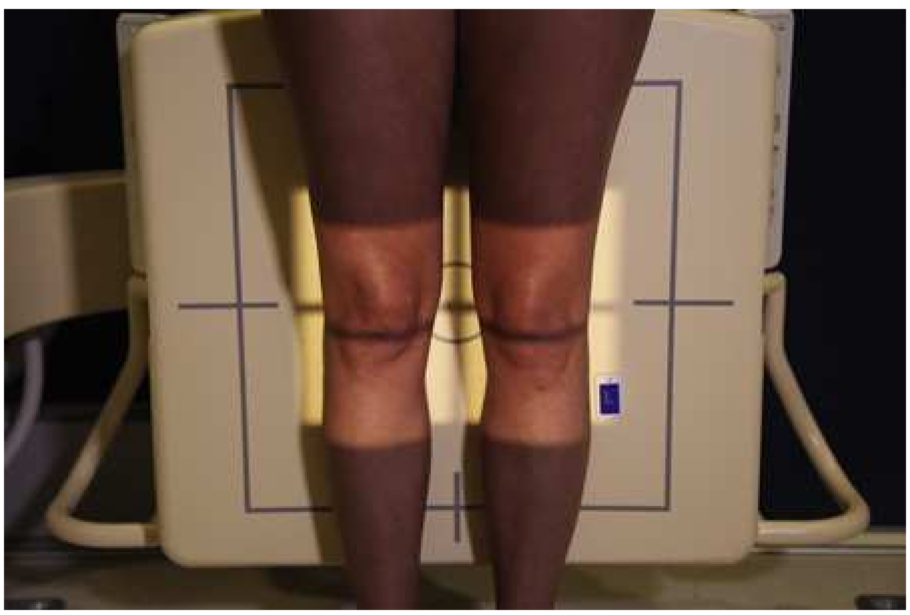

FIG. 7.127 AP bilateral weight-bearing knees.

A patient standing straight with back towards the vertical grid. The knees are fully extended. The side marker is in the collimated exposure field. The central ray is horizontal and perpendicular to the center of the I R, entering below the apices of the patellae.

FIG. 7.128 (A) AP bilateral weight-bearing knees. (B) Right knee has undergone total knee arthroplasty.

(A) An x-ray shows the joint spaces of both knees. The parts are labeled are as follows: femur, patella, joint space, tibia, fibula. (B) An x-ray shows a white region with a pointy end facing downwards on the right knee cap.

PA Projection

Rosenberg Method [21]

Weight-Bearing

Standing flexion

Image receptor + grid:

Positioned by manufacturer or department protocol for proper anatomy display orientation; CR plate: 14 × 17 inches (35 × 43 cm) crosswise for bilateral knees.

Position of patient

- Place the patient in the standing position with the anterior aspect of the knees centered to the vertical grid device.

Position of part

- For a direct PA projection, have the patient stand upright with the knees in contact with the vertical grid device.
- Center the IR at a level ½ inch (1.3 cm) below the apices of the patellae.
- Have the patient grasp the edges of the grid device and flex the knees to place the femora at an angle of 45 degrees (Fig. 7.129).
- *Shield gonads.*

Central ray

- Horizontal and perpendicular to the center of the IR, entering at the midpopliteal area and exiting ½ inch (1.3 cm) below the patellar apex. The central ray is perpendicular to the tibia and fibula. A 10-degree caudal angle is sometimes used.

Collimation

- Adjust the radiation field to 14 × 17 inches (35 × 43 cm) on the collimator. Adjust to 1 inch (2.5 cm) beyond the sides. Place a side marker in the collimated exposure field.

Structures shown

The PA weight-bearing method is useful for evaluating joint space narrowing and showing articular cartilage disease on the posterior surface of the femoral condyles (Fig. 7.130). The image is similar to radiographs of the intercondylar fossa.

Evaluation criteria

The following should be clearly seen:

- Evidence of proper collimation and the presence of a side marker placed clear of the anatomy of interest
- Both knees without rotation
- Knee joints centered to exposure area
- Tibial plateaus in profile
- Intercondylar fossae visible
- Bony trabecular detail and surrounding soft tissues

NOTE: For a weight-bearing study of a single knee, the patient puts full weight on the affected side. The patient may balance with slight pressure on the toes of the unaffected side.

FIG. 7.129 PA projection with patient's knees flexed 45 degrees and using perpendicular CR.

A patient is standing with knees flexed and the anterior aspect of the knees centered to the vertical grid device. The side marker is in the collimated exposure field. The central ray is perpendicular to the tibia and fibula.

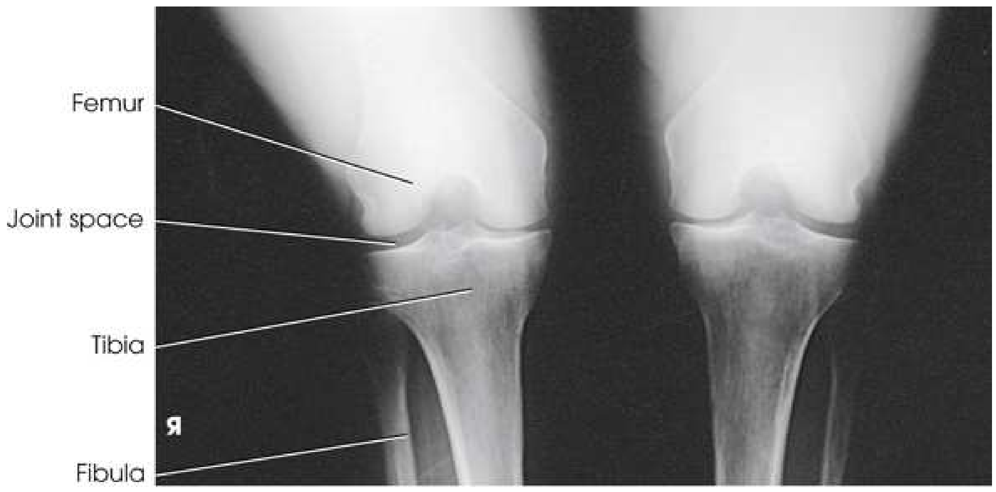

FIG. 7.130 PA projection with knees flexed 45 degrees and CR directed 10 degrees caudad.

Knee

AP Oblique Projection

Lateral rotation

Image receptor + grid:

Positioned by manufacturer or department protocol for proper anatomy display orientation; CR plate: 10 × 12 inches (24 × 30 cm) lengthwise.

Position of patient

- Place the patient on the radiographic table in the supine position and support the ankles.

Position of part

- If necessary, elevate the hip of the *unaffected* side enough to rotate the affected extremity.
- Support the elevated hip and knee of the unaffected side (Fig. 7.131).
- Center the IR ½ inch (1.3 cm) below the apex of the patella.

- Externally rotate the extremity 45 degrees.
- *Shield gonads.*

Central ray

•Directed ½ inch (1.3 cm) inferior to the patellar apex. The angle is variable, depending on the measurement between the ASIS and the tabletop, as follows:

<19 cm	3–5 degrees *caudad*
19–24 cm	0 degrees
>24 cm	3–5 degrees *cephalad*

Collimation

- Adjust the radiation field to 8 × 10 inches (18 × 24 cm) on the collimator. Adjust to 1 inch (2.5 cm) beyond the sides. Place a side marker in the collimated exposure field.

Structures shown

An AP oblique projection of the laterally rotated femoral condyles, patella, tibial condyles, and head of the fibula (Fig. 7.132).

Evaluation Criteria

The following should be clearly seen:

- Evidence of proper collimation and the presence of a side marker placed clear of the anatomy of interest
- Medial femoral and tibial condyles
- Tibial plateaus
- Fibula superimposed over the lateral half of the tibia
- Margin of the patella projected slightly beyond the edge of the lateral femoral condyle
- Open knee joint
- Bony trabecular detail and surrounding soft tissues

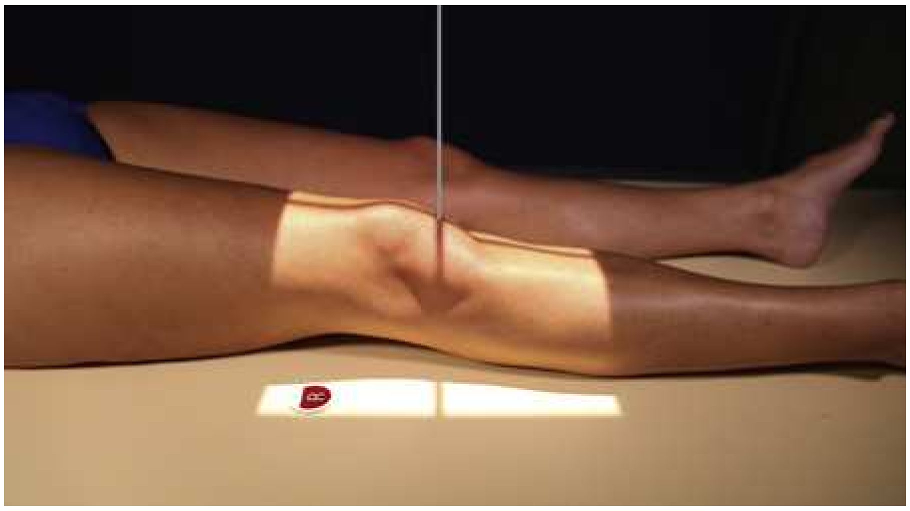

FIG. 7.131 AP oblique knee, lateral rotation.

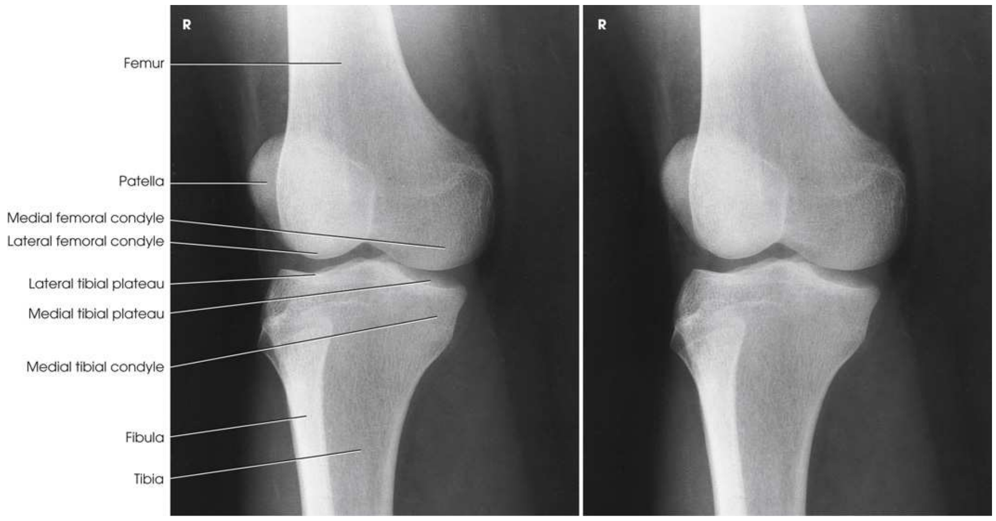

FIG. 7.132 AP oblique knee.

Two x-ray views show the femoral condyles, patella, tibial condyles, and head of the fibula. The knee joints are open and the joint space is prominent and dark. The parts labeled are as follows: femur, patella, medial femoral condyle, lateral femoral condyle, lateral tibial plateau, medial tibial plateau, medial tibial condyle, fibula, tibia.

AP Oblique Projection

Medial rotation

Image receptor + grid:

Positioned by manufacturer or department protocol for proper anatomy display orientation; CR plate: 10 × 12 inches (24 × 30 cm) lengthwise.

Position of patient

- Place the patient on the table in the supine position and support the ankles.

Position of part

- Medially rotate the extremity and elevate the hip of the affected side enough to rotate the extremity 45 degrees.
- Place a support under the hip, if needed (Fig. 7.133).
- *Shield gonads.*

Central ray

- Directed ½ inch (1.3 cm) inferior to the patellar apex; the angle is variable, depending on the measurement between the ASIS and the tabletop, as follows:

<19 cm	3–5 degrees *caudad*
19–24 cm	0 degrees
>24 cm	3–5 degrees *cephalad*

Collimation

- Adjust the radiation field to 8 × 10 inches (18 × 24 cm) on the collimator. Adjust to 1 inch (2.5 cm) beyond the sides. Place a side marker in the collimated exposure field.

Structures shown

An AP oblique projection of the medially rotated femoral condyles, patella, tibial condyles, proximal tibiofibular joint, and head of the fibula (Fig. 7.134).

Evaluation Criteria

The following should be clearly seen:

- Evidence of proper collimation and the presence of a side marker placed clear of the anatomy of interest
- Tibia and fibula separated at their proximal articulation
- Posterior tibia
- Lateral condyles of the femur and tibia
- Both tibial plateaus
- Margin of the patella projecting slightly beyond the medial side of the femoral condyle
- Open knee joint
- Bony trabecular detail and surrounding soft tissues

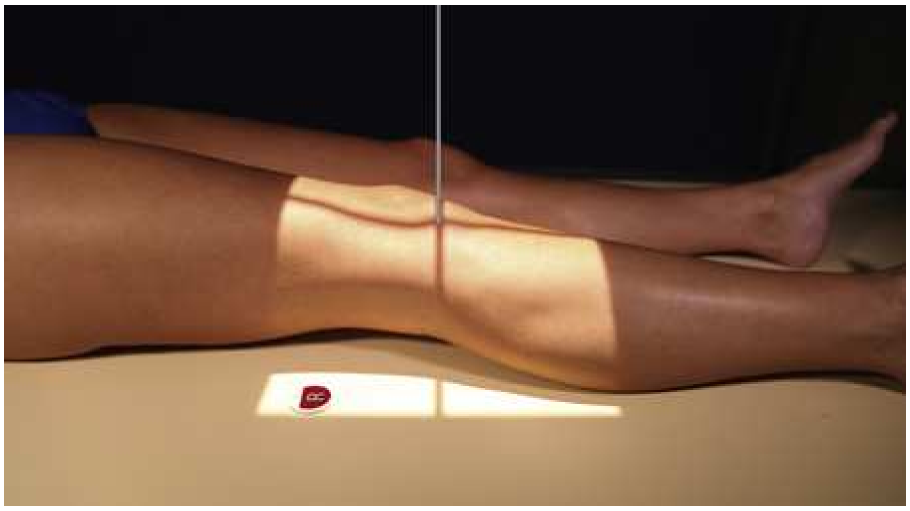

FIG. 7.133 AP oblique knee, medial rotation.

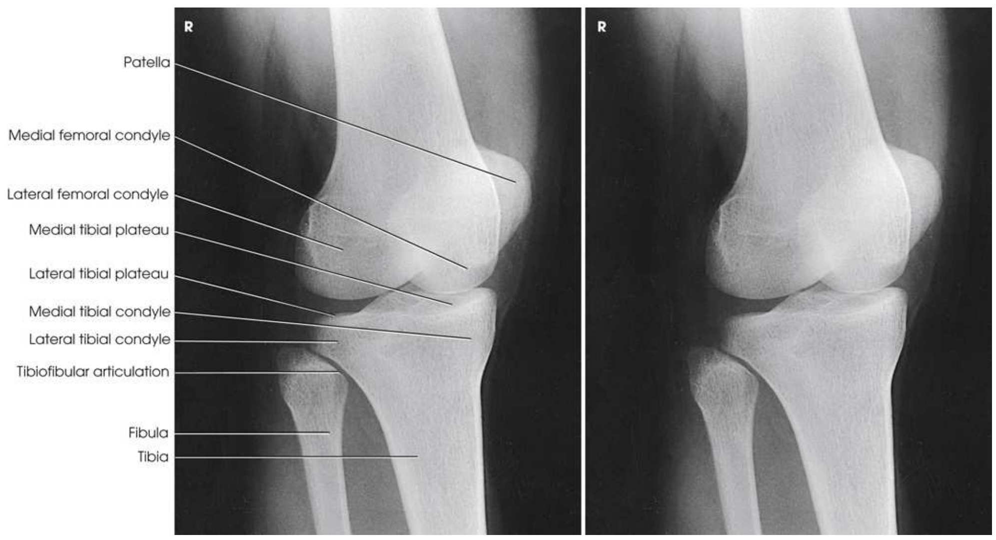

FIG. 7.134 AP oblique knee.

An x-ray shows the tibia and fibula separated at their proximal articulation. The knee joint is open. It appears grainy. The parts labeled are as follows: patella, medial femoral condyle, lateral femoral condyle, medial tibial plateau, lateral tibial plateau, medial tibial condyle, lateral tibial condyle, tibiofibular articulation, fibula, tibia.

Intercondylar Fossa

PA Axial Projection

Holmblad Method

The PA axial, or *tunnel,* projection, first described by Holmblad [22] in 1937, required that the patient assume a kneeling position on the radiographic table. In 1983, the Holmblad method [23] was modified so that if the patient's condition allowed, a standing position could be used.

Image receptor:

Positioned by manufacturer or department protocol for proper anatomy display orientation; CR plate: 10 × 12 inches (24 × 30 cm) lengthwise.

Position of patient

- After consideration of the patient's safety, place the patient in one of three positions: (1) standing with the knee of interest flexed and resting on a stool at the side of the radiographic table (Fig. 7.135); (2) standing at the side of the radiographic table with the affected knee flexed and placed in contact with the front of the IR (Fig. 7.136); or (3) kneeling on the radiographic table, as originally described by Holmblad, with the affected knee over the IR (Fig. 7.137). In all three approaches, the tibial portion of the knee is in contact with the IR, and the patient's upper body is stabilized with an appropriate support.

FIG. 7.135 PA axial intercondylar fossa, upright with the knee on a stool.

A patient is standing on one leg with the other knee flexed and resting on a stool at the side of the radiographic table. The side marker is in the collimated exposure field. The central ray is perpendicular to the lower leg, entering the superior aspect of the popliteal fossa.

FIG. 7.136 PA axial intercondylar fossa, standing using the horizontal CR.

A patient is standing at the side of the radiographic table with one knee flexed and placed in contact with the front of the I R. The side marker is in the collimated exposure field. The central ray is perpendicular to the lower leg, entering the superior aspect of the popliteal fossa.

FIG. 7.137 PA axial intercondylar fossa, kneeling on a radiographic table: original Holmblad method.

A patient is kneeling on the radiographic table. One knee is on the image receptor and the other knee is placed outside. The side marker is in the collimated exposure field. The central ray is perpendicular to the lower leg, entering the superior aspect of the popliteal fossa.

Position of part

- For all positions, place the IR against the anterior surface of the patient's knee, and center the IR to the apex of the patella. Flex the knee 70 degrees from full extension (20-degree difference from the central ray, as shown in Fig. 7.138).
- *Shield gonads.*

Central ray

- Perpendicular to the lower leg, entering the superior aspect of the popliteal fossa and exiting at the level of the patellar apex, for all three positions.

Collimation

• Adjust the radiation field to 8 × 10 inches (18 × 24 cm) on the collimator. Adjust to 1 inch (2.5 cm) beyond the sides. Place side marker in the collimated exposure field.

Structures shown

The intercondylar fossa and posteroinferior articular surfaces of the condyles of the femur, as well as the medial and lateral intercondylar tubercles of the intercondylar eminence and tibial plateaus in profile (Fig. 7.139). Holmblad [22] stated that the degree of flexion used in this position widens the joint space between the femur and tibia and gives an improved image of the joint and the surfaces of the tibia and femur.

Evaluation Criteria

The following should be clearly seen:

- Evidence of proper collimation and the presence of a side marker placed clear of the anatomy of interest
- Open intercondylar fossa
- Posteroinferior surface of the femoral condyles
- Knee joint space open, with one or both tibial plateaus in profile (superimposed anterior and posterior surfaces)
- Apex of the patella not superimposing the fossa
- No rotation, demonstrated by slight tibiofibular overlap and centered intercondylar eminence
- Bony trabecular detail and surrounding soft tissues

Note: The bilateral examination (Rosenberg method) is described on p. 353 (also see Fig. 7.130).

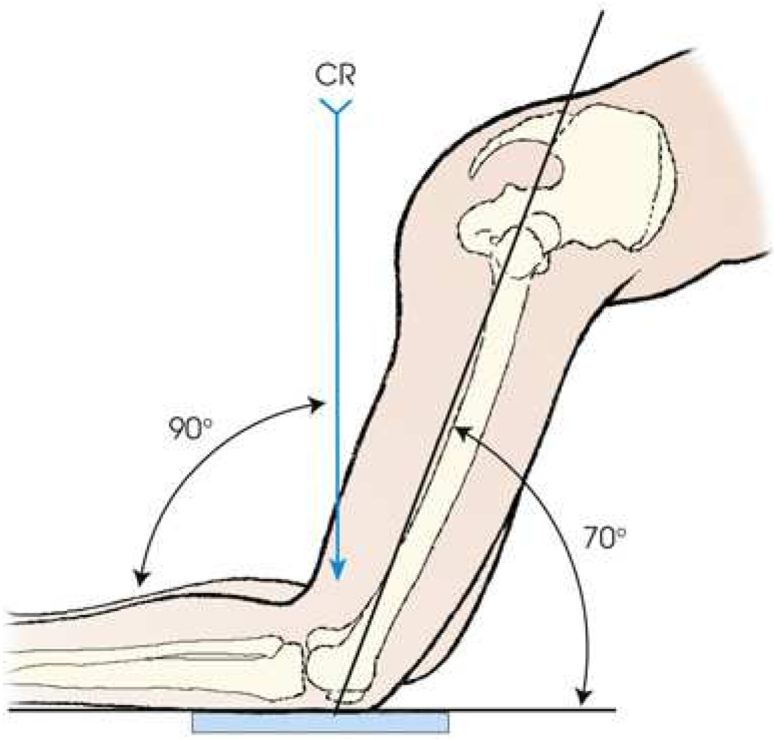

FIG. 7.138 Alignment relationship for any of three intercondylar fossa approaches: Holmblad method. CR is perpendicular to the tibia–fibula.

Diagram shows a patient kneeling on the radiographic table. The anterior surface of the knee is on the image receptor. The knee is flexed 70 degrees from full extension and 90 degrees at the back. The central ray is perpendicular to the lower leg, entering the superior aspect of the popliteal fossa.

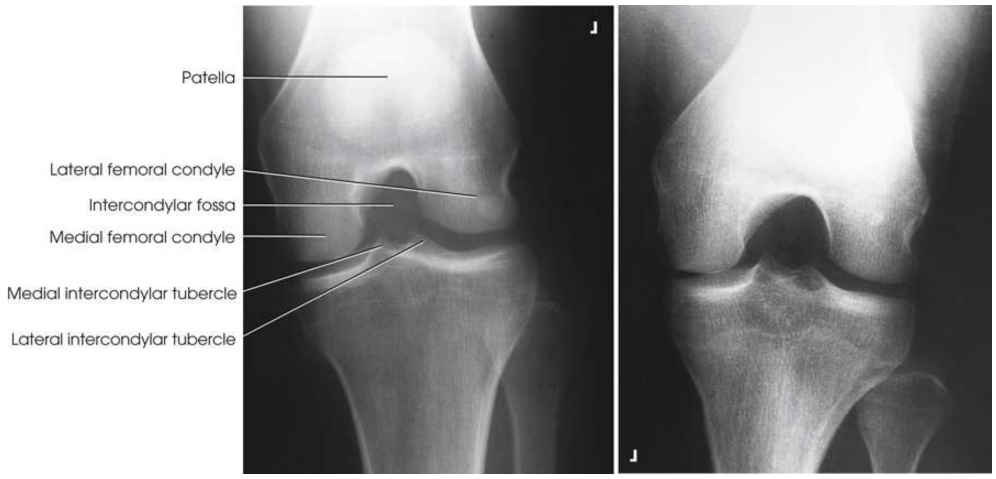

FIG. 7.139 PA axial (tunnel) intercondylar fossa: Holmblad method.

Two x-ray views show the open intercondylar fossa. It appears like a small arch. The patella appears radiopaque. The parts labeled are as follows: patella, lateral femoral condyle, intercondylar fossa, medial femoral condyle, medial intercondylar tubercle, lateral intercondylar tubercle.

PA Axial Projection

Camp-Coventry Method [24]

Image receptor:

Positioned by manufacturer or department protocol for proper anatomy display orientation; CR plate: 10 × 12 inches (24 × 30 cm) lengthwise.

Position of patient

- Place the patient in the prone position, and adjust the body so that it is not rotated.

Position of part

- Flex the patient's knee to a 40- or 50-degree angle, place the femoral portion of the knee on the IR, and rest the foot on a suitable support.
- Center the upper half of the IR to the knee joint; the central ray angulation projects the joint to the center of the IR (Figs. 7.140 and 7.141).
- A protractor may be used beside the leg to determine the correct leg angle.
- Adjust the leg so that the knee has no medial or lateral rotation.
- *Shield gonads.*

Central ray

- Perpendicular to the long axis of the lower leg, entering the popliteal fossa and exiting at the patellar apex.
- Angled 40 degrees when the knee is flexed 40 degrees and 50 degrees when the knee is flexed 50 degrees.

Collimation

- Adjust the radiation field to 8 × 10 inches (18 × 24 cm) on the collimator. Adjust to 1 inch (2.5 cm) beyond the sides. Place a side marker in the collimated exposure field.

Structures shown

The intercondylar fossa and posteroinferior articular surfaces of the condyles of the femur, as well as the medial and lateral intercondylar tubercles of the intercondylar eminence and tibial plateaus in profile (Figs. 7.142 and 7.143).

Evaluation Criteria

The following should be clearly seen:

- Evidence of proper collimation and the presence of a side marker placed clear of the anatomy of interest
- Open intercondylar fossa
- Posteroinferior surface of the femoral condyles

- Knee joint space open, with one or both tibial plateaus in profile (superimposed anterior and posterior surfaces)
- Apex of the patella not superimposing the fossa
- No rotation, demonstrated by slight tibiofibular overlap and centered intercondylar eminence
- Bony trabecular detail and surrounding soft tissues

NOTE: In examinations of the knee joint, an intercondylar fossa projection may be included to detect loose bodies ("joint mice"). This projection is also used in evaluating split and displaced cartilage in osteochondritis dissecans and flattening, or underdevelopment, of the lateral femoral condyle in congenital slipped patella.

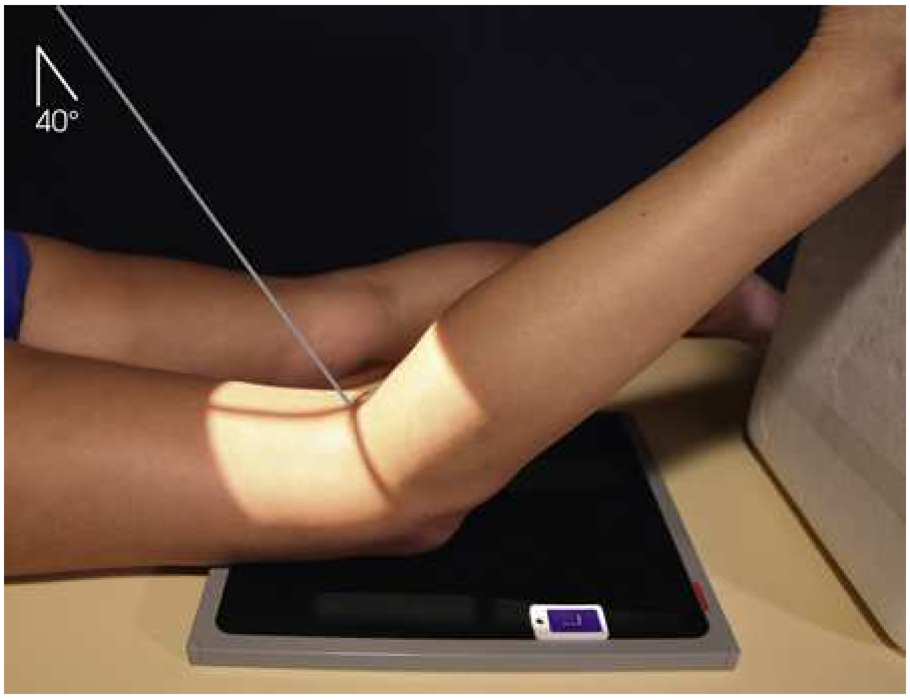

FIG. 7.140 PA axial (tunnel) intercondylar fossa: Camp-Coventry method.

A patient is in a prone position. The knee is flexed and the femoral portion of the knee is placed on the image receptor. The foot rests on a support. The side marker is in the collimated exposure field. The central ray is perpendicular to the long axis of the lower leg, entering the popliteal fossa.

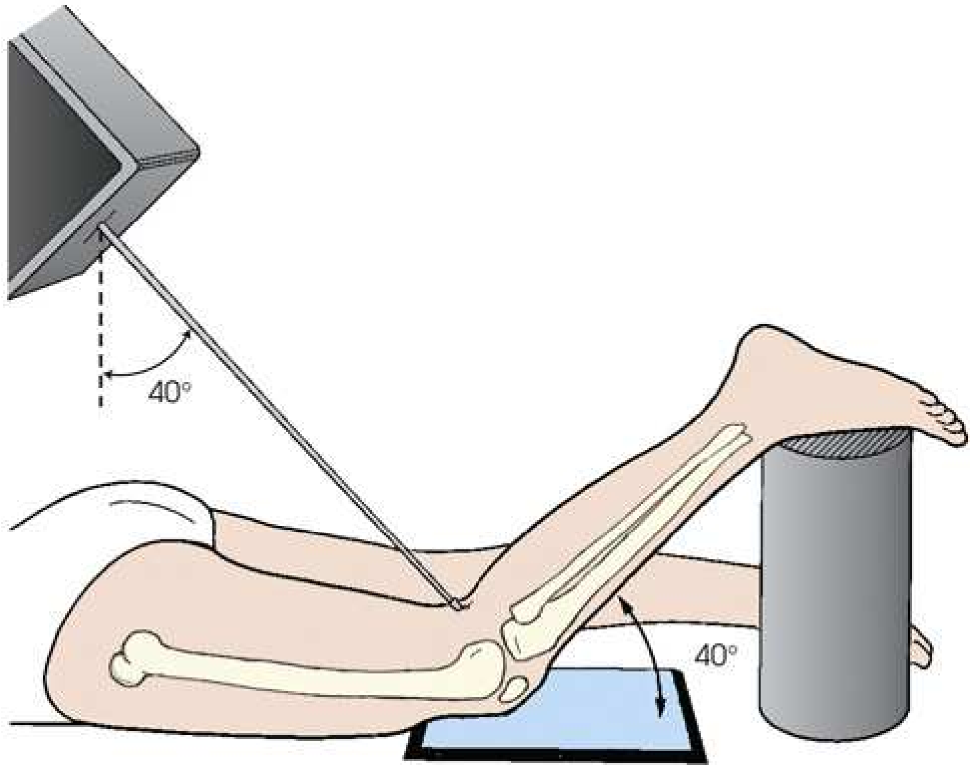

FIG. 7.141 PA axial (tunnel) intercondylar fossa: Camp-Coventry method.

Diagram shows a patient in a prone position. The knee is flexed 40 degrees and the femoral portion of the knee is placed on the image receptor. The foot rests on a support. The central ray is angled 40 degrees the long axis of the lower leg, entering the popliteal fossa.

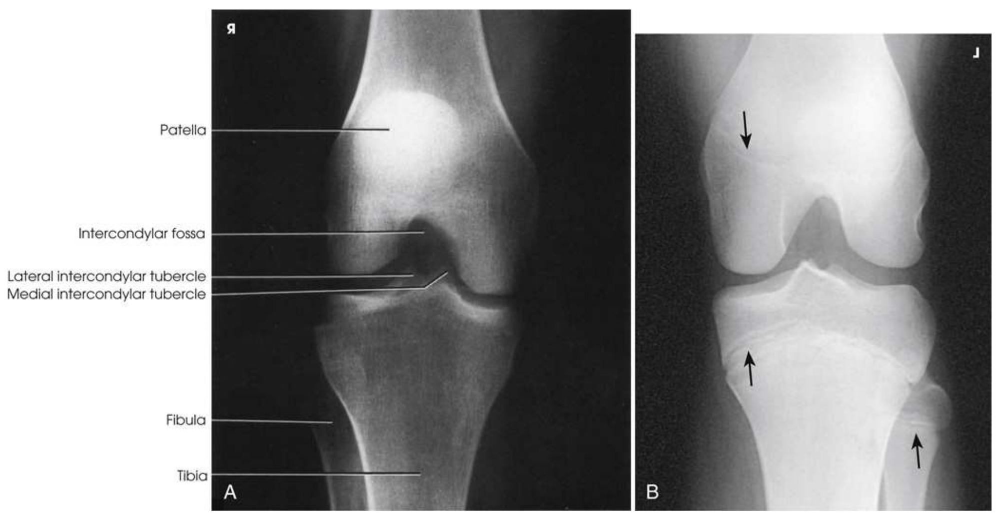

FIG. 7.142 Camp-Coventry method. (A) Flexion of the knee at 40 degrees. (B) Flexion of the knee at 40 degrees in a 13-year-old patient. Note epiphyses *(arrows)*.

(A) An x-ray shows the open knee joint spaces. It is dark and is shaped like an arch. The patella is circular and appears white. The parts labeled are as follows: patella, intercondylar fossa, lateral intercondylar tubercle, medial intercondylar tubercle, fibula, tibia. (B) An x-ray shows the open knee joint spaces. Three black arrows point at the epiphyses on the fibula, tibia, and femur. They appear in a different density.

FIG. 7.143 Flexion of the knee at 50 degrees (same patient as in Fig. 7.142): Camp-Coventry method.

An x-ray shows the intercondylar fossa and posteroinferior articular surfaces of the condyles of the femur, the medial and lateral intercondylar tubercles of the intercondylar eminence, and tibial plateaus. It appears grainy. The open joint space is dark and is shaped like an arch.

AP Axial Projection

Béclère Method

Image receptor:

Positioned by manufacturer or department protocol for proper anatomy display orientation; CR plate: 10 × 12 inches (24 × 30 cm) crosswise.

Position of patient

- Place the patient in the supine position and adjust the body so that it is not rotated.

Position of part

- Flex the affected knee enough to place the long axis of the femur at an angle of 60 degrees to the long axis of the tibia.
- Support the knee on sandbags (Fig. 7.144).
- Place the IR under the knee and position the IR so that the center point coincides with the central ray.
- Adjust the leg so that the femoral condyles are equidistant from the IR. Immobilize the foot with sandbags.
- *Shield gonads.*

Central ray

- Perpendicular to the long axis of the lower leg, entering the knee joint ½ inch (1.3 cm) below the patellar apex.

Collimation

- Adjust the radiation field to 8 × 10 inches (18 × 24 cm) on the collimator. Adjust to 1 inch (2.5 cm) beyond the sides. Place a side marker in the collimated exposure field.

Structures shown

The intercondylar fossa, intercondylar eminence, and knee joint (Fig. 7.145).

Evaluation Criteria

The following should be clearly seen:

- Evidence of proper collimation and the presence of a side marker placed clear of the anatomy of interest
- Open intercondylar fossa
- Posteroinferior surface of the femoral condyles
- Intercondylar eminence and knee joint space
- No superimposition of the fossa by the apex of the patella
- No rotation, as demonstrated by slight tibiofibular overlap
- Bony trabecular detail and surrounding soft tissues

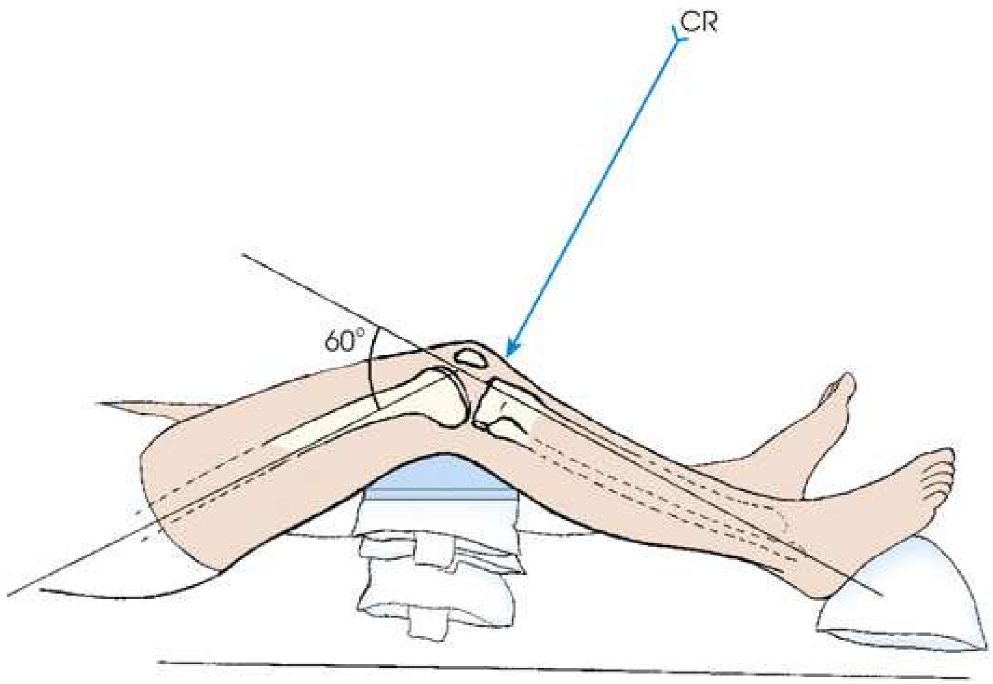

FIG. 7.144 AP axial intercondylar fossa with transverse IR: Béclère method.

Diagram shows a patient in the supine position. The knee is flexed and the long axis of the femur is placed at an angle of 60 degrees to the long axis of the tibia. The knee is supported on sandbags. The I R is placed under the knee. The central ray is perpendicular to the long axis of the lower leg, entering the knee joint.

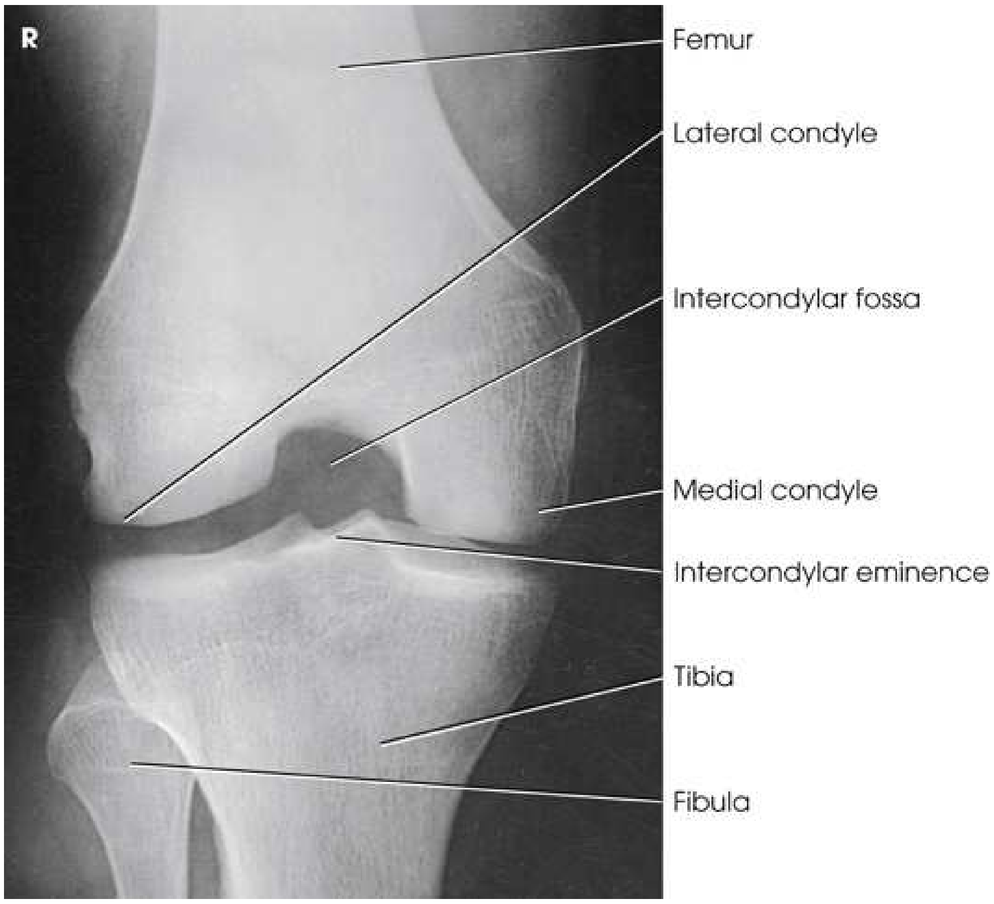

FIG. 7.145 AP axial intercondylar fossa: Béclère method with identified anatomy.

An x-ray shows the intercondylar fossa and posteroinferior articular surfaces of the condyles of the femur. The open joint space is dark and is shaped like an arch. The parts are labeled at right from top to bottom: femur, lateral condyle, intercondylar fossa, medial condyle, intercondylar eminence, tibia, fibula.

Patella

PA Projection

Image receptor + grid:

Positioned by manufacturer or department protocol for proper anatomy display orientation; CR plate: 10 × 12 inches (24 × 30 cm) lengthwise.

Position of patient

- Place the patient in the prone position.
- If the knee is painful, place one sandbag under the thigh and another under the leg to relieve pressure on the patella.

Position of part

- Center the IR to the patella.
- Adjust the position of the leg to place the patella parallel with the plane of the IR. This usually requires that the heel be rotated 5 to 10 degrees laterally (Fig. 7.146).
- *Shield gonads.*

Central ray

- Perpendicular to the midpopliteal area exiting the patella.
- Collimate closely to the patellar area.

Collimation

- Adjust the radiation field to 6 × 6 inches (15 × 15 cm) on the collimator. Place a side marker in the collimated exposure field.

Structures shown

The PA projection of the patella provides improved spatial resolution over the AP projection because of a closer object-to-IR distance (OID) (Figs. 7.147 and 7.148).

Evaluation Criteria

The following should be clearly seen:

- Evidence of proper collimation and the presence of a side marker placed clear of the anatomy of interest
- Patella completely superimposed by the femur
- No rotation
- Bony trabecular detail and surrounding soft tissues

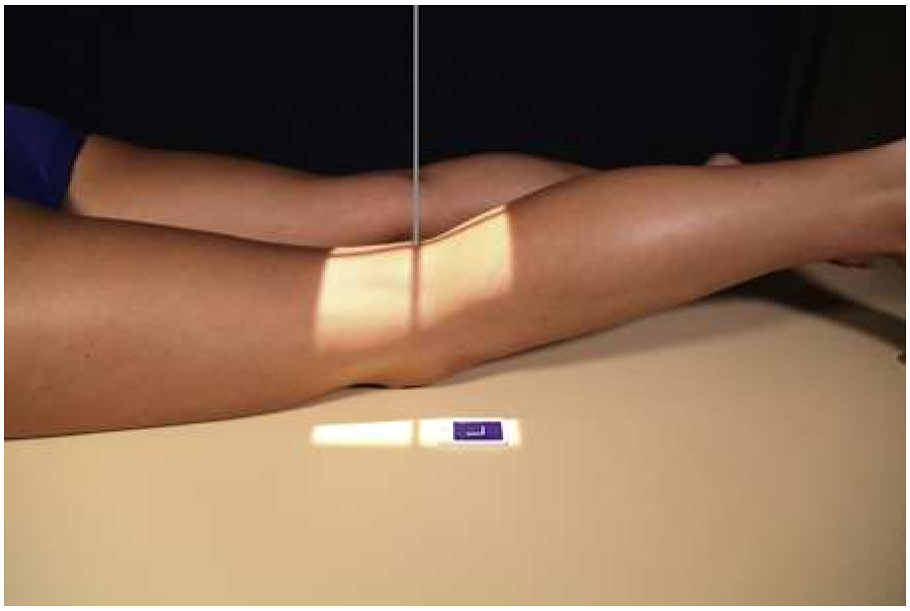

FIG. 7.146 PA patella.

A patient is in a prone position. The knee is flexed and the femoral portion of the knee is placed on the image receptor. The side marker is in the collimated exposure field. The central ray is perpendicular to the mid popliteal area exiting the patella.

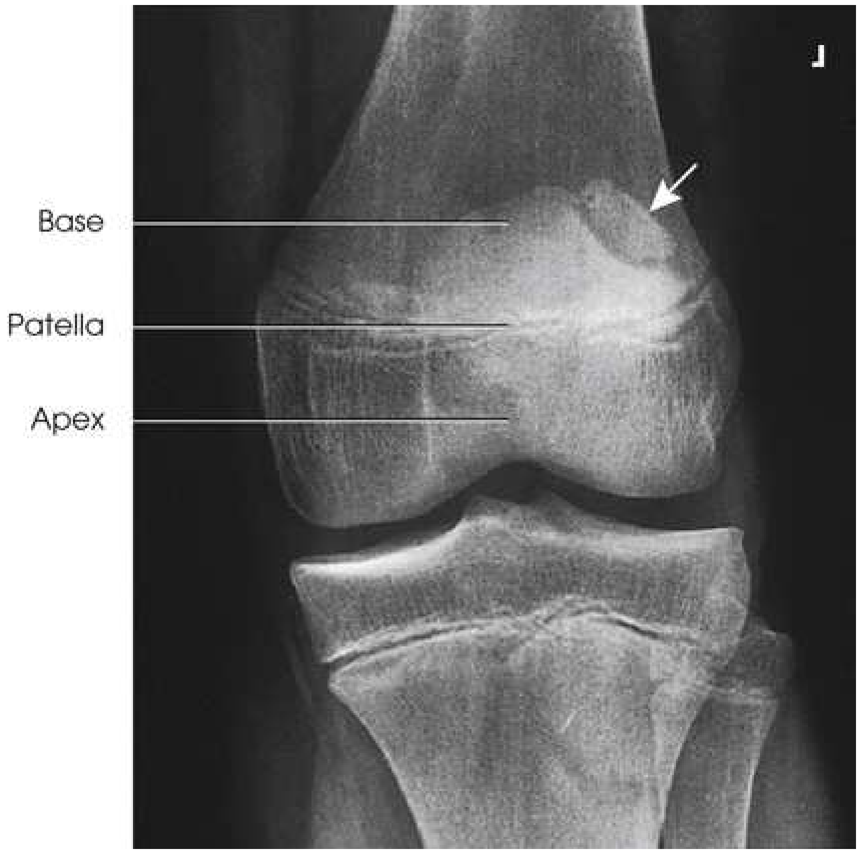

FIG. 7.147 AP patella showing fracture *(arrow)*.

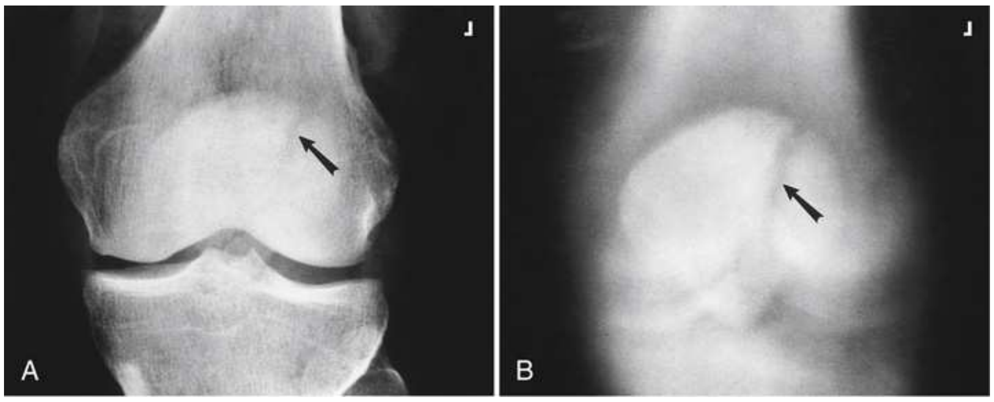

FIG. 7.148 (A) Conventional PA projection of patella shows vertical radiolucent line *(arrow)* passing through junction of lateral and middle third of patella. (B) On tomography, this defect *(arrow)* extends from the superior to the inferior margin of patella. It is a bipartite patella, not a fracture.

(A) An x-ray shows a vertical radiolucent line that is marked by an arrow passing through the junction of lateral and middle third of patella. (B) A tomographic view shows a bipartite patella. The patella has a gap on it. The gap appears darker than the other parts.

Lateral Projection

Mediolateral

Image receptor + grid:

Positioned by manufacturer or department protocol for proper anatomy display orientation; CR plate: 10 × 12 inches (24 × 30 cm) lengthwise.

Position of patient

- Place the patient in the lateral recumbent position.

Position of part

- Ask the patient to turn onto the affected hip. A sandbag may be placed under the ankle for support.

- Have the patient flex the unaffected knee and hip and place the unaffected foot in front of the affected extremity for stability.
- Flex the affected knee approximately 5 to 10 degrees. Increasing the flexion reduces the patellofemoral joint space.
- Adjust the knee in the lateral position so that the femoral epicondyles are superimposed, and the patella is perpendicular to the IR (Fig. 7.149).
- Center the IR to the patella.
- *Shield gonads.*

Central ray

- Perpendicular to the IR, entering the knee at the midpatellofemoral joint.

Collimation

- Adjust the radiation field to 4 × 4 inches (10 × 10 cm) on the collimator. Place a side marker in the collimated exposure field.

Structures shown

A lateral projection of the patella and patellofemoral joint space (Figs. 7.150 and 7.151).

Evaluation Criteria

The following should be clearly seen:

- Evidence of proper collimation and the presence of a side marker placed clear of the anatomy of interest
- Knee flexed 5 to 10 degrees
- Patella in lateral profile
- Open patellofemoral joint space
- Bony trabecular detail and surrounding soft tissues

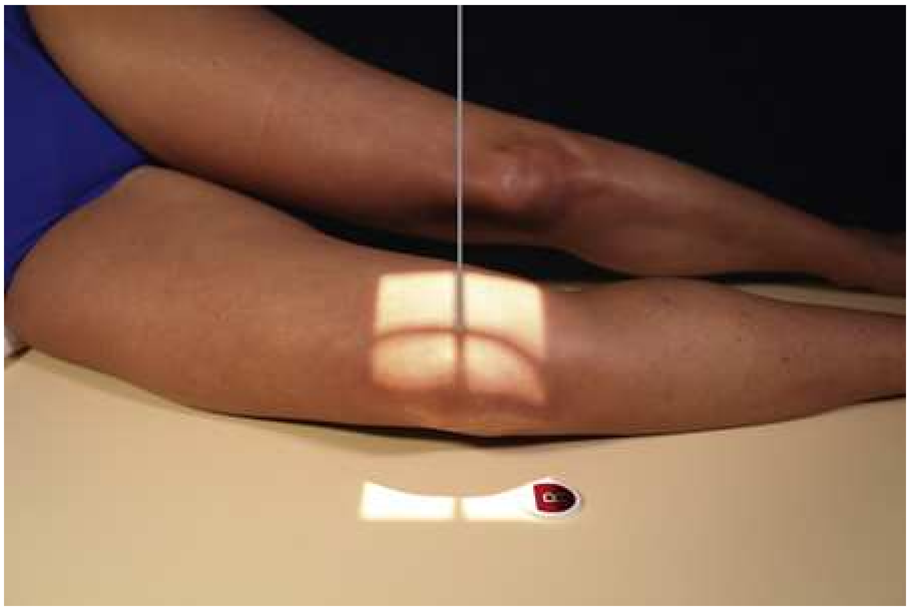

FIG. 7.149 Lateral patella, mediolateral.

A patient is in the lateral recumbent position. One knee and the hip are flexed and the other foot is placed in front of it. The knee is placed in a lateral position on the radiographic table. The side marker is in the collimated exposure field. The central ray is perpendicular to the image receptor entering the knee at the midpatellofemoral joint.

FIG. 7.150 Lateral patella, mediolateral.

FIG. 7.151 Sagittal MRI shows patella, patellofemoral joint, and surrounding soft tissues. Quadriceps tendon *(qten)* and patellar ligament *(pl)* are shown on this image.

The sagittal M R I shows the patella and patellofemoral joint space. The quadriceps tendon and patellar ligament appear darker. The parts are labeled are as follows: quadriceps tendon, patella, patellar ligament.

Patella and Patellofemoral Joint

Tangential Projection

Hughston Method [25, 26]

Radiography of the patella has been the topic of hundreds of articles. For a tangential radiograph, the patient may be placed in any of the following body positions: prone, supine, lying on the side, seated on the table, seated on the radiographic table with the leg hanging over the edge, or standing.

Various authors have described the degree of flexion of the knee joint as ranging from 20 to 120 degrees. Laurin [27] reported that patellar subluxation is easier to show when the knee is flexed 20 degrees and noted a limitation of using this small angle. Modern radiographic equipment often does not permit such small angles because of the large size of the collimator.

Fodor et al. [28] and Merchant et al. [29] recommended 45-degree flexion of the knee, and Hughston [25] recommended an approximately 55-degree angle with the central ray angled 45 degrees. In addition, Merchant et al. [29] stated that relaxation of the quadriceps muscles is required to show patellar subluxation.

Image receptor:

Positioned by manufacturer or department protocol for proper anatomy display orientation; CR plate: 10 × 12 inches (24 × 30 cm) lengthwise.

Position of patient

- Place the patient in a prone position with the foot resting on the radiographic table.
- Adjust the body so that it is not rotated.

Position of part

- Place the IR under the femoral portion of the knee, and slowly flex the affected knee so that the tibia and fibula form a 50- to 60-degree angle from the table.
- Rest the foot against the collimator or support it in position (Fig. 7.152).
- Ensure that the collimator surface is not hot because this could burn the patient.
- Adjust the patient's leg so that it is not rotated medially or laterally from the vertical plane.
- *Shield gonads.*

Central ray

- Angled 45 degrees cephalad and directed through the patellofemoral joint.

Collimation

- Adjust the radiation field to 4 × 4 inches (10 × 10 cm) on the collimator. Place a side marker in the collimated exposure field.

Structures shown

The tangential image shows subluxation of the patella and patellar fractures and allows radiologic assessment of the femoral condyles (Fig. 7.153). Hughston recommended that both knees be examined for comparison.

Evaluation Criteria

The following should be clearly seen:

- Evidence of proper collimation and the presence of a side marker placed clear of the anatomy of interest
- Patella in profile
- Femoral condyles and intercondylar sulcus
- Open patellofemoral articulation
- Bony trabecular detail and surrounding soft tissues

FIG. 7.152 Tangential patella and patellofemoral joint: Hughston method.

A patient is in a prone position with the femoral portion of the knee on the image receptor. The knee is flexed and the foot is resting on the collimator. The side marker is in the collimated exposure field. The central ray is angled 45 degrees cephalad and is directed through the patellofemoral joint.

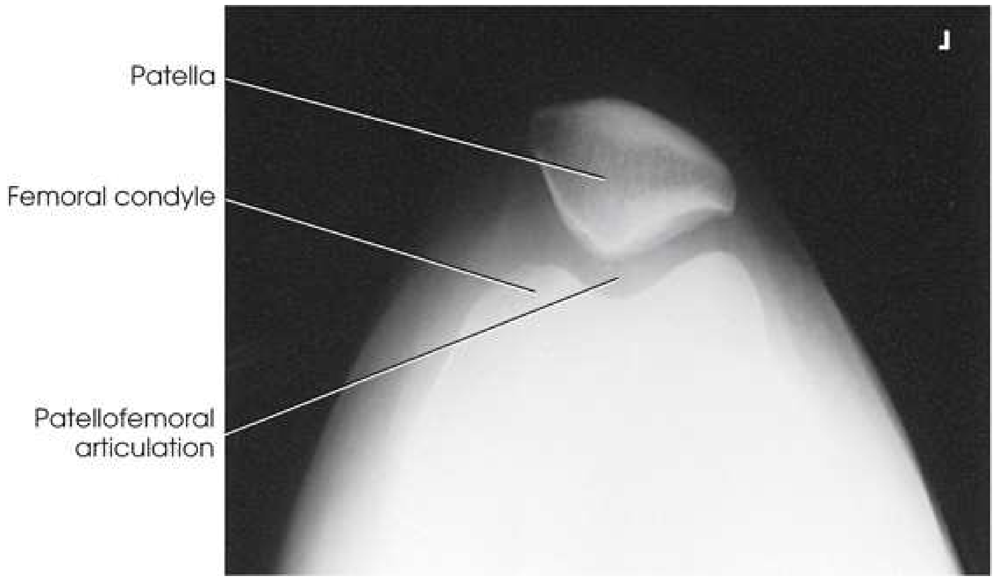

FIG. 7.153 Tangential patellofemoral joint: Hughston method.

An x-ray shows the subluxation of the patella. The image appears radiopaque. The patella appears darker. There is a gap between the patella and the femoral condyl. The parts labeled are as follows: patella, femoral condyle, patellofemoral articulation.

Tangential Projection

Merchant Method [29]

Image receptor:

Positioned by manufacturer or department protocol for proper anatomy display orientation; CR plate: 14 × 17 inches (35 × 43 cm) crosswise.

SID:

A 6-foot (2-m) SID is recommended to reduce magnification.

Position of patient

- Place the patient supine with both knees at the end of the radiographic table.
- Support the knees and lower legs with an adjustable IR-holding device (Axial Viewer). [30]

- To increase comfort and relaxation of the quadriceps femoris, place pillows or a foam wedge under the patient's head and back.

Position of part

- Using the Axial Viewer device, elevate the patient's knees approximately 2 inches to place the femora parallel with the tabletop (Figs. 7.154 and 7.155).
- Adjust the angle of knee flexion to 40 degrees. (Merchant reported that the degree of angulation may be varied between 30 degrees and 90 degrees to show various patellofemoral disorders.)
- Strap both legs together at the calf level to control leg rotation and allow patient relaxation.
- Place the IR perpendicular to the central ray and resting on the patient's shins (a thin foam pad aids comfort) approximately 1 foot distal to the patellae.
- Ensure that the patient is able to relax. Relaxation of the quadriceps femoris is crucial for an accurate diagnosis. If these muscles are not relaxed, a subluxated patella may be pulled back into the intercondylar sulcus, showing a false normal appearance.
- Record the angle of knee flexion for reproducibility during follow-up examinations because the severity of patella subluxation commonly changes inversely with the angle of knee flexion.
- *Shield gonads.*

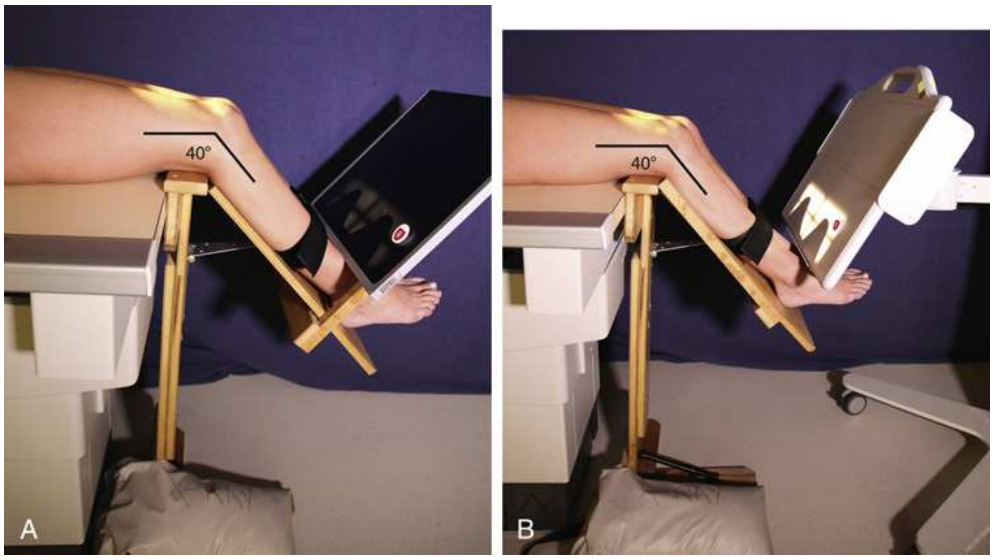

FIG. 7.154 Tangential patella and patellofemoral joint: Merchant method. Note the use of the Axial Viewer device. (A) Using a CR plate. (B) Using a DR detector in a rolling holder.

(A) A patient is supine with both knees at the end of the radiographic table. The knee is flexed at an angle of 40 degrees and is elevated using an axial viewer device. The lower legs are strapped together and are supported using an I R holding device. The I R is resting on the patient's shins. The side marker is in the collimated exposure field. The central ray is perpendicular to the I R. (B) A patient is supine with both knees at the end of the radiographic table. The knee is flexed at an angle of 40 degrees and is elevated using an axial viewer device. The lower legs are strapped together and are supported using a D R detector in a rolling holder. The side marker is in the collimated exposure field. The central ray is perpendicular to the D R detector in a rolling holder.

FIG. 7.155 DR detector in a rolling holder, from the patient's perspective. Note how the shadow of the knees is used to position the patella on the IR.

A patient's knees are elevated and the femora are parallel with the tabletop. The vertical grid is in front of the patient. The shadow of the knees falls on the vertical grid that is divided into four quadrants. The side marker is in the collimated exposure field.

Central ray

- Perpendicular to the IR.
- With 40-degree knee flexion, angle the central ray 30 degrees caudad from the horizontal plane (60 degrees from vertical) to achieve a 30-degree central ray-to-femur angle. The central ray enters midway between the patellae at the level of the patellofemoral joint (superior aspect of patella).

Collimation

- Adjust the radiation field to 2 inches (5 cm) above the patellar shadow and 1 inch on the sides. Place a side marker in the collimated exposure field.

Structures shown

The bilateral tangential image shows an axial projection of the patellae and patellofemoral joints (Fig. 7.156). Because of the right-angle alignment of the IR and central ray, the patellae are seen as nondistorted, albeit slightly magnified, images.

Evaluation Criteria

The following should be clearly seen:

- Evidence of proper collimation and the presence of a side marker placed clear of the anatomy of interest
- Patellae in profile
- Femoral condyles and intercondylar sulcus
- Open patellofemoral articulation
- Bony trabecular detail and surrounding soft tissues

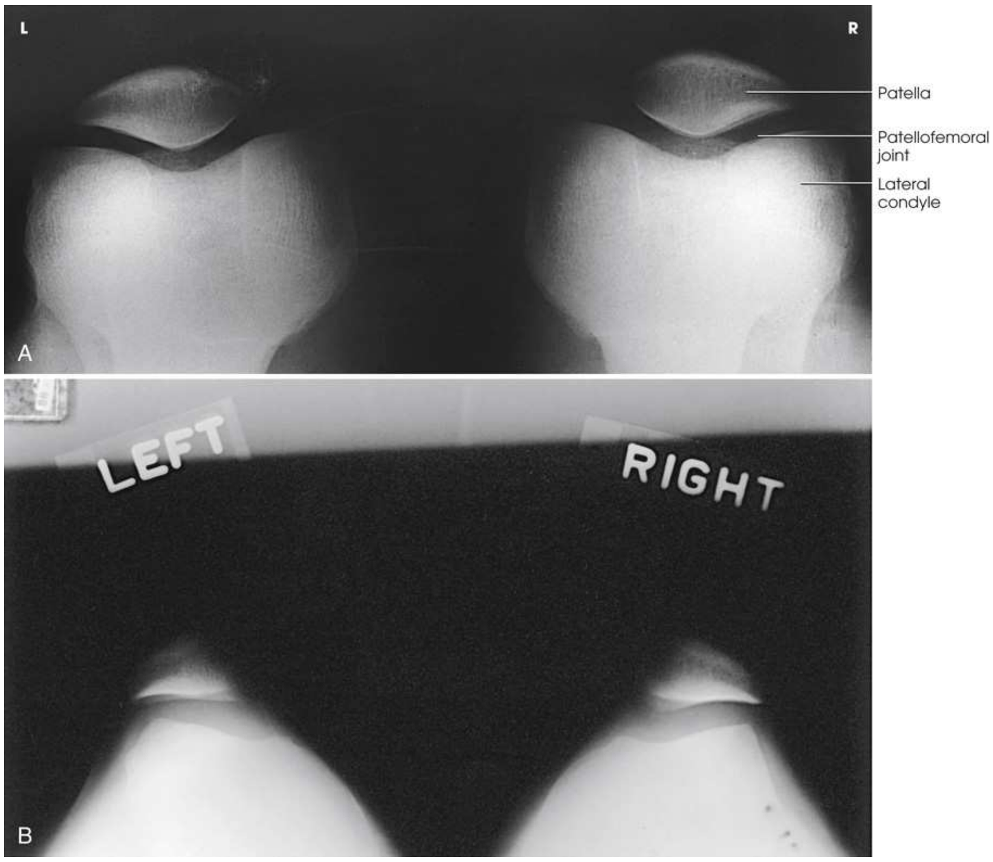

FIG. 7.156 (A) Normal tangential radiograph of congruent patellofemoral joints, showing patellae to be well centered with normal trabecular pattern. (B) Abnormal tangential radiograph showing abnormally shallow intercondylar sulci, misshapen and laterally subluxated patellae, and incongruent patellofemoral joints (left worse than right). Courtesy Alan J. Merchant.

(A) An x-ray shows the patellae and patellofemoral joints. The open patellofemoral articulation is prominent. The patella appears grainy and the lateral condyle appears radiopaque. The parts labeled are as follows: patella, patellofemoral joint, lateral condyle. (B) An x-ray shows shallow and oddly shaped patellae. The patellofemoral articulation appears hazy.

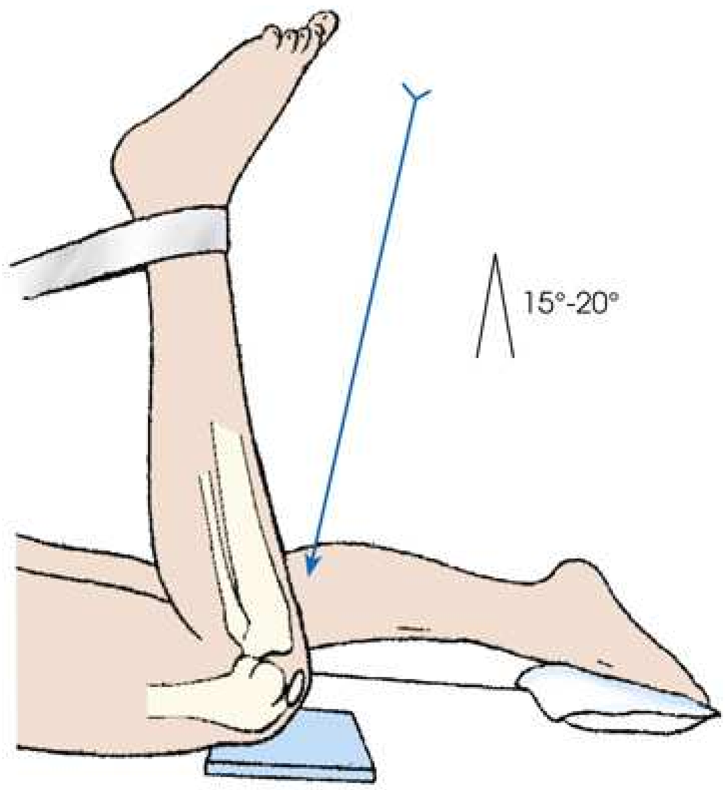

FIG. 7.157 Tangential patella and patellofemoral joint: Settegast method.

Diagram shows a patient in the prone position and one knee is flexed. The patella is perpendicular to the image receptor. The other foot is resting on a support. The side marker is in the collimated exposure field. The central ray is angulated 15 to 20 degrees on the joint space between the patella and the femoral condyles.

Tangential Projection

Settegast Method

Because of the danger of fragment displacement by the acute knee flexion required for this procedure, this projection should not be attempted until a transverse fracture of the patella has been ruled out with a lateral image, or if the patient is in pain.

Image receptor:

Positioned by manufacturer or department protocol for proper anatomy display orientation; CR plate: 10 × 12 inches (24 × 30 cm) lengthwise.

Position of patient

- Place the patient in the supine or prone position. The latter is preferable because the knee can usually be flexed to a greater degree, and immobilization is easier (Figs. 7.157 and 7.158).
- If the patient is seated on the radiographic table, hold the IR securely in place (Fig. 7.159). Alternative positions are shown in Figs. 7.160 and 7.161.

Position of part

- Flex the patient's knee slowly as much as possible or until the patella is perpendicular to the IR if the patient's condition permits. With *slow, even flexion,* the patient should be able to tolerate the position, whereas quick, uneven flexion may cause too much pain.
- If desired, loop a long strip of bandage around the patient's ankle or foot. Have the patient grasp the ends over the shoulder to hold the leg in position. Gently adjust the leg so that its long axis is vertical.

FIG. 7.158 Tangential patella and patellofemoral joint: Settegast method.

A patient is in the prone position and one knee is flexed. The patella is perpendicular to the image receptor. The side marker is in the collimated exposure field. The central ray is angulated 15 to 20 degrees on the joint space between the patella and the femoral condyles.

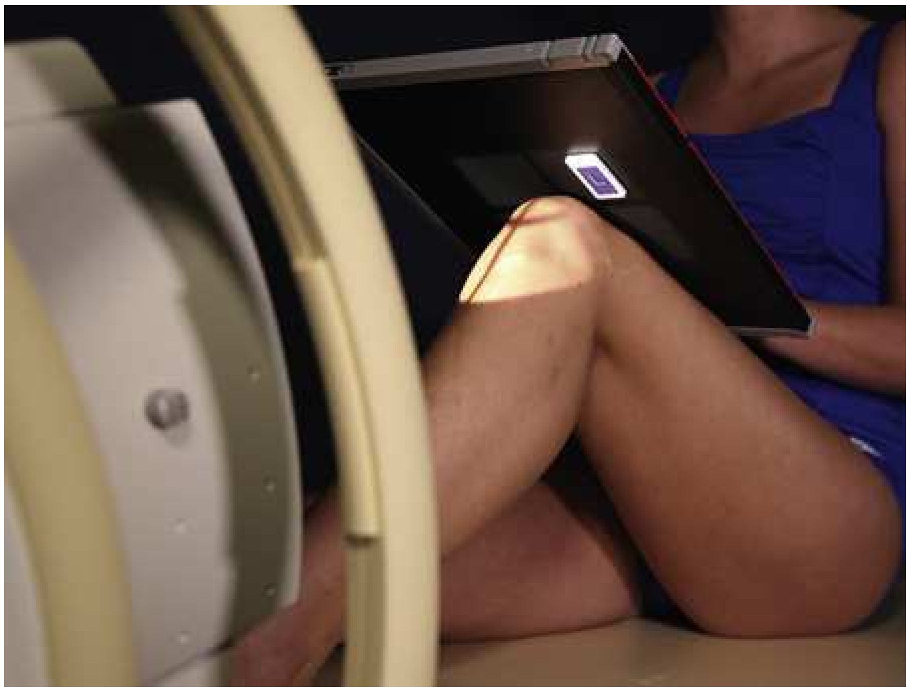

FIG. 7.159 Tangential patella and patellofemoral joint: Settegast method.

A patient is seated on the radiographic table with one knee flexed. The patient is holding the image receptor over the knees. The side marker is in the collimated exposure field. The central ray is perpendicular to the joint space between the patella and the femoral condyles.

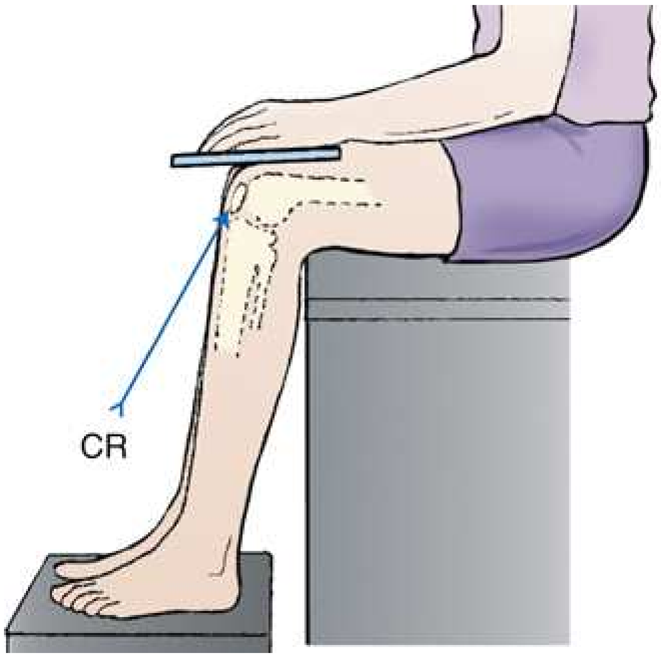

FIG. 7.160 Tangential patella and patellofemoral joint: patient seated.

A patient is sitting on the radiographic table and the feet are resting on a stool. The patient is holding the image receptor over the knees. The central ray is angulated 15 to 20 degrees on the joint space between the patella and the femoral condyles.

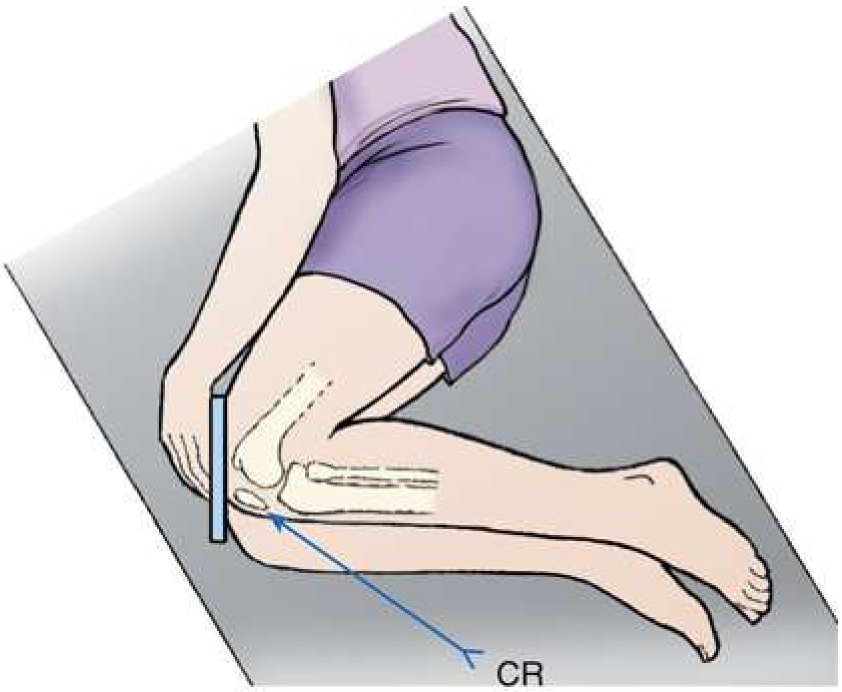

FIG. 7.161 Tangential patella and patellofemoral joint: patient lateral.

A patient is lying in a lateral position with both knees flexed. The patient is holding the image receptor over the knees. The central ray is angulated 15 to 20 degrees on the joint space between the patella and the femoral condyles.

- Place the IR transversely under the knee, and center it to the joint space between the patella and the femoral condyles.
- *Shield gonads.*
- By maintaining the same OID and SID relationships, this position can be obtained with the patient in a lateral or seated position (Figs. 7.160 and 7.161).

NOTE: When the central ray is directed toward the patient's upper body (Figs. 7.159 and 7.160), the thorax and thyroid should be shielded.

Central ray

- Perpendicular to the joint space between the patella and the femoral condyles when the joint is perpendicular. When the joint is not perpendicular, the degree of central ray angulation depends on the degree of flexion of the knee. The angulation typically is 15 to 20

degrees.
- Close collimation is recommended.

Collimation

- Adjust the radiation field to 4 × 4 inches (10 × 10 cm) on the collimator. Place a side marker in the collimated exposure field.

Structures shown

The articulating surfaces of the patellofemoral joint. Vertical fractures of the patella will be shown (Figs. 7.162 and 7.163).

Evaluation criteria

The following should be clearly seen:

- Evidence of proper collimation and the presence of a side marker placed clear of the anatomy of interest
- Patella in profile
- Femoral condyles and intercondylar sulcus
- Open patellofemoral articulation
- Bony trabecular detail and surrounding soft tissues

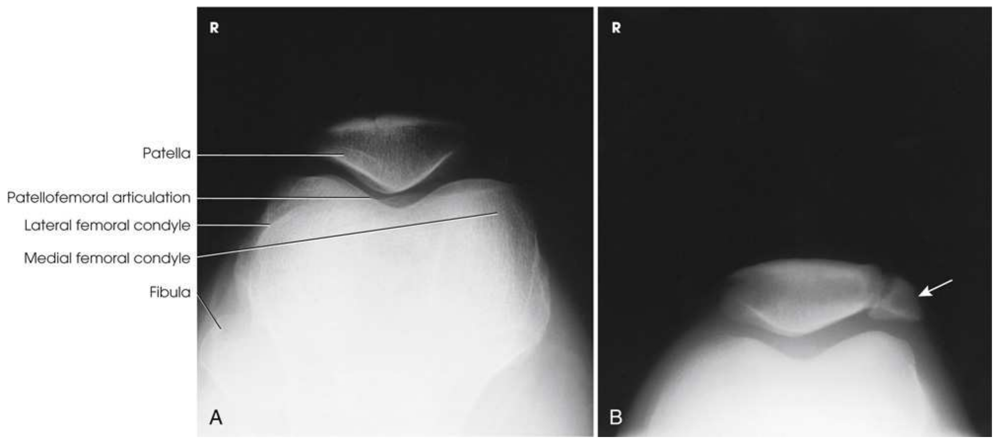

FIG. 7.162 (A) Tangential patella and patellofemoral joint: Settegast method. (B) Fracture *(arrow)*.

(A) An x-ray shows the articulating surfaces of the patellofemoral joint. The patella appears dark and grainy. The parts labeled are as follows: patella, patellofemoral articulation, lateral femoral condyle, medial femoral condyle, fibula. (B) An x-ray shows a small triangular area on the patella marked by a white arrow.

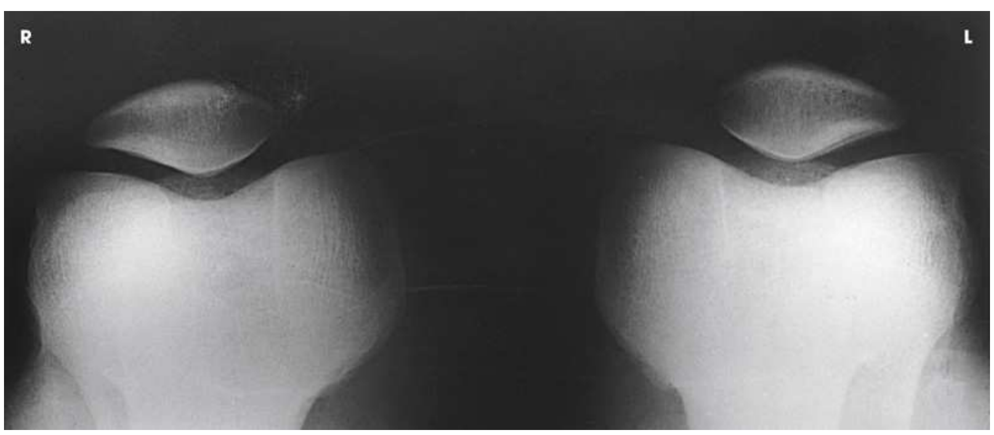

FIG. 7.163 Bilateral patella examination. For this examination, the legs should be strapped together at the level of the calf, using appropriate binding to control femoral rotation.

Femur

AP Projection

If the femoral heads are separated by an unusually broad pelvis, the bodies (shafts) are more strongly angled toward the midline.

Image receptor + grid:

Positioned by manufacturer or department protocol for proper anatomy display orientation; CR plate: 14 × 17 inches (35 × 43 cm) lengthwise.

Position of patient

- Place the patient in the supine position.
- Check the pelvis to ensure it is not rotated.

Position of part

- Center the affected thigh to the midline of the IR. When the patient is too tall to include the entire femur, include on a single image the joint closest to the area of interest.

With the knee included

- For projection of the *distal* femur, rotate the patient's extremity internally to place it in true anatomic position. The extremity is naturally turned externally when the patient is lying on the table. Ensure that the epicondyles are parallel with the IR.
- Place the bottom of the IR 2 inches (5 cm) below the knee joint (Fig. 7.164).

With the hip included

- For projection of the *proximal* femur, which must include the hip joint, place the top of the IR at the level of the ASIS (Fig. 7.165).
- Rotate the extremity internally 10 to 15 degrees to place the femoral neck in profile.
- *Shield gonads.*

Central ray

- Perpendicular to the midfemur and the center of the IR.

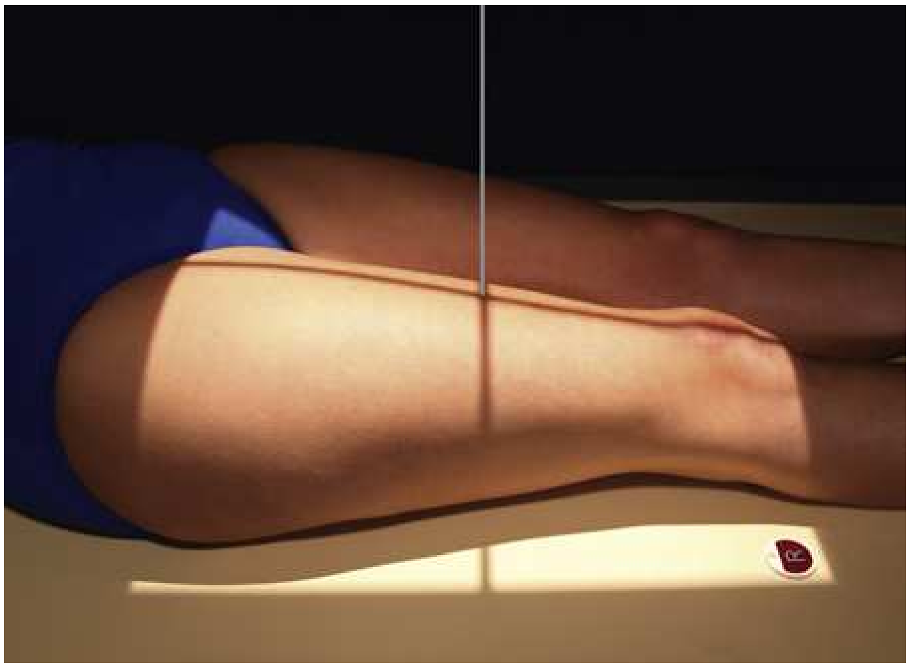

FIG. 7.164 AP distal femur.

A patient is in a supine position. One of the thighs is in the midline of the image receptor. The side marker is in the collimated exposure field. The central ray is perpendicular to the mid femur and the center of the I R.

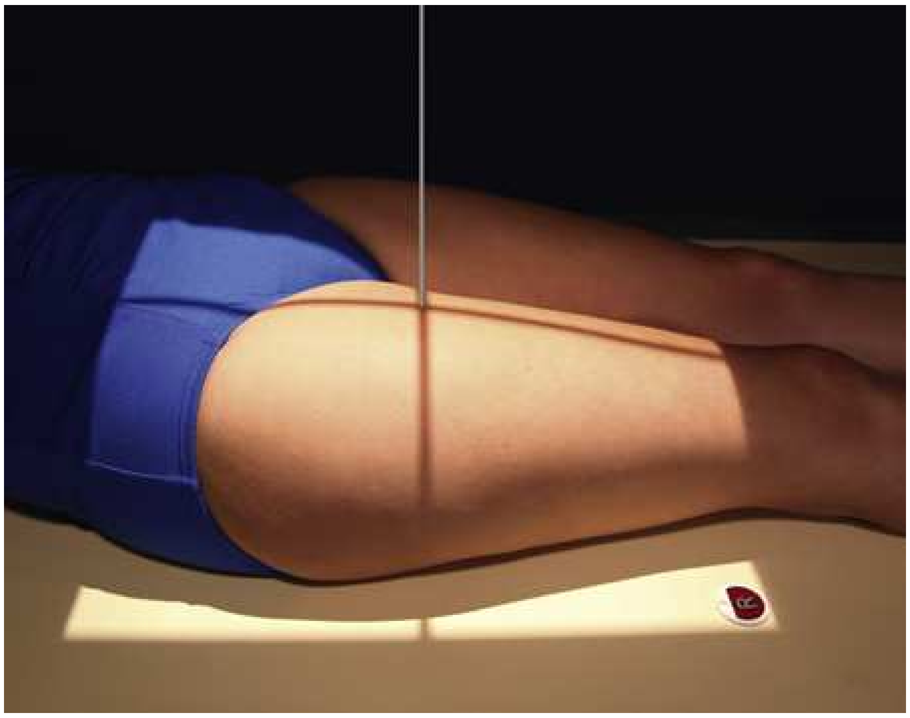

FIG. 7.165 AP right proximal femur.

A patient is in a supine position. The image receptor is at the level of the A S I S. The side marker is in the collimated exposure field. The central ray is perpendicular to the mid femur and the center of the I R.

Collimation

- Adjust the radiation field to 1 inch (2.5 cm) on the sides of the shadow of the thigh and 17 inches (43 cm) in length. Place a side marker in the collimated exposure field.

Structures shown

An AP projection of the femur, including the knee joint or hip or both (Figs. 7.166 and 7.167).

Evaluation Criteria

The following should be clearly seen:

- Evidence of proper collimation and the presence of a side marker placed clear of the anatomy of interest
- Most of the femur and the joint nearest to the pathologic condition or site of injury (a second projection of the other joint is recommended)
- Femoral neck not foreshortened on the proximal femur
- Lesser trochanter not seen beyond the medial border of the femur or only a very small portion seen on the proximal femur
- No knee rotation on the distal femur
- Any orthopedic appliance in its entirety
- Bony trabecular detail and surrounding soft tissues

FIG. 7.166 AP right distal femur.

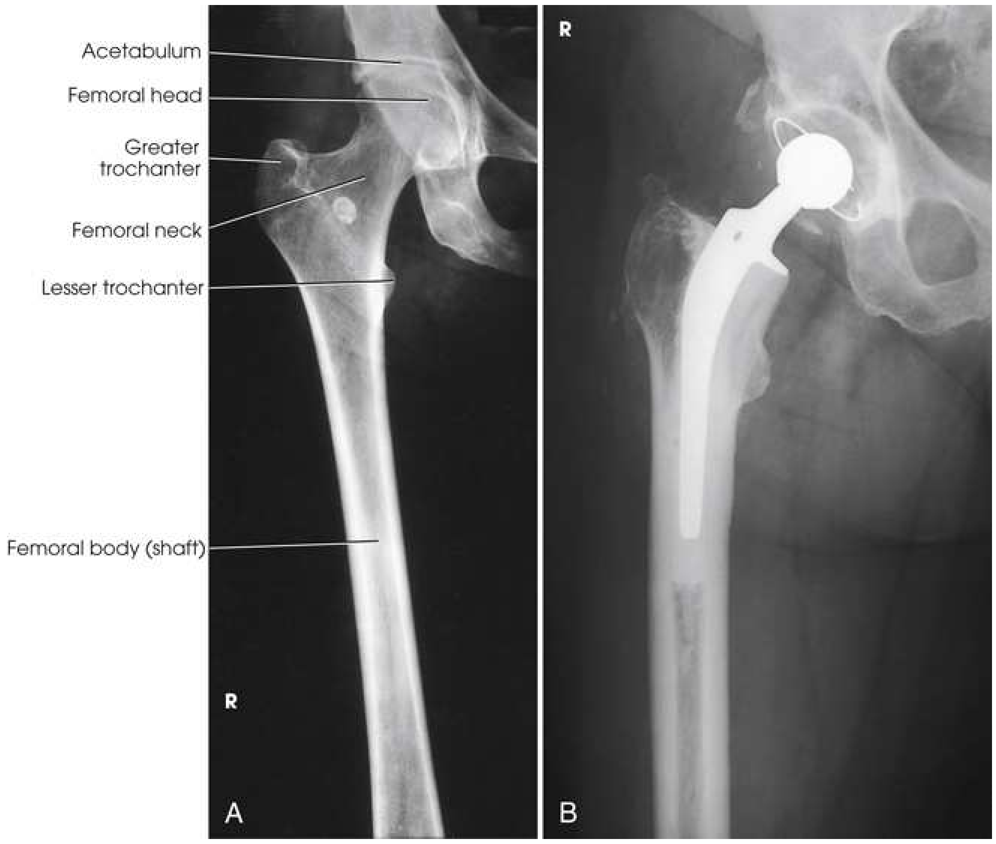

FIG. 7.167 (A) AP proximal femur. (B) AP proximal femur showing "total hip" arthroplasty procedure.

(A) An x-ray image shows femur, including the hip joint. A small circular white area is near the femoral neck. The parts labeled are as follows: acetabulum, femoral head, greater trochanter, femoral neck, lesser trochanter, femoral body. (B) shows the femur and the orthobullet implanted in the socket leading to the femur. The orthobullet appears radiopaque.

Lateral Projection

Mediolateral

Image receptor + grid:

Positioned by manufacturer or department protocol for proper anatomy display orientation; CR plate: 14 × 17 inches (35 × 43 cm) lengthwise.

Position of patient

- Ask the patient to turn onto the affected side.
- Adjust the body position to center the affected thigh to the midline of the grid.

Position of part

With the knee included

- For projection of the *distal* femur, draw the patient's uppermost extremity posterior and support it (Fig. 7.168). This position can also be accomplished by drawing the upper extremity forward and supporting it at hip level (Fig. 7.169).
- Adjust the pelvis in a true lateral position.
- Flex the affected knee about 45 degrees, place a sandbag under the ankle, and adjust the body rotation to place the epicondyles perpendicular to the tabletop.
- Adjust the position of the Bucky tray so that the IR projects approximately 2 inches (5 cm) beyond the knee to be included.

With the hip included

- For projection of the *proximal* femur, place the top of the IR at the level of the ASIS.
- Draw the upper most extremity posteriorly and support it.
- Adjust the pelvis so that it is rolled posteriorly just enough to prevent superimposition; 10 to 15 degrees from the lateral position is sufficient (Fig. 7.170).
- *Shield gonads.*

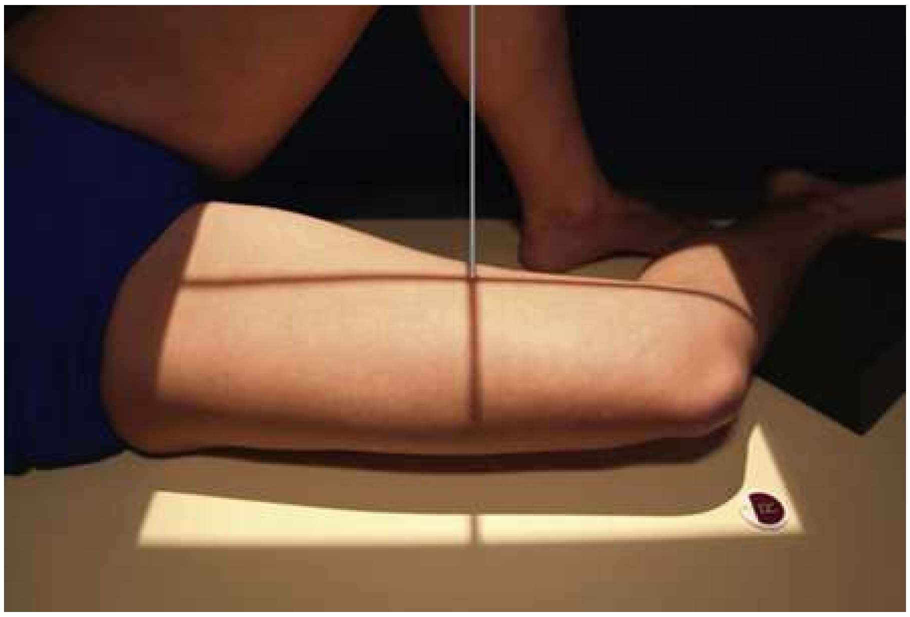

FIG. 7.168 Lateral distal femur, unaffected extremity positioned posterior.

A patient is lying on one side on the radiographic table and the knee is flexed about 45 degrees and a sandbag is placed under the ankle. The thigh is centered to the midline of the grid. The side marker is in the collimated exposure field. The central ray is perpendicular to the mid femur and the center of the I R.

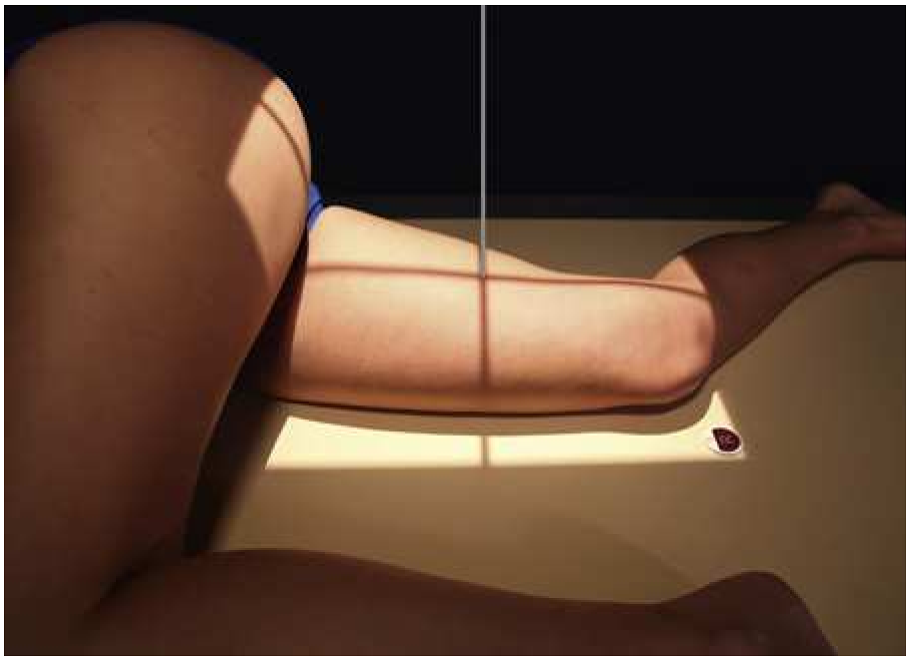

FIG. 7.169 Lateral distal femur, unaffected extremity positioned anterior.

A patient is lying on one side of the radiographic table. The uppermost extremity is drawn forward and is supported at hip level. The thigh is centered to the midline of the grid which divides the thigh into four quadrants. The side marker is in the collimated exposure field. The central ray is perpendicular to the mid femur and the center of the I R.

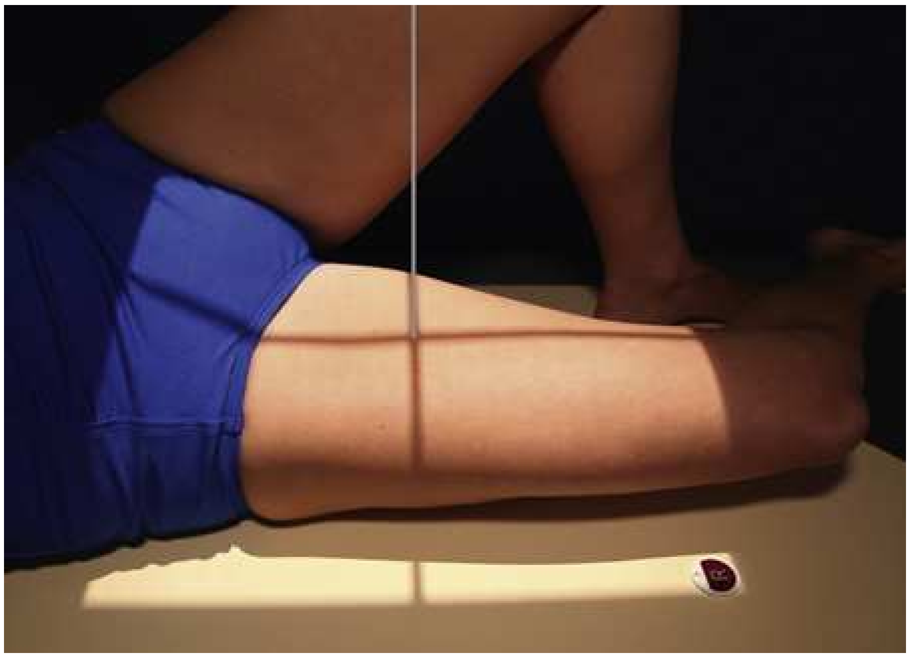

FIG. 7.170 Lateral proximal femur.

A patient is lying on one side on the radiographic table and the knee is flexed about 45 degrees and a sandbag is placed under the ankle. The I R is placed at the level of the A S I S which divides the thigh into four quadrants. The side marker is in the collimated exposure field. The central ray is perpendicular to the midfemur and the center of the I R.

Central ray

- Perpendicular to the midfemur and the center of the IR.

Collimation

- Adjust the radiation field to 1 inch (2.5 cm) on the sides of the shadow of the thigh and 17 inches (43 cm) in length. Place a side marker in the collimated exposure field.

Structures shown

A lateral projection of about three-quarters of the femur and the adjacent joint. If needed, use two IRs to show the entire length of the adult femur (Figs. 7.171 and 7.172).

Evaluation Criteria

The following should be clearly seen:

- Evidence of proper collimation and the presence of a side marker placed clear of the anatomy of interest
- Most of the femur and the joint nearest to the pathologic condition or site of injury (a second radiograph of the other end of the femur is recommended)
- Any orthopedic appliance in its entirety
- Bony trabecular detail and surrounding soft tissues

With the knee included

- Superimposed anterior surface of the femoral condyles
- Patella in profile
- Open patellofemoral space
- Inferior surface of the femoral condyles not superimposed because of divergent rays

With the hip included

- Opposite thigh not over proximal femur and hip joint
- Greater trochanter superimposed over distal femoral neck
- Lesser trochanter visible on medial aspect of proximal femur

NOTE: Because of the danger of fragment displacement, the aforementioned position is not recommended for patients with fracture or patients who may have destructive disease. Patients with these conditions should be examined in the supine position by placing the IR vertically along the medial or lateral aspect of the thigh and knee and then directing the central ray horizontally. A wafer grid or a grid-front IR should be used to minimize scattered radiation.

FIG. 7.171 Lateral distal femur.

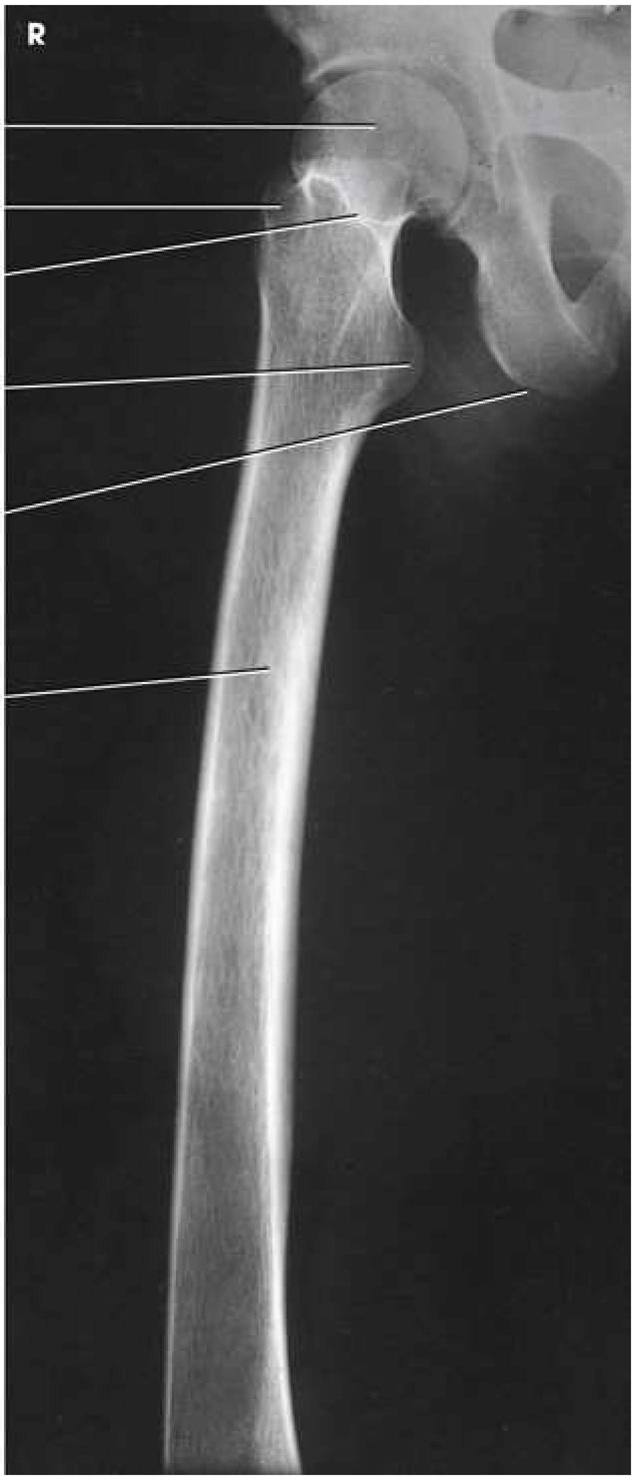

FIG. 7.172 Lateral proximal femur.

An x-ray shows the femur and the hip joint. The parts labeled are as follows: femoral head, greater trochanter, femoral neck, lesser trochanter, ischial tuberosity, femoral body. The outline of the femoral neck is white and prominent.

Lower Extremities

Long Bone Measurement

Long bone measurement to evaluate for length discrepancy may be accomplished by radiography, microdose digital radiography, ultrasonography (US), computed tomography (CT), and MRI. [31] Traditional radiographic methods included orthoroentgenography, scanography, and teleoroentgenography. Both the orthoroentgenogram and the scanogram required three precisely centered exposures at the hip, knee, and ankle joints, and include the use of a radiopaque ruler taped to the table between the extremities. The IR size is the primary difference, with the orthoroentgenogram using a single IR that remained stationary while the table and the x-ray tube moved to an unexposed section. The scanogram technique uses three separate IRs. The teleoroentgenogram was a single upright AP exposure of both extremities on a special long IR at an SID of at least 6 ft (180 cm). Digital imaging, using either DR or CR, usually employs a hybrid of these traditional techniques by obtaining the three exposures centered at the hip, knee, and ankle joints with the patient standing upright. Digital postprocessing “stitches” the three images together, creating an image similar to the orthoroentgenogram and the teleoroentgenogram, for equally accurate measurements of the entire lower extremities with a lower radiation dose than that used in the traditional methods. [31, 32] A scanogram procedure also can be accomplished using digital imaging. Other variations are also performed including full lower extremity length IRs that contain multiple CR IPs creating images similar to those accomplished with the teleoroentgenographic procedure. Although long bone measurement procedures are occasionally performed for the upper extremities, the procedure is most frequently applied to the lower extremities. This section will focus on long bone measurement imaging of the lower extremities.

Radiation Protection

Differences in extremity length are common in children and may occur in association with various disorders. Patients with unequal bone growth may require yearly imaging evaluations. More frequent examinations may be necessary for patients who have undergone surgical procedures to equalize extremity length. For these reasons, radiation protection is a primary consideration in imaging for long bone measurement. Gonad shielding is recommended, as are careful patient positioning, secure immobilization, and accurate centering of a closely collimated beam of radiation to prevent unnecessary repeat exposures. Microdose digital radiography yields the lowest dose but requires specialized equipment, which can be cost prohibitive. MRI and US have promise as means to safely image for long bone measurement, with recent research demonstrating 99% accuracy and reliability for MRI measurements.[31, 33]

Long Bone Measurement Procedure

Modern radiographic procedures for long bone measurements of the lower extremities are accomplished with digital imaging technology. For this reason, the section will present the procedural details used with DR or CR. Both upright "stitched" entire leg procedures and supine scanogram procedures will be discussed in detail. Procedures with long IRs are being phased out, so they will not be included.

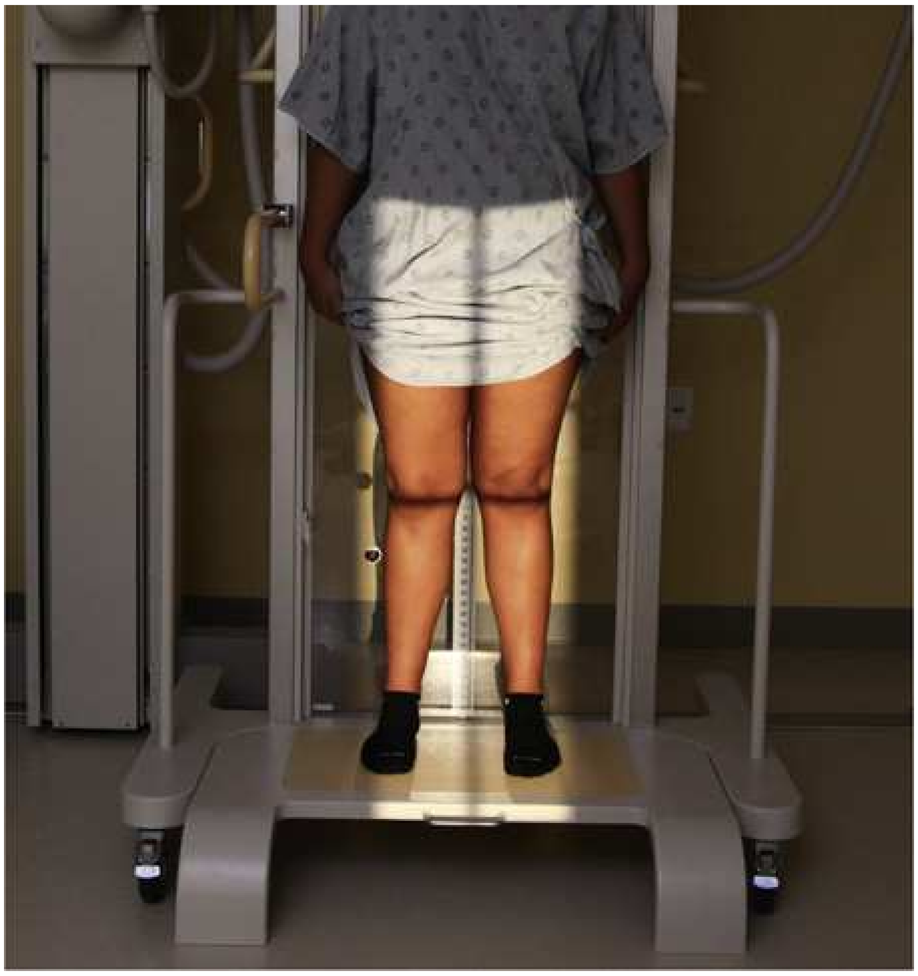

FIG. 7.173 Patient in position for radiograph of lower extremities: hips, knees, and ankles. The patient is placed in the anatomic position. The patient is standing on a raised platform so that the ankles are included.

Upright Leg Measurement Procedure

Image receptor + grid:

Positioned by manufacturer or department protocol for proper anatomy display orientation; CR plate: 14 × 17 inches (35 × 43 cm).

Position of patient

- Stand the patient upright with the back against the vertical imaging stand.

Position of part

• Adjust and immobilize the extremities for an AP projection.
• If the two lower extremities are examined simultaneously, separate the ankles 5 to 6 inches (13 to 15 cm) and place the specialized ruler between the patient and the IR, with the top at the level of the pelvis and extending down between the legs (Fig. 7.173).
• If the extremities are examined separately, position the patient with the special ruler behind each extremity.

Localization of joints

• Localize each joint and mark the central ray centering point. If a significant discrepancy in length is suspected it may be necessary to mark the joints of each side independently.
• Locate the *hip joint* by placing a mark 1 to 1¼ inches (2.5 to 3.2 cm) (depending on the size of the patient) laterodistally and at a right angle to the midpoint of an imaginary line extending from the ASIS to the pubic symphysis.
• Locate the *knee joint* just below the apex of the patella at the level of the depression between the femoral and tibial condyles.
• Locate the *ankle joint* directly below the depression midway between the malleoli.

Procedure

The three-exposure sequence may be made manually, with the radiographer moving the tube and IR for each exposure, or automatically, with the equipment programmed by the radiographer adjusting the field to include the ASIS at the top of the field and the ankles at the bottom (Fig. 7.174). For the automated procedure, the radiographer activates the sequence, and the tube and DR detector move first to the hip joint level, then to the knee joint level, and finally to the ankle joint level.

For both the manual and automated procedures, exposures are made as follows:

• The exposure field is centered to the patient's hip, and the first IR is exposed (see Fig. 7.174A).
• The exposure field is centered to the patient's knee joint, and the second IR is exposed (see Fig. 7.174B).
• The exposure field is centered to the patient's ankle joint, and the third IR is exposed (see Fig. 7.174C).

When a significant discrepancy in length of the two extremities exists, it will not be possible to place the CR at the level of both joints for a bilateral procedure. In these cases, the radiographer must use professional judgment to place the CR as close as possible to the center of both joints.

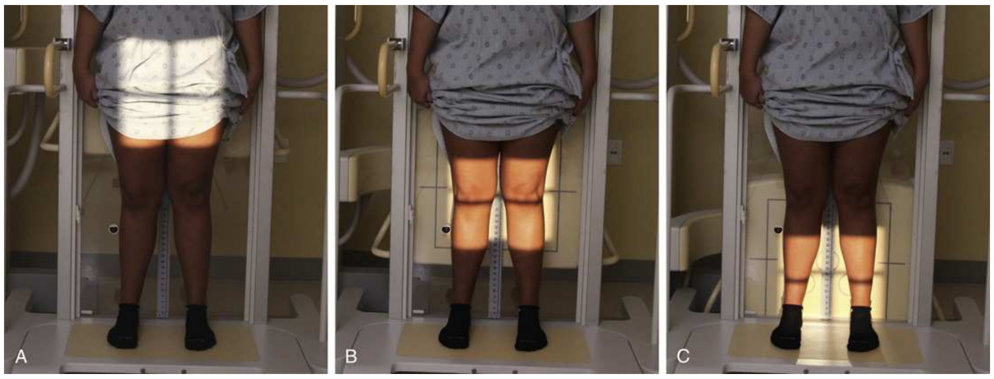

FIG. 7.174 Upright leg measurement procedure. Three radiographs are taken. (A) The first includes the hips; (B) the second includes the knees; (C) the third includes the ankles.

(A) The patient is standing upright on a raised platform facing the vertical grid. The legs are centered on the image receptor. The exposure field is centered on the patient's hip. (B) The patient is standing upright on a raised platform facing the vertical grid. The legs are centered on the image receptor. The exposure field is centered on the knee joint. (C) The patient is standing upright on a raised platform facing front. The legs are centered on the image receptor. The exposure field is centered on the patient's ankle joint.

Central ray

• Perpendicular to the center of the IR for the manual procedure. For the automated procedure, there may be a small cephalad angle for the hip exposure and a small caudad angle for the ankle exposure.

Collimation

• Adjust the radiation field to approximately 14 × 17 inches (35 × 43 cm) on the collimator. For smaller patients, collimate to within 1 inch (2.5 cm) of shadow of the lateral thighs.

Structures shown

A composite of the three exposures digitally stitched into one image, which includes all anatomy from the hip joints to the ankle joints (Fig. 7.175).

Evaluation Criteria

The following should be clearly seen:

- Evidence of proper collimation and the presence of a side marker placed clear of the anatomy of interest
- Image of the special ruler
- All lower extremity anatomy, including the hip joint, the knee joint, and the ankle joint
- Bony trabecular detail and surrounding soft tissues

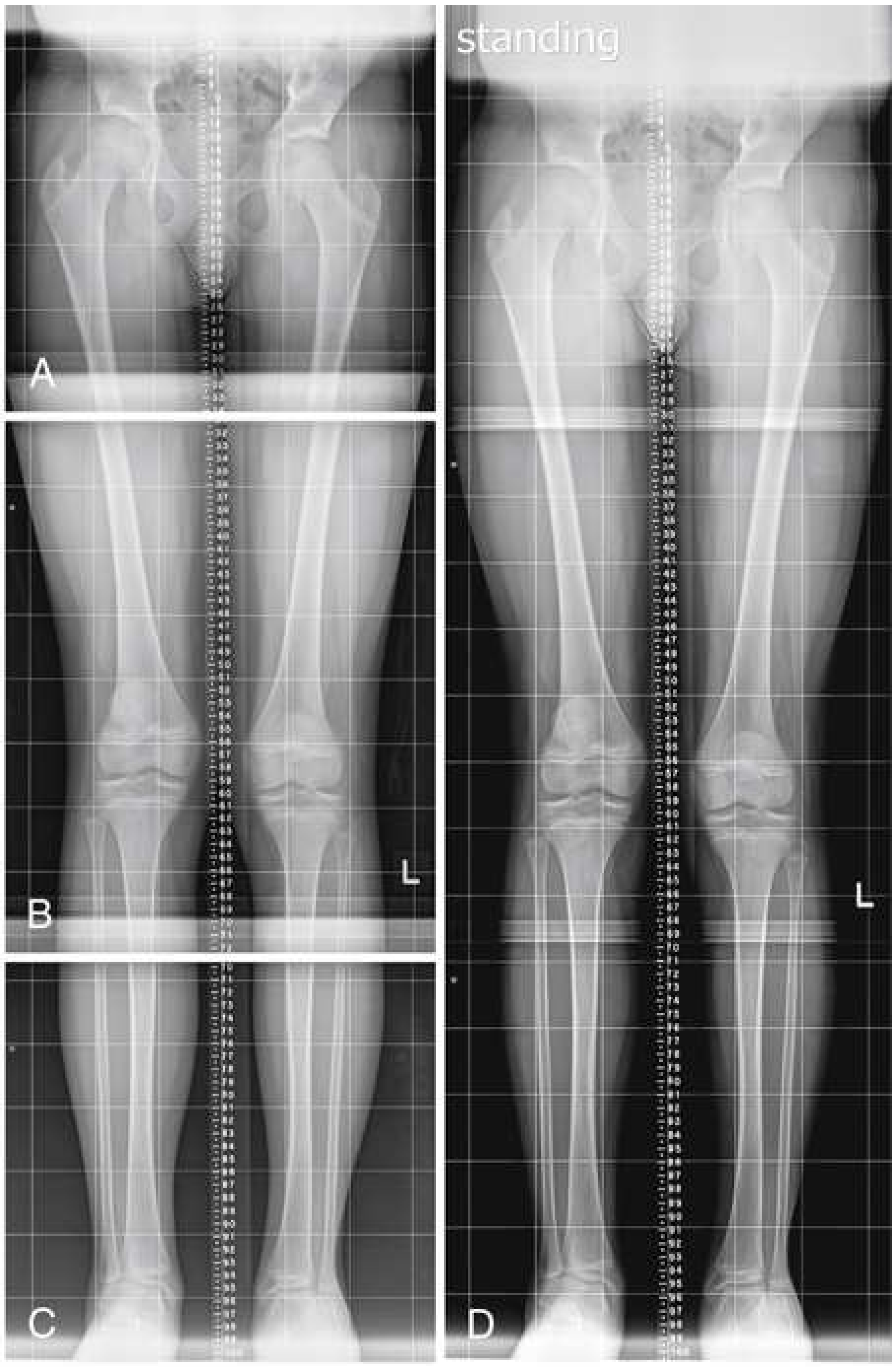

FIG. 7.175 The three images that include the (A) hips, (B) knees, and (C) ankles are digitally "stitched" together to create a composite image (D) of the entire lower extremities.

A composite of the three exposures (A), (B), (C) digitally stitched into one image, which includes all anatomy from the hip joints to the ankle joints. (A) shows the x-ray view of the hips. (B) shows the x-ray view of the knee joints. (C) shows the x-ray view of the ankles. (D) shows an x-ray view of the entire lower extremity. The entire extremity is divided into three portions such as the hips, knees, and ankles.

Supine Scanogram Procedure

Image receptor + grid:

Positioned by manufacturer or department protocol for proper anatomy display orientation; CR plate: 14 × 17 inches (35 × 43 cm).

Position of patient

- Place the patient in the supine position.

Position of part

- Adjust and immobilize the extremities for an AP projection.
- If the two lower extremities are examined simultaneously, separate the ankles 5 to 6 inches (13 to 15 cm) and place the specialized ruler between the patient and the IR, with the top at the level of the pelvis and extending down between the legs.
- If the extremities are examined separately, position the patient with the special ruler behind each extremity.

Localization of joints

- Localize each joint and mark the central ray centering point. If a significant discrepancy in length is suspected it may be necessary to mark the joints of each side independently.
- Locate the *hip joint* by placing a mark 1 to 1¼ inches (2.5 to 3.2 cm) (depending on the size of the patient) laterodistally and at a right angle to the midpoint of an imaginary line extending from the ASIS to the pubic symphysis.
- Locate the *knee joint* just below the apex of the patella at the level of the depression between the femoral and tibial condyles.
- Locate the *ankle joint* directly below the depression midway between the malleoli.

Procedure

Three exposures are made, with the radiographer moving the tube and IR for each exposure.

Exposures are made as follows:

- The exposure field is centered to the patient's hip, and the first IR is exposed (Fig. 7.176A).
- The exposure field is centered to the patient's knee joint, and the second IR is exposed (see Fig. 7.176B).
- The exposure field is centered to the patient's ankle joint, and the third IR is exposed (see Fig. 7.176C).

When a significant discrepancy in length of the two extremities exists, it will not be possible to place the CR at the level of both joints for a bilateral procedure. In these cases, the radiographer must use professional judgment to place the CR as close as possible to the center of both joints.

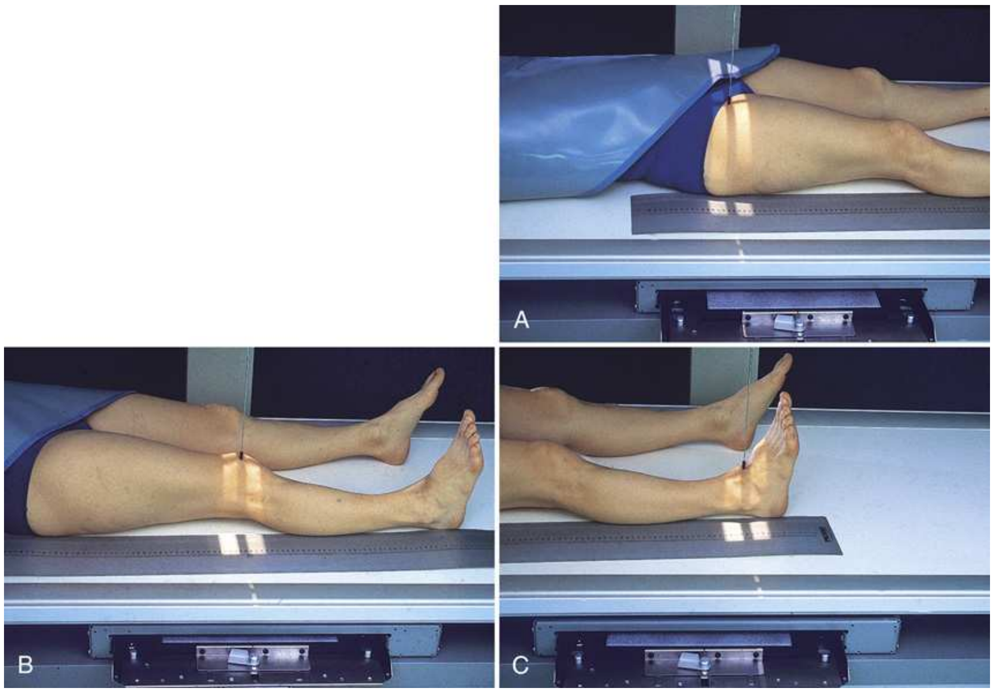

FIG. 7.176 Supine scanogram procedure. Three radiographs are taken. (A) The first is at the level of the hip joints; (B) the second is at the level of the knee joints; and (C) the third is at the level of the ankle joints.

(A) A patient is in the supine position on the radiographic table with legs spread wide apart. The exposure field is centered to the patient's hip. (B) A patient is in the supine position on the radiographic table with ankles separated from each other. The exposure field is centered on the patient's knee joint. (C) A patient is in the supine position on the radiographic table with legs spread wide apart. The exposure field is centered to the patient's ankle joint.

Central ray

- Perpendicular to the center of the IR at the level of the joints for a bilateral procedure and through each joint space for a unilateral procedure.

Collimation

- Adjust the radiation field to 6 inches (15 cm) in length and to 1 inch (2.5 cm) beyond the lateral shadow of the hip, knee, or ankle.

Structures shown

Three images that include the special ruler, one of the hip joint(s), one of the knee joint(s), and one of the ankle joint(s) (Fig. 7.177).

Evaluation criteria

The following should be clearly seen:

- Evidence of proper collimation and the presence of a side marker placed clear of the anatomy of interest
- Image of the special ruler
- Pertinent lower extremity anatomy on each image, including the hip joint, the knee joint, or the ankle joint
- Bony trabecular detail and surrounding soft tissues

FIG. 7.177 Scanogram images. The three images include both joints at each level and the special ruler.

The scanogram on top shows the hip joints. The bones appear radiopaque and the insides appear dark and hazy. The scanogram in the middle shows the knee joints. The open space between the joints is prominent. The scanogram at the end shows the ankle joints. The joints appear radiopaque.

Long Bone Measurement

Other Long Bone Measurement Techniques

Although lower extremity long bone measurement procedures are commonly performed using DR or CR, large children's hospitals may perform these procedures using low-dose/microdose systems. An example of this type of equipment is seen in Fig. 7.178. This particular system uses two slit-beam x-ray sources and dual digital IRs to capture both PA/AP and lateral images simultaneously by scanning the selected portion of the body. Since these patients require multiple imaging procedures, the initial procedure can be done with a low-dose exposure. Subsequent procedures are usually done with microdose exposures since detailed images are not required. The resulting image (Fig. 7.179) has only preliminary measurement lines because the image data set is registered in space, so the accompanying software allows the surgeon to create very precise measurements needed for surgical planning or follow-up.

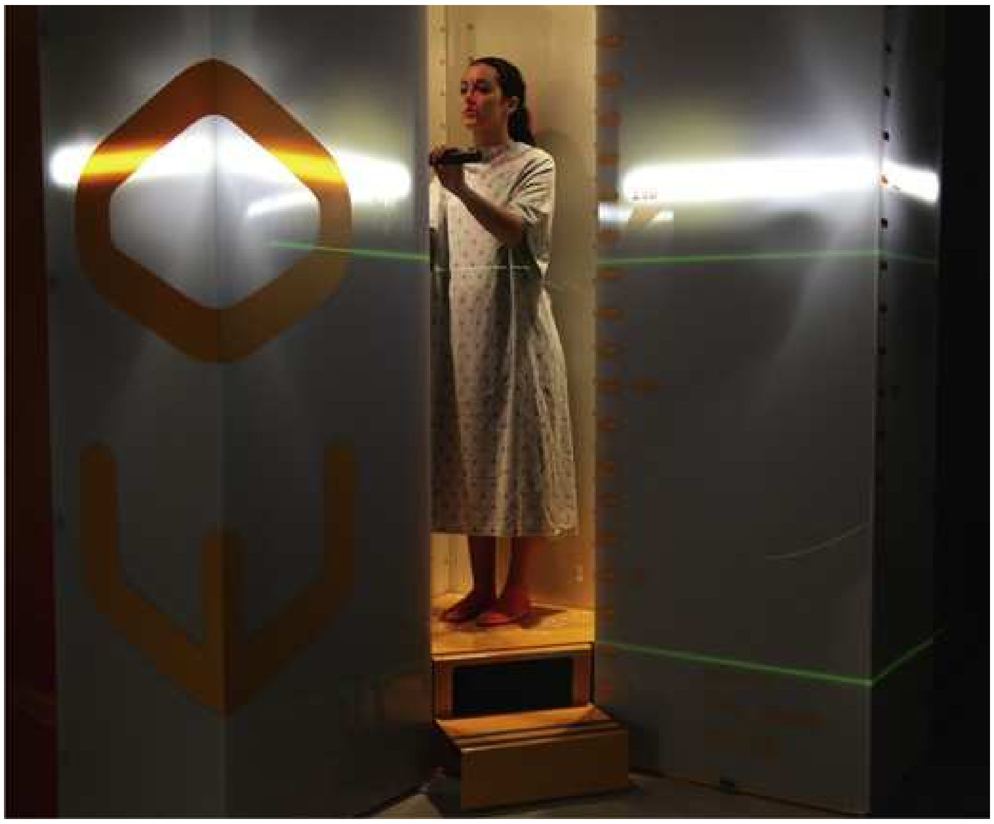

FIG. 7.178 The patient is positioned for a lower extremity long bone measurement procedure using a low-dose slit-scanning system. AP and lateral images are acquired simultaneously. The green laser lines define the area to be scanned.

FIG. 7.179 Lower extremity image acquired by the low-dose system from Fig. 7.178.

Helms and McCarthy [34] reported a method for using CT to measure discrepancies in leg length. Temme et al. [35] compared conventional orthoroentgenograms with CT scans for long bone measurements. Both sets of investigators concluded that the CT scanogram is more consistently reproduced and that it causes less radiation exposure to the patient than the conventional radiographic approach (Figs. 7.180 and 7.181).

The accuracy of the CT examination depends on proper placement of the cursor. Helms and McCarthy [34] found that accuracy improved when the cursors were placed three times and the values obtained were averaged. These authors also reported that CT examinations used radiation doses that were 50 to 200 times less than those used with conventional radiography, while Sabharwal and Kumar [31] reported the CT dose as 80% less than that of orthoroentgenograms. CT examination requires about the same amount of time as conventional radiography, and the costs are comparable. [31]

Although uncommon, long bone measurement imaging is also performed on the upper extremities (Figs. 7.182 and 7.183).

FIG. 7.180 CT measurement of femurs. The right femur is 1 cm shorter than the left femur.

FIG. 7.181 CT measurement of legs in the same patient as Fig. 7.180.

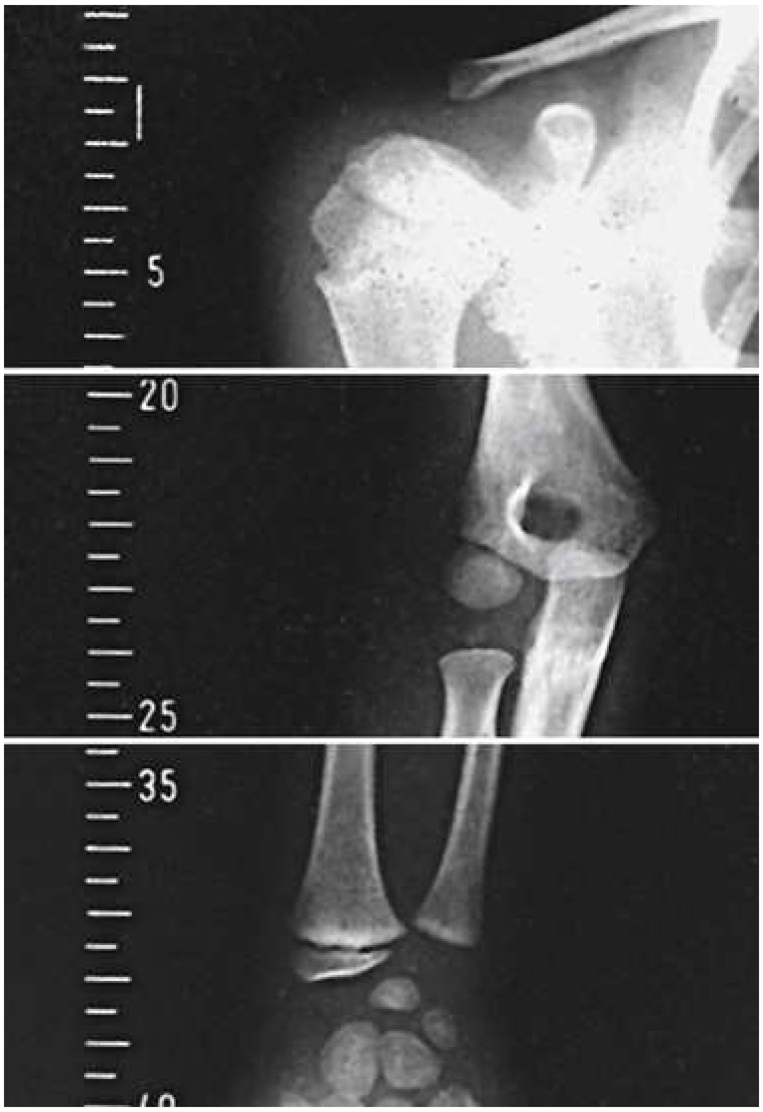

FIG. 7.182 Scanogram images of an upper extremity.

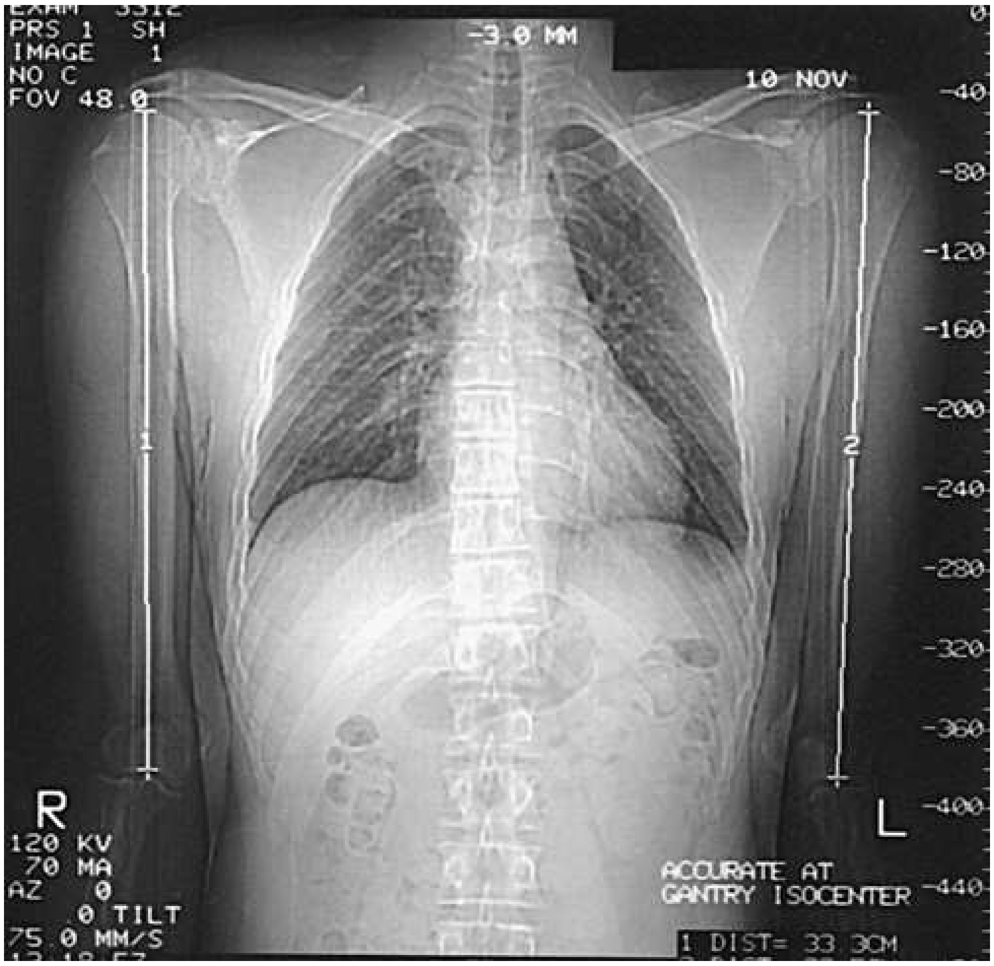

FIG. 7.183 CT measurement of arms.

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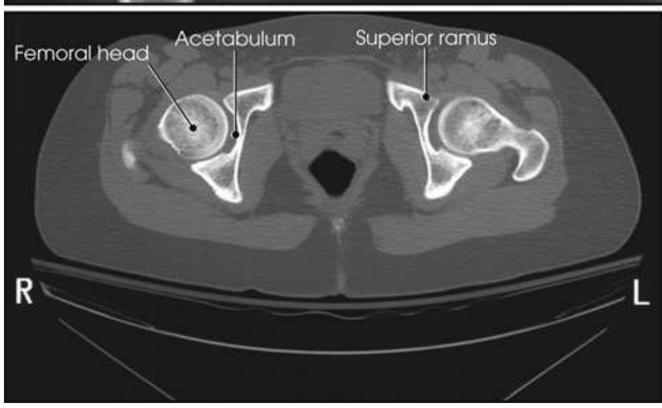
8: Pelvis and Hip



OUTLINE

Summary of Projections

Projections, Positions, and Methods					
Page	**Essential**	**Anatomy**	**Projection**	**Position**	**Method**
393		Pelvis and proximal femora	AP		
396		Pelvis and proximal femora	Lateral	R or L	
398		Femoral necks	AP oblique		MODIFIED CLEAVES
400		Femoral necks	Axiolateral		ORIGINAL CLEAVES
402		Hip	AP		
404		Hip	Lateral (mediolateral)		LAUENSTEIN, HICKEY
406		Hip	Axiolateral		DANELIUS-MILLER
408		Hip	Modified axiolateral		CLEMENTS-NAKAYAMA
410		Acetabulum	PA axial oblique	RAO or LAO	TEUFEL
412		Acetabulum	AP oblique	RPO or LPO	JUDET, MODIFIED JUDET
414		Anterior pelvic bones	AP axial (outlet)		TAYLOR
416		Anterior pelvic bones	Superoinferior axial (inlet)		BRIDGMAN
417		Ilium	AP and PA oblique	RPO and LPO, RAO and LAO	

The icons in the Essential column indicate projections frequently performed in the United States and Canada. Students should become competent in these projections.

AP, Anteroposterior; *L,* left; *LAO,* left anterior oblique; *LPO,* left posterior oblique; *PA,* posteroanterior; *R,* right; *RAO,* right anterior oblique; *RPO,* right posterior oblique.

Anatomy

The *pelvis* serves as a base for the trunk and a girdle for the attachment of the lower limbs. The pelvis consists of four bones: two *hip bones,* the *sacrum,* and the *coccyx*. The *pelvic girdle* is composed of only the two hip bones.

Hip Bone

The *hip bone* is often referred to as the *os coxae,* and some textbooks continue to refer to it as the *innominate bone*. The most widely used term is *hip bone* (Figs. 8.1 and 8.2).

The hip bone consists of the *ilium, pubis,* and *ischium* (Fig. 8.3A). These three bones join together to form the *acetabulum,* the cup-shaped socket that receives the head of the femur. The ilium, pubis, and ischium are separated by cartilage in children but become fused into one bone in adults.

The hip bone is divided further into two distinct areas: the *iliopubic column* and the *ilioischial column* (see Fig. 8.3B). These columns are used to identify fractures around the acetabulum.

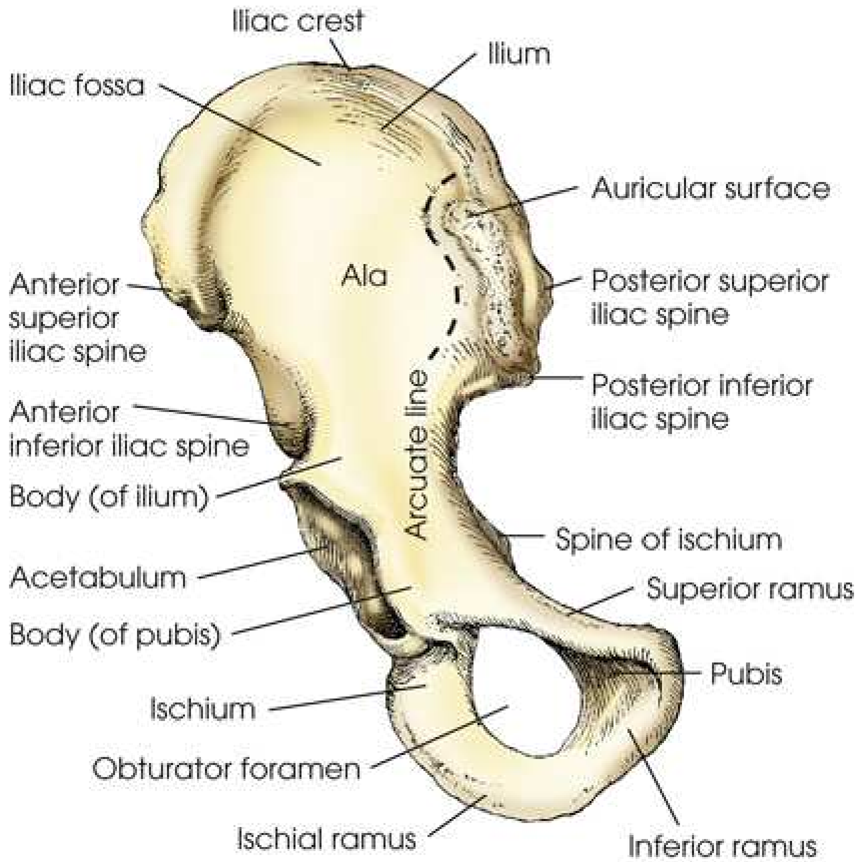


FIG. 8.1 Anterior aspect of right hip bone.

Diagram shows the anterior aspect of the right hip bone. The obturator foramen is a hollow circle. The parts labeled in the diagram are marked clockwise as follows.: ischial ramus, obturator foramen, ischium, body (of the pubis), acetabulum, body (of ilium), anterior inferior iliac spine, anterior superior iliac spine, iliac fossa, iliac crest, ilium, auricular surface, posterior superior iliac spine, posterior inferior iliac spine, the spine of ischium, superior ramus, pubis, and an inferior ramus.

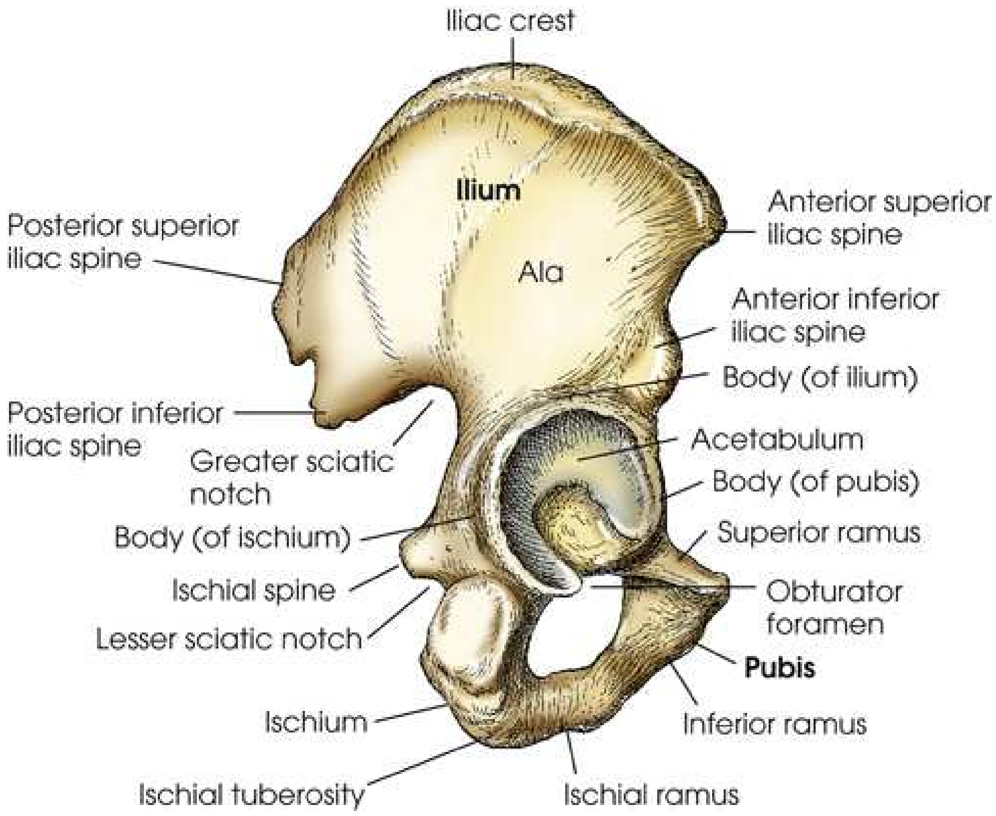


FIG. 8.2 Lateral aspect of right hip bone.

Diagram shows the lateral aspect of the right hip bone. A cup-shaped socket receives the head of the femur. The parts labeled in the diagram are marked clockwise as follows: ischial tuberosity, ischium, lesser sciatic notch, ischial spine, body (of ischium), greater sciatic notch, posterior inferior iliac spine, posterior superior iliac spine, iliac crest, Ilium, ala, anterior superior iliac spine, anterior inferior iliac spine, body (of ilium), acetabulum, body (of the pubis), superior ramus, obturator foramen, pubis, inferior ramus, and ischial ramus.

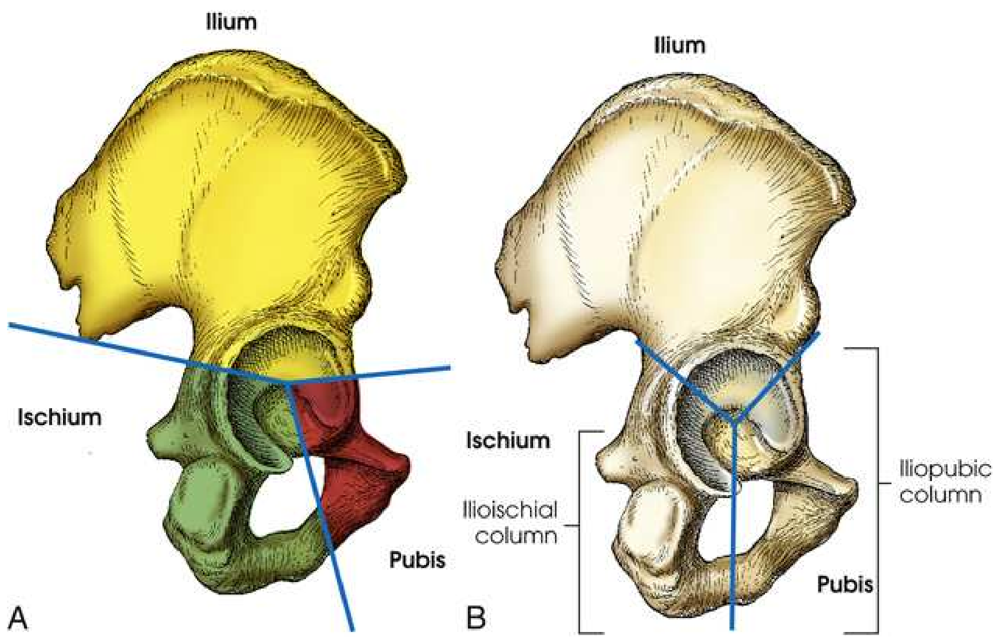


FIG. 8.3 (A) Color-coded lateral aspect of right hip bone showing its three parts. Key: *yellow,* ilium; *green,* ischium; *red,* pubis. (B) Lateral aspect of hip bone showing ilioischial and iliopubic columns.

Diagram (A) shows the color-coded lateral aspect of the right hip bone showing its three parts. These three bones join together to form the acetabulum, the cup-shaped socket that receives the head of the femur. Yellow is the ilium, green is the ischium, red is the pubis. Diagram (B) shows the hip bone is divided into two distinct areas: the iliopubic column and the ilioischial column. The parts labeled in the diagram are ilioischial column and iliopubic column.

Ilium

The *ilium* consists of a *body* and a broad, curved portion called the *ala*. The body of the ilium forms approximately two-fifths of the acetabulum superiorly (see Figs. 8.1 and 8.2). The ala projects superiorly from the body to form the prominence of the hip. The ala has three borders: anterior, posterior, and superior. The anterior and posterior borders present four prominent projections:

- Anterior superior iliac spine (ASIS)
- Anterior inferior iliac spine
- Posterior superior iliac spine
- Posterior inferior iliac spine

The *ASIS* is an important and frequently used radiographic positioning reference point. The superior margin extending from the ASIS to the posterior superior iliac spine is called the *iliac crest*. The medial surface of the wing contains the *iliac fossa* and is separated from the body of the bone by a smooth, arc-shaped ridge—the *arcuate line*—which forms part of the circumference of the pelvic brim. The arcuate line passes obliquely, inferiorly, and medially to its junction with the pubis. The inferior and posterior portions of the wing present a large, rough surface—the *auricular surface*—for articulation with the sacrum. This articular surface and the articular surface of the adjacent sacrum have irregular elevations and depressions that cause a partial interlock of the two bones. The ilium curves inward below this surface, forming the *greater sciatic notch*.

Pubis

The *pubis* consists of a *body,* the *superior ramus,* and the *inferior ramus*. The body of the pubis forms approximately one-fifth of the acetabulum anteriorly (see Figs. 8.1 and 8.2). The superior ramus projects inferiorly and medially from the acetabulum to the midline of the body. There, the bone curves inferiorly and then posteriorly and laterally to join the ischium. The lower prong is termed the *inferior ramus*.

Ischium

The *ischium* consists of a *body* and the *ischial ramus*. The body of the ischium forms approximately two-fifths of the acetabulum posteriorly (see Figs. 8.1 and 8.2). It projects posteriorly and inferiorly from the acetabulum to form an expanded portion called the *ischial tuberosity*. When the body is in a seated or upright position, its weight rests on the two ischial tuberosities. The ischial ramus projects anteriorly and medially from the tuberosity to its junction with the inferior ramus of the pubis. By this posterior union, the rami of the pubis and ischium enclose the *obturator foramen*. At the superoposterior border of the body is a prominent projection called the *ischial spine*. An indentation, the *lesser sciatic notch,* is just below the ischial spine.

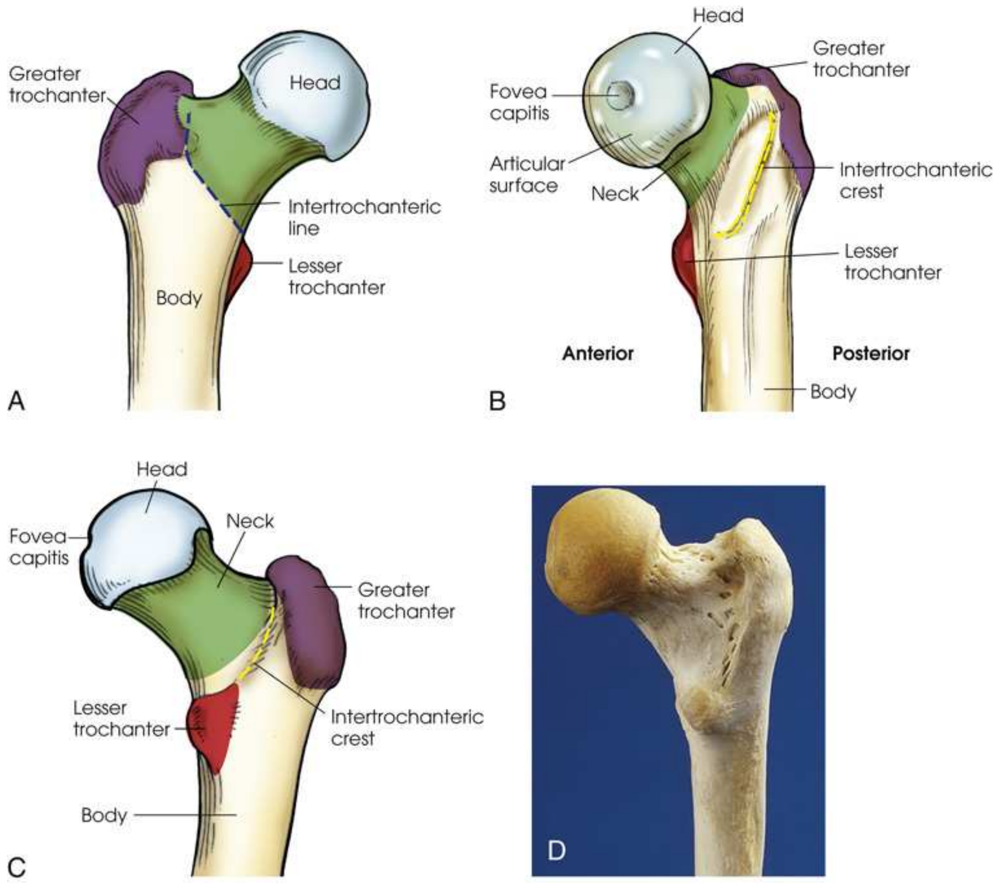


FIG. 8.4 Proximal right femur. Color-coded (A) Anterior aspect. (B) Medial aspect. The body is positioned 15 to 20 degrees posterior from the head. (C) Posterior aspect. Key: *purple,* greater trochanter; *red,* lesser trochanter; *green,* neck; *light blue,* head. Outlined structures are: *yellow,* intertrochanteric crest; *blue (dashed line),* intertrochanteric line. (D) Photo of posterior aspect of right proximal human femur. Note anatomic details and compare with C.

Diagram (A) shows the proximal end of the femur. The smooth, rounded head is connected to the femoral body by a pyramid-shaped neck. The parts labeled in the diagram are as follows: greater trochanter, head, body, intertrochanteric line, and lesser trochanter. Diagram (B) shows the medial aspect of the proximal right femur. A small depression at the center of the head, the fovea capitis, attaches to the ligamentum capitis femoris. The parts labeled in the diagram are marked clockwise as follows: neck, articular surface, fovea capitis, head, greater trochanter, intertrochanteric crest, lesser trochanter, and body. Diagram (C) shows the posterior aspect of the proximal right femur. The neck is constricted near the head but expands to a broad base at the body of the bone. The parts labeled in the diagram are marked clockwise as follows: body, lesser trochanter, fovea capitis, head, neck, greater trochanter, and intertrochanteric crest. (D) shows the posterior aspect of the right proximal human femur. The smooth, rounded head is connected to the femoral body by a pyramid-shaped neck.

Proximal Femur

The *femur* is the longest, strongest, and heaviest bone in the body. The proximal end of the femur consists of a *head,* a *neck,* and two large processes—the *greater* and *lesser trochanters* (Fig. 8.4). The smooth, rounded head is connected to the femoral body by a pyramid-shaped neck and is received into the acetabular cavity of the hip bone. A small depression at the center of the head, the *fovea capitis,* attaches to the ligamentum capitis femoris (Fig. 8.5; see also Fig. 8.4). The neck is constricted near the head but expands to a broad base at the *body* of the bone. The neck projects medially, superiorly, and anteriorly from the body. The trochanters are situated at the junction of the body and the base of the neck. The greater trochanter is at the superolateral part of the femoral body, and the lesser trochanter is at the posteromedial part. The prominent ridge extending between the trochanters at the base of the neck on the posterior surface of the body is called the *intertrochanteric crest*. The less prominent ridge connecting the trochanters anteriorly is called the *intertrochanteric line*. The femoral neck and the intertrochanteric crest are two common sites of fracture in elderly adults. The superior portion of the greater trochanter projects above the neck and curves slightly posteriorly and medially.

FIG. 8.5 Hip joint. AP hip demonstrating the fovea capitis.

The angulation of the neck of the femur varies considerably with age, sex, and stature. In the average adult, the neck projects anteriorly from the body at an angle of approximately 15 to 20 degrees and superiorly at an angle of approximately 120 to 130 degrees to the long axis of the femoral body (Fig. 8.6). The longitudinal plane of the femur is angled approximately 10 degrees from vertical. In children, the latter angle is wider (i.e., the neck is more vertical in position). In wide pelves, the angle is narrower, placing the neck in a more horizontal position.

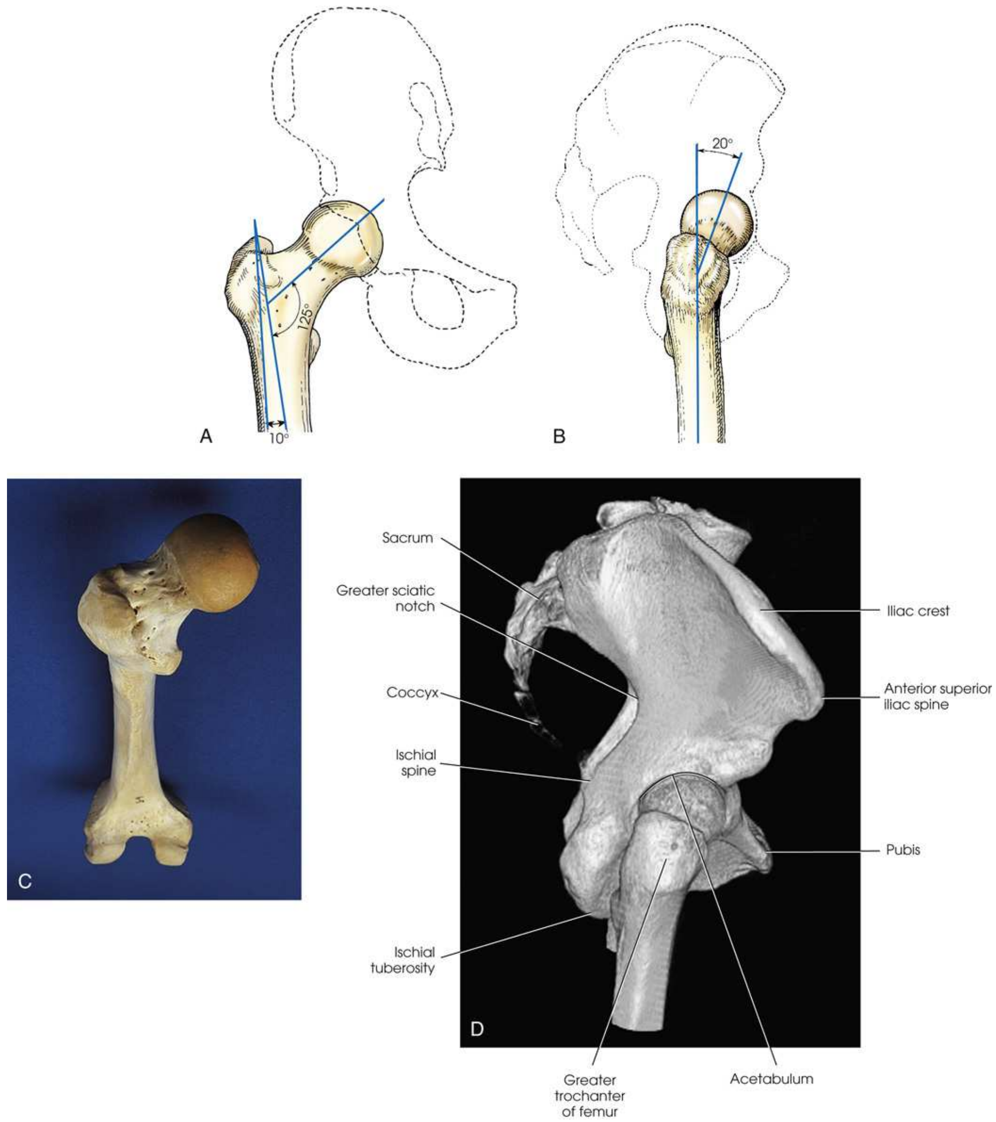


FIG. 8.6 (A) Anterior aspect of right femur. (B) Lateral aspect of right femur. (C) Superoinferior view of posterior aspect of a human femur showing 15- to 20-degree anterior angle of femoral neck. (D) Three-dimensional computed tomography (CT) scan of lateral hip bone and proximal femur.

Diagram (A) shows the longitudinal plane of the femur is angled approximately 10 degrees from vertical. Diagram (B) shows the neck projects anteriorly from the body at an angle of approximately 15 to 20 degrees. Diagram (C) shows a 15 to 20-degree anterior angle of the femoral neck. (D) shows the three-dimensional computed tomography (C T) scan of the lateral hip bone and proximal femur. The sacrum is triangular shaped and appears to have a rough surface. The coccyx extends from the sacrum. The parts labeled are marked clockwise as follows: greater trochanter of femur, ischial tuberosity, ischial spine, coccyx, greater sciatic notch, sacrum, iliac crest, anterior superior iliac spine, pubis, and acetabulum.

Articulations of the Pelvis

Table 8.1 and Fig. 8.7 provide a summary of the three joints of the pelvis and upper femora. The articulation between the acetabulum and the head of the femur (the hip joint) is a *synovial ball-and-socket* joint that permits free movement in all directions. The knee and ankle joints are hinge joints; the wide range of motion of the lower limb depends on the ball-and-socket joint of the hip. Because the knee and ankle joints are hinge joints, medial and lateral rotations of the foot cause rotation of the entire limb, which is centered at the hip joint.

The pubes of the hip bones articulate with each other at the anterior midline of the body, forming a joint called the *pubic symphysis*. The pubic symphysis is a *cartilaginous symphysis* joint.

The right and left ilia articulate with the sacrum posteriorly at the *sacroiliac* (SI) joints. These two joints angle 25 to 30 degrees relative to the midsagittal plane (MSP) (see Fig. 8.7B). The SI articulations are *synovial irregular gliding* joints. Because the bones of the SI joints interlock, movement is limited or nonexistent.

TABLE 8.1

Joint	Structural classification		Movement
	Tissue	Type	
Hip joint	Synovial	Ball and socket	Freely movable
Pubic symphysis	Cartilaginous	Symphysis	Slightly movable
Sacroiliac	Synovial	Irregular gliding[a]	Slightly movable

[a] Some anatomists term this a synovial fibrous joint.

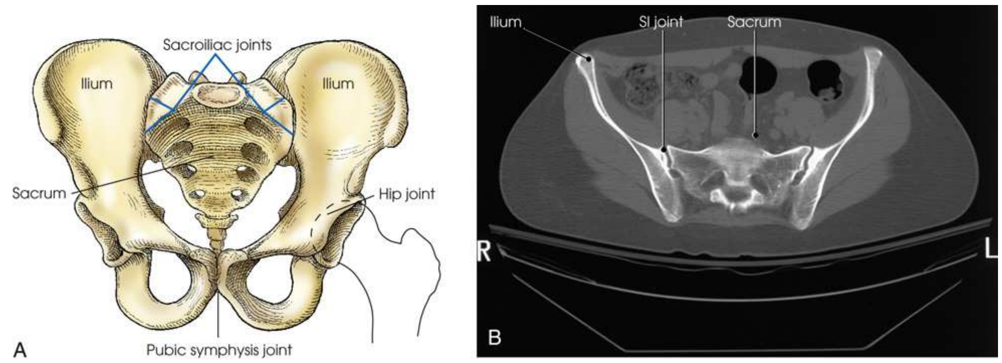


FIG. 8.7 (A) Joints of pelvis and upper femora. (B) Axial computed tomography (CT) image of pelvis showing SI joints. Note 25- to 30-degree angulation of joint. B, Modified from Kelley L, Petersen CM. *Sectional anatomy for imaging professionals.* ed 2, St Louis: Mosby; 2007.

Diagram (A) shows the three joints of the pelvis and upper femora. The parts labeled in the diagram are marked clockwise as follows: pubic symphysis joint, sacrum, ilium, sacroiliac joints, and hip joint. (B) shows the axial computed tomography (C T) image of the pelvis. The parts labeled in the diagram are marked as follows ilium, SI joint, and sacrum. There is a gap between the S I joint and the sacrum. Two irregular dark circles are above the sacrum towards the left.

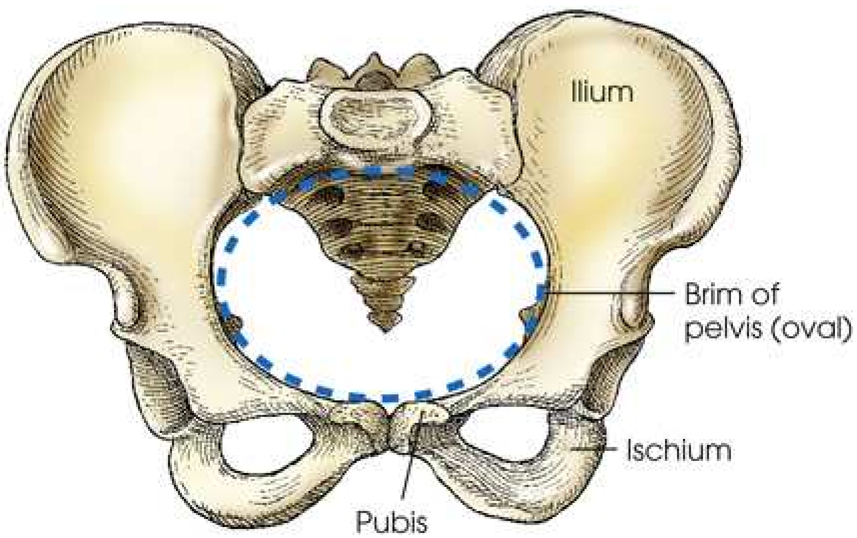


FIG. 8.8 Female pelvis.

Diagram shows the female pelvis which is wider and shallower, and the inlet is larger and more oval in shape A dotted circle is marked around it. The parts labeled in the diagram are labeled as follows: pubis, ischium, the brim of the pelvis (oval), and ilium.

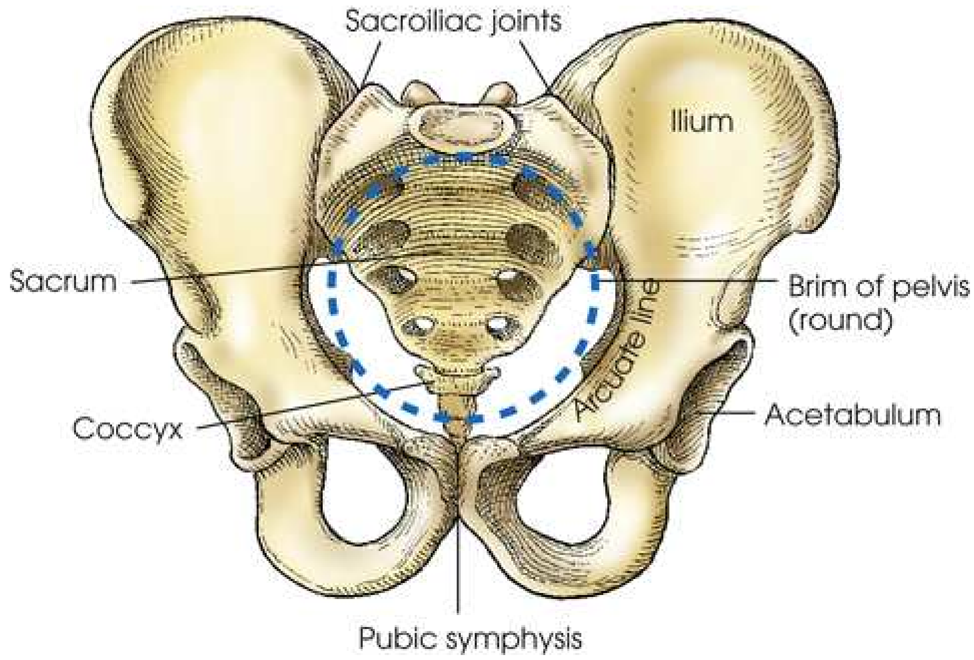


FIG. 8.9 Male pelvis.

Diagram shows the male pelvis which is shaped like a circle. A dotted circle is marked around it. The parts labeled in the diagram are marked clockwise as follows: pubic symphysis, coccyx, sacrum, sacroiliac joints, ilium, the brim of the pelvis (round), and acetabulum.

Pelvis

The female pelvis (Fig. 8.8) is lighter in structure than the male pelvis (Fig. 8.9). It is wider and shallower, and the inlet is larger and more oval in shape. The sacrum is wider; it curves more sharply posteriorly, and the sacral promontory is flatter. The width and depth of the pelvis vary with stature and gender (Table 8.2). The female pelvis is shaped for childbearing and delivery.

The pelvis is divided into two portions by an oblique plane that extends from the upper anterior margin of the sacrum to the upper margin of the pubic symphysis. The boundary line of this plane is called the *brim of the pelvis* (see Figs. 8.8 and 8.9). The region above the brim is called the *false* or *greater pelvis,* and the region below the brim is called the *true* or *lesser pelvis*.

The brim forms the *superior aperture,* or *inlet,* of the true pelvis. The *inferior aperture,* or *outlet,* of the true pelvis is measured from the tip of the coccyx to the inferior margin of the pubic symphysis in the AP direction and between the ischial tuberosities in the horizontal direction. The region between the inlet and the outlet is called the *pelvic cavity* (Fig. 8.10).

When the body is in the upright or seated position, the brim of the pelvis forms an angle of approximately 60 degrees to the horizontal plane. This angle varies with other body positions; the degree and direction of the variation depend on the lumbar and sacral curves.

TABLE 8.2

Female and male pelvis characteristics

Feature	Female	Male
Shape	Wide, shallow	Narrow, deep
Bony structure	Light	Heavy
Superior aperture (inlet)	Oval	Round
Inferior aperture (outlet)	Wide	Narrow

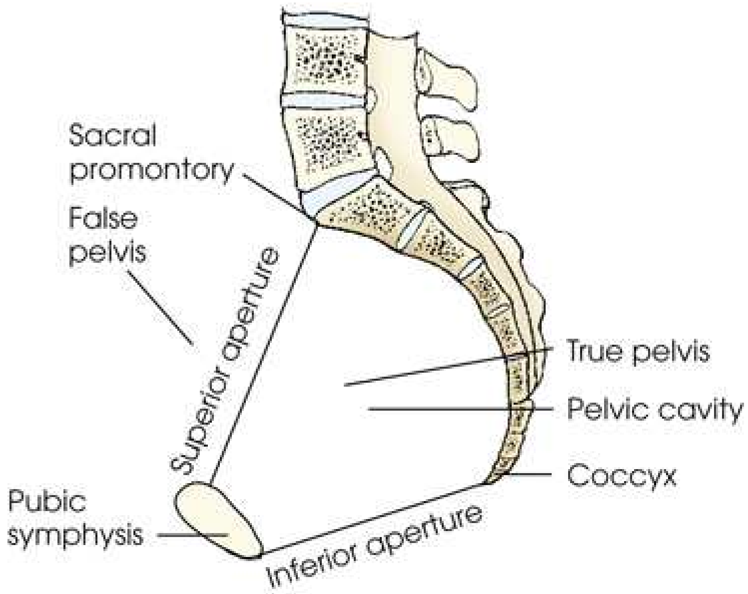


FIG. 8.10 Midsagittal section showing inlet and outlet of true pelvis.

Diagram shows the inlet and outlet of the true pelvis. The parts labeled in the diagram are marked clockwise as follows.: pubic symphysis, superior aperture, false pelvis, sacral promontory, true pelvis, pelvic cavity, coccyx, and inferior aperture. The inferior aperture is measured from the tip of the coccyx to the inferior margin of the pubic symphysis. The superior aperture is measured from the tip of the coccyx to the inferior margin of the pubic symphysis

Localizing Anatomic Structures

The bony landmarks used in radiography of the pelvis and hips are as follows:

- Iliac crest
- ASIS
- Pubic symphysis
- Greater trochanter of the femur
- Ischial tuberosity
- Tip of the coccyx

Most of these points are palpable, even in hypersthenic patients (Fig. 8.11). The highest point of the iliac crest, located on the posterior aspect of the ilium, may be more difficult to locate in heavily muscled patients. To avoid positioning errors, this structure may be more easily palpated while the patient breathes out because the abdominal muscles will then be relaxed.

The highest point of the greater trochanter, which can be palpated immediately below the depression in the soft tissues of the lateral surface of the hip, is in approximately the same horizontal plane as the midpoint of the hip joint and the coccyx. The most prominent point of the greater trochanter is in the same horizontal plane as the pubic symphysis (see Fig. 8.11).

The greater trochanter is most prominent laterally and more easily palpated when the lower leg is medially rotated. When properly used, medial rotation assists in localization of hip and pelvis centering points and avoids foreshortening of the femoral neck during radiography. Improper rotation of the lower leg can rotate the pelvis. Consequently, positioning of the lower leg is important in radiographing the hip and pelvis. Traumatic injuries or pathologic conditions of the pelvis or lower limb may rule out the possibility of medial rotation.

The pubic symphysis can be localized by palpation of the lateral surface of the hip region because it lies on the same horizontal plane as the greater trochanters. *To avoid possible embarrassment or misunderstanding, the radiographer should advise the patient in advance that this and other palpations of pelvic landmarks are part of normal procedure and necessary for an accurate examination.* When performed in an efficient and professional manner with respect for the patient's condition, such palpations are generally well tolerated.

The hip joint can be located by palpating the ASIS and the greater trochanter to ascertain the superior margin of the pubic symphysis. *Radiographers are advised to avoid palpating the pubic symphysis.* The midpoint of an imaginary line connecting the ASIS to the pubic symphysis is directly above the center of the dome of the acetabular cavity. An imaginary line drawn at right angles to the midpoint of the first line lies parallel to the long axis of the femoral neck of an average adult in the anatomic position. The femoral head lies 1.5 inches (3.8 cm) distal, and the femoral neck is 2.5 inches (6.3 cm) distal to this midpoint (Fig. 8.12).

For accurate localization of the femoral neck in atypical patients or in patients in whom the limb is not in the anatomic position, an imaginary line is drawn between the ASIS and the superior margin of the pubic symphysis; a second line is then drawn from a point 1 inch (2.5 cm) inferior to the greater trochanter to the midpoint of the previously marked line. The femoral head and neck lie along this line (see Fig. 8.12).

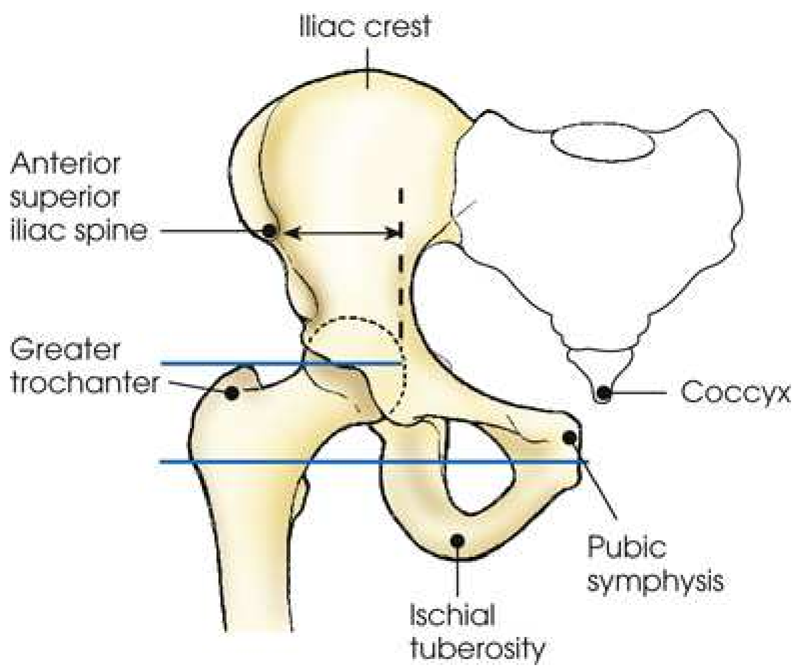


FIG. 8.11 Bony landmarks and localization planes of pelvis.

Diagram shows the bony landmarks and the localization planes of the pelvis. The parts labeled in the diagram are marked clockwise as follows: ischial tuberosity, greater trochanter, anterior superior iliac spine, iliac crest, coccyx, and pubic symphysis. A dashed circle is marked at the greater trochanter to indicate medial rotation. A vertical dotted line is marked from the iliac crest to the greater trochanter.

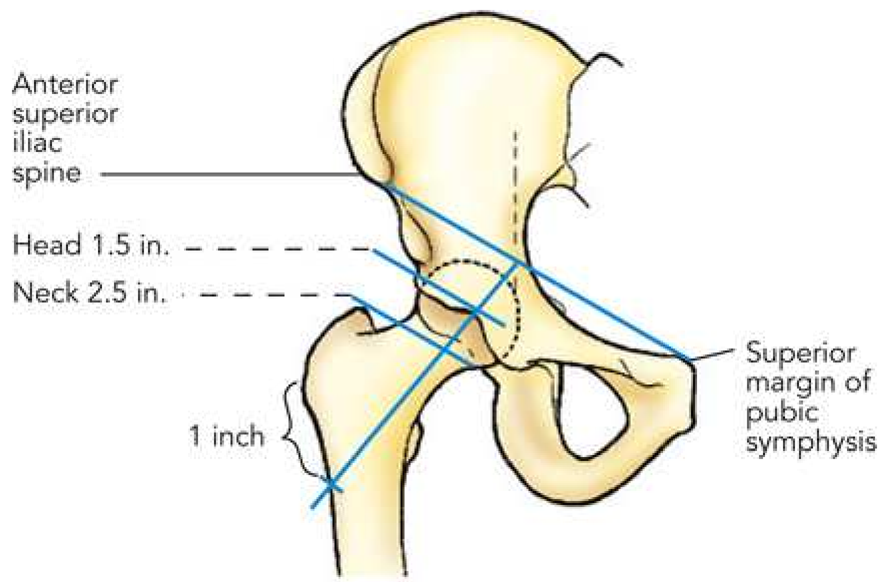


FIG. 8.12 Method of localizing right hip joint and long axis of femoral neck. Note that localization of the pubic symphysis is by palpation of the greater trochanter, as these lie in the same horizontal plane, as shown in Fig. 8.11.

Diagram shows the method of localizing the right hip joint and the long axis of the femoral neck. The femoral head lies 1.5 inches distal, and the femoral neck is 2.5 inches distal to the midpoint. The superior margin of the pubic symphysis and the anterior superior iliac spine is labeled.

Alternative Positioning Landmark

In many radiology departments, it is no longer considered appropriate practice for a radiographer to palpate the pubic bone as a landmark for location of anatomy during radiographic positioning. Bello [1] described an alternative positioning landmark for the pelvis and hip, which can be generalized for radiography of any body part that recommends use of the pubic symphysis as a positioning landmark. His research determined that the distance from the ASIS to the superior aspect of the pubic symphysis ranges from 2.5 to 3.5 inches (6.3 to 8.8 cm), with an average of 3 inches (7.5 cm). He also found the same distance from the superior margin of the iliac crest to the ASIS—average 3 inches (7.5 cm). However, this article was not published through the peer-review process, and the sample size was small, so the *Atlas* authors cannot advocate use of these measurements without support of more formal research and peer-reviewed publication.

Summary of Anatomy

Pelvis

- Hip bones (two)
- Sacrum
- Coccyx
- Pelvic girdle

Hip bone

- Ilium
- Pubis
- Ischium
- Acetabulum

Ilium

- Body
- Ala
- Superior spine
- Inferior spine
- Anterior superior iliac spine (ASIS)
- Anterior inferior iliac spine
- Posterior superior iliac spine
- Posterior inferior iliac spine
- Iliac crest
- Iliac fossa
- Arcuate line
- Auricular surface
- Greater sciatic notch

Pubis

- Body
- Superior ramus
- Inferior ramus
- Iliopubic column

Ischium

- Body
- Ischial ramus
- Ischial tuberosity
- Obturator foramen
- Ischial spine
- Lesser sciatic notch
- Ilioischial column

Femur (proximal aspect)

- Head
- Neck
- Body
- Fovea capitis
- Greater trochanter
- Lesser trochanter
- Intertrochanteric crest
- Intertrochanteric line

Articulations

- Hip
- Pubic symphysis

Sacroiliac joints

Pelvis

Brim of the pelvis
Greater or false pelvis
Lesser or true pelvis
Superior aperture or inlet
Inferior aperture or outlet
Pelvic cavity
Intertrochanteric crest
Intertrochanteric line

Abbreviations Used in Chapter 8

ASIS	Anterior superior iliac spine
MCP	Midcoronal plane
MSP	Midsagittal plane
SI	Sacroiliac

See Addendum A for a summary of all abbreviations used in Volume 1.

Summary of Pathology

Condition	Definition
Ankylosing spondylitis	Rheumatoid arthritis variant involving the SI joints and spine
Congenital hip dysplasia	Malformation of the acetabulum causing displacement of the femoral head
Dislocation	Displacement of a bone from the joint space
Fracture	Disruption in the continuity of bone
Legg-Calvé-Perthes disease	Flattening of the femoral head due to vascular interruption
Metastasis	Transfer of a cancerous lesion from one area to another
Osteoarthritis or degenerative joint disease	Form of arthritis marked by progressive cartilage deterioration in synovial joints and vertebrae
Osteopetrosis	Increased density of atypically soft bone
Osteoporosis	Loss of bone density
Paget disease	Thick, soft bone marked by bowing and fractures
Slipped epiphysis	Proximal portion of femur dislocated from distal portion at the proximal epiphysis
Tumor	New tissue growth where cell proliferation is uncontrolled
Chondrosarcoma	Malignant tumor arising from cartilage cells
Multiple myeloma	Malignant neoplasm of plasma cells involving the bone marrow and causing destruction of the bone

Eponymous (named) pathologies are listed in nonpossessive form to conform to the *AMA manual of style: a guide for authors and editors*, ed 10, Oxford, 2009, Oxford University Press.

Sample Exposure Technique Chart Essential Projections

These techniques were accurate for the equipment used to produce each exposure. However, use caution in applying them in your department because “there is considerable variability in image receptor response owing to varying scatter sensitivity, the use of grids with different grid ratios, collimation, beam filtration, the choice of kilovoltage, source-to-image distance, and image receptor size." Generator output characteristics and IR energy sensitivities vary widely. [1]

This chart was created in collaboration with Dennis Bowman, AS, RT(R), Clinical Instructor, Community Hospital of the Monterey Peninsula, Monterey, CA. http://digitalradiographysolutions.com/.

Pelvis and Proximal Femora

Part	cm	kVp[a]	SID[b]	Collimation	CR[c] mAs	CR[c] Dose (mGy)[e]	DR[d] mAs	DR[d] Dose (mGy)[e]
Pelvis and proximal femora—*AP*[f]	19	85	40″	17″ × 14″(43 × 35 cm)	25[g]	3.620	12.5[g]	1.805
Femoral necks—*AP oblique*[f]	19	85	40″	17″ × 10″(43 × 25 cm)	28[g]	3.960	14[g]	1.977
Hip—*AP*[f]	18	85	40″	8″ × 12″(20 × 30 cm)	20[g]	2.740	10[g]	1.367
Hip—lateral (Lauenstein-Hickey)[f]	18	85	40″	10″ × 8″(25 × 20 cm)	18[g]	2.430	9[g]	1.206
Hip—axiolateral (Danelius-Miller)[f]	24	90	40″	12″ × 8″(30 × 20 cm)	71[g]	12.48	32[g]	5.600

[1] ACR-AAPM-SIMM Practice Parameter for Digital Radiography, revised 2017.

[a] kVp values are for a high-frequency generator.

[b] 40-inch minimum; 44–48 inches recommended to improve spatial resolution (mAs increase needed, but no increase in patient dose will result).

[c] AGFA CR MD 4.0 General IP, CR 75.0 reader, 400 speed class, with 6:1 (178LPI) grid when needed.

[d] GE Definium 8000, with 13:1 grid when needed.

[e] All doses are skin entrance for average adult (160- to 200-lb male, 150- to 190-lb female) at part thickness indicated.

[f] Bucky/grid.

[g] Large focal spot.

Radiography

Radiation Protection

Protection of the patient from unnecessary radiation is a professional responsibility of the radiographer (see Chapter 1 for specific guidelines). The National Council on Radiation Protection (NCRP) Statement No. 13, published in January 2021, recommends ending routine gonadal shielding during abdominal and pelvic radiography. This research states that shielding increases the risk of repeat exposures due to the shield obscuring anatomy of interest and interference with proper automatic exposure control (AEC) function. [2] In this chapter, the *Shield gonads* statement at the end of the *Position of part* section has been deleted. Students and technologists are strongly encouraged to protect the patient from unnecessary radiation by restricting the radiation beam through the use of proper collimation.

Pelvis and Proximal Femora

AP Projection

Image receptor + grid: Positioned by manufacturer or department protocol for proper anatomy display orientation; CR plate 14 × 17 inches (35 × 43 cm) crosswise.

Position of patient

- Place the patient on the table in the supine position.

Position of part

- Center the MSP of the body to the midline of the grid and adjust it in a true supine position.
- Unless contraindicated because of trauma or pathologic factors, medially rotate the feet and lower limbs approximately 15 to 20 degrees to place the femoral necks parallel with the plane of the image receptor (IR) (Figs. 8.13 and 8.14). Medial rotation is easier for the patient to maintain if the knees are supported. The heels should be placed approximately 8 to 10 inches (20 to 24 cm) apart.
- Immobilize the legs with a sandbag across the ankles if necessary.
- Check the distance from the ASIS to the tabletop on each side to ensure that the pelvis is not rotated.

FIG. 8.13 (A) AP pelvis with femoral necks and trochanters poorly positioned because of lateral rotation of limbs. (B) Feet and lower limbs in natural, laterally rotated tabletop position, causing poor profile of proximal femora in A.

(A) An x-ray shows the femoral necks and trochanters. The entire pelvis and proximal femora appear white. The soft tissues appear dark. (B) The heels are placed together and the feet are laterally rotated.

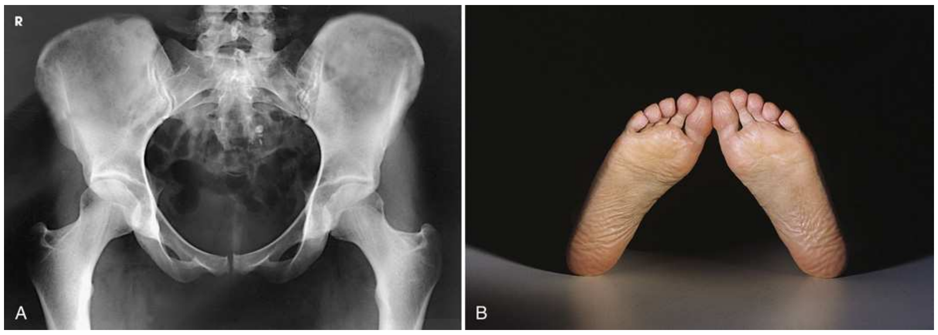


FIG. 8.14 (A) AP pelvis with femoral necks and trochanters in correct position. (B) Feet and lower limbs medially rotated 15 to 20 degrees, correctly placed with upper femora in correct profile in A.

(A) An x-ray shows the femoral necks and trochanters. The entire pelvis and proximal femora appear white. The soft tissues appear faded and hazy. (B) The heels are placed apart from each other. The feet are medially rotated 15 to 20 degrees and the toes touch each other.

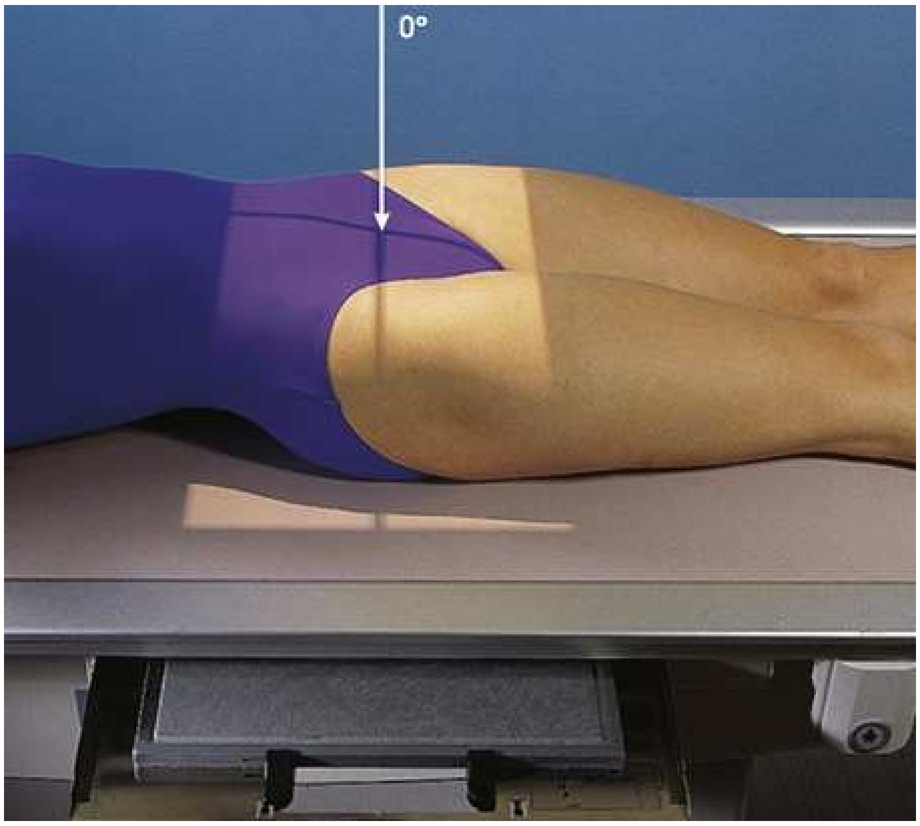


FIG. 8.15 AP pelvis.

The patient is lying in the supine position on the radiographic table. The I R is centered inferior to the A S I S and superior to the pubic symphysis. The central ray is perpendicular to the midpoint of the I R.

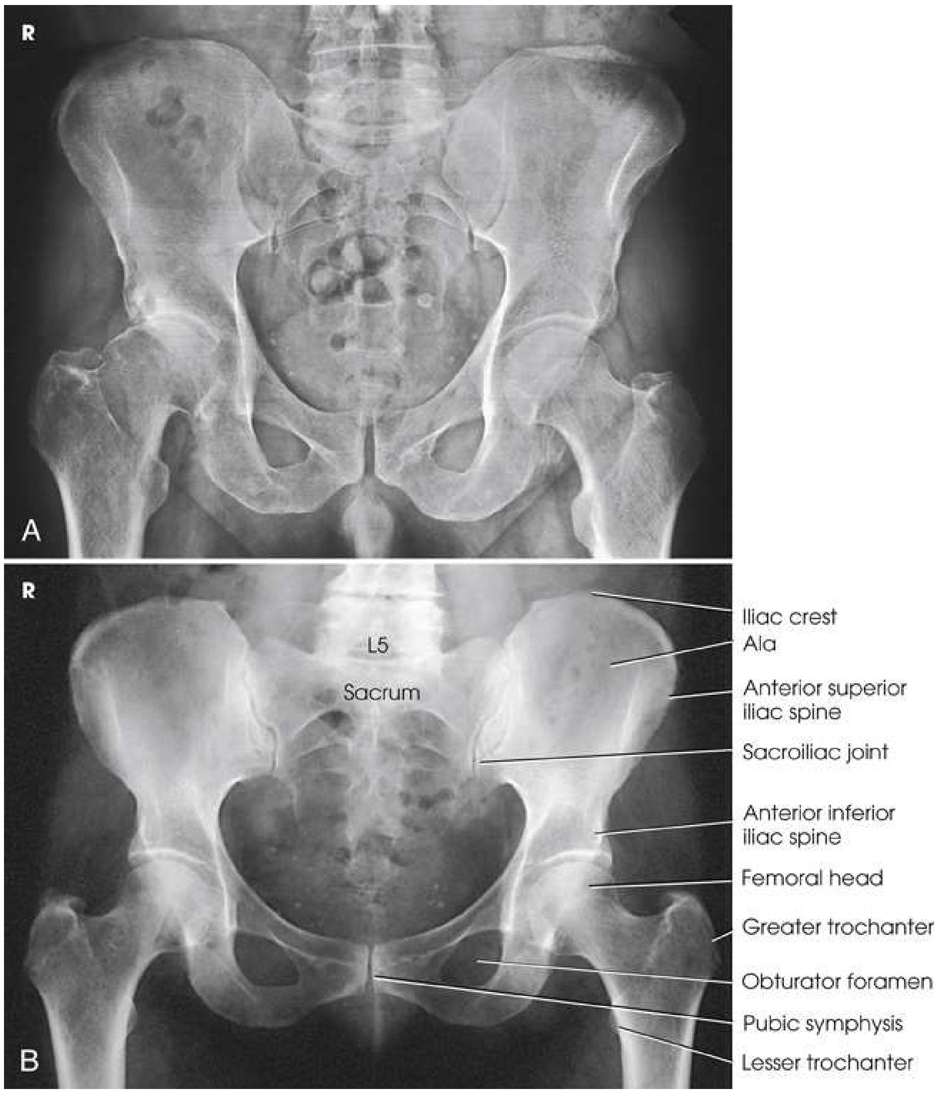


FIG. 8.16 (A) Male AP pelvis. (B) Female AP pelvis.

(A) The x-ray shows the pelvis and the head, neck, trochanters, and proximal one-third or one-fourth of the shaft of the femora. (B) The x-ray shows the entire pelvis and proximal femora. The parts labeled are marked from top to bottom as follows: iliac crest, ala, anterior superior iliac spine, sacroiliac joint, anterior inferior iliac spine, femoral head, greater trochanter, obturator foramen, pubic symphysis, and lesser trochanter.

- Center the IR at the level of the soft tissue depression just above the palpable prominence of the greater trochanter (approximately 1.5 inches [3.8 cm]), which is also midway between the ASIS and the pubic symphysis. In average-sized patients, the center of the IR is approximately 2 inches (5 cm) inferior to the ASIS and 2 inches (5 cm) superior to the pubic symphysis (Fig. 8.15).
- If the pelvis is deep, palpate for the iliac crest and adjust the position of the IR so that its upper border projects 1 to 1.5 inches (2.5 to 3.8 cm) above the crest.
- *Respiration:* Suspend.

Central ray

- Perpendicular to the midpoint of the IR.

Collimation

- Adjust radiation field to 14 × 17 inches (35 × 43 cm) on the collimator. For smaller patients, collimate 1 inch (2.5 cm) beyond the skin shadow on the sides. Place side marker in the collimated exposure field.

Structures shown

An AP projection of the pelvis and of the head, neck, trochanters, and proximal one-third or one-fourth of the shaft of the femora (Fig. 8.16).

Evaluation Criteria

The following should be clearly seen:

- Evidence of proper collimation and presence of side marker placed clear of anatomy of interest

- Entire pelvis and proximal femora
- Both ilia and greater trochanters equidistant from the edge of the radiograph
- Lower vertebral column centered to the middle of the radiograph
- No rotation of pelvis
  - Symmetric ilia
  - Symmetric obturator foramina
  - Ischial spines equally seen
  - Sacrum and coccyx aligned with the pubic symphysis
- Proper rotation of proximal femora
  - Femoral necks in their full extent without superimposition
  - Greater trochanters in profile
  - Lesser trochanters, if seen, visible on the medial border of the femora
- Bony trabecular detail and surrounding soft tissues

Congenital dislocation of the hip

Martz and Taylor [3] recommended two AP projections of the pelvis to show the relationship of the femoral head to the acetabulum in patients with congenital dislocation of the hip. The first projection is obtained with the central ray directed perpendicular to the pubic symphysis to detect any lateral or superior displacement of the femoral head. The second projection is obtained with the central ray directed to the pubic symphysis at a cephalic angulation of 45 degrees (Fig. 8.17). This angulation casts the shadow of an anteriorly displaced femoral head above that of the acetabulum and the shadow of a posteriorly displaced head below that of the acetabulum.

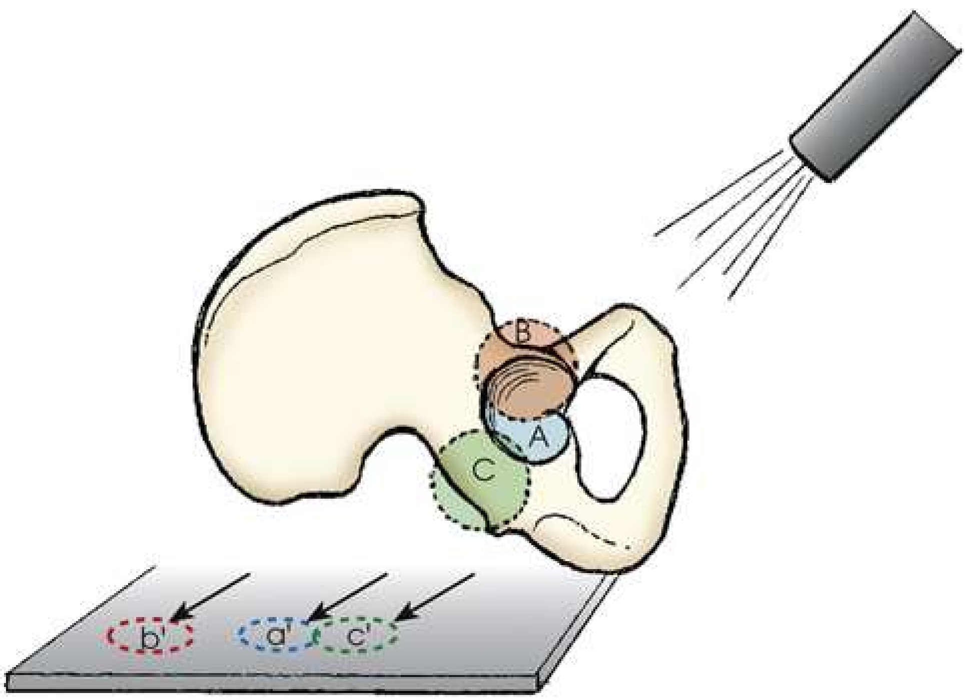


FIG. 8.17 Special projection taken for congenital dislocation of hip.

Diagram shows the angulation casting a shadow A, B, C from an anteriorly displaced femoral head above that of the acetabulum and the shadow of a posteriorly displaced head below that of the acetabulum.

Lateral Projection

Right or left position

Image receptor + grid: Positioned by manufacturer or department protocol for proper anatomy display orientation; CR plate 14 × 17 inches (35 × 43 cm) lengthwise.

Position of patient

- Place the patient in the lateral recumbent, dorsal decubitus, or upright position.

Position of part

Recumbent position

- When the patient can be placed in the lateral position, center the midcoronal plane (MCP) of the body to the midline of the grid.
- Extend the thighs enough to prevent the femora from obscuring the pubic arch.

- Place a support under the lumbar spine and adjust it to place the vertebral column parallel with the tabletop (Fig. 8.18). If the vertebral column is allowed to sag, the pelvis tilts in the longitudinal plane.
- Adjust the pelvis in a true lateral position, with the ASIS lying in the same vertical plane.
- Place one knee directly over the other knee. A pillow or other support between the knees promotes stabilization and patient comfort.
- Berkebile et al. [4] recommended a dorsal decubitus lateral projection of the pelvis to show the “gull wing” sign in cases of fracture-dislocation of the acetabular rim and posterior dislocation of the femoral head.

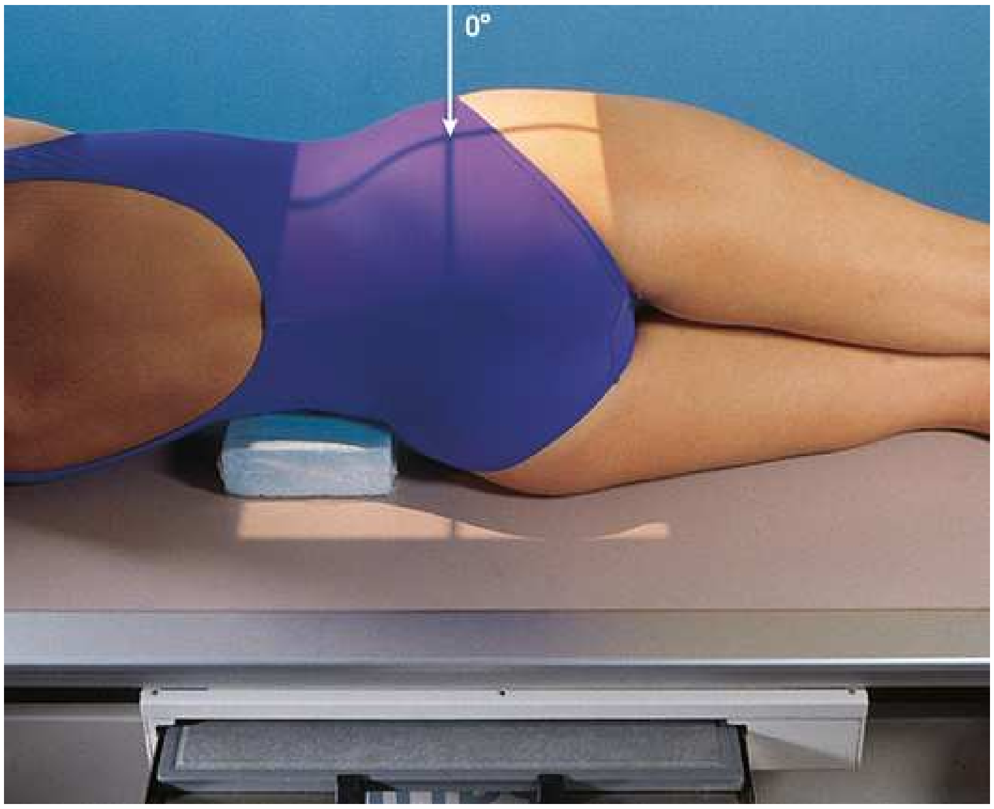


FIG. 8.18 Lateral pelvis.

A patient is in the lateral recumbent position and the thighs are extended. A support is placed under the lumbar spine to place the vertebral column-parallel with the tabletop. The central ray is perpendicular to a point centered at the level of the soft tissue.

Upright position

- Place the patient in the lateral position in front of a vertical grid device and center the MCP of the body to the midline of the grid.
- Have the patient stand straight, with the weight of the body equally distributed on the feet, so that the MSP is parallel with the plane of the IR.
- If the limbs are of unequal length, place a support of suitable height under the foot of the shorter side.
- Have the patient grasp the side of the stand for support.
- *Respiration:* Suspend.

Central ray

- Perpendicular to a point centered at the level of the soft tissue depression just above the palpable prominence of the greater trochanter (approximately 2 inches [5 cm]) and to the midpoint of the IR.
- Center the IR to the central ray.

Collimation

- Adjust radiation field to 14 × 17 inches (35 × 43 cm). Place side marker in the collimated exposure field.

Structures shown

A lateral radiograph of the lumbosacral junction, sacrum, coccyx, and superimposed hip bones and upper femora (Fig. 8.19).

Evaluation Criteria

The following should be clearly seen:

- Evidence of proper collimation and presence of side marker placed clear of anatomy of interest
- Entire pelvis and the proximal femora
- Sacrum and coccyx
- Pelvis in true lateral position without rotation
    - Superimposed posterior margins of the ischium and ilium
    - Superimposed femora
    - Superimposed acetabular shadows (The larger circle of the fossa [farther from the IR] is equidistant from the smaller circle of the fossa nearer the IR throughout their circumference.)
- Pubic arch unobscured by the femora
- Bony trabecular detail and surrounding soft tissues

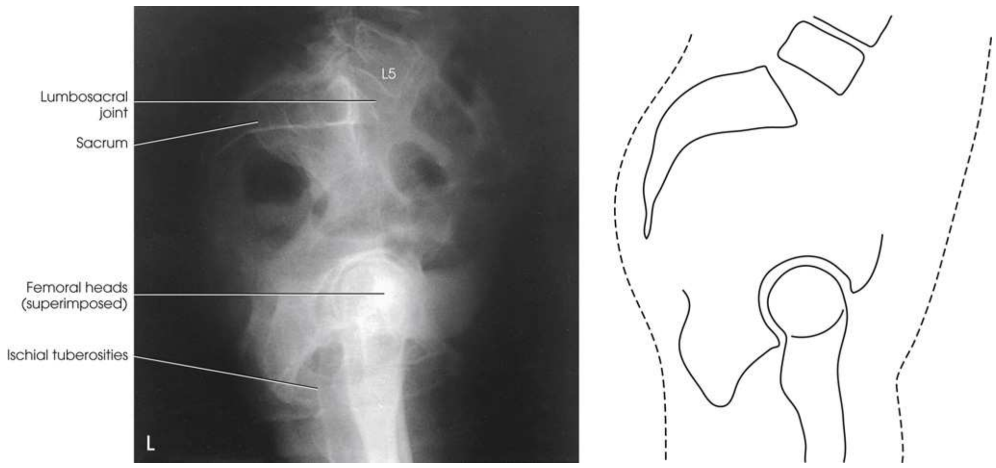


FIG. 8.19 Lateral pelvis.

An x-ray shows the entire pelvis and the proximal femora. It appears hazy. The femoral head appears radiopaque. The parts labeled are marked from top to bottom as follows: lumbosacral joint, sacrum, femoral heads (superimposed), and ischial tuberosities. Diagram on the right shows a drawing of the lateral pelvis highlighting the lumbosacral junction, sacrum, coccyx, and superimposed hip bones and upper femora.

Proximal Femora and Femoral Necks

AP Oblique Projection

Modified Cleaves Method

Image receptor + grid: Positioned by manufacturer or department protocol for proper anatomy display orientation; CR plate: 14 × 17 inches (35 × 43 cm) crosswise.

This projection is often called the bilateral *frog-leg* position.

NOTE: This examination is contraindicated for a patient suspected to have a fracture or other pathologic disease.

Position of patient

- Place the patient in the supine position.

Position of part

- Center the MSP of the body to the midline of the grid.
- Flex the patient's elbows, and rest the hands on the upper chest.
- Adjust the patient so that the pelvis is not rotated. This position can be achieved by placing the two ASISs equidistant from the radiographic table.
- Place a compression band across the patient well above the hip joints for stability if necessary.

Bilateral projection

Step 1

- Have the patient flex the hips and knees and draw the feet up as much as possible (i.e., enough to place the femora in a nearly vertical position if the affected side permits).

• Instruct the patient to hold this position, which is relatively comfortable, while the x-ray tube and IR are adjusted.

Step 2

• Center the IR 1 inch (2.5 cm) superior to the pubic symphysis.

Step 3

• Abduct the thighs as much as possible and have the patient turn the feet inward to brace the soles against each other for support. According to Cleaves, the angle may vary between 25 and 45 degrees, depending on how vertically the femora can be placed.
• Center the feet to the midline of the grid (Fig. 8.20).
• If possible, abduct the thighs approximately 45 degrees from the vertical plane to place the long axes of the femoral necks parallel with the plane of the IR.
• Check the position of the thighs, being careful to abduct them to the same degree.

Unilateral projection

• Adjust the body position to center the ASIS of the affected side to the midline of the grid.
• Have the patient flex the hip and knee of the affected side and draw the foot up to the opposite knee as much as possible.
• After adjusting the perpendicular central ray and positioning the IR tray, have the patient brace the sole of the foot against the opposite knee and abduct the thigh laterally approximately 45 degrees (Fig. 8.21). The pelvis may rotate slightly.
• *Respiration:* Suspend.

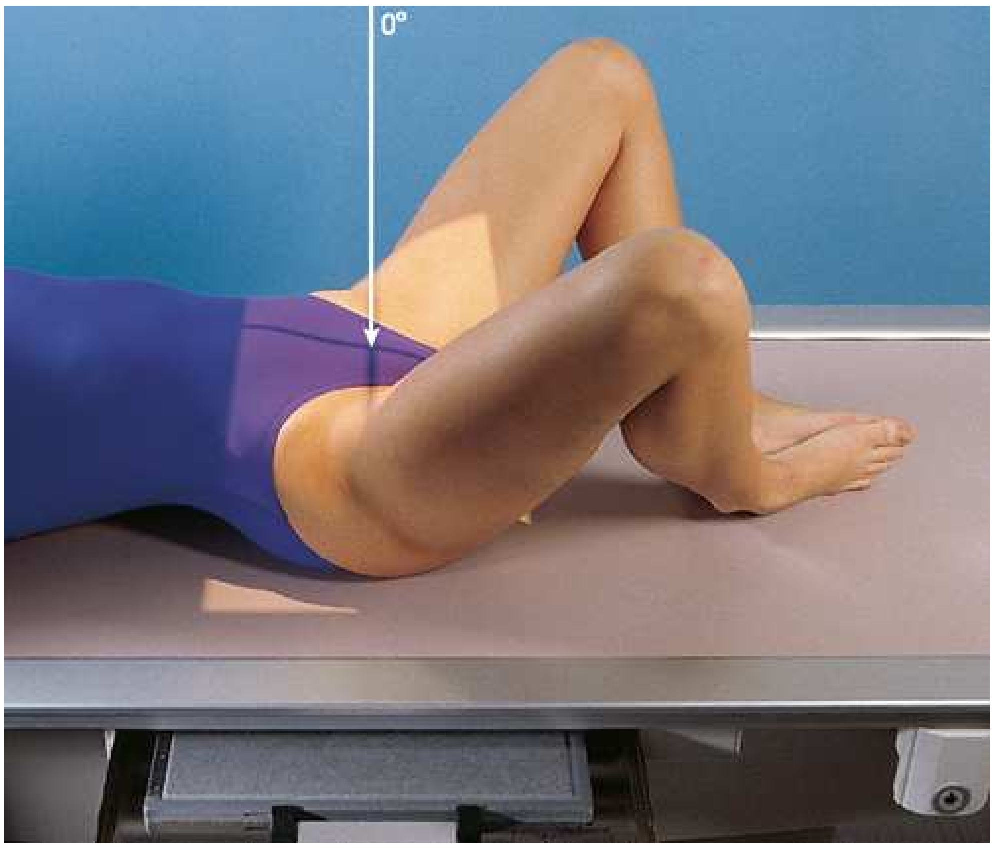


FIG. 8.20 AP oblique femoral necks with perpendicular central ray: modified Cleaves method.

A patient is in the supine position on the radiographic table. The thighs are abducted and the feet are turned inward. The soles are braced against each other. The feet are centered to the midline of the grid. The central ray is perpendicular to enter the patient's M S P.

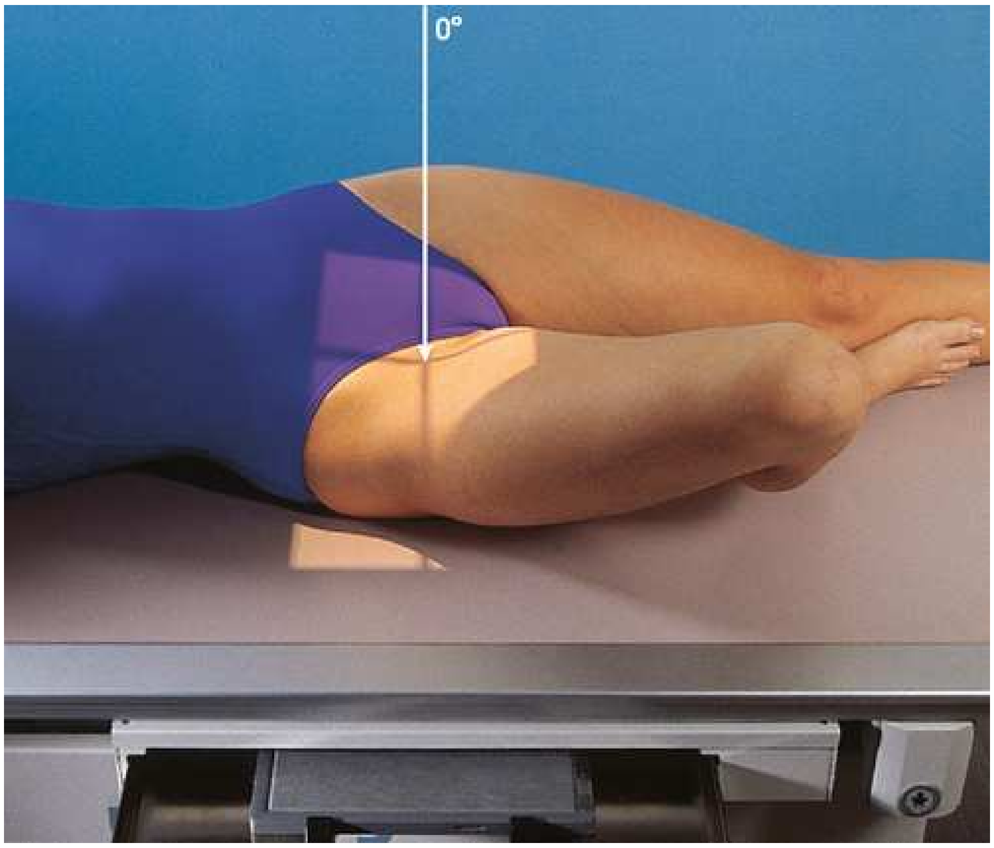


FIG. 8.21 Unilateral AP oblique femoral neck: modified Cleaves method.

A patient is in the supine position on the radiographic table. The hip and the knee of the affected side of the patient are flexed. The sole of the foot is braced against the opposite knee and the thigh is abducted laterally. The central ray is directed to the femoral neck.

Central ray

- Perpendicular to enter the patient's MSP at the level 1 inch (2.5 cm) superior to the pubic symphysis. May center lower to include more of the femur. For the unilateral position, direct the central ray to the femoral neck (see Fig. 8.12).

Collimation

- Adjust radiation field to 14 × 17 inches (35 × 43 cm) on the collimator. For smaller patients, collimate 1 inch (2.5 cm) beyond the skin shadow on the sides. Place side marker in the collimated exposure field.

Structures shown

The bilateral image shows an AP oblique projection of the femoral heads, necks, and trochanteric areas onto one radiograph for comparison (Figs. 8.22 through 8.24).

Evaluation Criteria

The following should be clearly seen:

- Evidence of proper collimation and presence of side marker placed clear of anatomy of interest
- No rotation of the pelvis, as demonstrated by a symmetric appearance
- Acetabulum, femoral head, and femoral neck
- Lesser trochanter on the medial side of the femur
- Femoral neck without superimposition by the greater trochanter; excess abduction causes the greater trochanter to obstruct the neck
- Femoral axes extended from the hip bones at equal angles
- Bony trabecular detail and surrounding soft tissues

FIG. 8.22 AP femoral necks. Note fixation device in right hip and male gonad shield.

FIG. 8.23 AP oblique femoral necks: modified Cleaves method (same patient as in Fig. 8.22).

An x-ray shows the acetabulum, femoral head, and femoral neck. The fixation device in the right hip is long and cylindrical. It appears white. The male gonad shield appears white. The parts labeled are as follows: femoral head, femoral neck, greater trochanter, lesser trochanter.

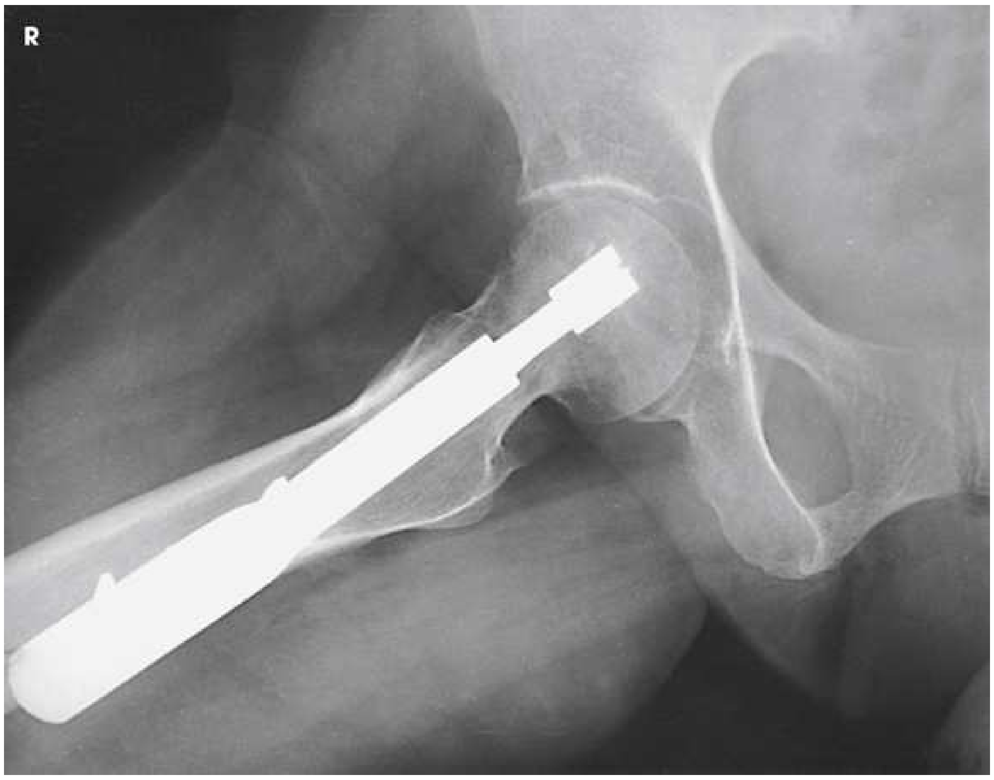


FIG. 8.24 AP oblique femoral neck: modified Cleaves method.

Axiolateral Projection

Original Cleaves Method [5]

NOTE: This examination is contraindicated for patients with suspected fracture or pathologic condition.

Image receptor + grid: Positioned by manufacturer or department protocol for proper anatomy display orientation; CR plate: 14 × 17 inches (35 × 43 cm) crosswise.

Position of patient

- Place the patient in the supine position.

Position of part

NOTE: This is the same part position as the modified Cleaves method previously described. The projection can be performed unilaterally or bilaterally.

- Before having the patient abduct the thighs (described in step 3 on p. 398), direct the x-ray tube parallel to the long axes of the femoral shafts (Fig. 8.25).
- Adjust the IR so that the midpoint coincides with the central ray.
- *Respiration:* Suspend.

Central ray

- Parallel with the femoral shafts. According to Cleaves, [5] the angle may vary between 25 and 45 degrees, depending on how vertically the femora can be placed.

Collimation

- Adjust radiation field to 14 × 17 inches (35 × 43 cm) on the collimator. For smaller patients, collimate 1 inch (2.5 cm) beyond the skin shadow on the sides. Place side marker in the collimated exposure field.

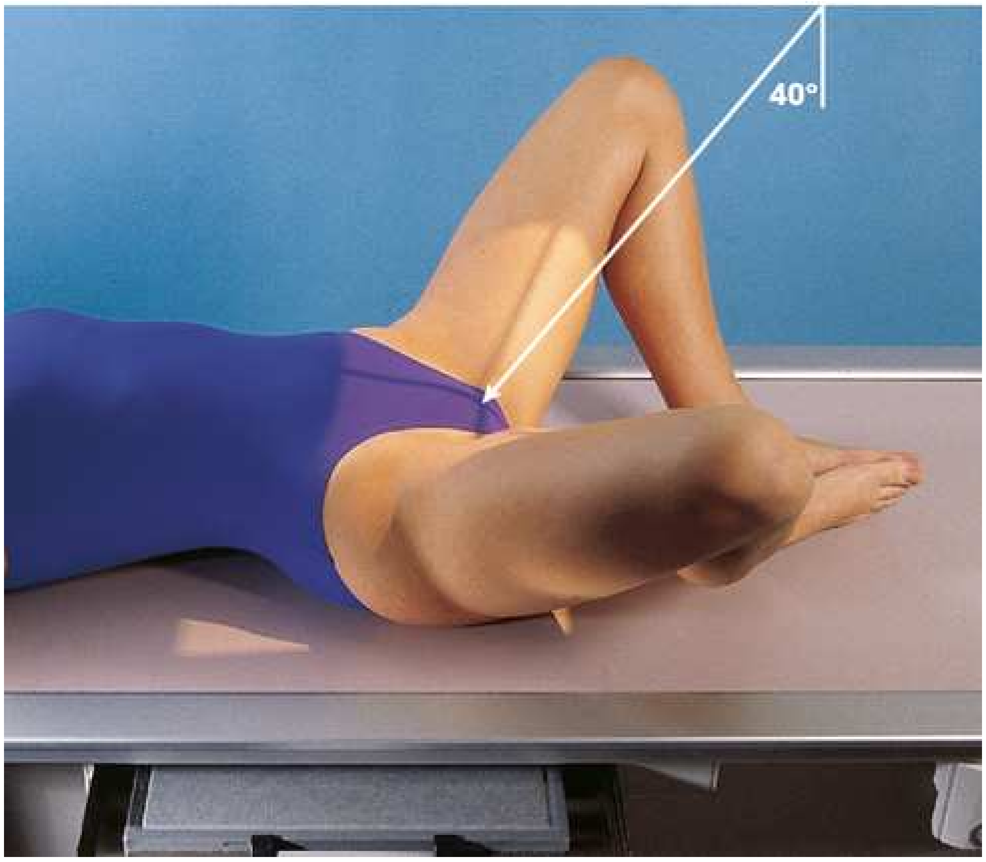


FIG. 8.25 Axiolateral femoral necks: Cleaves method.

Structures shown

An axiolateral projection of the femoral heads, necks, and trochanteric areas (Fig. 8.26).

Evaluation Criteria

The following should be clearly seen:

- Evidence of proper collimation and presence of side marker placed clear of anatomy of interest
- No rotation of the pelvis, as demonstrated by a symmetric appearance
- Axiolateral projections of the femoral necks
- Femoral necks without overlap from the greater trochanters
- Small parts of the lesser trochanters on the posterior surfaces of the femora
- Small parts of the greater trochanters on the posterior and anterior surfaces of the femora
- Both sides equidistant from the edge of the radiograph
- Greater amount of the proximal femur on a unilateral examination
- Femoral neck angles approximately 15 to 20 degrees superior to the femoral bodies
- Bony trabecular detail and surrounding soft tissues

Congenital dislocation of the hip

The diagnosis of congenital dislocation of the hip in newborns has been discussed in numerous articles. Andren and von Rosén [6] described a method that is based on certain theoretic considerations. Their method requires accurate and judicious application of the positioning technique to make an accurate diagnosis. The Andren–von Rosén approach involves taking a bilateral hip projection with both legs forcibly abducted to at least 45 degrees with appreciable inward rotation of the femora. Knake and Kuhns [7] described the construction of a device that controlled the degree of abduction and rotation of both limbs. They reported that the device essentially eliminated and greatly simplified positioning difficulties, reducing the number of repeat examinations.

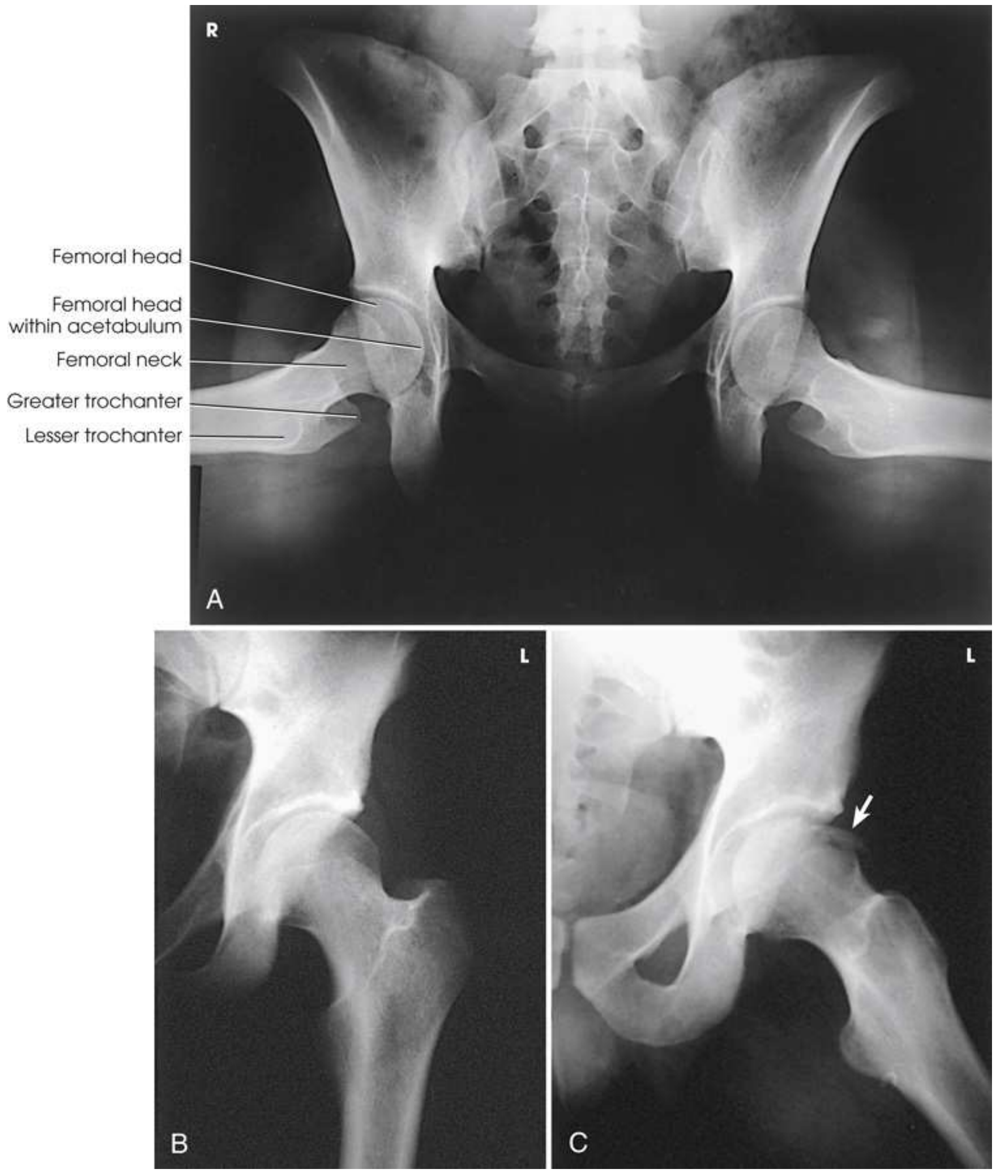


FIG. 8.26 Axiolateral femoral necks: Cleaves method. (A) Bilateral examination. (B and C) Unilateral hip examination of a patient who fell. No fractures were seen on initial AP hip radiograph (B), and a second projection using the Cleaves method was performed. Chip fracture of femoral head *(arrow)* was seen (C). At least two projections are required in trauma diagnoses.

(A) shows the x-ray view of femoral heads, necks, and trochanteric areas. Both sides are equidistant from the edge of the radiograph. The parts labeled are marked as follows: femoral head, femoral head within the acetabulum, femoral neck, greater trochanter, and lesser trochanter. (B) shows the x-ray view of the chip fracture of the femoral head. It is marked by an arrow. (C) shows the x-ray view of the chip fracture of the femoral head that is marked by a white arrow.

Hip

AP Projection

Image receptor + grid: Positioned by manufacturer or department protocol for proper anatomy display orientation; CR plate: 10 × 12 inches (24 × 30 cm) lengthwise.

Position of patient

- Place the patient in the supine position.

Position of part

- Adjust the patient's pelvis so that it is not rotated. This is accomplished by placing the ASIS equidistant from the table (Figs. 8.27 and 8.28).
- Place the patient's arms in a comfortable position.

- Medially rotate the lower limb and foot approximately 15 to 20 degrees to place the femoral neck parallel with the plane of the IR unless this maneuver is contraindicated or other instructions are given.
- Place a support under the knee and a sandbag across the ankle. This makes it easier for the patient to maintain this position.
- *Respiration:* Suspend.

Central ray

- Perpendicular to the femoral neck; using the localizing technique previously described (see Fig. 8.12), place the central ray approximately 2.5 inches (6.4 cm) distal on a line drawn perpendicular to the midpoint of a line between the ASIS and the pubic symphysis (see Fig. 8.28B).
- Center the IR to the central ray.
- Make any necessary adjustments in the IR size and central ray point when an entire orthopedic device is to be shown on one image.

Collimation

- Adjust radiation field to 10 × 12 inches (24 × 30 cm) on the collimator. Place side marker in the collimated exposure field.

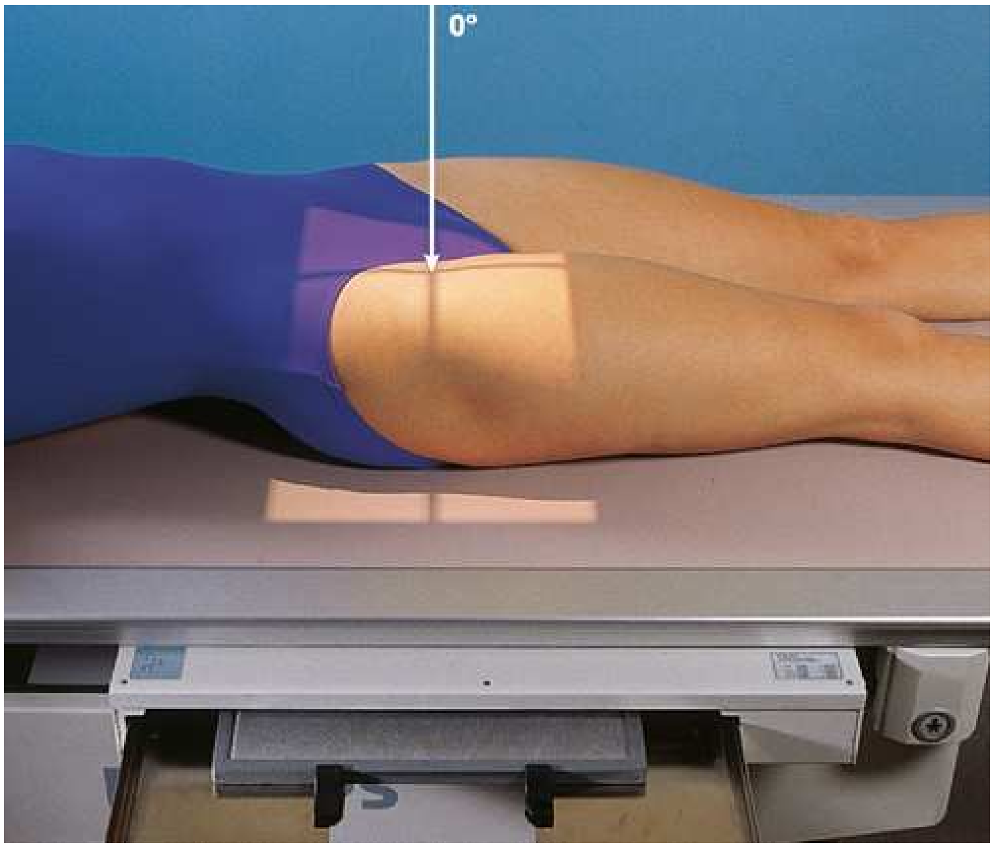


FIG. 8.27 AP hip.

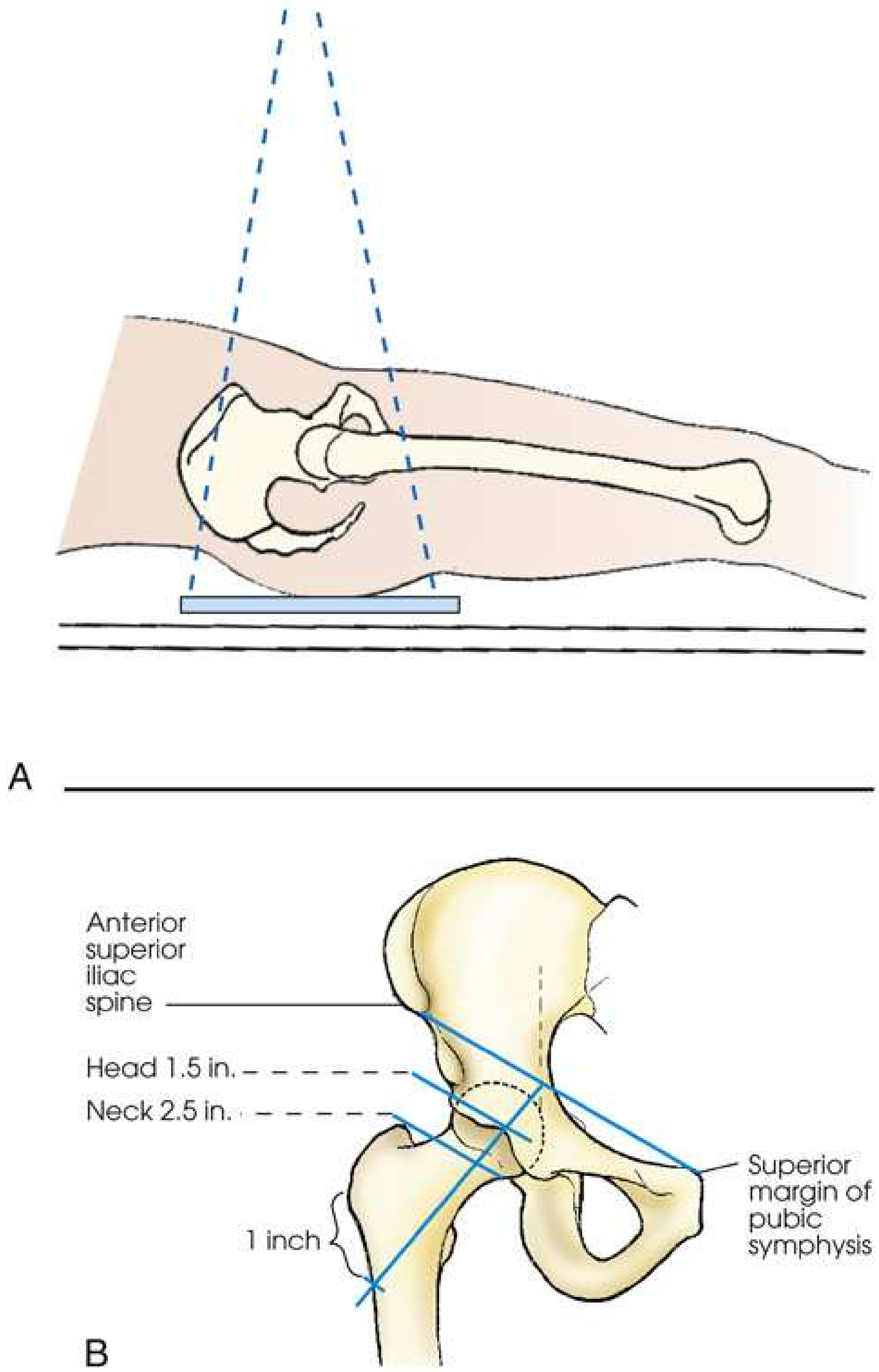


FIG. 8.28 (A) AP hip. (B) Localization planes of pelvis.

Diagram (A) shows the patient is in the supine position. The I R is centered on the central ray. The central ray is perpendicular to the femoral neck. Diagram (C) shows the method of localizing the right hip joint and the long axis of the femoral neck. The femoral head lies 1.5 inches distal, and the femoral neck is 2.5 inches distal to the midpoint. The superior margin of the pubic symphysis and the anterior superior iliac spine is labeled.

Structures shown

The head, neck, trochanters, and proximal one-third of the body of the femur (Fig. 8.29). In the initial examination of a hip lesion, whether traumatic or pathologic in origin, the AP projection is often obtained using an IR large enough to include the entire pelvic girdle and upper femora. Progress studies may be restricted to the affected side.

Evaluation Criteria

The following should be clearly seen:

- Evidence of proper collimation and presence of side marker placed clear of anatomy of interest

- Regions of the ilium and pubic bones adjoining the pubic symphysis
- Hip joint
- Proximal one-third of the femur
- Femoral head, penetrated and seen through the acetabulum
- Entire long axis of the femoral neck not foreshortened
- Greater trochanter in profile
- Lesser trochanter usually not projected beyond the medial border of the femur or only a very small amount of the trochanter visible
- Any orthopedic appliance in its entirety
- Bony trabecular detail and surrounding soft tissues

NOTE: Trauma patients who have sustained severe injury usually are not transferred to the radiographic table but are radiographed on the stretcher or bed. After the localization point has been established and marked, one assistant should be on each side of the stretcher to grasp the sheet and lift the pelvis just enough for placement of the IR, while a third person supports the injured limb. Any necessary manipulation of the limb must be made by a physician.

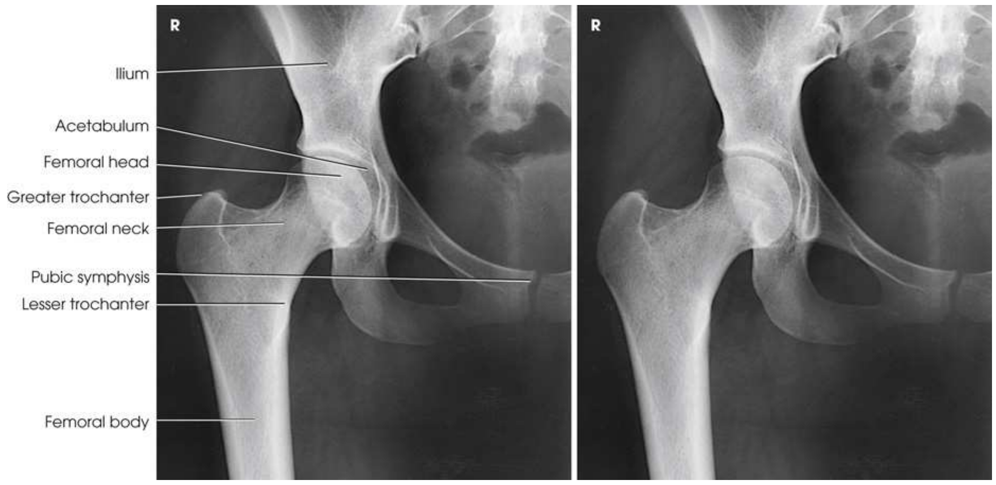


FIG. 8.29 AP hip.

Two x-ray shows the femoral head, penetrated and seen through the acetabulum. The parts labeled in the diagram are as follows: ilium, acetabulum, femoral head, greater trochanter, femoral neck, pubic symphysis, lesser trochanter, and femoral body.

Lateral Projection

Lauenstein and Hickey Methods

Mediolateral

NOTE: This examination is contraindicated for patients with a suspected fracture or pathologic condition.

The Lauenstein and Hickey methods are used to show the hip joint and the relationship of the femoral head to the acetabulum. This position is similar to the previously described modified Cleaves method.

Image receptor + grid: Positioned by manufacturer or department protocol for proper anatomy display orientation; CR plate: 10 × 12 inches (24 × 30 cm) crosswise.

Position of patient

- From the supine position, rotate the patient slightly toward the affected side to an oblique position. The degree of obliquity depends on how much the patient can abduct the leg.

Position of part

- Adjust the patient's body and center the affected hip to the midline of the grid.
- Ask the patient to flex the affected knee and draw the thigh up to a position at nearly a right angle to the hip bone.
- Keep the body of the affected femur parallel to the table.
- Extend the opposite limb and support it at hip level and under the knee.
- Rotate the pelvis no more than necessary to accommodate flexion of the thigh and avoid superimposition of the affected side (Fig. 8.30).
- *Respiration:* Suspend.

Central ray

- Perpendicular through the hip joint, which is located midway between the ASIS and the pubic symphysis for the Lauenstein method (Fig. 8.31) and at a cephalic angle of 20 to 25 degrees and an additional 1 inch (2.5 cm) more inferior for the Hickey method (Fig. 8.32).
- Center the IR to the central ray.

Collimation

- Adjust radiation field to 10 × 12 inches (24 × 30 cm) on the collimator. Place side marker in the collimated exposure field.

Structures shown

A lateral projection of the hip, including the acetabulum, the proximal end of the femur, and the relationship of the femoral head to the acetabulum (see Figs. 8.31 and 8.32).

Evaluation Criteria

The following should be clearly seen:

- Evidence of proper collimation and presence of side marker placed clear of anatomy of interest
- Hip joint centered to the radiograph
- Hip joint, acetabulum, and femoral head
- Femoral neck overlapped by the greater trochanter in the Lauenstein method
- With cephalic angulation in the Hickey method, the femoral neck free of superimposition
- Bony trabecular detail and surrounding soft tissues

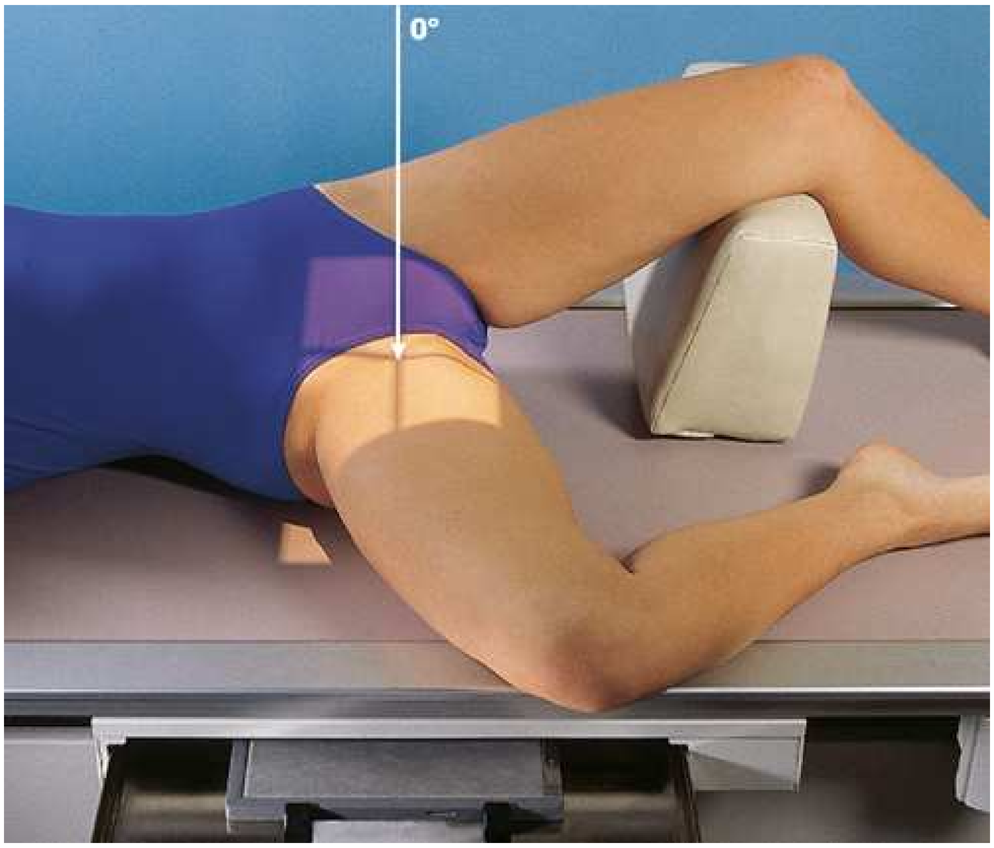


FIG. 8.30 Mediolateral hip: Lauenstein method.

The patient is in the supine position. The affected knee is flexed and the thigh is drawn up to a position at nearly a right angle to the hip bone. The opposite limb is extended and is supported. The central ray is perpendicular through the hip joint, which is located midway between the A S I S.

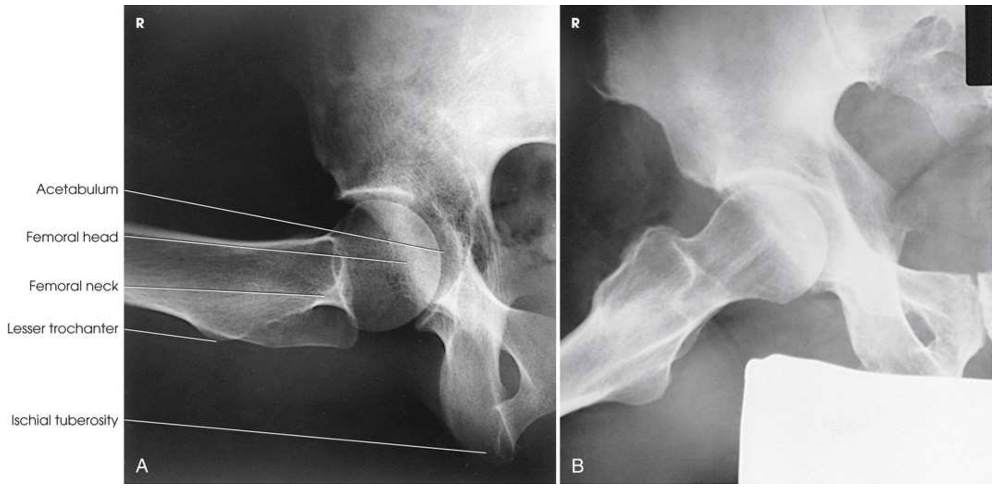


FIG. 8.31 (A) Mediolateral hip with perpendicular central ray: Lauenstein method. (B) Mediolateral hip with perpendicular central ray using male gonad (contact) shield.

(A) shows the x-ray view of the hip, including the acetabulum, the proximal end of the femur, and the relationship of the femoral head to the acetabulum. The parts labeled in the diagram are as follows: acetabulum, femoral head, femoral neck, lesser trochanter, and ischial tuberosity. (B) shows the x-ray view of the femoral neck overlapped by the greater trochanter. The male gonad shield is at the bottom right.

FIG. 8.32 Mediolateral hip with 20-degree cephalad angulation: Hickey method.

Axiolateral Projection

Danelius-Miller Method

This projection is often called the *cross-table* or *surgical-lateral* projection.

Image receptor + grid: Positioned by manufacturer or department protocol for proper anatomy display orientation; CR plate: 10 × 12 inches (24 × 30 cm) lengthwise.

Position of patient

- Place the patient in the supine position.

Position of part

- When examining a patient who is thin or lying on a soft bed, elevate the pelvis on a firm pillow or folded sheets sufficiently to center the most prominent point of the greater trochanter to the midline of the IR. The support must not extend beyond the lateral surface of the body; otherwise, it would interfere with placement of the IR.
- When the pelvis is elevated, support the affected limb at hip level on sandbags or firm pillows.
- Flex the knee and hip of the unaffected side to elevate the thigh in a vertical position.
- Rest the unaffected leg on a suitable support that does not interfere with the central ray. Special support devices are available. *Do not rest the foot on the x-ray tube or collimator.*
- Adjust the pelvis so that it is not rotated (Figs. 8.33 and 8.34).
- Unless contraindicated, grasp the heel and medially rotate the foot and lower limb of the affected side approximately 15 to 20 degrees. A sandbag may be used to hold the leg and foot in this position, and a small support can be placed under the knee. Manipulation of patients with unhealed fractures should be performed by a physician.

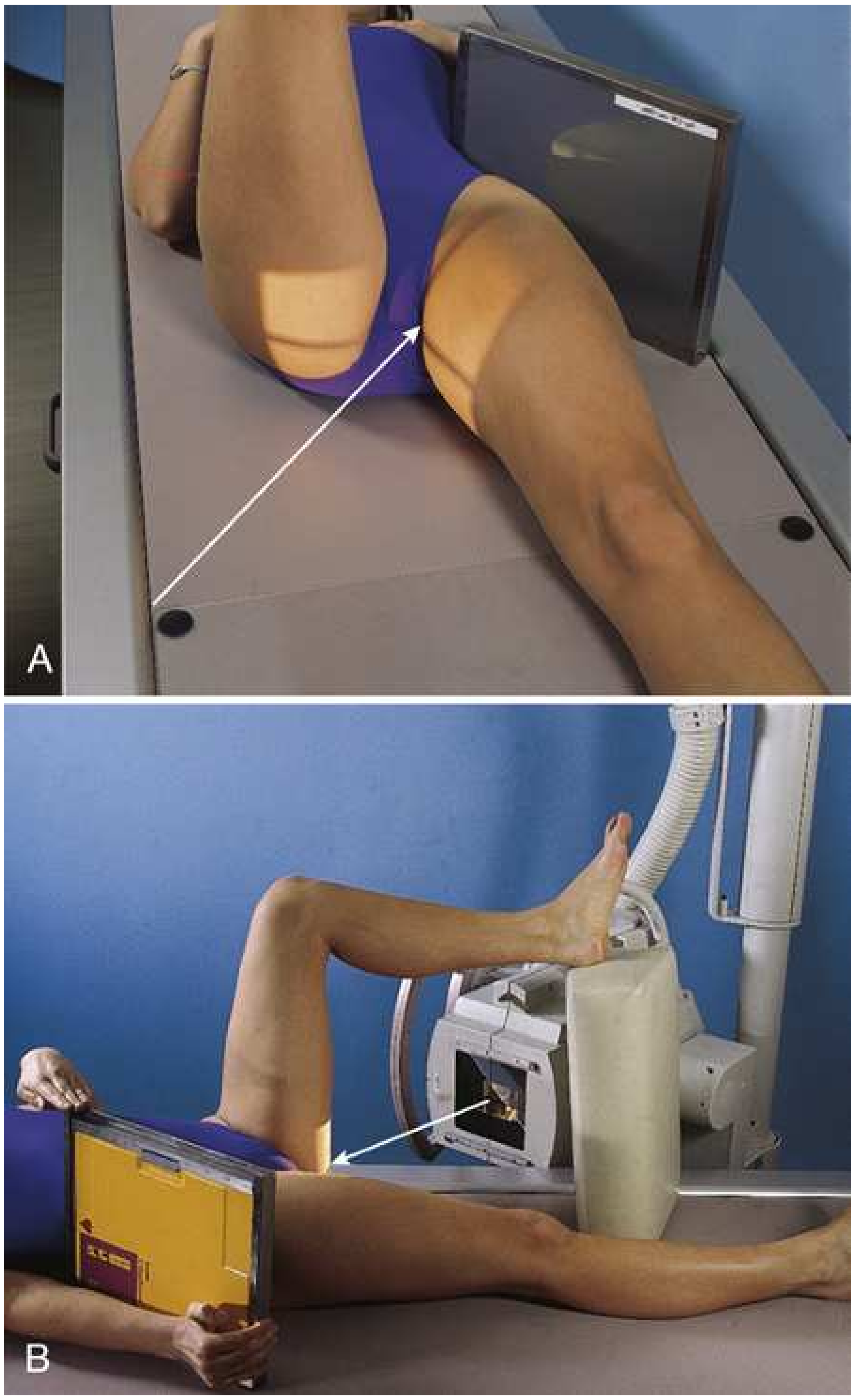


FIG. 8.33 (A) Axiolateral hip: Danelius-Miller method, IR supported with sandbags. (B) Same projection, patient holding IR. Foot is on a footrest.

(A) The patient is in the supine position. The knee and hip are flexed and the thigh is elevated in a vertical position. The other leg is extended. The I R is placed near the iliac crest. The central ray enters the groin area at a point midway between the anterior and posterior surfaces of the upper thigh. (B) shows the patient is in the supine position. The knee and hip are flexed and the thigh is elevated in a vertical position and the foot is placed on a footrest. The other leg is extended. The patient is holding the I R near the iliac crest. The central ray enters the groin area at a point midway between the anterior and posterior surfaces of the upper thigh.

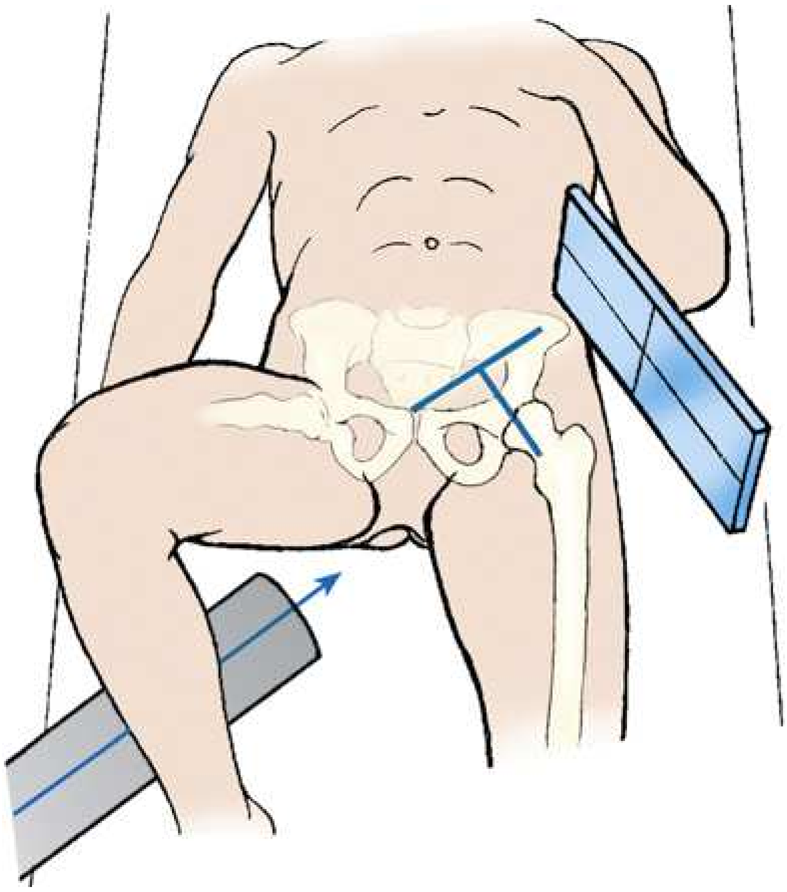


FIG. 8.34 Axiolateral hip: Danelius-Miller method.

Diagram shows the patient in the supine position. The knee and hip are flexed and the thigh is elevated in a vertical position. The other leg is extended. The I R is placed near the iliac crest. The central ray enters the groin area at a point midway between the anterior and posterior surfaces of the upper thigh.

Position of IR

- Place the IR in the vertical position with its upper border in the soft tissue crease above the iliac crest.
- Angle the IR away from the body until it is exactly parallel with the long axis of the femoral neck.
- Support the IR in this position with sandbags or a vertical IR holder. These are the preferred methods. Alternatively, the patient may support the IR with a hand.
- Be careful to position the grid vertically but with the lead strips oriented horizontally.
- *Respiration:* Suspend.

Central ray

- Perpendicular to the long axis of the femoral neck. The central ray enters the groin area at a point midway between the anterior and posterior surfaces of the upper thigh and passes through the femoral neck, which is approximately 2.5 inches (6.4 cm) below the point of intersection of the localization lines described previously (see Fig. 8.12).

Collimation

- Adjust radiation field to 10 × 12 inches (24 × 30 cm) on the collimator. Place side marker in the collimated exposure field.

Compensating Filter

This projection is improved dramatically and can be performed with one exposure with the use of a specially designed compensating filter.

Structures shown

The acetabulum, head, neck, and trochanters of the femur (Fig. 8.35).

Evaluation Criteria

The following should be clearly seen:

- Evidence of proper collimation and presence of side marker placed clear of anatomy of interest
- Hip joint with the acetabulum
- Femoral neck without overlap from the greater trochanter
- Small amount of the lesser trochanter on the posterior surface of the femur
- Small amount of the greater trochanter on the anterior and posterior surfaces of the proximal femur when the femur is properly inverted
- Ischial tuberosity below the femoral head and neck
- Soft tissue shadow of the unaffected thigh not overlapping the hip joint or proximal femur
- Any orthopedic appliance in its entirety
- Bony trabecular detail and surrounding soft tissues

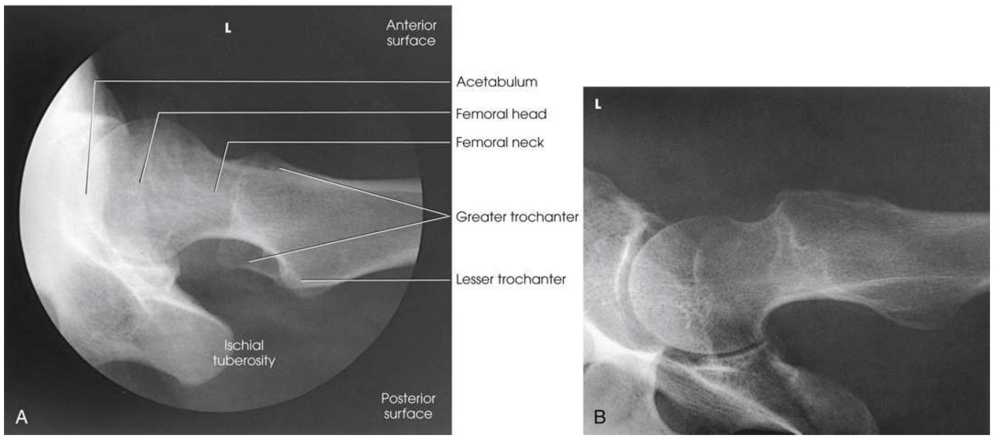


FIG. 8.35 (A) Axiolateral hip: Danelius-Miller method. (B) Same projection with use of compensating filter. Note excellent detail of acetabular area and femur.

(A) An x-ray shows the hip joint with the acetabulum. It appears hazy. The parts labeled are marked as follows: acetabulum, femoral head, femoral neck, greater trochanter, and lesser trochanter. (B) An x-ray shows the acetabulum, head, neck, and trochanters of the femur. It appears grainy.

Modified Axiolateral Projection

Clements-Nakayama Modification

When the patient has bilateral hip fractures, bilateral hip arthroplasty (plastic surgery of the hip joints), or limitation of movement of the unaffected leg, the Danelius-Miller method cannot be used. Clements and Nakayama [8] described a modification using a 15-degree posterior angulation of the central ray (Fig. 8.36).

Image receptor + grid: Positioned by manufacturer or department protocol for proper anatomy display orientation; CR plate: 10 × 12 inches (24 × 30 cm) lengthwise.

Position of patient

- Position the patient supine on the radiographic table with the affected side near the edge of the table.

Position of part

- For this position, do not rotate the lower limb internally. Instead, the limb remains in a neutral or slightly externally rotated position.
- Support a grid IR on the Bucky tray so that its lower margin is below the patient. Position the grid so that the lines run parallel with the floor.
- Adjust the grid parallel to the axis of the femoral neck and tilt its top back 15 degrees.
- *Respiration:* Suspend.

FIG. 8.36 Axiolateral hip: Clements-Nakayama method.

The patient is lying in a supine position with the affected side near the edge of the radiographic table. The I R is placed parallel to the axis of the femoral neck. The central ray is directed 15 degrees posteriorly and aligned perpendicular to the femoral neck.

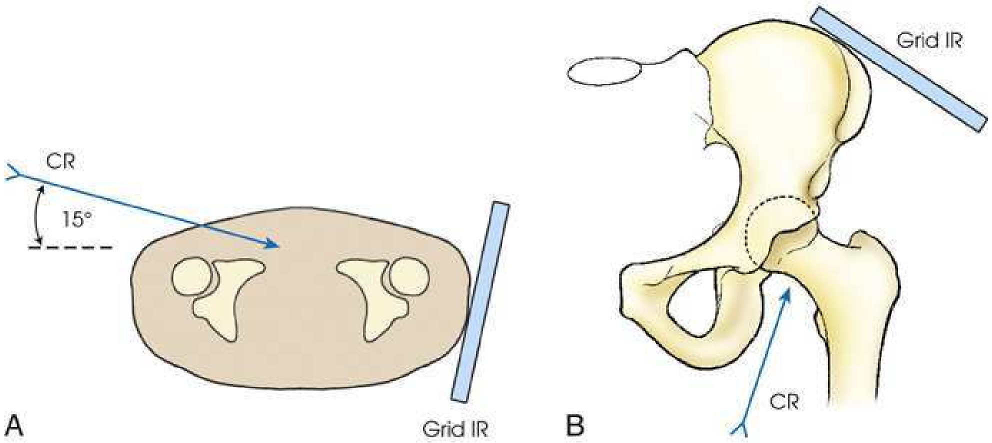


FIG. 8.37 CR angles for Clements-Nakayama method. (A) 15 degrees posteriorly. Note grid IR tilted 15 degrees. (B) Perpendicular to femoral neck and grid IR.

Diagram (A) shows the central ray is directed 15 degrees posteriorly and aligned perpendicular to the femoral neck and the grid I R. Diagram (B) shows the central ray is perpendicular to the femoral neck and the grid I R.

Central ray

- Directed 15 degrees posteriorly and aligned perpendicular to the femoral neck and the grid IR (Fig. 8.37).

Collimation

- Adjust radiation field to 10 × 12 inches (24 × 30 cm) on the collimator. Place side marker in the collimated exposure field.

Structures shown

The acetabulum and proximal femur—including the head, neck, and trochanters—in lateral profile. The Clements-Nakayama modification (Fig. 8.38) can be compared with the Danelius-Miller approach described previously (Fig. 8.39).

Evaluation Criteria

The following should be clearly seen:

- Evidence of proper collimation and presence of side marker placed clear of anatomy of interest

- Hip joint with the acetabulum
- Femoral head, neck, and trochanters
- Any orthopedic appliance in its entirety
- Bony trabecular detail and surrounding soft tissues

FIG. 8.38 Clements-Nakayama method with 15-degree central ray angulation in same patient as in Fig. 8.39.

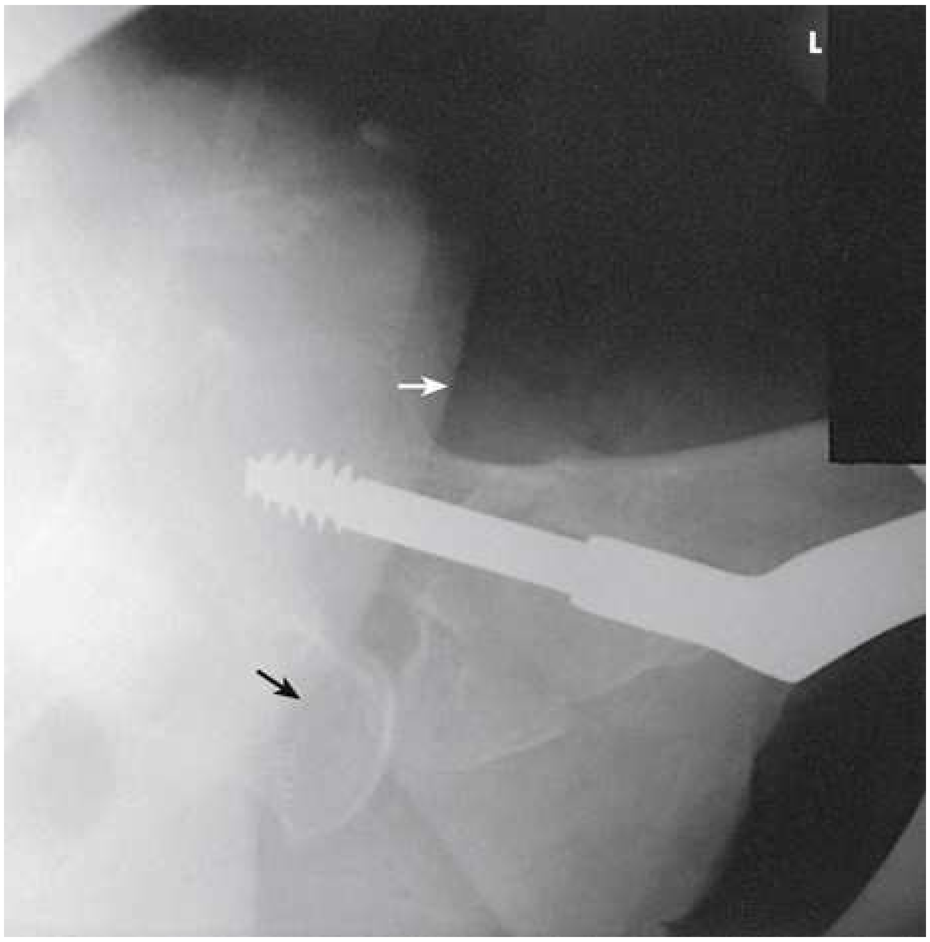


FIG. 8.39 Postoperative Danelius-Miller method used for a patient who was unable to flex unaffected hip. Contralateral thigh *(arrows)* is obscuring femoral head and acetabular area.

Acetabulum

PA Axial Oblique Projection

Teufel Method

RAO or LAO position

Image receptor + grid: Positioned by manufacturer or department protocol for proper anatomy display orientation; CR plate: 10 × 12 inches (24 × 30 cm) lengthwise.

Position of patient

- Have the patient lie recumbent in an anterior oblique position on the affected side.

Position of part

- Align the body and center the hip being examined to the midline of the grid.
- Elevate the unaffected side so that the anterior surface of the body forms a 38-degree angle from the table (Fig. 8.40).
- Have the patient support the body on the forearm and flexed knee of the elevated side.
- With the IR in the Bucky tray, adjust the position of the IR so that its midpoint coincides with the central ray.
- *Respiration:* Suspend.

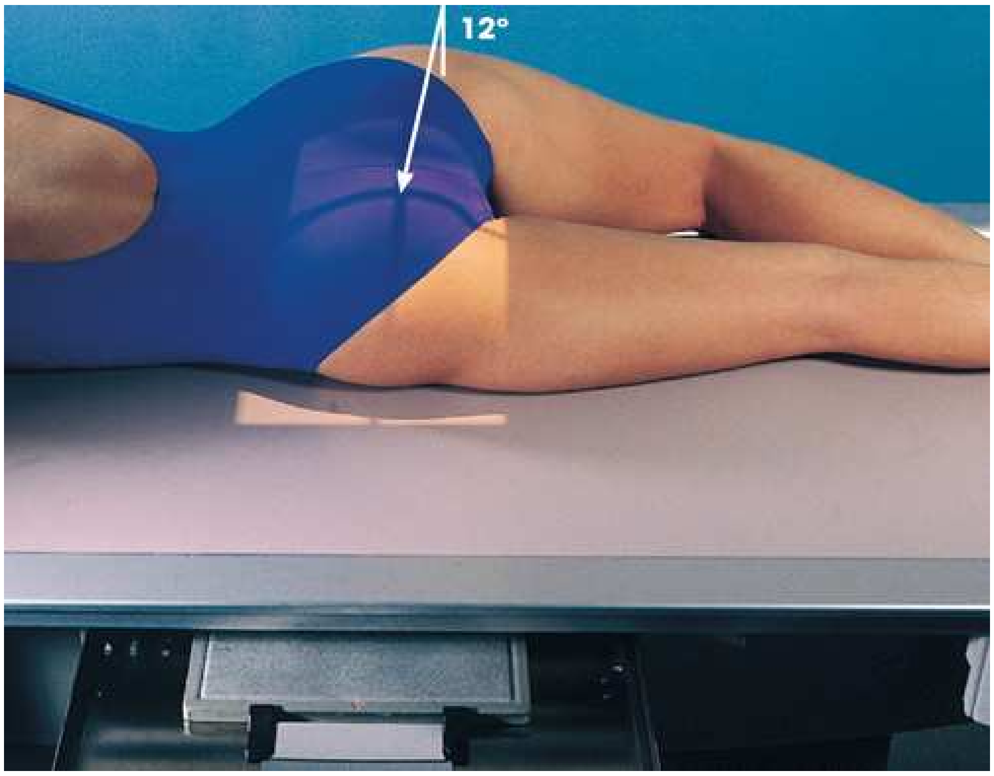


FIG. 8.40 PA axial oblique acetabulum: Teufel method.

Central ray

- Directed through the acetabulum at an angle of 12 degrees cephalad. The central ray enters the body at the inferior level of the coccyx and approximately 2 inches (5 cm) lateral to the MSP toward the side being examined.

Collimation

- Adjust radiation field to 10 × 12 inches (24 × 30 cm) on the collimator. Place side marker in the collimated exposure field.

Structures shown

The fovea capitis and the superoposterior wall of the acetabulum (Fig. 8.41).

Evaluation Criteria

The following should be clearly seen:

- Evidence of proper collimation and presence of side marker placed clear of anatomy of interest
- Hip joint and acetabulum near the center of the radiograph
- Femoral head in profile to show the concave area of the fovea capitis
- Superoposterior wall of the acetabulum
- Bony trabecular detail and surrounding soft tissues

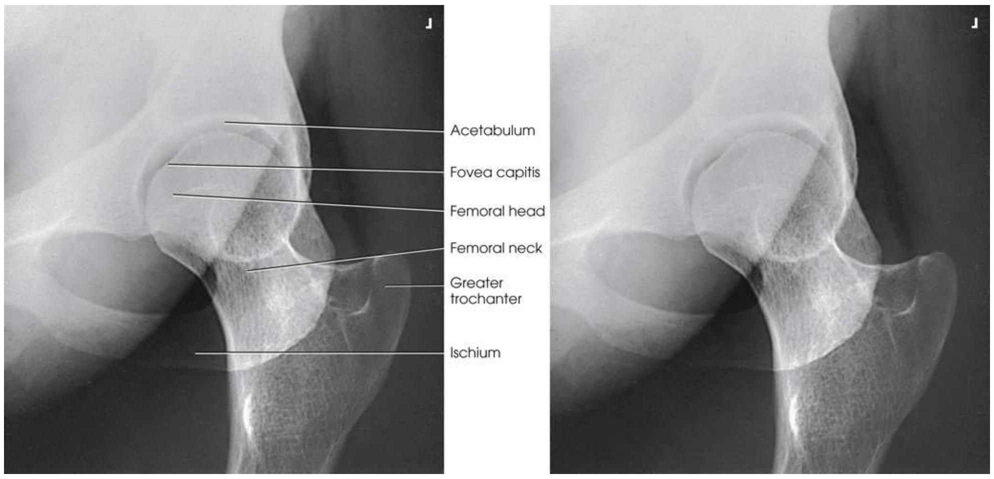


FIG. 8.41 PA axial oblique acetabulum: Teufel method.

Two x-ray shows hip joint and acetabulum near the center of the radiograph. A concave area is in the fovea capitalis. The parts labeled are marked from top to the bottom as follows: acetabulum, fovea capitis, femoral head, femoral neck, greater trochanter, and ischium.

AP Oblique Projection

Judet Method [9]

Modified Judet Method [10]

RPO and LPO positions

Judet et al. [9] described ***two*** 45-degree posterior oblique positions that are useful in diagnosing fractures of the acetabulum: the internal oblique position (affected side up) and the external oblique position (affected side down). Both positions must be performed to demonstrate the entire acetabulum, as well as the iliopubic and ilioischial columns of the affected side.

Image receptor + grid: Positioned by manufacturer or department protocol for proper anatomy display orientation; CR plate: 10 × 12 inches (24 × 30 cm) lengthwise.

Internal oblique

The internal oblique position is used for a patient with a suspected fracture of the *iliopubic column* (anterior) and the posterior rim of the acetabulum.

NOTE: The *iliopubic column* (anterior), composed of a short segment of the ilium and the pubis, extends up as far as the anterior spine of the ilium and from the symphysis pubis and obturator foramen through the acetabulum to the ASIS.

Position of patient

- Place the patient in a posterior oblique position with the affected hip *up*.

Position of part

- Align the body and center the hip being examined to the middle of the IR.
- Elevate the affected side so that the MCP of the body forms a 45-degree angle from the table (Fig. 8.42A).
- *Respiration:* Suspend.

Central ray

- Perpendicular to the IR and entering 2 inches (5 cm) inferior to the ASIS of the affected side

External oblique

The external oblique is used for a patient with a suspected fracture of the *ilioischial column* (posterior) and the anterior rim of the acetabulum.

Position of patient

- Place the patient in a posterior oblique position with the affected hip *down*.

Position of part

- Align the body and center the hip being examined to the middle of the IR.

• Elevate the unaffected side so that the MCP of the body forms a 45-degree angle from the table (Fig. 8.42B).
• *Respiration:* Suspend.

Central ray

• Perpendicular to the IR and entering at the pubic symphysis

Collimation

• Adjust radiation field to 10 × 12 inches (24 × 30 cm) on the collimator. Place side marker in the collimated exposure field.

Structures shown

The acetabular rim (Fig. 8.43).

NOTE: The *ilioischial column* (posterior), composed of the vertical portion of the ischium and the portion of the ilium immediately above the ischium, extends from the obturator foramen through the posterior aspect of the acetabulum.

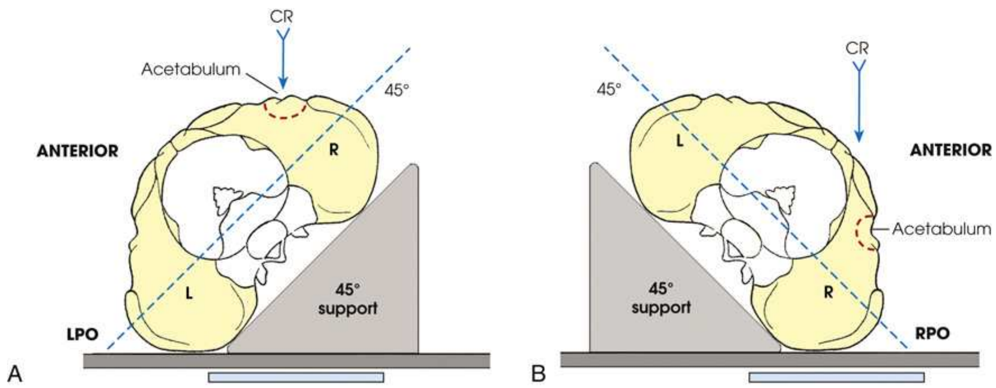


FIG. 8.42 AP oblique projection, Judet method for right hip. (A) LPO places right hip in *internal* oblique position. (B) RPO places right hip in *external* oblique position.

Diagram (A) shows a patient in an internal oblique position. The affected side is elevated using a support and the M C P of the body forms a 45 degree angle from the table. The central ray is perpendicular to the I R. Diagram (B) shows a patient in a external oblique position. The affected side is elevated using a support and the M C P of the body forms a 45 degree angle from the table. The central ray is perpendicular to the I R and entering at the pubic symphysis.

Evaluation Criteria

The following should be clearly seen:

- Evidence of proper collimation and presence of side marker placed clear of anatomy of interest
- Acetabulum centered to the IR
- The iliopubic column and the posterior rim of the affected acetabulum on the internal oblique
- The ilioischial column and the anterior rim of the acetabulum on the external oblique
- Bony trabecular detail and surrounding soft tissues

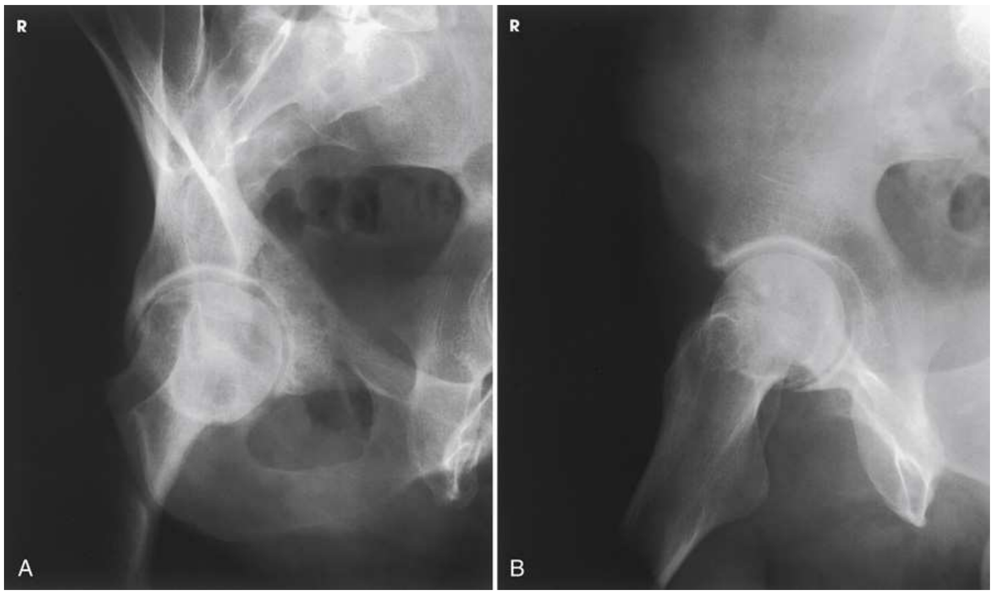


FIG. 8.43 AP oblique projection, Judet method, right hip. (A) LPO. (B) RPO. (From Long BW, Rafert JA. *Orthopedic Radiography.* Philadelphia: Saunders; 1995.)

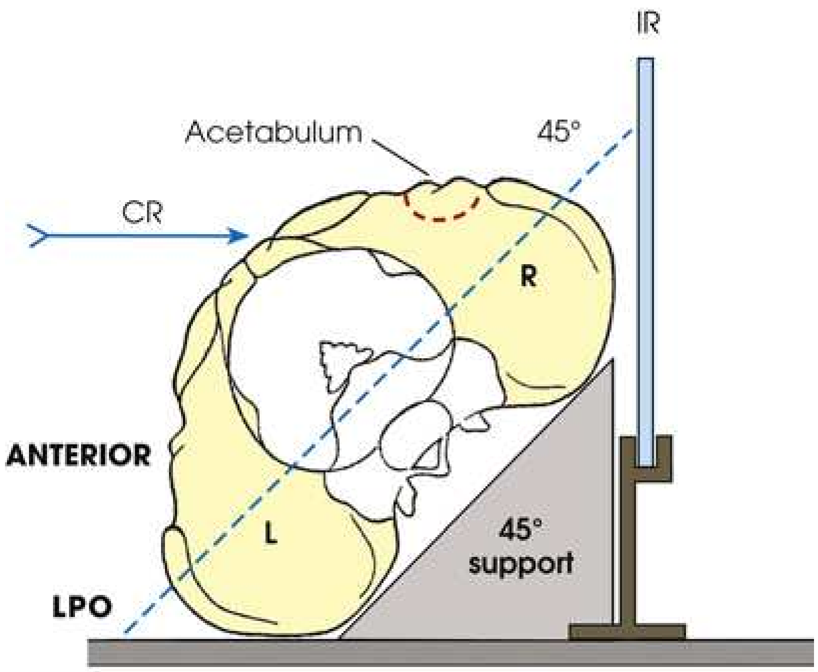


FIG. 8.44 AP oblique projection, *modified Judet method* for right hip on a trauma patient. *External* oblique projection is obtained using cross-table CR and grid IR. *Internal oblique* is obtained on a trauma patient in same position using vertical CR (same as Fig. 8.42A). **NOTE:** Rafert and Long [10] described a modification of the Judet method on trauma patients. The patient is not required to lie on the affected side for the external oblique (Fig. 8.44).

Diagram shows a patient in an internal oblique position. The affected side is elevated using a support and the M C P of the body forms a 45-degree angle from the table. The central ray is perpendicular to the I R.

Anterior Pelvic Bones

AP Axial Outlet Projection

Taylor Method [11]

Image receptor + grid: Positioned by manufacturer or department protocol for proper anatomy display orientation; CR plate: 14 × 17 inches (35 × 43 cm) crosswise.

Position of patient

- Place the patient in the supine position.

Position of part

- Center the MSP of the patient's body to the midline of the grid and adjust the pelvis so that it is not rotated. The ASIS should be equidistant from the table (Fig. 8.45).
- Flex the knees slightly with a support underneath if the patient is uncomfortable.
- With the IR in the Bucky tray, adjust the tray's position so that the midpoint of the IR coincides with the central ray.
- *Respiration:* Suspend.

Central ray

Men

- Directed 20 to 35 degrees cephalad and entering the midline at a point 2 inches (5 cm) inferior to the superior border of the pubic symphysis

Women

- Directed 30 to 45 degrees cephalad and entering the midline at a point 2 inches (5 cm) inferior to the superior border of the pubic symphysis

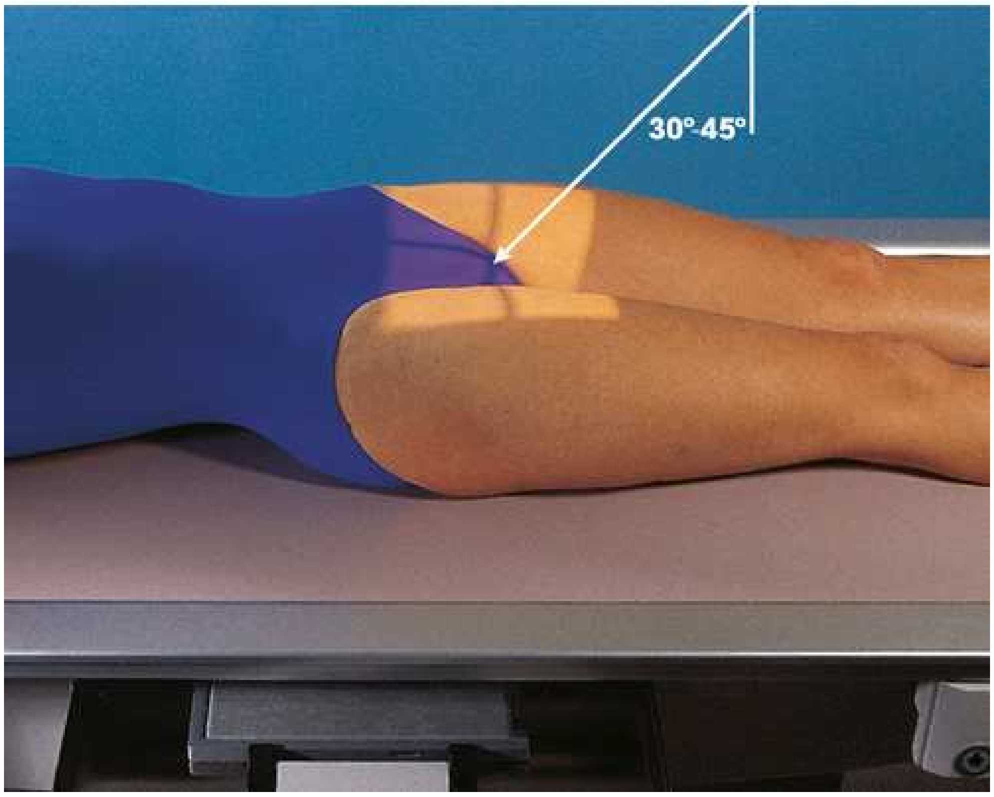


FIG. 8.45 AP axial pelvic bones: Taylor method.

The patient is lying in the supine position. The patient's body is central to the midline of the grid. The central ray is directed 30 to 45 degrees cephalad entering the midline inferior to the superior border of the pubic symphysis.

Collimation

- Adjust radiation field to 14 × 17 inches (35 × 43 cm) on the collimator. For smaller patients, collimate 1 inch (2.5 cm) beyond the skin shadow on the sides. Place side marker in the collimated exposure field.

Structures shown

The superior and inferior rami without the foreshortening seen in a PA or an AP projection because the central ray is more perpendicular to the rami (Figs. 8.46 and 8.47).

Evaluation Criteria

The following should be clearly seen:

- Evidence of proper collimation and presence of side marker placed clear of anatomy of interest
- Pubic and ischial bones magnified with pubic bones superimposed over the sacrum and coccyx

- Symmetric obturator foramina
- Pubic and ischial rami near the center of the radiograph
- Hip joints
- Bony trabecular detail and surrounding soft tissues

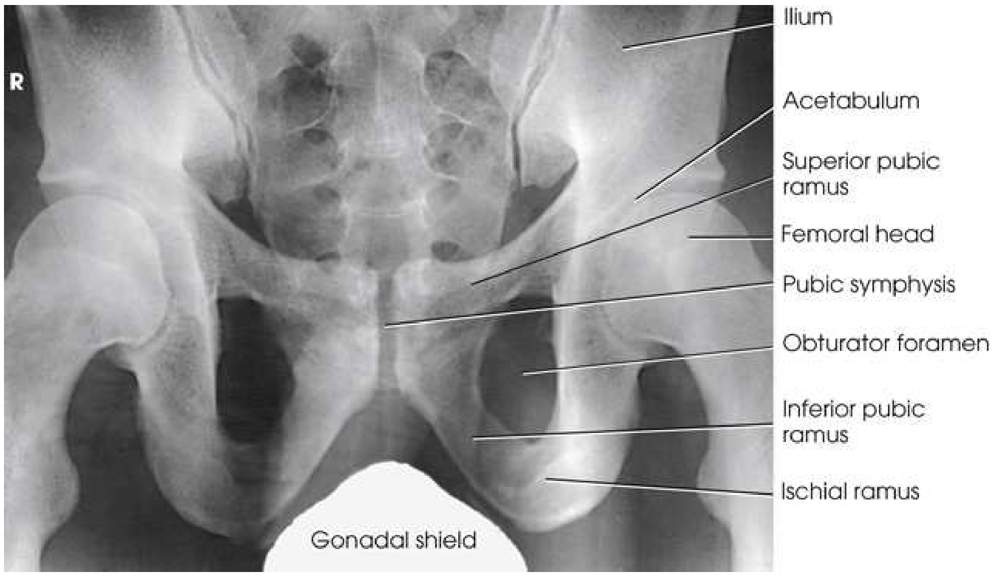


FIG. 8.46 Male AP axial pelvic bones: Taylor method.

An x-ray shows the male superior and inferior rami. The parts labeled are as follows: ilium, acetabulum, superior pubic ramus, femoral head, pubic symphysis, obturator foramen, inferior pubic ramus, and ischial ramus. The obturator foramen appears as two dark circles on either side. The gonadal shield is at the bottom.

FIG. 8.47 Female AP axial pelvic bones: Taylor method.

Superoinferior Axial Inlet Projection

BRIDGMAN Method [12]

Image receptor + grid: Positioned by manufacturer or department protocol for proper anatomy display orientation; CR plate: 14 × 17 inches (35 × 43 cm) crosswise.

Position of patient

• Place the patient on the radiographic table in the supine position.

Position of part

• Center the MSP of the patient's body to the midline of the grid.
• Flex the knees slightly and support them to relieve strain.
• Adjust the pelvis so that the ASISs are equidistant from the table.
• With the IR in the Bucky tray, center it at the level of the greater trochanters (Fig. 8.48).
• *Respiration:* Suspend.

Central ray

• Directed 40 degrees caudad, entering the midline at the level of ASIS

Collimation

• Adjust radiation field to 14 × 17 inches (35 × 43 cm) on the collimator. For smaller patients, collimate 1 inch (2.5 cm) beyond the skin shadow on the sides. Place side marker in the collimated exposure field.

Structures shown

An axial projection of the pelvic ring, or inlet, in its entirety (Fig. 8.49).

Evaluation Criteria

The following should be clearly seen:

- Evidence of proper collimation and presence of side marker placed clear of anatomy of interest
- Medially superimposed superior and inferior rami of the pubic bones
- Nearly superimposed lateral two-thirds of the pubic and ischial bones
- Symmetric pubes and ischial spines
- Hip joints
- Anterior pelvic bones
- Bony trabecular detail and surrounding soft tissues

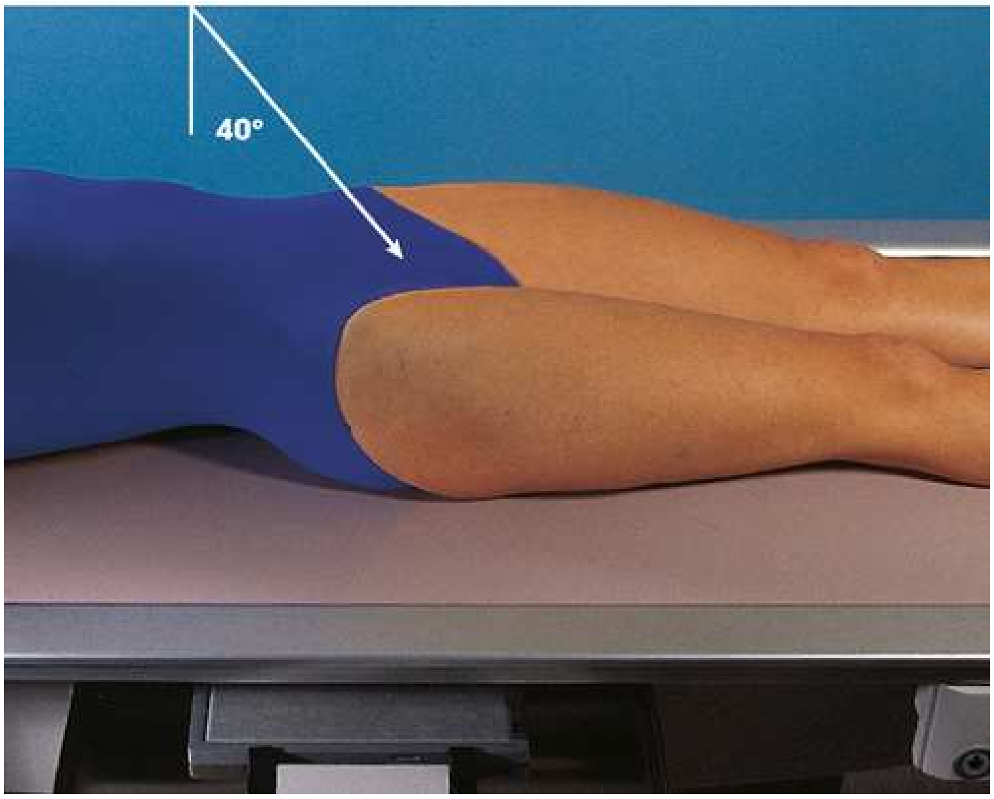


FIG. 8.48 AP axial pelvic bones: Bridgman method.

FIG. 8.49 AP axial inlet projection.

Ilium

AP And PA Oblique Projections

Image receptor + grid: Positioned by manufacturer or department protocol for proper anatomy display orientation; CR plate: 10 × 12 inches (24 × 30 cm) lengthwise.

RPO and LPO positions

Position of patient

- Place the patient in the supine position.

Position of part

- Center the sagittal plane passing through the hip joint of the affected side to the midline of the grid.
- Elevate the unaffected side approximately 40 degrees to place the broad surface of the wing of the affected ilium parallel with the plane of the IR.
- Support the elevated shoulder, hip, and knee on sandbags.
- Adjust the position of the uppermost limb to place the ASIS in the same transverse plane (Fig. 8.50).
- Center the IR at the level of the ASIS.
- *Respiration:* Suspend.

RAO and LAO positions

Position of patient

- Place the patient in the prone position.

Position of part

- Center the sagittal plane passing through the hip joint of the affected side to the midline of the grid.
- Elevate the unaffected side about 40 degrees to place the affected ilium perpendicular to the plane of the IR.
- Have the patient rest on the forearm and flexed knee of the elevated side.
- Adjust the position of the uppermost thigh to place the iliac crests in the same horizontal plane.
- Center the IR at the level of the ASIS (Fig. 8.51).
- *Respiration:* Suspend.

Central ray

- Perpendicular to the midpoint of the IR

Collimation

- Adjust radiation field to 10 × 12 inches (24 × 30 cm) on the collimator. Place side marker in the collimated exposure field.

Structures shown

AP oblique image shows an unobstructed projection of the ala and sciatic notches and a profile image of the acetabulum (Fig. 8.52). PA oblique image shows the ilium in profile and the femoral head within the acetabulum (Fig. 8.53).

Evaluation Criteria

The following should be clearly seen:

- Evidence of proper collimation and presence of side marker placed clear of anatomy of interest
- Entire ilium
- Hip joint, proximal femur, and SI joint
- Bony trabecular detail and surrounding soft tissues

AP Oblique Projection

- Broad surface of the iliac wing without rotation

PA Oblique Projection

- Ilium in profile

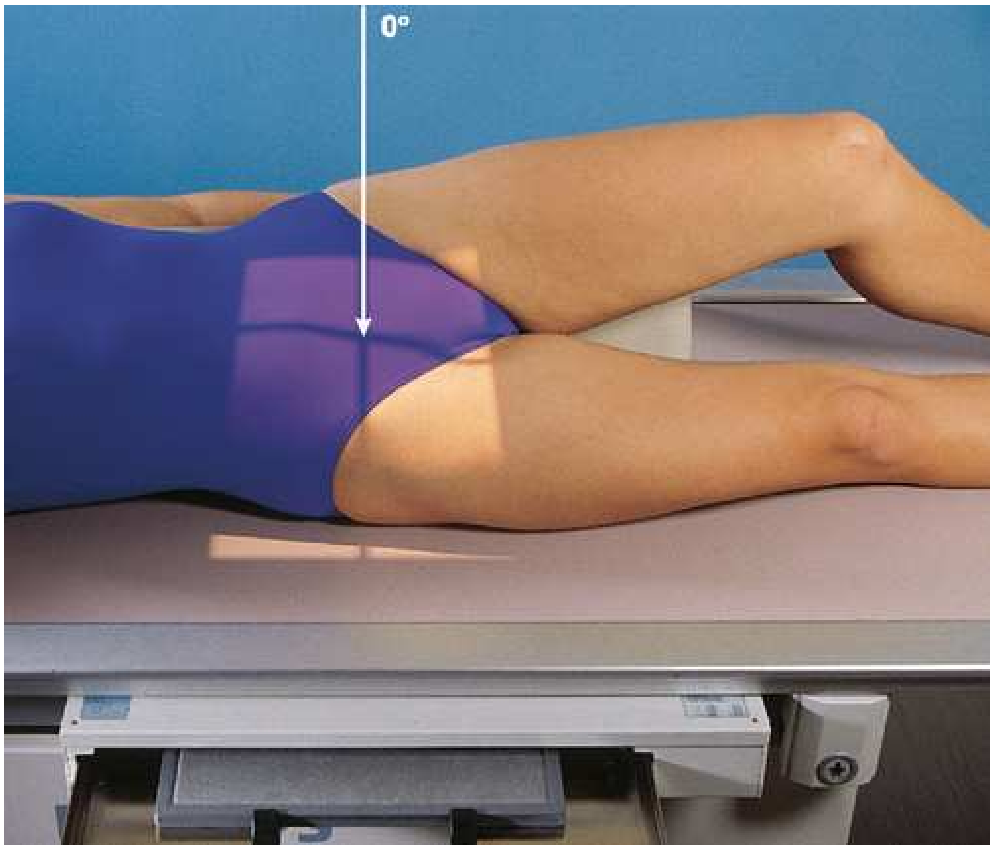


FIG. 8.50 AP oblique ilium, RPO.

The patient is lying in the supine position. The unaffected side is elevated and the broad surface of the wing of the affected ilium is placed parallel with the plane of the I R. The elevated hip and knee are supported on sandbags. The central ray is perpendicular to the midpoint of the I R.

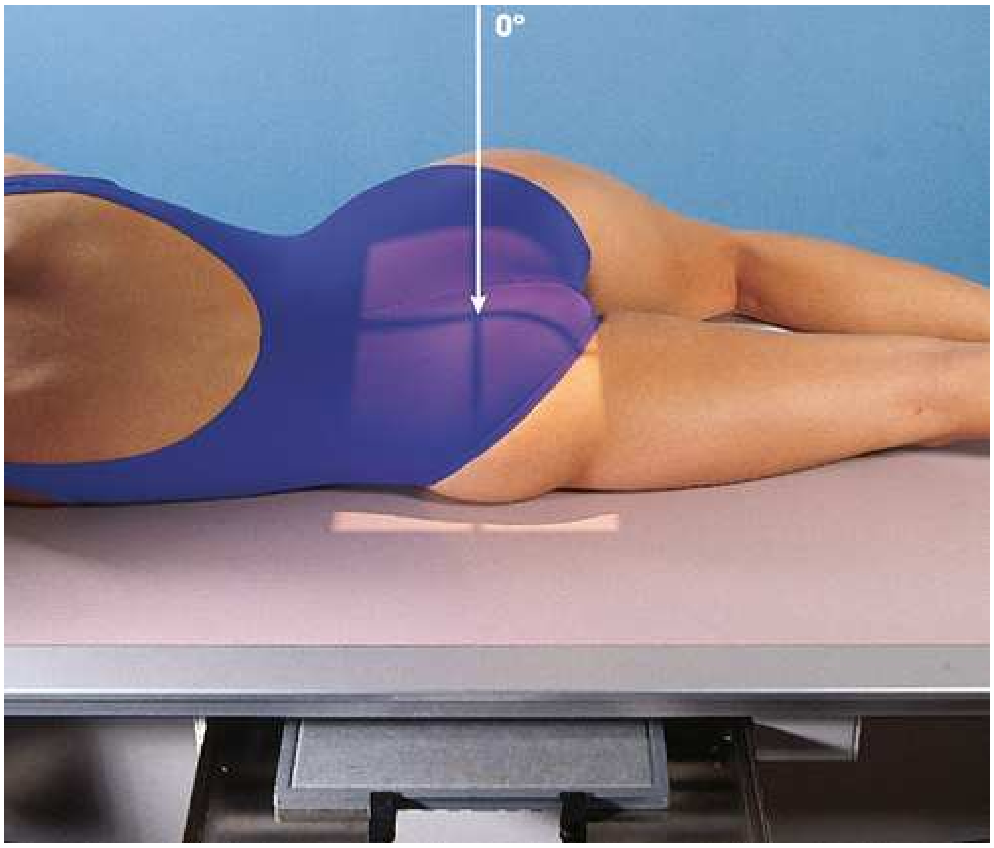


FIG. 8.51 PA oblique ilium, LAO.

The patient is lying in a prone position. The unaffected side is elevated and the affected ilium is placed perpendicular to the plane of the I R. The patient is resting on the flexed knee of the elevated side. The central ray is perpendicular to the midpoint of the I R.

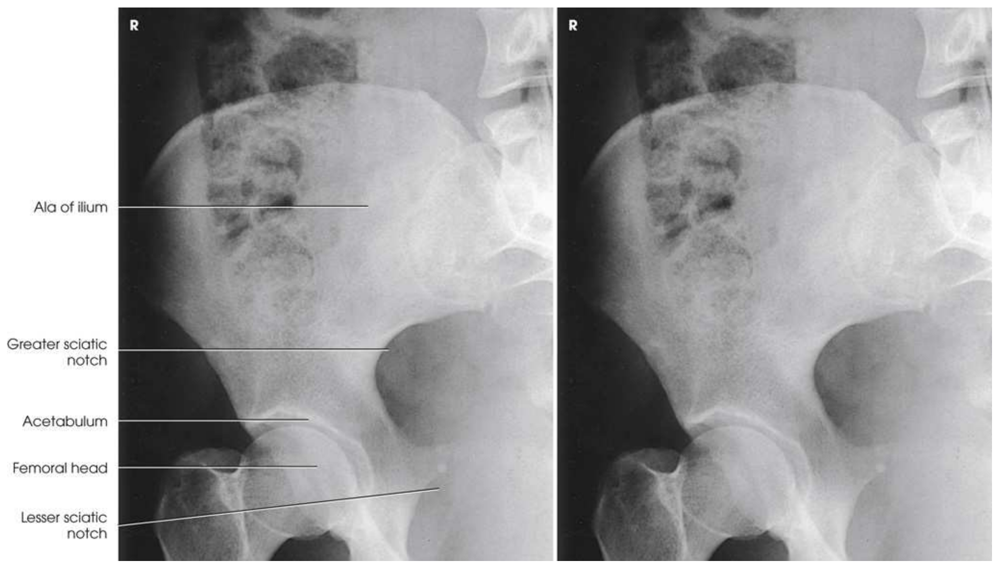


FIG. 8.52 AP oblique ilium, RPO.

Two x-ray shows of the ala and sciatic notches. The parts labeled in the x-ray on the left are marked from top to the bottom as follows: ala of ilium, greater sciatic notch, acetabulum, femoral head, and lesser sciatic notch. The greater sciatic notch is C-shaped.

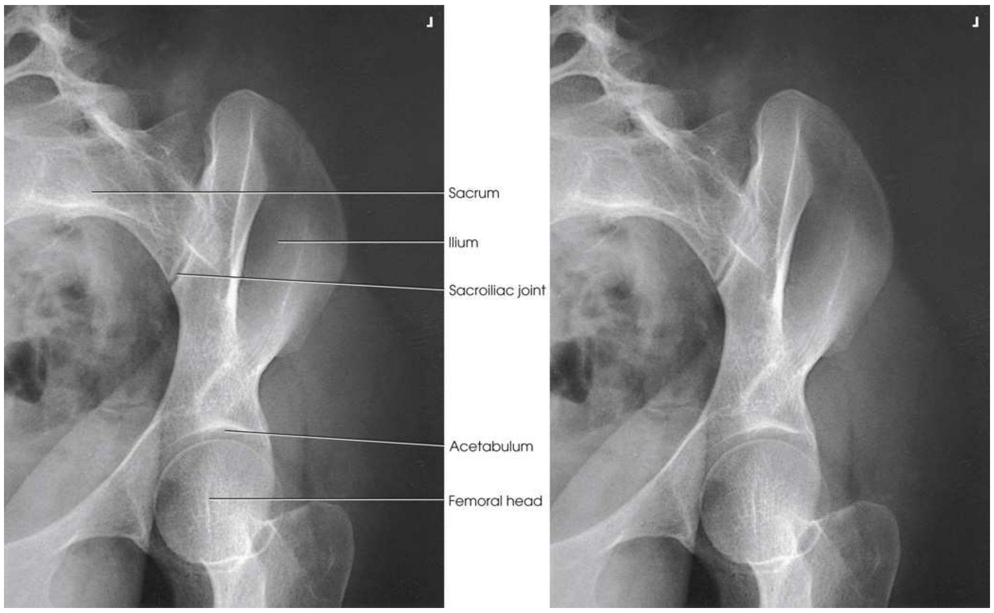


FIG. 8.53 PA oblique ilium, LAO.

An x-ray shows the hip joint, proximal femur, and S I joint. The parts labeled are marked from top to the bottom as follows: sacrum, ilium, sacroiliac joint, acetabulum, and femoral head. The femoral head is within the acetabulum.

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9: Vertebral Column

OUTLINE

Summary of Projections

Projections, Positions, And Methods					
Page	**Essential**	**Anatomy**	**Projection**	**Position**	**Method**
441		Dens	AP		FUCHS
442		Atlas and axis	AP	Open mouth	
444		Atlas and axis	Lateral	R or L	
445		Cervical vertebrae	AP axial		
447		Cervical vertebrae	Lateral	R or L	GRANDY
449		Cervical vertebrae	Lateral	R or L flexion and extension	
451		Cervical intervertebral foramina	AP axial oblique	RPO and LPO	
452		Cervical intervertebral foramina	AP oblique	Flexion and extension	
453		Cervical intervertebral foramina	PA axial oblique	RAO and LAO	
455		Cervical vertebrae	AP		OTTONELLO
457		Cervical and upper thoracic vertebrae: *vertebral arch (pillars)*	AP axial		
459		Cervical and upper thoracic vertebrae: *vertebral arch (pillars)*	AP axial oblique	R and L head rotations	
460		Cervicothoracic region	Lateral	R or L	SWIMMER'S TECHNIQUE
462		Thoracic vertebrae	AP		
465		Thoracic vertebrae	Lateral	R or L	
468		Thoracic zygapophyseal joints	AP, PA oblique	RAO and LAO, RPO and LPO	
471		Lumbar-lumbosacral vertebrae	AP		
471		Lumbar-lumbosacral vertebrae	PA		
475		Lumbar-lumbosacral vertebrae	Lateral	R or L	
477		L5–S1 lumbosacral junction	Lateral	R or L	
479		Lumbar zygapophyseal joints	AP oblique	RPO and LPO	
481		Lumbar zygapophyseal joints	PA oblique	RAO and LAO	
483		Lumbosacral junction and sacroiliac joints	AP, PA axial		FERGUSON
485		Sacroiliac joints	AP oblique	RPO and LPO	
487		Sacroiliac joints	PA oblique	RAO and LAO	
489		Sacrum and coccyx	AP, PA axial		
491		Sacrum and coccyx	Lateral	R or L	
493		Lumbar intervertebral disks	PA	R and L bending	WEIGHT-BEARING
495		Thoracolumbar spine: scoliosis	PA, lateral		FRANK ET AL.
499		Thoracolumbar spine: scoliosis	PA		FERGUSON
501		Lumbar spine: spinal fusion	AP	R and L bending	
503		Lumbar spine: spinal fusion	Lateral	R or L flexion and extension	

Icons in the Essential column indicate projections that are frequently performed in the United States and Canada. Students should be competent in these projections.

AP, Anteroposterior; *L,* left; *LAO,* left anterior oblique; *LPO,* left posterior oblique; *PA,* posteroanterior; *R,* right; *RAO,* right anterior oblique; *RPO,* right posterior oblique.

Anatomy

Vertebral Column

The *vertebral column,* or *spine,* forms the central axis of the skeleton and is centered in the midsagittal plane (MSP) of the posterior part of the trunk. The vertebral column has many functions: It encloses and protects the spinal cord, acts as a support for the trunk, supports the skull superiorly, and provides for attachment to the deep muscles of the back and the ribs laterally. The upper limbs are supported indirectly via the ribs, which articulate with the sternum. The sternum articulates with the shoulder girdle. The vertebral column articulates with each hip bone at the sacroiliac joints. This articulation supports the vertebral column and transmits the weight of the trunk through the hip joints to the lower limbs.

The vertebral column is composed of small segments of bone called *vertebrae.* Disks of fibrocartilage are interposed between the vertebrae and act as cushions. The vertebral column is held together by ligaments, and it is jointed and curved so that it has considerable flexibility and resilience.

In early life, the vertebral column usually consists of 33 small, irregularly shaped bones. These bones are divided into five groups and are named according to the region they occupy (Fig. 9.1). The seven superior-most vertebrae occupy the region of the neck and are termed *cervical vertebrae.* The succeeding 12 bones lie in the dorsal, or posterior portion of the thorax and are called the *thoracic vertebrae.* The five vertebrae occupying the region of the loin are termed *lumbar vertebrae.* The next five vertebrae, located in the pelvic region, are termed *sacral vertebrae.* The terminal vertebrae, also in the pelvic region, vary from three to five in number in adults and are termed the *coccygeal vertebrae.*

The 24 vertebral segments in the upper three regions remain distinct throughout life and are termed the *true* or movable vertebrae. The pelvic segments in the two lower regions are called *false* or fixed vertebrae because of the change they undergo in adults. The sacral segments usually fuse into one bone called the *sacrum,* and the coccygeal segments, referred to as the *coccyx,* also fuse into one bone.

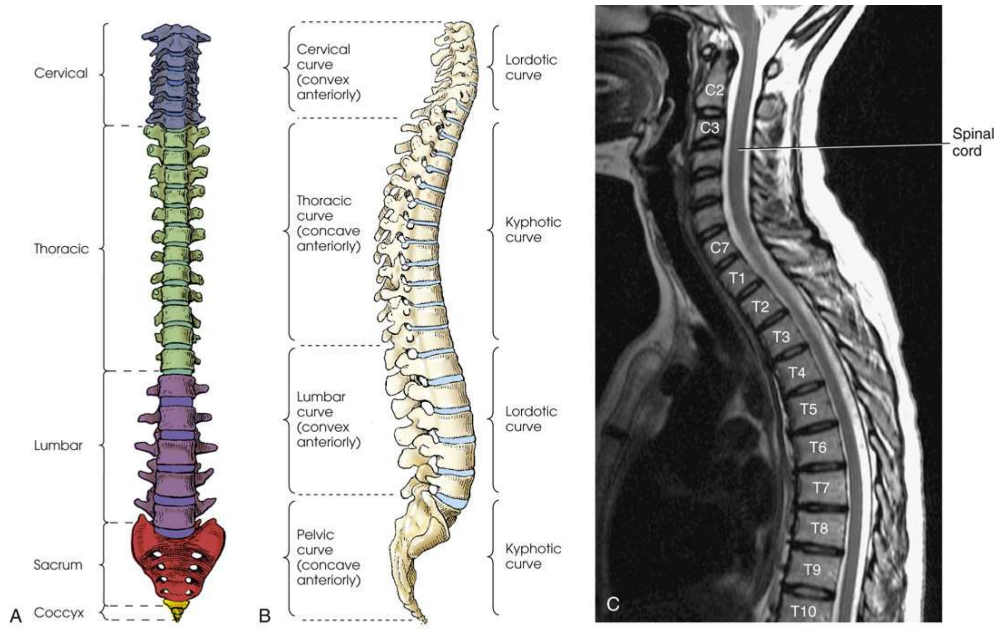


FIG. 9.1 (A) Color-coded anterior aspect of vertebral column. *blue*, Cervical vertebrae; *green*, thoracic vertebrae; *purple*, lumbar vertebrae; *red*, sacrum; *yellow*, coccyx. (B) Lateral aspect of vertebral column, showing regions and curvatures. (C) Midsagittal MRI scan of cervical and thoracic spine. Note curves and spinal cord protected by vertebrae.

Diagram (A) shows the color-coded anterior aspect of the vertebral column. Blue is the Cervical vertebrae, green is the thoracic vertebrae, purple is the lumbar vertebrae, red is the sacrum, yellow is the coccyx. Diagram (B) shows the bones divided into five groups and are named according to the region they occupy The parts labeled on the diagram on the left are as follows: Cervical curve (convex anteriorly), thoracic curve (concave anteriorly), lumbar curve (convex anteriorly), and pelvic curve (concave anteriorly). (C) shows the midsagittal M R I scan of the cervical and thoracic spine. The thoracic and pelvic curves are concave anteriorly and are called kyphotic curves. The cervical and thoracic curves merge smoothly. The parts labeled on the diagram are as follows: spinal cord, C2, C3, C7, T1, T2, T3, T4, T5, T6, T7, T8, T9, T10, lordotic curve, kyphotic curve, lordotic curve, and kyphotic curve. The spinal cord is long, slender, and curved. It appears dar. The vertebrae appear as segments.

Vertebral Curvature

Viewed from the side, the vertebral column has four curves that arch anteriorly and posteriorly from the midcoronal plane of the body. The *cervical, thoracic, lumbar,* and *pelvic* curves are named for the regions they occupy.

In this text, the vertebral curves are discussed in reference to the *anatomic position* and are referred to as "convex anteriorly" or "concave anteriorly." Because physicians and surgeons evaluate the spine from the posterior aspect of the body, *convex* and *concave* terminology can be the exact opposites. When viewed posteriorly, the normal lumbar curve can correctly be referred to as "concave posteriorly." Whether the curve is described as "convex anteriorly" or "concave posteriorly," the curvature of the patient's spine is the same. The cervical and lumbar curves, which are convex anteriorly, are called *lordotic* curves. The thoracic and pelvic curves are concave anteriorly and are called *kyphotic* curves (see Fig. 9.1B). The cervical and thoracic curves merge smoothly.

The lumbar and pelvic curves join at an obtuse angle termed the *lumbosacral angle*. The acuity of the angle in the junction of these curves varies among patients. The thoracic and pelvic curves are called *primary curves* because they are present at birth. The cervical and lumbar curves are called *secondary* or *compensatory curves* because they develop after birth. The cervical curve, which is the least pronounced of the curves, develops when an infant begins to hold the head up at about 3 or 4 months of age and begins to sit alone at about 8 or 9 months of age. The lumbar curve develops when the child begins to walk at about 1 to 1½ years of age. The lumbar and pelvic curves are more pronounced in females, who have a more acute angle at the lumbosacral junction.

Any abnormal increase in the anterior concavity (or posterior convexity) of the thoracic curve is termed *kyphosis* (Fig. 9.2B). Any abnormal increase in the anterior convexity (or posterior concavity) of the lumbar or cervical curve is termed *lordosis*.

In frontal view, the vertebral column varies in width in several regions (see Fig. 9.1). In general, the width of the spine gradually increases from the second cervical vertebra to the superior part of the sacrum and then decreases sharply. A *slight* lateral curvature is sometimes present in the upper thoracic region. The curve is to the right in right-handed persons and to the left in left-handed persons. For this reason, the lateral curvature of the vertebral column is believed to be the result of muscle action and to be influenced by occupation. An abnormal lateral curvature of the spine is called *scoliosis*. This condition also causes the vertebrae to rotate toward the concavity. The vertebral column develops a second or compensatory curve in the opposite direction to keep the head centered over the feet (see Fig. 9.2A).

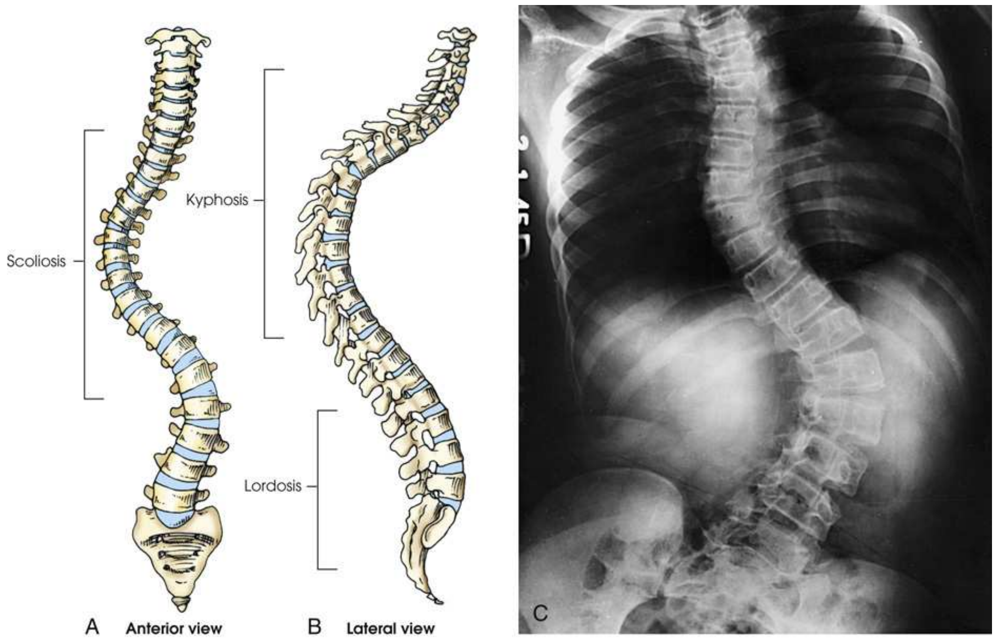


FIG. 9.2 (A) Scoliosis, lateral curvature of spine. (B) Kyphosis, increased convexity of thoracic spine, and lordosis, increased concavity of lumbar spine. (C) PA thoracic and lumbar spine showing severe scoliosis.

Diagram (A) shows a concave curve and a second curve in the opposite direction and is labeled as scoliosis Diagram (B) shows the increased convexity of the thoracic spine, and increased concavity of the lumbar spine. They are labeled as kyphosis and lordosis respectively. (C) shows an x-ray view of the lumbar spine with a concave curve and a second curve in the opposite direction.

Typical Vertebra

A typical vertebra is composed of two main parts—an anterior mass of bone called the *body* and a posterior ringlike portion called the *vertebral arch* (Figs. 9.3 and 9.4). The vertebral body and arch enclose a space called the *vertebral foramen*. In the articulated column, the vertebral foramina form the *vertebral canal*.

The body of the vertebra is approximately cylindric in shape and is largely composed of cancellous bony tissue covered by a layer of compact tissue. From the superior aspect, the posterior surface is flattened, and from the lateral aspect, the anterior and lateral surfaces are concave. The superior and inferior surfaces of the bodies are flattened and are covered by a thin plate of *articular cartilage*.

In the articulated spine, the vertebral bodies are separated by *intervertebral disks,* forming the cartilaginous intervertebral joints. These disks account for approximately one-fourth of the length of the vertebral column. Each disk has a central mass of soft, pulpy, semigelatinous material called the *nucleus pulposus,* which is surrounded by an outer fibrocartilaginous disk called the *annulus fibrosus*. It is common for the pulpy nucleus to rupture or protrude into the vertebral canal, impinging on a spinal nerve. This condition is called *herniated nucleus pulposus* (HNP) or, more commonly, *slipped disk*. HNP most often occurs in the lumbar region as a result of improper body mechanics, and it can cause considerable discomfort and pain. HNP also occurs in the cervical spine as a result of trauma (i.e., whiplash injuries) or degeneration.

The vertebral arch (see Figs. 9.3 and 9.4) is formed by two *pedicles* and two *laminae* that support four articular processes, two transverse processes, and one spinous process. The pedicles are short, thick processes that project posteriorly, one from each side, from the superior and lateral parts of the posterior surface of the vertebral body. The superior and inferior surfaces of the pedicles, or roots, are concave. These concavities are called *vertebral notches*. By articulating with the vertebrae above and below, the notches form *intervertebral foramina* for the transmission of spinal nerves and blood vessels. The broad, flat *laminae* are directed posteriorly and medially from the pedicles.

The *transverse processes* project laterally and slightly posteriorly from the junction of the pedicles and laminae. The *spinous process* projects posteriorly and inferiorly from the junction of the laminae in the posterior midline. A congenital defect of the vertebral column in which the laminae fail to unite posteriorly at the midline is called *spina bifida*. In serious cases of spina bifida, the spinal cord may protrude from the affected individual's body.

Four articular processes—two superior and two inferior—arise from the junction of the pedicles and laminae to articulate with the vertebrae above and below (see Fig. 9.4). The articulating surfaces of the four articular processes are covered with fibrocartilage and are called *facets*. In a typical vertebra, each *superior articular process* has an articular facet on its posterior surface, and each *inferior articular process* has an articular facet on its anterior surface. The direction of planes of the facets varies in different regions of the vertebral column and often vary within the same vertebra. The articulations between the articular processes of the vertebral arches are the synovial intervertebral joints, referred to as *zygapophyseal joints*. Some texts refer to these joints as *interarticular facet joints*.

The movable vertebrae, with the exception of the first and second cervical vertebrae, are similar in general structure. Each group has certain distinguishing characteristics, however, that must be considered in radiography of the vertebral column.

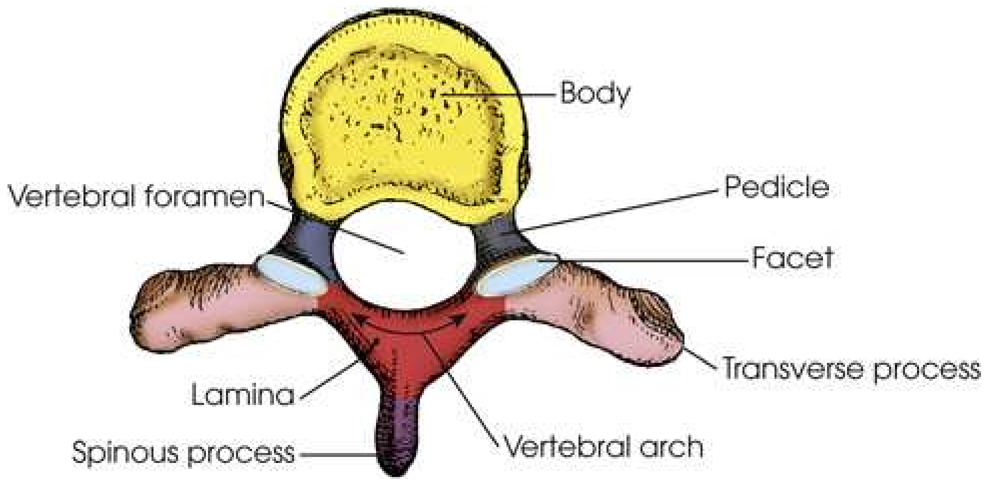


FIG. 9.3 Superior aspect of thoracic vertebra, showing color-coded structures common to all vertebral regions. *blue*, Pedicle; *pink*, transverse process; *purple*, spinous process; *red*, lamina; *yellow*, body.

Diagram shows an anterior mass of bone called the body and a posterior ring-like portion called the vertebral arch. The color-coded regions are as follows: blue is the pedicle, pink is the transverse process, purple is the spinous process, red is the lamina and yellow is the body.

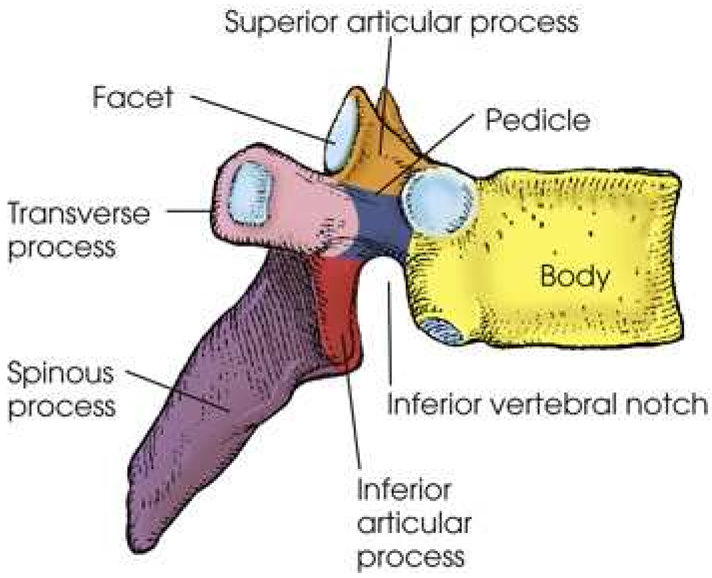


FIG. 9.4 Lateral aspect of thoracic vertebra, showing structures common to all vertebral regions.

Diagram shows the formation of the vertebral arch. The superior and inferior surfaces of the pedicles, or roots, are concave. The parts labeled on the diagram marked clockwise are as follows: spinous process, transverse process, facet, superior articular process, pedicle, body, inferior vertebral notch, and inferior articular process.

Cervical Vertebrae

The first two cervical vertebrae are atypical in that they are structurally modified to join the skull. The seventh vertebra is also atypical and is slightly modified to join the thoracic spine. Atypical and typical vertebrae are described in the following sections.

ATLAS

The *atlas,* the first cervical vertebra (C1), is a ringlike structure with no body and a very short spinous process (Fig. 9.5). The atlas consists of an *anterior arch,* a *posterior arch,* two *lateral masses,* and two *transverse processes*. The anterior and posterior arches extend between the lateral masses. The ring formed by the arches is divided into anterior and posterior portions by a ligament called the *transverse atlantal ligament*. The anterior portion of the ring receives the dens (odontoid process) of the axis, and the posterior portion transmits the proximal spinal cord.

The transverse processes of the atlas are longer than those of the other cervical vertebrae, and they project laterally and slightly inferiorly from the lateral masses. Each lateral mass bears a superior and an inferior articular process. The superior processes lie in a horizontal plane, are large and deeply concave, and are shaped to articulate with the occipital condyles of the occipital bone of the cranium.

AXIS

The *axis,* the second cervical vertebra (C2; Figs. 9.6 and 9.7), has a strong conical process arising from the upper surface of its body. This process, called the *dens* or *odontoid process,* is received into the anterior portion of the atlantal ring to act as the pivot or body for the atlas. At each side of the dens on the superior surface of the vertebral body are the superior articular processes, which are adapted to join with the inferior articular processes of the atlas. These joints, which differ in position and direction from the other cervical zygapophyseal joints, are clearly visualized in an anteroposterior (AP) projection if the patient is properly positioned. The inferior articular processes of the axis have the same direction as the processes of the succeeding cervical vertebrae. The laminae of the axis are broad and thick. The spinous process is horizontal in position. Fig. 9.8 shows the relationship of C1 and C2 with the occipital condyles.

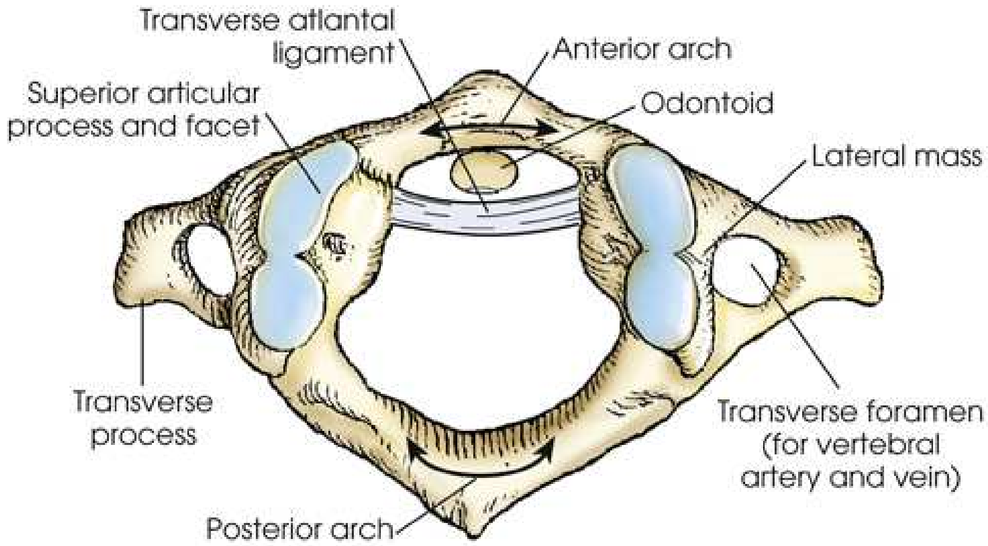


FIG. 9.5 Superior aspect of atlas (C1).

Diagram shows a ring-like structure with no body and a very short spinous process (C 1). The ring formed by the arches is divided into anterior and posterior portions. The parts labeled on the diagram are listed as follows: posterior arch, transverse process, superior articular process and facet, transverse atlantal ligament, anterior arch, odontoid, lateral mass, and transverse foramen (for vertebral artery and vein).

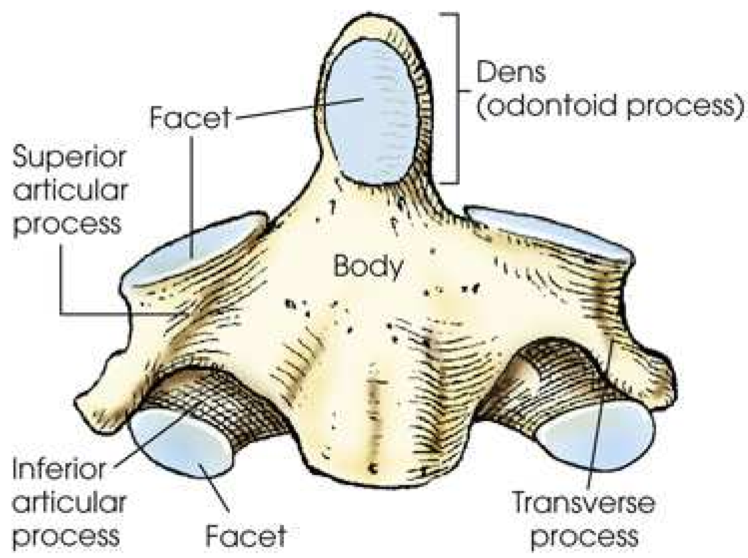


FIG. 9.6 Anterior aspect of axis (C2).

Diagram shows a conical process arising from the upper surface of the body (C 2). The anterior portion has a ring. The parts labeled on the diagram are as follows: facet, Inferior articular process, superior articular process, dens (odontoid process), and the transverse process.

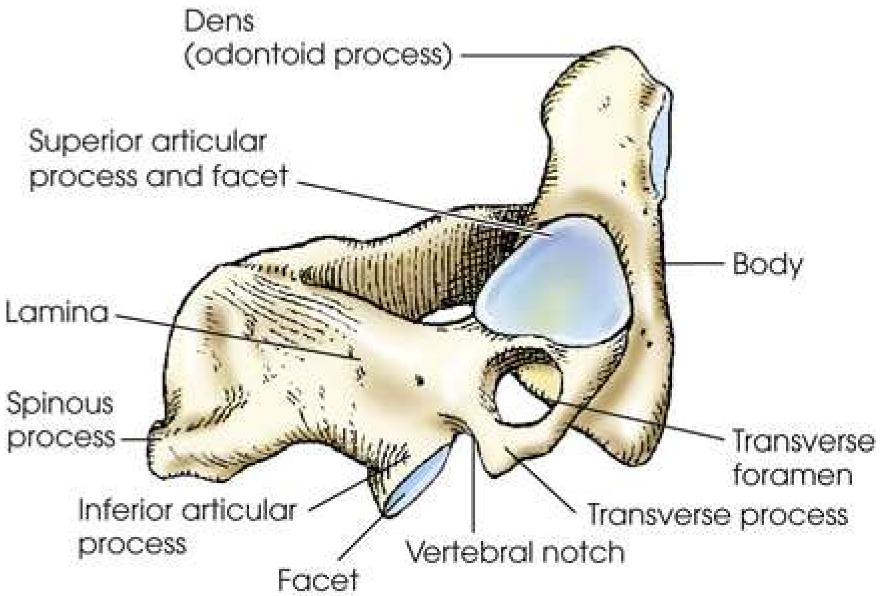


FIG. 9.7 Lateral aspect of axis (C2).

Diagram shows the lateral aspect of axis (C 2). The parts labeled on the diagram are listed as follows: facet, inferior articular process, spinous process, lamina, superior articular process and facet, dens (odontoid process), body, transverse foramen, transverse process, and vertebral notch.

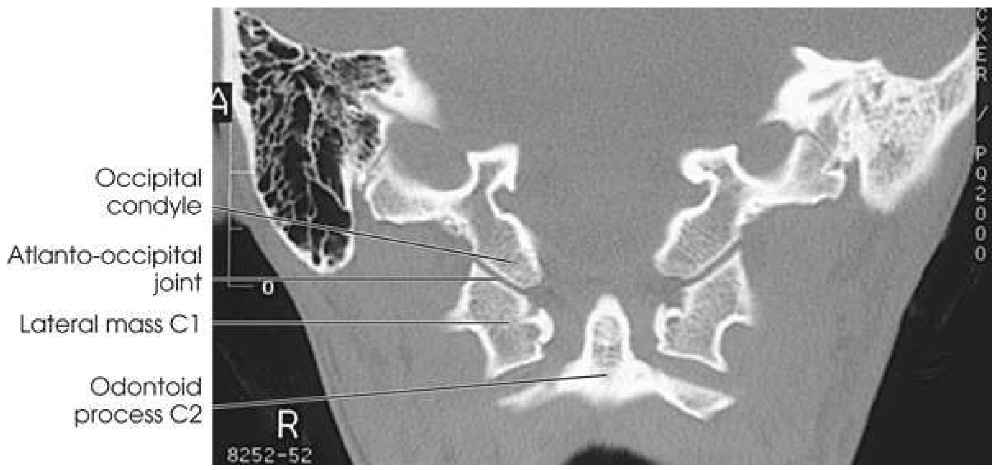


FIG. 9.8 Coronal MRI shows atlas, axis, and occipital bone of skull and their relationship. Courtesy Siemens Medical Systems, Iselin, NJ.

The coronal M R I shows C 1 and C 2 with the occipital condyles. The parts labeled on it from top to bottom are as follows: occipital condyle, atlanto-occipital joint, lateral mass C 1, and odontoid process C 2. The odontoid process is conical. There is a dark triangular area near the occipital condyle.

Seventh Vertebra

The seventh cervical vertebra (C7), termed the *vertebra prominens,* has a long, prominent spinous process that projects almost horizontally to the posterior. The spinous process of this vertebra is easily palpable at the posterior base of the neck. It is convenient to use this process as a guide in localizing other vertebrae.

Typical Cervical Vertebra

The *typical cervical vertebrae* (C3–C6) have a small, transversely located, oblong body with slightly elongated anteroinferior borders (Fig. 9.9). The result is AP overlapping of the bodies in the articulated column. The transverse processes of the typical cervical vertebra arise partly from the sides of the body and partly from the vertebral arch. These processes are short and wide, are perforated by the *transverse foramina* for transmission of the vertebral artery and vein, and present a deep concavity on their upper surfaces for passage of the spinal nerves. All cervical vertebrae contain three foramina: the right and left transverse foramina and the vertebral foramen.

The pedicles of the typical cervical vertebra project laterally and posteriorly from the body, and their superior and inferior vertebral notches are nearly equal in depth. The laminae are narrow and thin. The spinous processes are short, have double-pointed (bifid) tips, and are directed posteriorly and slightly inferiorly. Their palpable tips lie at the level of the interspace below the body of the vertebra from which they arise.

The superior and inferior articular processes are located posterior to the transverse processes at the point where the pedicles and laminae unite. Together, the processes form short, thick columns of bone called *articular pillars*. The fibrocartilaginous articulating surfaces of the articular pillars contain facets. The zygapophyseal facet joints of the second through seventh cervical vertebrae lie at right angles to the MSP and are clearly shown in a lateral projection (Fig. 9.10A).

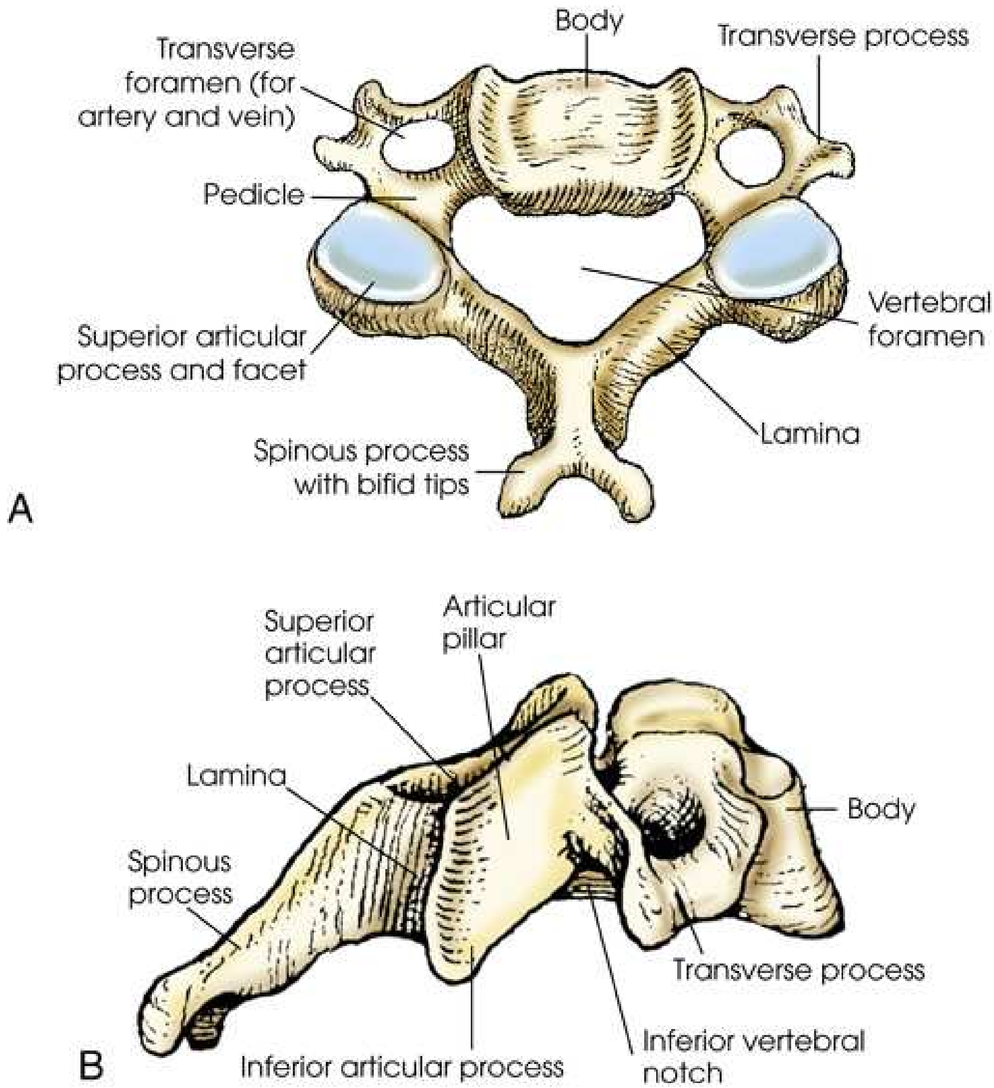


FIG. 9.9 (A) Superior aspect of typical cervical vertebra. (B) Lateral aspect of typical cervical vertebra.

Diagram (A) shows a small, transversely located, oblong body with slightly elongated anteroinferior borders. The laminae are narrow and thin. The spinous processes are short, have double-pointed (bifid) tips, and are directed posteriorly and slightly inferiorly The parts labeled on the diagram marked in clockwise are as follows: spinous process with bifid tips, superior articular process and facet, pedicle, transverse foramen (for artery and vein), body, transverse process, vertebral foramen, and lamina. Diagram (B) shows the lateral aspect of the typical cervical vertebra. The parts labeled on the diagram marked clockwise are as follows: inferior articular process, spinous process, lamina, superior articular process, articular pillar, body, transverse process, and inferior vertebral notch.

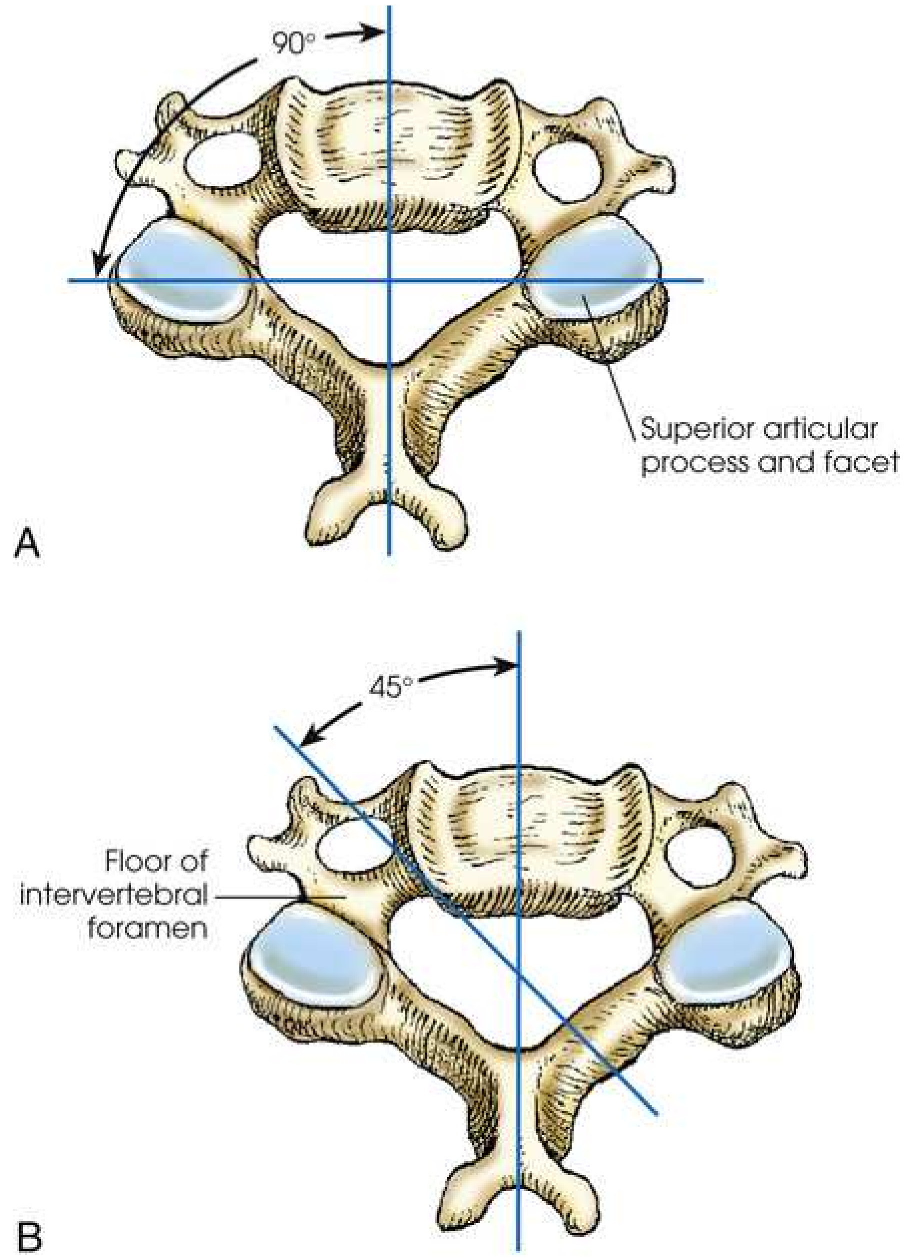


FIG. 9.10 (A) Direction of cervical zygapophyseal joints. (B) Direction of cervical intervertebral foramina.

Diagram (A) shows the direction of cervical zygapophyseal joints. A horizontal and a vertical line divided the diagram into four quadrants. Each quadrant measures 90 degrees. The zygapophyseal facet joints of the second through seventh cervical vertebrae lie at right angles to the M S P. Diagram (B) shows the direction of cervical intervertebral foramina. The intervertebral foramina of the cervical region are directed anteriorly at a 45-degree angle from the M S P of the body.

The intervertebral foramina of the cervical region are directed anteriorly at a 45-degree angle from the MSP of the body (Fig. 9.11; also see Fig. 9.10B). The foramina are also directed at a 15-degree inferior angle to the horizontal plane of the body. Accurate radiographic demonstration of these foramina requires a 15-degree longitudinal angulation of the central ray and a 45-degree medial rotation of the patient (or a 45-degree medial angulation of the central ray). A lateral projection is necessary to show the cervical zygapophyseal joints. The positioning rotations required for showing the intervertebral foramina and zygapophyseal joints of the cervical spine are summarized in Table 9.1. A full view of the cervical spine along with surrounding tissues is shown in Fig. 9.12.

TABLE 9.1

Positioning rotations needed to show intervertebral foramina and zygapophyseal joints

Area of spine	Intervertebral foramina	Zygapophyseal joint
Cervical spine	45 degrees [a] oblique	Lateral
	AP side up	
	PA side down	
Thoracic spine	Lateral	70 degrees [a] oblique
		AP side up
		PA side down
Lumbar spine	Lateral	30–60 degrees [a] oblique
		AP side down
		PA side up

[a] From the anatomic position.

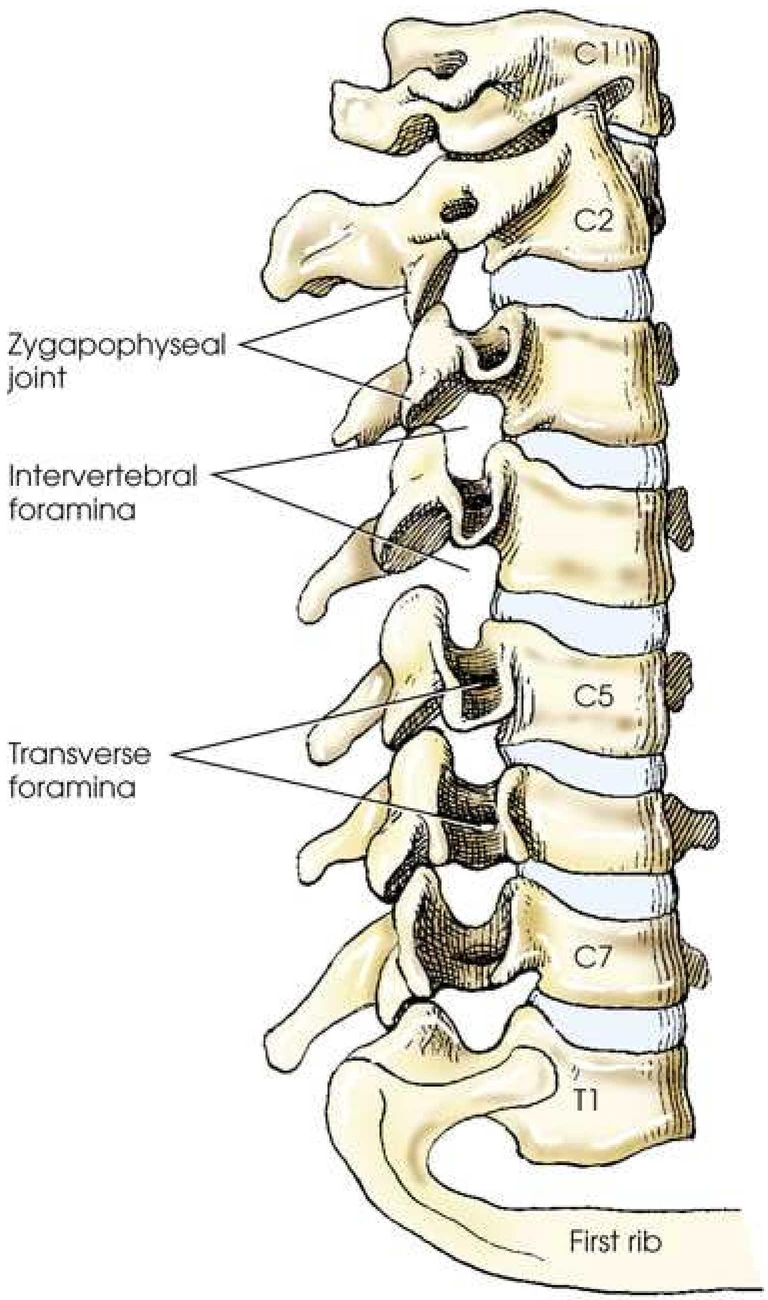


FIG. 9.11 Anterior oblique of cervical vertebrae, showing intervertebral transverse foramina and zygapophyseal joints.

Diagram shows the anterior oblique of cervical vertebrae. The parts labeled on the diagram marked from top to the bottom are as follows: zygapophyseal joint, intervertebral foramina, and transverse foramina.

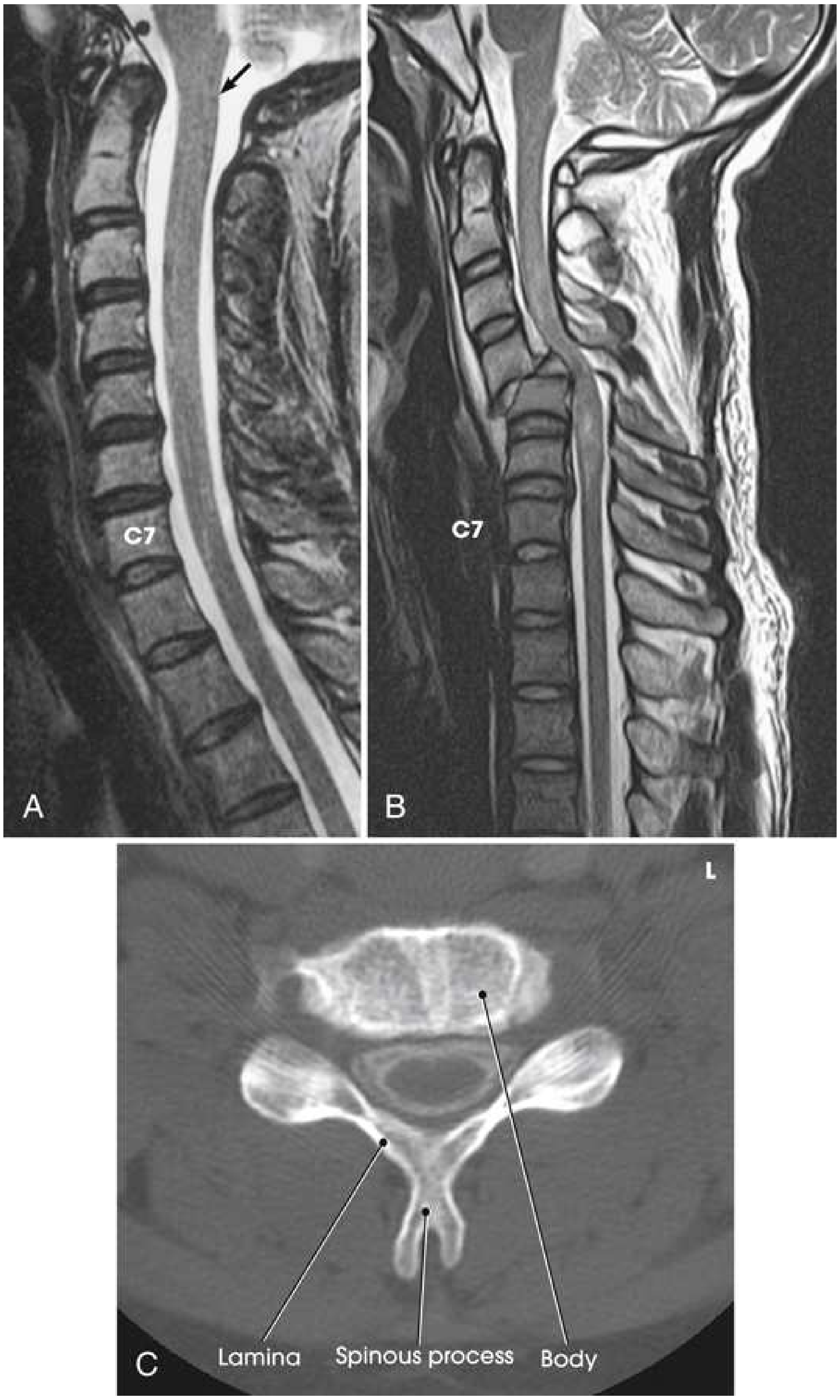


FIG. 9.12 (A) MRI sagittal plane of cervical spine. Note position of spinal cord *(arrow)* in relation to vertebral bodies. (B) MRI sagittal plane showing anterior displacement of C4 on C5. Narrowed spinal canal compresses spinal cord causing paralysis. (C) Axial CT of typical cervical vertebra. B, Modified from Jackson SA, Thomas RM. *Cross-sectional imaging made easy.* New York: Churchill Livingstone; 2004. C, Modified from Kelley LL, Petersen CM. *Sectional anatomy for imaging professionals,* 2nd ed. St. Louis: Mosby; 2007.

(A) The M R I sagittal plane of the cervical spine shows the full view of the cervical spine along with surrounding tissues. The position of the spinal cord is marked by a black arrow in relation to vertebral bodies. (B) The M R I sagittal plane showing anterior displacement of C 4 on C 5. The spinal cord appears narrow. (C) The Axial C T shows the typical cervical vertebra. The parts labeled are as follows: lamina, spinous process, body. The body appears oblong. The laminae are narrow and thin. The spinous processes are short, have double-pointed (bifid) tips.

Thoracic Vertebrae

The bodies of the thoracic vertebrae increase in size from the first to the twelfth vertebrae. They also vary in form, with the superior thoracic bodies resembling cervical bodies and the inferior thoracic bodies resembling lumbar bodies. The bodies of the typical (third through ninth) thoracic vertebrae are approximately triangular in form (Figs. 9.13 and 9.14). These vertebral bodies are deeper posteriorly than anteriorly, and their posterior surface is concave from side to side.

The posterolateral margins of each thoracic body have *costal facets* for articulation with the heads of the ribs (Fig. 9.15). The body of the first thoracic vertebra presents a whole costal facet near its superior border for articulation with the head of the first rib and presents a *demifacet* (half-facet) on its inferior border for articulation with the head of the second rib. The bodies of the second through eighth thoracic vertebrae contain demifacets superiorly and inferiorly. The ninth thoracic vertebra has only a superior demifacet. Finally, the tenth, eleventh, and twelfth thoracic vertebral bodies have a single whole facet at the superior margin for articulation with the eleventh and twelfth ribs (Table 9.2).

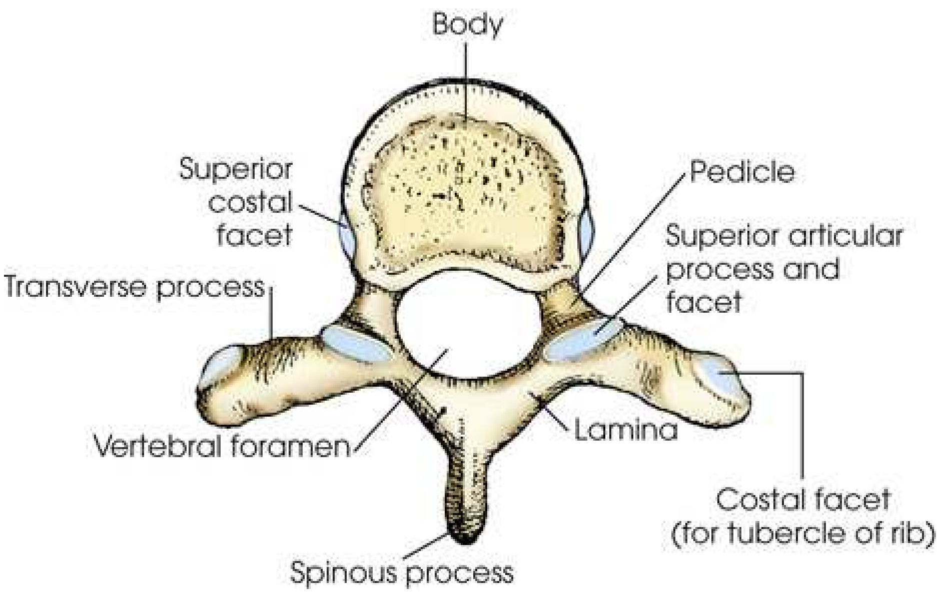


FIG. 9.13 Superior aspect of thoracic vertebra.

Diagram shows the superior aspect of the thoracic vertebra. The parts labeled on the diagram marked clockwise are as follows: spinous process, vertebral foramen, transverse process, superior costal facet, body, pedicle, superior articular process and facet, costal facet (for tubercle of rib), and lamina. The body appears grainy.

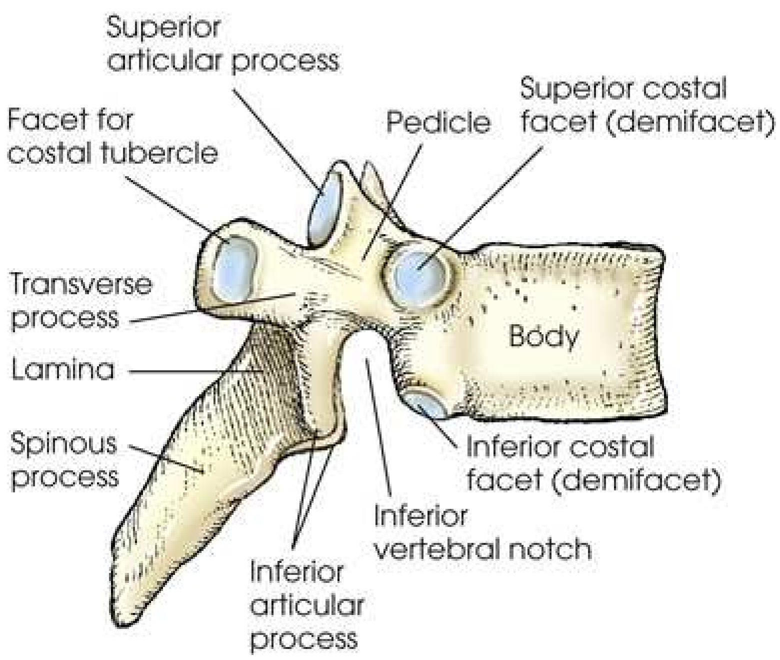


FIG. 9.14 Lateral aspect of thoracic vertebra.

Diagram shows the lateral aspect of the thoracic vertebra. The body is rectangular. The parts labeled on the diagram marked clockwise are as follows: inferior articular process, spinous process, lamina, transverse process, facet for costal tubercle, superior articular process, pedicle, superior costal facet (demifacet), body, inferior costal facet (demifacet), and inferior vertebral notch.

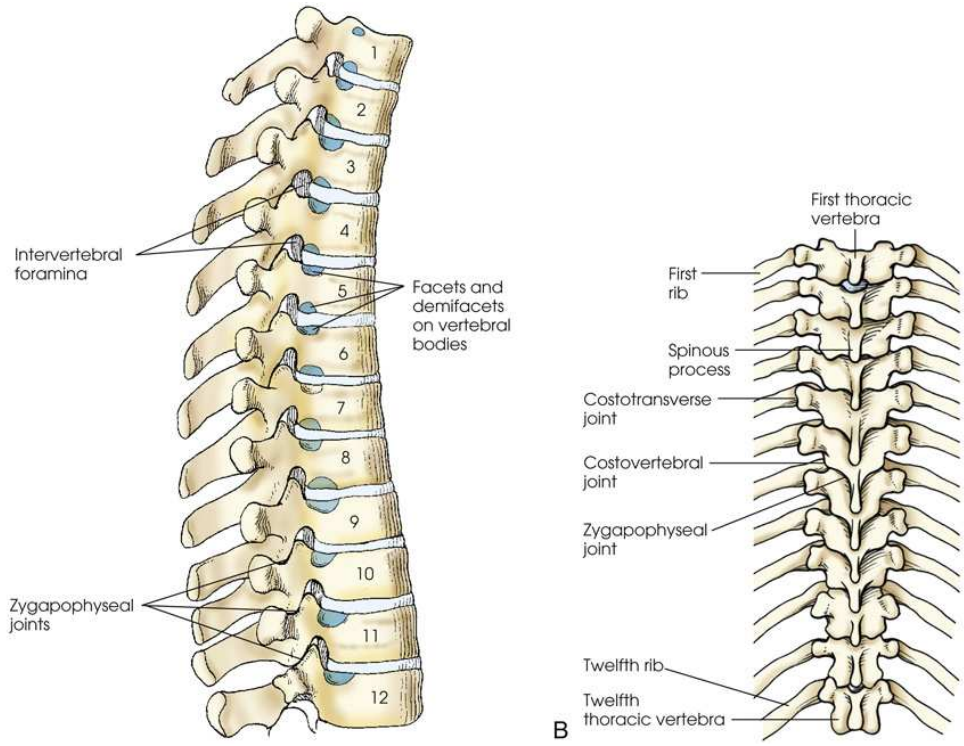


FIG. 9.15 Thoracic spine. (A) Posterior oblique aspect showing zygapophyseal joints, intervertebral foramina, and facets and demifacets (see Table 9.2). (B) Posterior aspect showing attachment of ribs and joints.

Diagram (A) shows the posterolateral margins of each thoracic body with costal facets for articulation with the heads of the ribs. The parts labeled on it are intervertebral foramina, zygopophyseal joints, and facets and demofacets on vertebral bodies. Diagram (B) shows the posterior aspect showing attachment of ribs and joints. The parts labeled on the diagram are as follows: first thoracic vertebra, first rib, spinous process, costotransverse joint, costovertebral joint, zygapophyseal joint, twelfth rib, and twelfth thoracic vertebra.

The transverse processes of the thoracic vertebrae project obliquely, laterally, and posteriorly. With the exception of the eleventh and twelfth pairs, each process has on the anterior surface of its extremity a small concave facet for articulation with the tubercle of a rib. The laminae are broad and thick, and they overlap the subjacent lamina. The spinous processes are long. From the fifth to the ninth vertebrae, the spinous processes project sharply inferiorly and overlap each other, but they are less vertical above and below this region. The palpable tip of each spinous process of the fifth to ninth thoracic vertebrae corresponds in position to the interspace *below* the vertebra from which it projects.

The zygapophyseal joints of the thoracic region (except the inferior articular processes of the twelfth vertebra) angle anteriorly approximately 15 to 20 degrees to form an angle of 70 to 75 degrees (open anteriorly) to the MSP of the body (Fig. 9.16A; also see Fig. 9.15). To show the zygapophyseal joints of the thoracic region radiographically, the patient's body must be rotated 70 to 75 degrees from the anatomic position or 15 to 20 degrees from the lateral position.

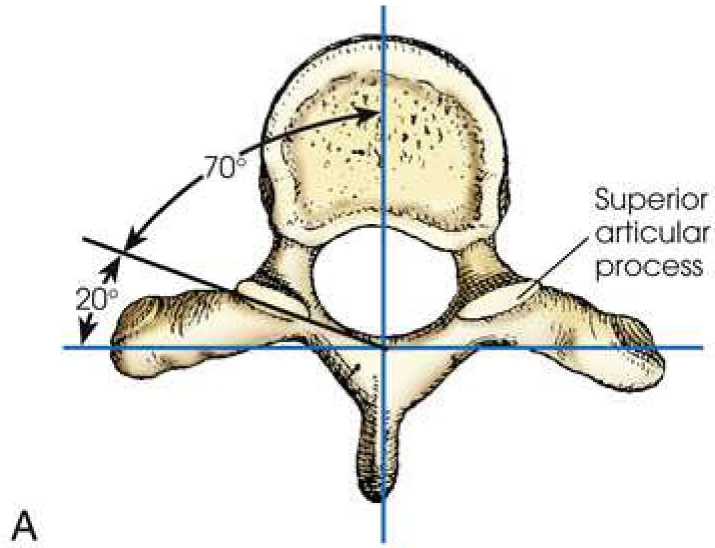
The intervertebral foramina of the thoracic region are perpendicular to the MSP of the body (see Figs. 9.15 and 9.16B). These foramina are clearly shown radiographically in the patient in a true lateral position (see Table 9.1). During inspiration, the ribs are elevated. The arms must also be raised enough to elevate the ribs, which otherwise cross the intervertebral foramina. A full view of the thoracic vertebrae along with surrounding tissues is seen in Fig. 9.17.

TABLE 9.2

Costal facets and demifacets

Vertebrae	Vertebral border	Facet/demifacet [a]
T1	Superior	Whole facet
	Inferior	Demifacet
T2–T8	Superior	Demifacet
	Inferior	Demifacet
T9	Superior	Demifacet
	Inferior	None
T10–T12	Superior	Whole facet
	Inferior	None

[a] On *each side* of a vertebral body.



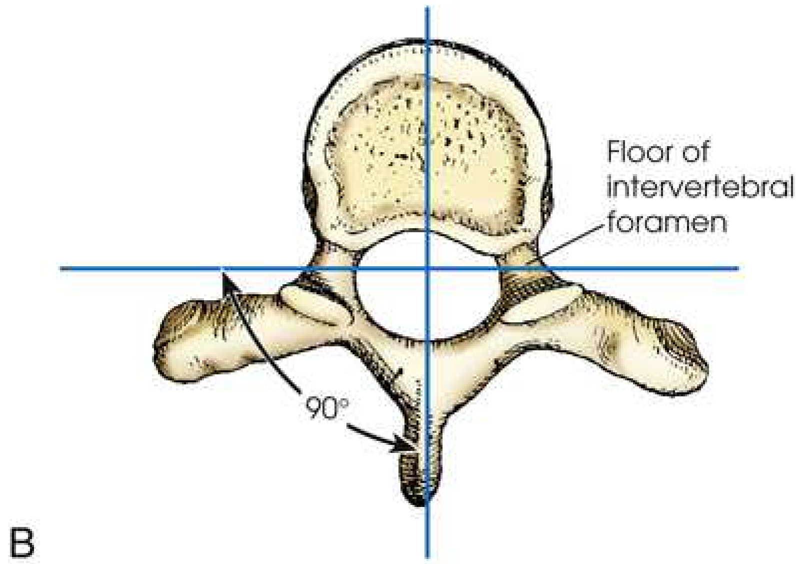


FIG. 9.16 (A) Direction of thoracic zygapophyseal joints. (B) Direction of thoracic intervertebral foramina.

Diagram (A) shows the direction of thoracic zygapophyseal joints. The zygapophyseal joints of the thoracic region are rotated 70 to 75 degrees from the anatomic position or 15 to 20 degrees from the lateral position. The superior articular process is labeled on the diagram. Diagram (B) shows intervertebral foramina of the thoracic region are perpendicular to the M S P of the body. A horizontal and a vertical line divided the diagram into four quadrants. Each quadrant measures 90 degrees. The floor of the intervertebral foramen is marked on the diagram.

FIG. 9.17 MRI sagittal plane of thoracic vertebrae region showing vertebral bodies and relationship to spinal cord.

Lumbar Vertebrae

The lumbar vertebrae have large, bean-shaped bodies that increase in size from the first to the fifth vertebra in this region. The lumbar bodies are deeper anteriorly than posteriorly, and their superior and inferior surfaces are flattened or slightly concave (Fig. 9.18A). At their posterior surface, these vertebrae are flattened anteriorly to posteriorly, and they are transversely concave. The anterior and lateral surfaces are concave from the top to the bottom (see Fig. 9.18B).

The transverse processes of lumbar vertebrae are smaller than those of thoracic vertebrae. The superior three pairs are directed almost exactly laterally, whereas the inferior two pairs are inclined slightly superiorly. The lumbar pedicles are strong and are directed posteriorly, and the laminae are thick. The spinous processes are large, thick, and blunt, and they have an almost horizontal projection posteriorly. The palpable tip of each spinous process corresponds in position with the interspace below the vertebra from which it projects. The *mammillary process* is a smoothly rounded projection on the back of each superior articular process. The *accessory process* is at the back of the root of the transverse process.

The body of the fifth lumbar segment is considerably deeper in front than behind, which gives it a wedge shape that adapts it for articulation with the sacrum. The intervertebral disk of this joint is also more wedge-shaped than the disks in the interspaces above the lumbar region. The spinous process of the fifth lumbar vertebra is smaller and shorter, and the transverse processes are much thicker than those of the upper lumbar vertebrae.

The laminae lie posterior to the pedicles and transverse processes. The part of the lamina between the superior and inferior articular processes is called the *pars interarticularis* (Fig. 9.19).

The zygapophyseal joints of the lumbar region (Figs. 9.20 and 9.21A) are inclined posteriorly from the coronal plane, forming an average angle (open posteriorly) of 30 to 60 degrees to the MSP of the body.

The average angle increases from cephalad to caudad with L1–L2 at 15 degrees, L2–L3 at 30 degrees, and L3–L4 through L5–S1 at 45 degrees. Table 9.3 shows that these joint angles may vary widely at each level. Numerous upper joints have no angle, and many lower joints have an angle of 60 degrees or more. Although the customary 45-degree oblique body position shows most clinically significant lumbar zygapophyseal joints (L3 through S1), 25% of L1–L2 and L2–L3 joints are shown on an AP projection, and a small percentage of L4–L5 and L5–S1 joints are seen on a lateral projection.

The intervertebral foramina of the lumbar region are situated at right angles to the MSP of the body, except for the fifth, which turns slightly anteriorly (Fig. 9.21B). The superior four pairs of foramina are shown radiographically with the patient in a true lateral position; the last pair requires slight obliquity of the body (see Table 9.1).

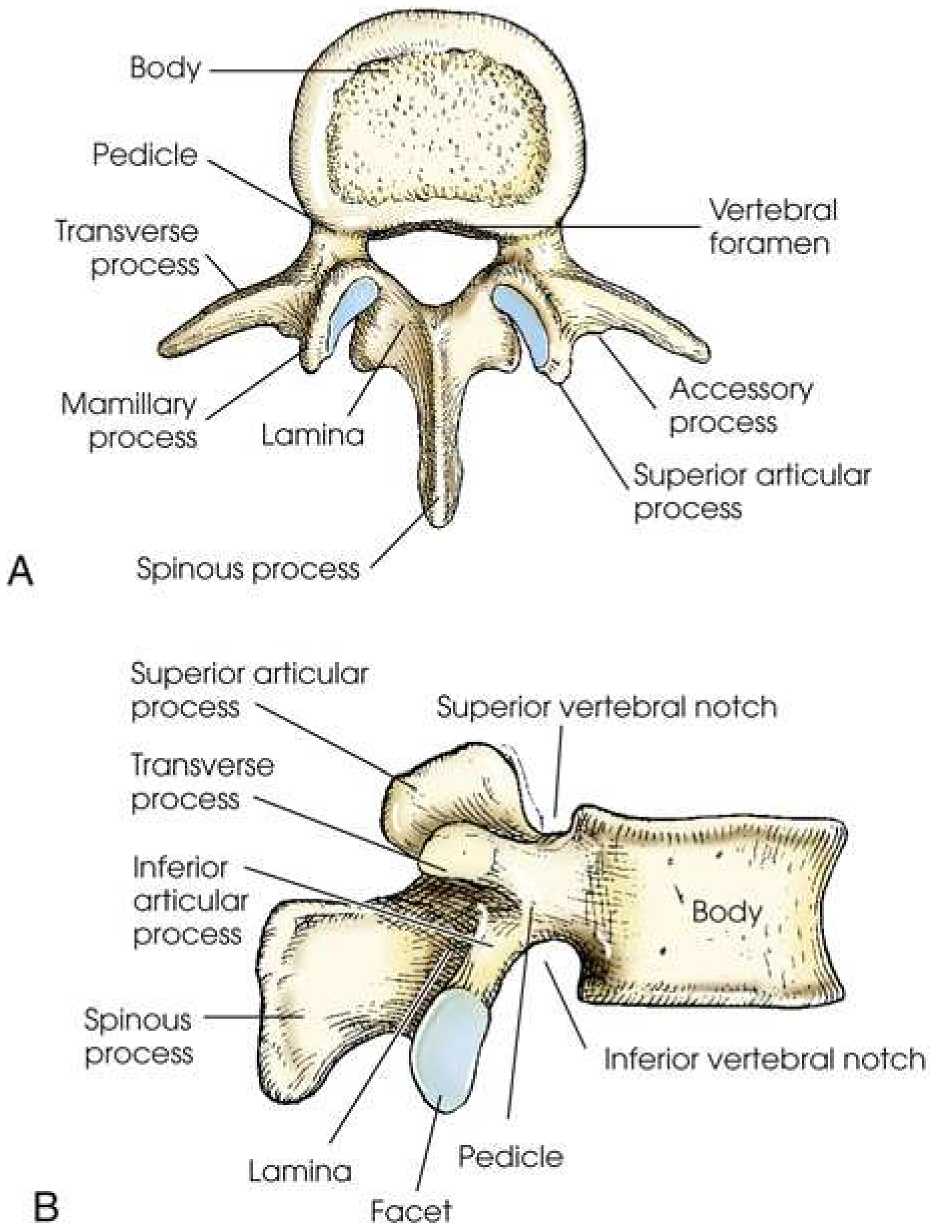


FIG. 9.18 (A) Superior aspect of lumbar vertebra. (B) Lateral aspect of lumbar vertebra.

Diagram (A) shows the Superior aspect of the lumbar vertebra. The parts labeled on the diagram marked clockwise are listed as follows. Spinous process, Lamina, Mamillary process, Transverse process, Pedicle, Body, Superior articular process, Accessory process, and Vertebral foramen. Diagram (B) shows the Lateral aspect of the lumbar vertebra. The parts labeled on the diagram marked clockwise are listed as follows. Superior articular process, Transverse process, Lamina, Spinous process, Inferior articular process, Pedicle, Body, Facet, Superior vertebral notch, and Inferior vertebral notch.

FIG. 9.19 Axial CT image of L5 showing fractures of right and left pars interarticularis *(arrows)*.

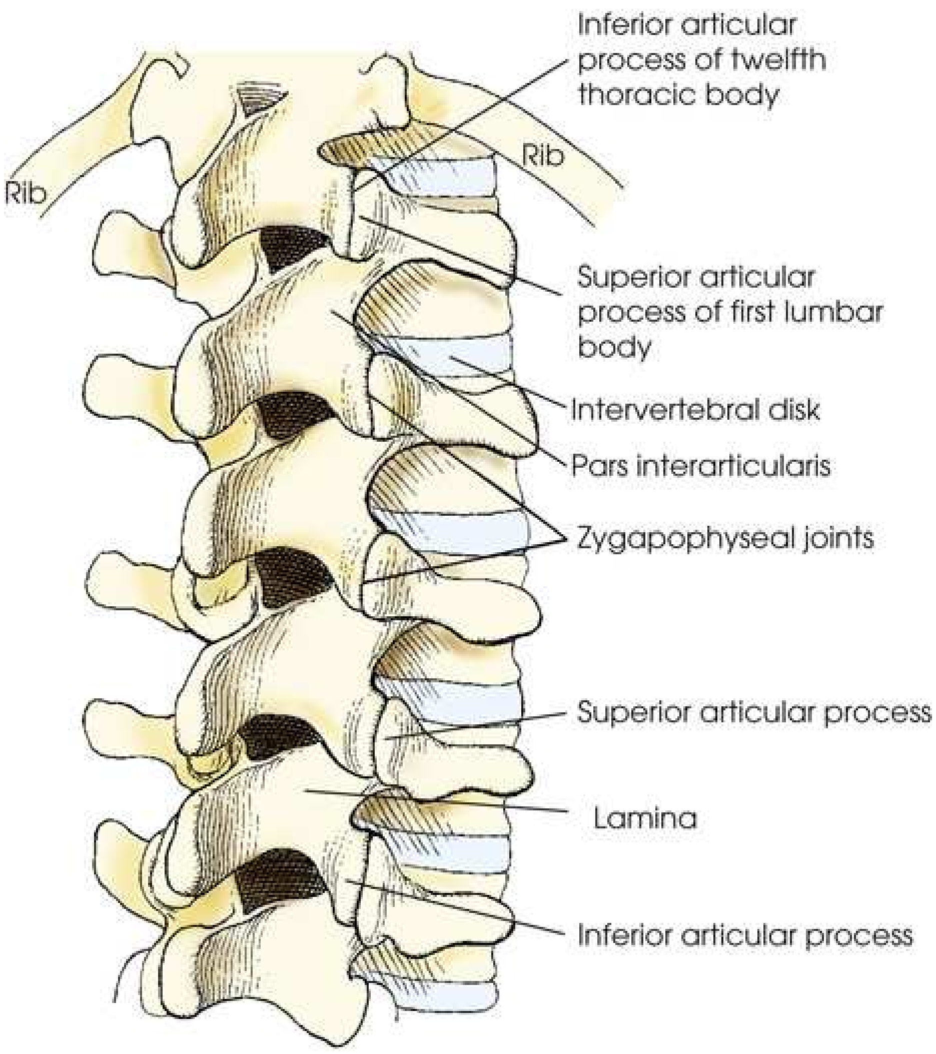


FIG. 9.20 Right posterior oblique view of lumbar vertebrae, showing zygapophyseal joints and pars interarticularis.

Diagram shows the zygapophyseal joints and pars interarticularis of the lumbar vertebrae. The parts labeled on the diagram are marked from top to the bottom as follows: inferior articular process of twelfth thoracic body, rib, superior articular process of first lumbar body, intervertebral disk, pars interarticularis, zygapophyseal joints, superior articular process, Lamina, and inferior articular process.

Spondylolysis is an acquired bony defect occurring in the pars interarticularis—the area of the lamina between the two articular processes. The defect may occur on one or both sides of the vertebra, resulting in a condition termed *spondylolisthesis*. This condition is characterized by the anterior displacement of one vertebra over another, generally the fifth lumbar over the sacrum. Spondylolisthesis almost exclusively involves the lumbar spine (Fig. 9.22).

Spondylolisthesis is of radiologic importance because oblique-position radiographs show the "neck" area of the "Scottie dog" (i.e., the pars interarticularis) (oblique positions involving the lumbar spine, including the Scottie dog, are presented later in this chapter, starting with Fig. 9.95). A full view of the lumbar vertebrae along with surrounding tissues is seen in Fig. 9.23.

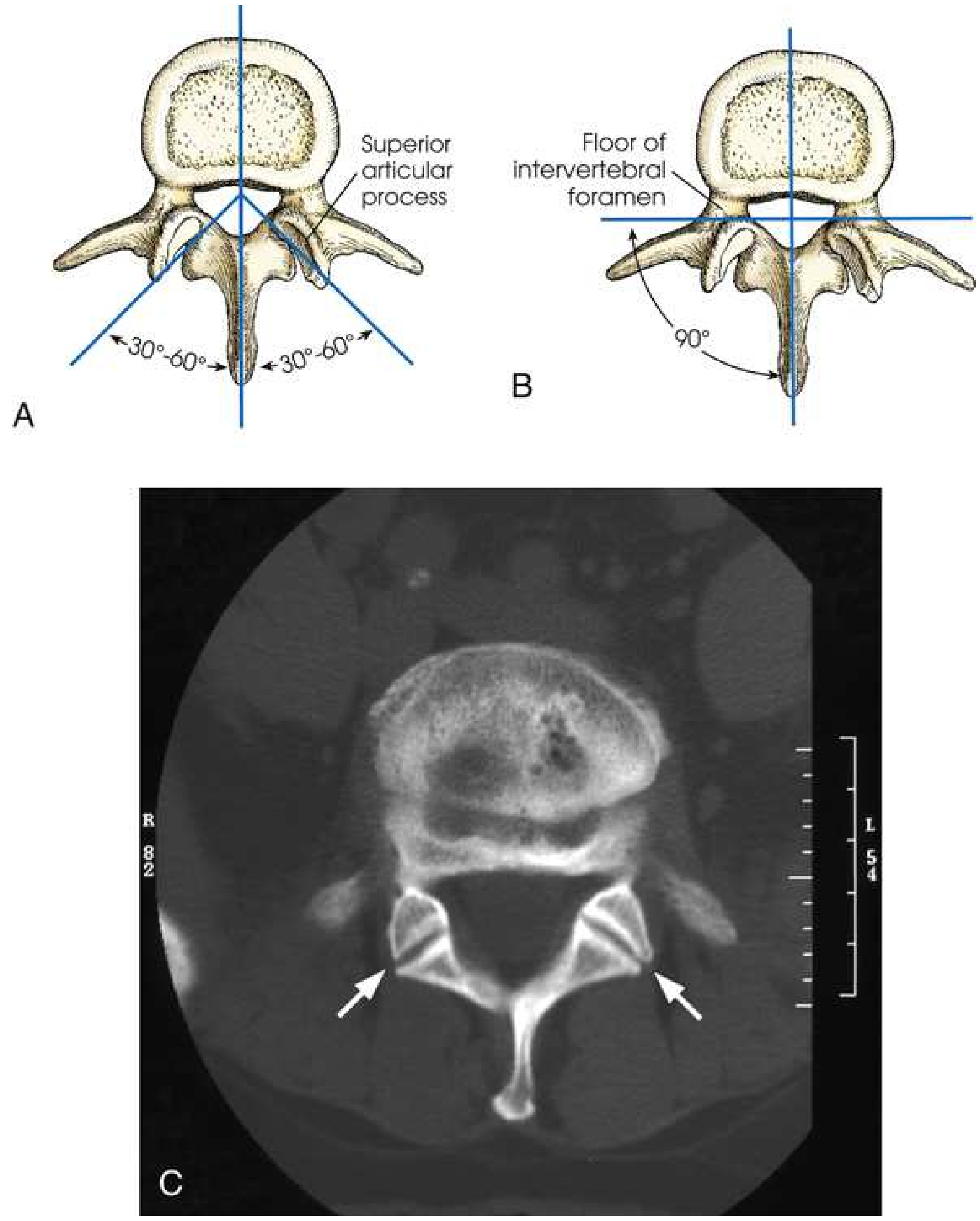


FIG. 9.21 (A) Direction of lumbar zygapophyseal joints. (B) Superior aspect showing orientation of lumbar intervertebral foramina. (C) Axial CT image of lumbar spine showing angles of zygapophyseal joints *(arrows)*.

Diagram (A) shows the direction of lumbar zygapophyseal joints. The zygapophyseal joints of the lumbar region are inclined posteriorly from the coronal plane, forming an average angle (open posteriorly) of 30 to 60 degrees to the M S P of the body. The Superior articular process is labeled on the diagram. Diagram (B) shows the superior aspect showing the orientation of lumbar intervertebral foramina. The intervertebral foramina of the lumbar region are situated at right angles to the M S P of the body, except for the fifth, which turns slightly anteriorly. The floor of the intervertebral foramen is labeled on the diagram. (C) shows the C T image of the lumbar spine with angles of zygapophyseal joints. It is marked by two white arrows.

TABLE 9.3

Joint	Average angle (degrees)	Average range (degrees)	% at 0 degrees[b]	% at 90 degrees[c]
L1–L2	15	0–30	25	0
L2–L3	30	0–30	25	0
L3–L4	45	15–45	10	0
L4–L5	45	45–60	3	2
L5–S1	45	45–60	5	7

[a] In relation to the sagittal plane.

[b] Joint space oriented parallel to sagittal plane.

[c] Joint space perpendicular to sagittal plane.

From Bogduk N, Twomey L. *Clinical anatomy of the lumbar spine*, 3rd ed. London: Churchill Livingstone; 1997.

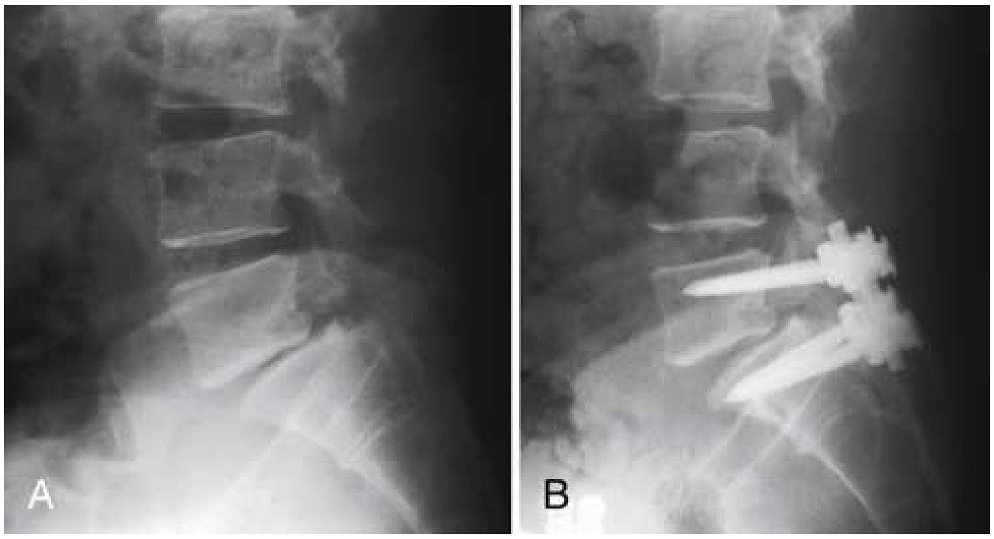


FIG. 9.22 Lateral lumbar spine showing spondylolisthesis. (A) A 53-year-old man presenting with pain in the legs and difficulty standing for longer than 5 minutes without pain. L4 is anteriorly displaced 20% over L5. (B) Surgery performed to stabilize spondylolisthesis. The patient recovered fully from pain.

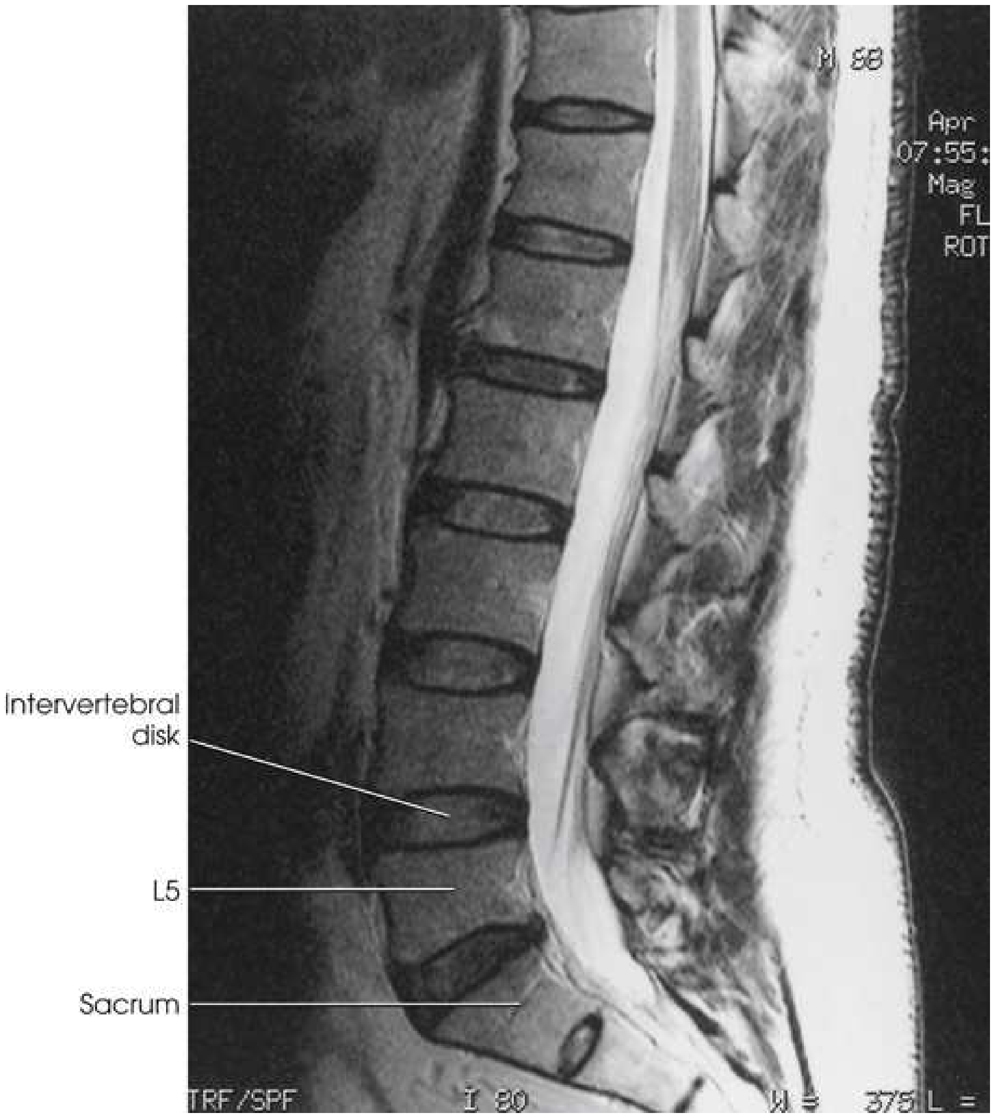


FIG. 9.23 MRI sagittal plane of lumbar spine. Note intervertebral disks between vertebral bodies.

Sacrum

The *sacrum* is formed by fusion of the five sacral vertebral segments into a curved, triangular bone (Figs. 9.24 and 9.25). The sacrum is wedged between the iliac bones of the pelvis, with its broad base directed obliquely, superiorly, and anteriorly, and its apex directed posteriorly and inferiorly. Although the size and degree of curvature of the sacrum vary considerably in different patients, the bone is normally longer, narrower, more evenly curved, and more vertical in position in males than in females. The female sacrum is more acutely curved, with its greatest curvature in the lower half of the bone; it also lies in a more oblique plane, which results in a sharper angle at the junction of the lumbar and pelvic curves.

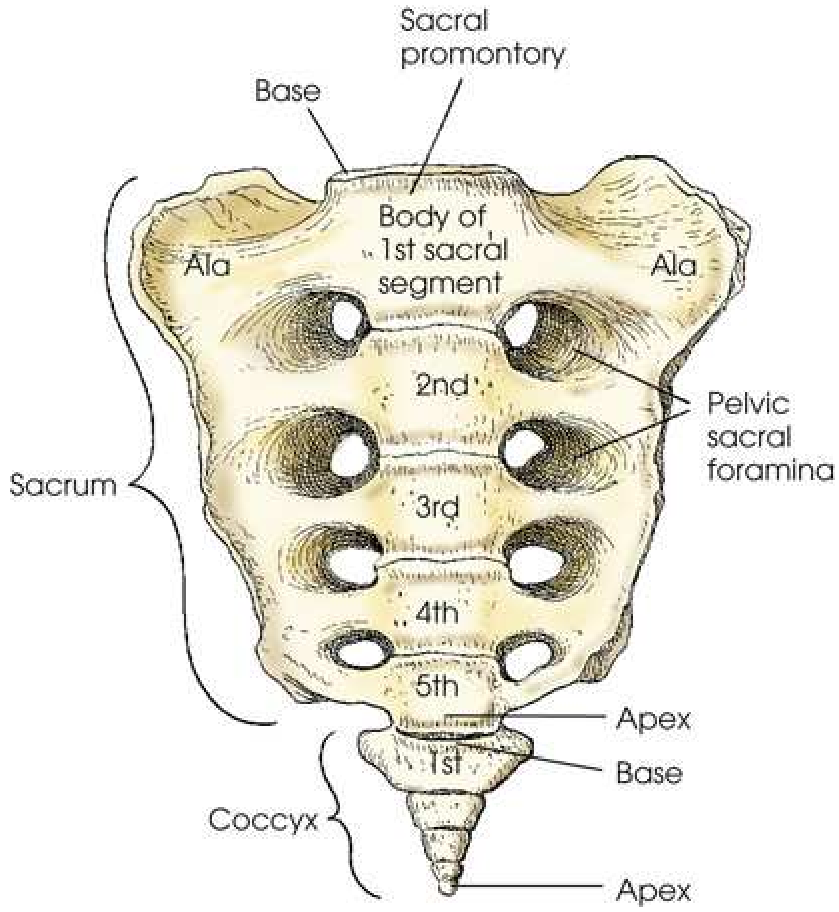


FIG. 9.24 Anterior aspect of sacrum and coccyx.

Diagram shows an anterior aspect of the sacrum and coccyx. The parts labeled on the diagram marked clockwise are as follows: ala, base, sacral promontory, pelvic, sacral foramina, body of first sacral segment, second, third, fourth, fifth, sixth, sacrum, coccyx, apex, and Base. There are four pelvic sacral formina on the left and four on the right.

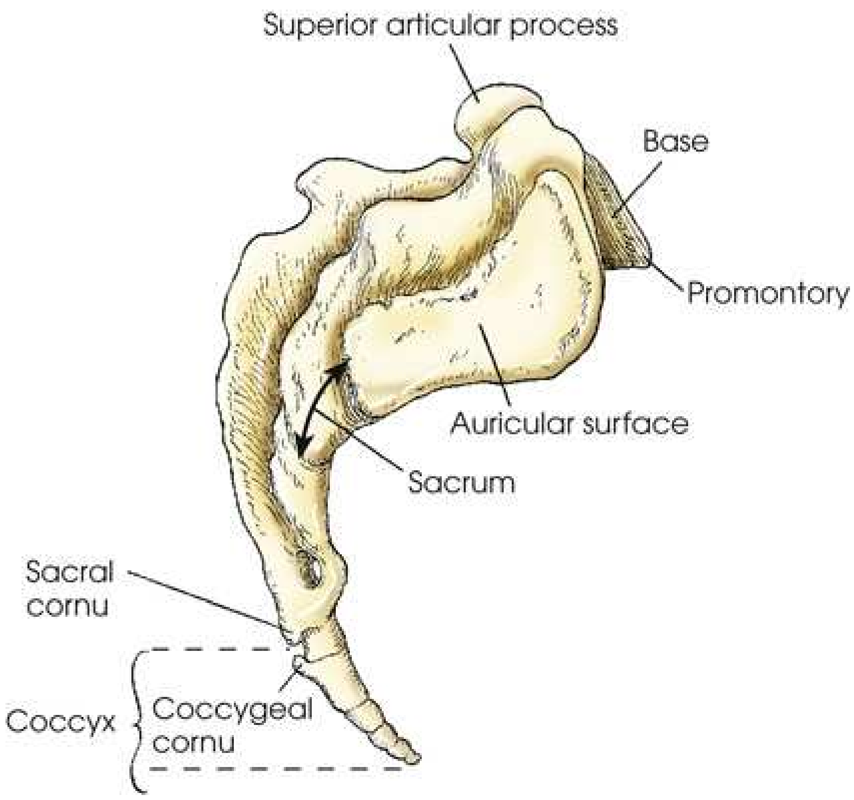


FIG. 9.25 Lateral aspect of sacrum and coccyx.

Diagram shows a curved triangular bone. The parts labeled on the diagram marked clockwise are as follows: sacral cornu, coccyx, coccygeal, corn, superior articular process, base, promontory, auricular surface, and sacrum.

The superior portion of the first sacral segment remains distinct and resembles the vertebrae of the lumbar region (Fig. 9.26). The superior surface of the *base* of the sacrum corresponds in size and shape to the inferior surface of the last lumbar segment, with which it articulates to form the lumbosacral junction. The concavities on the upper surface of the pedicles of the first sacral segment and the corresponding concavities on the lower surface of the pedicles of the last lumbar segment form the last pair of intervertebral foramina. The *superior articular processes* of the first sacral segment articulate with the inferior articular processes of the last lumbar vertebra to form the last pair of zygapophyseal joints.

At its superior anterior margin, the base of the sacrum has a prominent ridge termed the *sacral promontory*. Directly behind the bodies of the sacral segments is the *sacral canal*, which is the continuation of the vertebral canal. The sacral canal is contained within the bone and transmits the sacral nerves (Fig. 9.27). Each of the anterior and posterior walls of the sacral canal is perforated by four pairs of *pelvic sacral foramina* for passage of the sacral nerves and blood vessels.

On each side of the sacral base is a large, winglike lateral mass called the *ala*. At the superoanterior part of the lateral surface of each ala is the *auricular surface*—a large articular process for articulation with similarly shaped processes on the iliac bones of the pelvis.

The inferior surface of the *apex* of the sacrum has an oval facet for articulation with the coccyx and the *sacral cornua*—two processes that project inferiorly from the posterolateral aspect of the last sacral segment to join the *coccygeal cornua*.

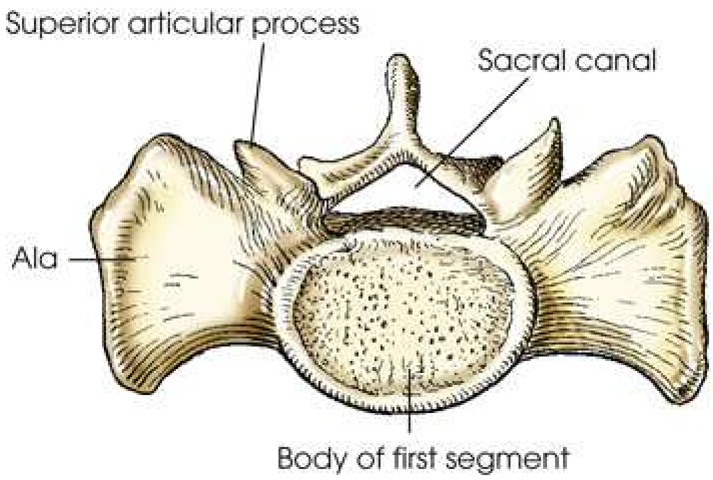


FIG. 9.26 Superior aspect of sacrum.

Diagram shows the superior aspect of the sacrum resembling the vertebrae of the lumbar region. The parts labeled on the diagram marked clockwise are as follows: body of first segment, ala, superior articular process, and sacral canal. The body of the first segment appears grainy.

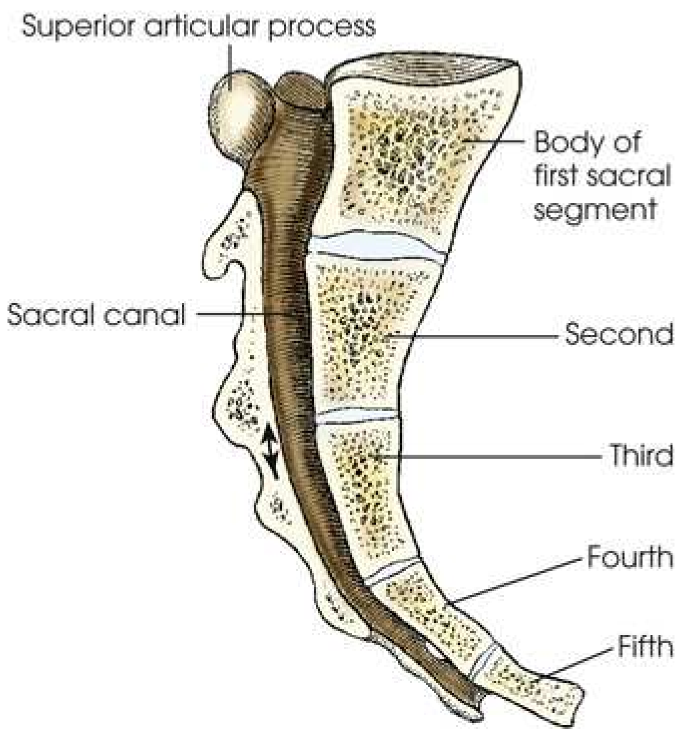


FIG. 9.27 Sagittal section of sacrum.

Diagram shows the sacral canal contained within the bone and transmitting the sacral nerves. The parts labeled on the diagram marked clockwise are as follows: the superior articular process, the sacral canal, the body of the first sacral segment, the second, the third, the fourth, and the fifth. The sacral canal is brown and the body appears grainy. The spinal articular process is a small circular bulge.

Coccyx

The *coccyx* is composed of three to five (usually four) rudimentary *vertebrae* that have a tendency to fuse into one bone in the adult (see Figs. 9.24 and 9.25). The coccyx diminishes in size from its *base* inferiorly to its *apex*. From its articulation with the sacrum, it curves inferiorly and anteriorly, often deviating from the midline of the body. The *coccygeal cornua* project superiorly from the posterolateral aspect of the first coccygeal segment to join the sacral cornua.

Vertebral Articulations

The joints of the vertebral column are shown in Fig. 9.28 and are summarized in Table 9.4. A detailed description follows.

The vertebral articulations consist of two types of joints: (1) *intervertebral* joints, which are between the two vertebral bodies and are *cartilaginous symphysis* joints that permit only slight movement of individual vertebrae but considerable motility for the column as a whole, and (2) *zygapophyseal* joints, which are between the articulation processes of the vertebral arches and are *synovial gliding* joints that permit free movement (see Fig. 9.20). Movements permitted in the vertebral column by the combined action of the joints are flexion, extension, lateral flexion, and rotation.

The articulations between the atlas and the occipital bone are *synovial ellipsoidal* joints and are called the *atlantooccipital articulations* (see Fig. 9.8). The anterior arch of the atlas rotates around the dens of the axis to form the *atlantoaxial* joint, which is a synovial gliding articulation and a *synovial pivot* articulation (see Table 9.4).

In the thoracic region, the heads of the ribs articulate with the bodies of the vertebrae to form the *costovertebral* joints, which are synovial gliding articulations. The tubercles of the ribs and the transverse processes of the thoracic vertebrae articulate to form *costotransverse* joints, which are also synovial gliding articulations (see Fig. 9.15).

The articulations between the sacrum and the two ilia—the sacroiliac joints—are discussed in Chapter 8.

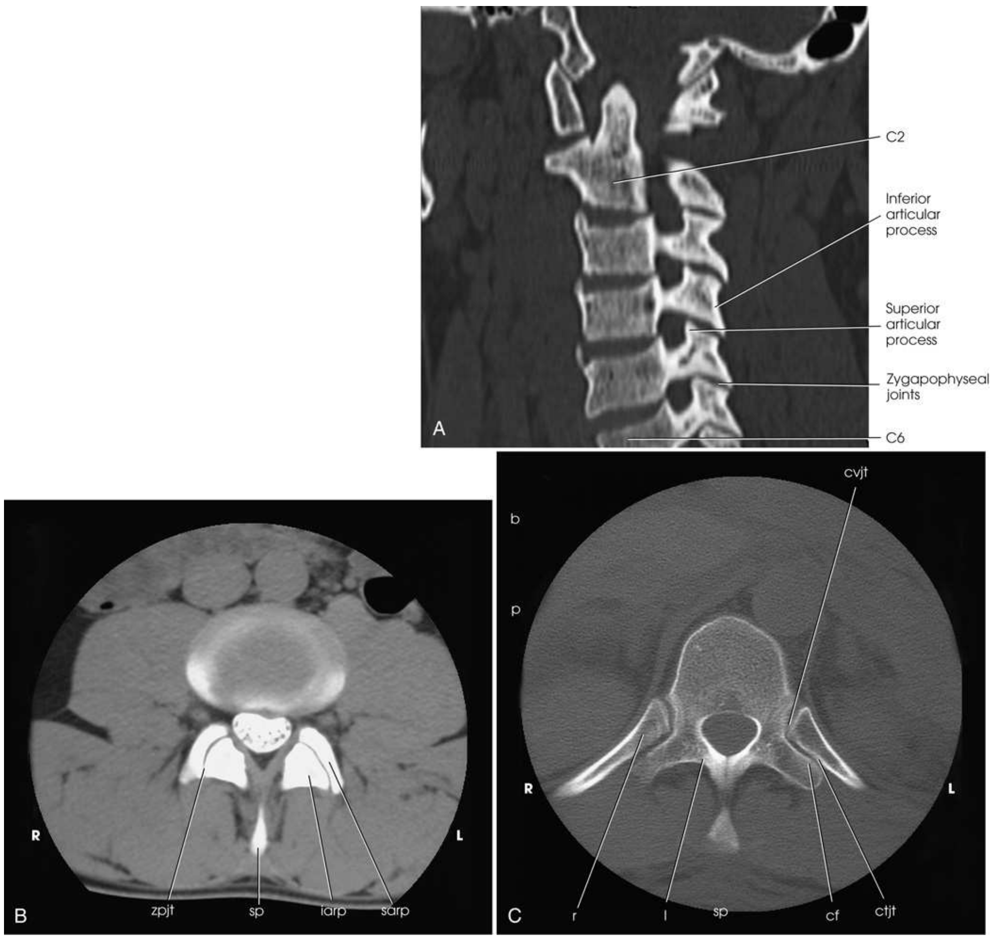


FIG. 9.28 Vertebral articulations. (A) CT reformat of cervical spine showing zygapophyseal joints. (B) CT scan of lumbar spine showing zygapophyseal joints. *iarp*, Inferior articulating process; *sarp*, superior articulating process; *zpjt*, zygapophyseal joint. (C) CT scan of thoracic vertebra. *cf*, Costal facet; *ctjt*, costotransverse joint; *cvjt*, costovertebral joint; *l*, lamina; *r*, rib.

(A) A C T shows joints of the vertebral column. The parts labeled are marked from top to the bottom as follows: C 2, inferior articular process, superior articular process, zygapophyseal joints, and C 6. (B) shows the C T scan of the lumbar spine with zygapophyseal joints. i a r p, inferior articulating process, s a r p, superior articulating process, z p j t, zygapophyseal joint. They appear white. (C) shows the C T scan of the thoracic vertebra. The parts labeled are as follows: costal facet, costotransverse joint, costovertebral joint, lamina, rib. The outlines appear white.

Summary of Anatomy

Vertebral column (spine)

- Vertebrae (24)
  - Cervical (7)
  - Thoracic (12)
  - Lumbar (5)
  - Sacral
  - Coccygeal
- True vertebrae
- False vertebrae
- Sacrum
- Coccyx

Vertebral curvature

- Curves
- Cervical
- Thoracic
- Lumbar
- Pelvic
- Lordotic curve
- Kyphotic curve
- Lumbosacral angle
- Primary curves
- Secondary or compensatory curves

Typical vertebra

- Body
- Vertebral arch
- Vertebral foramen
- Vertebral canal
- Articular cartilage plate
- Intervertebral disks
- Nucleus pulposus
- Annulus fibrosus
- Pedicles
- Vertebral notches
- Intervertebral foramina
- Laminae
- Transverse processes
- Spinous process
- Facets
- Superior articular processes
- Inferior articular processes

Cervical vertebrae

- Atlas (first)
  - Anterior arch
  - Posterior arch
  - Lateral masses
  - Transverse atlantal ligament
- Axis (second)
  - Dens (odontoid process)
- Cervical (seventh)
  - Vertebra prominens
- Typical cervical vertebra
  - Transverse foramina
  - Articular pillars

Thoracic vertebrae

- Costal facets
- Demifacets

Lumbar vertebrae

- Mammillary process
- Accessory process
- Pars interarticularis

Sacrum

- Base
- Superior articular processes
- Sacral promontory
- Sacral canal
- Pelvic sacral foramina
- Ala
- Auricular surface
- Apex
- Sacral cornua

Coccyx

- Base
- Apex
- Coccygeal cornua

Vertebral articulations

- Atlantooccipital
- Atlantoaxial
  - Lateral (2)
  - Medial (1—dens)
- Costovertebral
- Costotransverse
- Intervertebral
- Zygapophyseal (facet)

Abbreviations Used In Chapter 9

EAM	External acoustic meatus
HNP	Herniated nucleus pulposus
IOML	Infraorbitomeatal line
MSP	Midsagittal plane

See Addendum A for a summary of all abbreviations used in Volume 1.

TABLE 9.4

	Structural classification		
Joint	**Tissue**	**Type**	**Movement**
Atlantooccipital	Synovial	Ellipsoidal	Freely movable
Atlantoaxial			
Lateral (2)	Synovial	Gliding	Freely movable
Medial (1—dens)	Synovial	Pivot	Freely movable
Intervertebral	Cartilaginous	Symphysis	Slightly movable
Zygapophyseal	Synovial	Gliding	Freely movable
Costovertebral	Synovial	Gliding	Freely movable
Costotransverse	Synovial	Gliding	Freely movable

Summary of Pathology

Condition	Definition
Ankylosing spondylitis	Rheumatoid arthritis variant involving the sacroiliac joints and spine
Fracture	Disruption in the continuity of bone
Clay shoveler's	Avulsion fracture of the spinous process in the lower cervical and upper thoracic region
Compression	Fracture that causes compaction of bone and a decrease in length or width
Hangman's	Fracture of the anterior arch of C2 owing to hyperextension
Jefferson	Comminuted fracture of the ring of C1
Herniated nucleus pulposus	Rupture or prolapse of the nucleus pulposus into the spinal canal
Kyphosis	Abnormally increased anterior concavity (posterior convexity) in the thoracic curvature
Lordosis	Abnormally increased anterior convexity (posterior concavity) of the cervical and lumbar spine
Metastasis	Transfer of a cancerous lesion from one area to another
Osteoarthritis or degenerative joint disease and vertebrae	Form of arthritis marked by progressive cartilage deterioration in synovial joints
Osteopetrosis	Increased density of atypically soft bone
Osteoporosis	Loss of bone density
Paget disease	Thick, soft bone marked by bowing and fractures
Scheuermann disease or adolescent kyphosis	Kyphosis with onset in adolescence
Scoliosis	Lateral deviation of the spine with possible vertebral rotation
Spina bifida	Failure of the posterior encasement of the spinal cord to close
Spondylolisthesis	Forward displacement of a vertebra over a lower vertebra, usually L5–S1
Spondylolysis	Breaking down of the vertebra
Subluxation	Incomplete or partial dislocation
Tumor	New tissue growth where cell proliferation is uncontrolled
Multiple myeloma	Malignant neoplasm of plasma cells involving the bone marrow and causing destruction of bone

Eponymous (named) pathologies are listed in nonpossessive form to conform to the *AMA manual of style: a guide to authors and editors*, ed 10, Oxford, 2009, Oxford University Press.

Sample Exposure Technique Chart Essential Projections

These techniques were accurate for the equipment used to produce each exposure. However, use caution when applying them in your department because "there is considerable variability in image receptor response owing to varying scatter sensitivity, the use of grids with different grid ratios, collimation, beam filtration, the choice of kilovoltage, source-to-image distance, and image receptor size." [a]

This chart was created in collaboration with Dennis Bowman, AS, RT(R), Clinical Instructor, Community Hospital of the Monterey Peninsula, Monterey, CA. http://digitalradiographysolutions.com/.

Vertebral Column								
Part	cm	kVp[b]	SID[c]	Collimation	CR[d]		DR[e]	
					mAs	Dose (mGy)[f]	mAs	Dose (mGy)[f]
Atlas and axis—*AP*[g]	11	85	40″	6″ × 4″ (15 × 10 cm)	8[h]	0.776	3.6[h]	0.346
Dens—*AP (Fuchs)*[g]	14	85	40″	5″ × 5″ (13 × 13 cm)	12.5[h]	1.380	7.1[h]	0.782
Cervical vertebrae—*AP axial*[g]	11	85	40″	5″ × 10″ (13 × 25 cm)	6.3[h]	0.697	3.2[h]	0.351
Cervical vertebrae—*lateral (Grandy)*[g]	11	85	72″	7″ × 10″ (18 × 25 cm)	16[h]	1.848	8[h]	0.921
Cervical vertebrae—*hyperflexion and hyperextension*[g]	11	85	72″	8″ × 10″ (20 × 25 cm)	18[h]	2.092	7.1[h]	0.821
Cervical intervertebral foramina—*AP and PA axial oblique*[g]	11	85	72″	6″ × 10″ (15 × 25 cm)	22[h]	2.530	10[h]	1.144
Cervicothoracic region—*lateral (swimmer's)*[g]	24	96	40″	7″ × 12″ (18 × 30 cm)	65[i]	14.23	28[i]	6.110
Thoracic vertebrae—*AP*[g]	21	90	40″	5″ × 17″ (13 × 43 cm)	20[i]	3.270	8[i]	1.296
Thoracic vertebrae—*lateral*[g]	33	90	40″	8″ × 17″ (20 × 43 cm)	50[i]	12.87	25[i]	6.410
Lumbar vertebrae—*AP*[g]	21	90	40″	9″ × 14″ (23 × 35 cm)	20[i]	3.650	10[i]	1.826
Lumbar vertebrae—*lateral*[g]	27	96	40″	8″ × 14″ (20 × 35 cm)	56[i]	13.66	28[i]	6.790
Lumbar L5–S1—*lateral*[g]	31	96	40″	5″ × 5″ (13 × 13 cm)	100[i]	18.01	45[i]	8.060
Zygapophyseal joints—*AP oblique*[g]	23	90	40″	8″ × 14″ (20 × 35 cm)	36[i]	7.010	18[i]	3.480
Lumbosacral junction and sacroiliac joints—*AP axial*[g]	17	90	40″	10″ × 8″ (25 × 20 cm)	28[i]	4.560	14[i]	2.270
Sacroiliac joints—*AP oblique*[g]	17	90	40″	10″ × 7″ (25 × 18 cm)	36[i]	5.820	16[i]	2.580
Sacrum—*AP axial*[g]	17	90	40″	8″ × 7″ (20 × 18 cm)	28[i]	4.480	14[i]	2.233
Sacrum—*lateral*[g]	31	96	40″	8″ × 5″ (20 × 13 cm)	100[i]	19.95	45[i]	10.07
Coccyx—*AP axial*[g]	17	85	40″	4″ × 5″ (10 × 13 cm)	32[i]	3.480	14[i]	1.519
Coccyx—*lateral*[g]	31	85	40″	4″ × 5″ (10 × 13 cm)	90[i]	10.98	40[i]	4.580
Thoracolumbar spine-scoliosis—*PA (Frank and Ferguson)*[g]	23	90	40″	8″ × 17″ (20 × 43 cm)	28[i]	5.530	12.5[i]	2.460

[a] ACR-AAPM-SIMM Practice Parameter for Digital Radiography, revised 2017.

[b] kVp values are for a high-frequency generator.

[c] 40 inches minimum; 44 to 48 inches recommended to improve spatial resolution (mAs increase needed, but no increase in patient dose will result).

[d] AGFA CR MD 4.0 General IP, CR 75.0 reader, 400 speed class, with 6:1 (178LPI) grid when needed.

[e] GE Definium 8000, with 13:1 grid when needed.

[f] All doses are skin entrance for average adult (160- to 200-pound male, 150- to 190-pound female) at part thickness indicated.

[g] Bucky/Grid.

[h] Small focal spot.

[i] Large focal spot.

Radiography

Summary of Oblique Projections

Projection	Position—degrees	Structures shown	CR (degrees)
Cervical obliques			
AP obliques	LPO—45	R: IFs (side up)	15–20
	RPO—45	L: IFs (side up)	15–20
PA obliques	LAO—45	L: IFs (side down)	15–20
	RAO—45	R: IFs (side down)	15–20
Thoracic obliques			
AP obliques	LPO—70	R: Z joints (joints up)	0
	RPO—70	L: Z joints (joints up)	0
PA obliques	LAO—70	L: Z joints (joints down)	0
	RAO—70	R: Z joints (joints down)	0
Lumbar obliques			
AP obliques	LPO—45	L: Z joints (joints down)	0
	RPO—45	R: Z joints (joints down)	0
PA obliques	LAO—45	R: Z joints (joints up)	0
	RAO—45	L: Z joints (joints up)	0
Sacroiliac obliques			
AP obliques	LPO—25–30	R: SI joint (joint up)	0
	RPO—25–30	L: SI joint (joint up)	0
PA obliques	LAO—25–30	L: SI joint (joint down)	0
	RAO—25–30	R: SI joint (joint down)	0

Atlas and Axis

Ap Projection

Fuchs Method

Fuchs [1] recommended the AP projection to show the dens when its upper half is not clearly shown in the open-mouth position. This patient position must not be attempted if fracture or degenerative disease of the upper cervical region is suspected.

Image receptor + grid: Positioned by manufacturer or department protocol for proper anatomy display orientation; CR plate: 10 × 12 inches (24 × 30 cm) crosswise.

Position of patient

- Place the patient in the supine position.
- Center the MSP of the body to the midline of the grid.
- Place the arms along the sides of the body.
- Place a support under the patient's knees for comfort.

Position of part

- Place the IR in the Bucky tray, then center the IR to the level of the tips of the mastoid processes.
- Extend the chin until the tip of the chin and the tips of the mastoid process are vertical (Fig. 9.29).
- Adjust the head so that the MSP is perpendicular to the plane of the grid.
- *Shield gonads.*
- *Respiration:* Suspend.

Central ray

- Perpendicular to the midpoint of the IR; enters the neck on the MSP just distal to the tip of the chin

Collimation

- Adjust radiation field to 5 × 5 inches (13 × 13 cm) on the collimator. Place the side marker in the collimated exposure field.

Structures shown

An AP projection of the dens lying within the circular foramen magnum (Fig. 9.30).

Evaluation Criteria

The following should be clearly seen:

- Evidence of proper collimation and presence of the side marker placed clear of anatomy of interest
- Entire dens within the foramen magnum
- No rotation of the head or neck, demonstrated by symmetry of the mandible, cranium, and vertebrae
- Bony trabecular detail and surrounding soft tissues

PA Projection

Judd Method

Because of the difficulty in positioning the patient, especially a patient who has a potential fracture, this projection is no longer described in full. In addition, computed tomography (CT) is now used to evaluate the upper cervical area. This method is described in the tenth and previous editions.

FIG. 9.29 AP dens: Fuchs method.

The patient is lying in a supine position. The chin is extended until the tip of the chin and the tips of the mastoid process are vertical. The side marker is in the collimated exposure field. The central ray enters the neck on the M S P just distal to the tip of the chin.

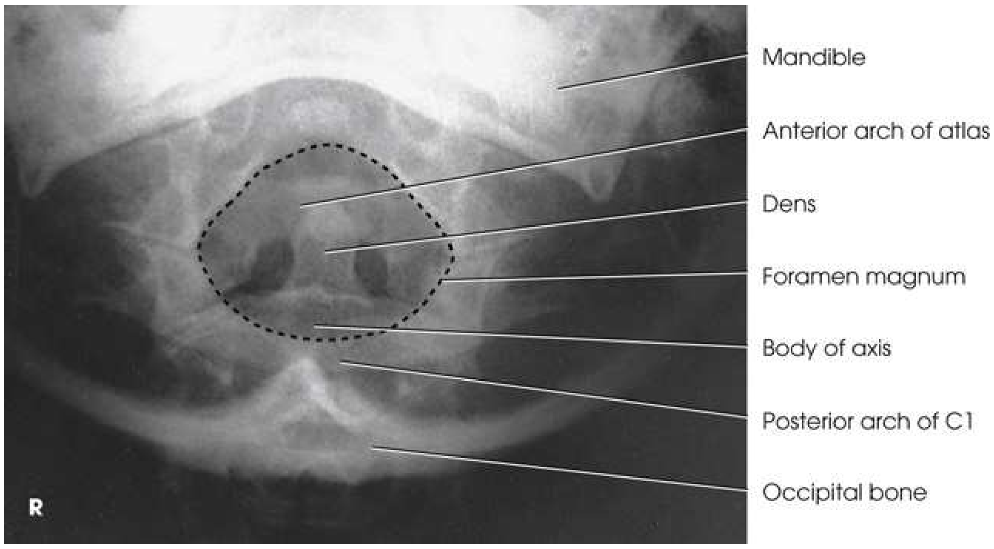


FIG. 9.30 AP dens: Fuchs method.

An x-ray shows the dens lying within the circular foramen magnum. The parts labeled are as follows: mandible, posterior arch of C 1, anterior arch of atlas, dens, foramen magnum, body of axis, and occipital bone. The dens in the foramen magnum appear dark and the outline is marked by a dashed line.

Ap Projection

Open-mouth

The open-mouth technique was described by Albers-Schönberg [2] in 1910 and by George [3] in 1919.

Image receptor + grid: Positioned by manufacturer or department protocol for proper anatomy display orientation; CR plate: 10 × 12 inches (24 × 30 cm).

SID:

A 30-inch (76-cm) SID may be used for this projection to increase the field of view of the odontoid area. See Chapter 1 for use of a 30-inch (76-cm) SID.

Position of patient

- Place the patient in the supine position.
- Center the MSP of the body to the midline of the grid.
- Place the patient's arms along the sides of the body and adjust the shoulders to lie in the same horizontal plane.
- Place a support under the patient's knees for comfort.

Position of part

- Place the IR in the Bucky tray, and center the IR at the level of the axis.
- Adjust the patient's head so that the MSP is perpendicular to the plane of the table (Figs. 9.31 and 9.32).
- Select the exposure factors and move the x-ray tube into position so that any minor change can be made quickly after the final adjustment of the patient's head. Although this position is not easy to hold, the patient is usually able to cooperate fully unless he or she is kept in the final, strained position too long.
- Have the patient open the mouth as wide as possible, and then adjust the head so that a line from the lower edge of the upper incisors to the tip of the mastoid process (occlusal plane) is perpendicular to the IR. A small support under the back of the head may be needed to facilitate opening of the mouth while proper alignment of the upper incisors and mastoid tips is maintained.
- *Shield gonads.*
- *Respiration:* Instruct the patient to keep the mouth wide open and to phonate "ah" softly during the exposure to place the tongue in the floor of the mouth so that it is not projected on the atlas and axis and prevent movement of the mandible.

Central ray

- Perpendicular to the center of the IR and entering the midpoint of the open mouth

Collimation

- Adjust radiation field to 5 × 5 inches (13 × 13 cm) on the collimator. Place the side marker in the collimated exposure field.

FIG. 9.31 AP atlas and axis.

A patient is lying in a supine position. The mouth of the patient is wide open. The side marker is in the collimated exposure field. The central ray is perpendicular to the center of the I R and entering the midpoint of the open mouth.

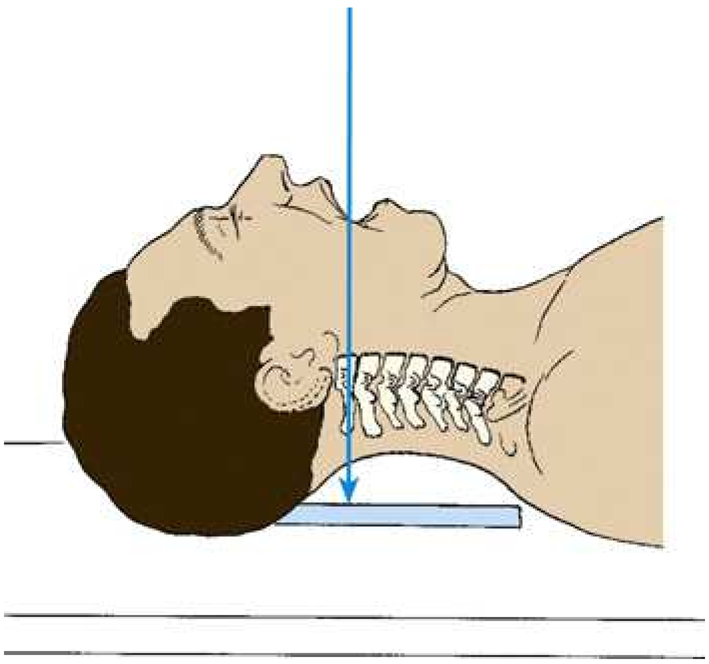


FIG. 9.32 Open-mouth spine alignment.

Diagram shows a patient lying in a supine position. The mouth of the patient is wide open. The side marker is in the collimated exposure field. The central ray is perpendicular to the center of the I R and entering the midpoint of the open mouth.

Structures shown

An AP projection of the atlas and axis through the open mouth (Figs. 9.33 and 9.34). If the patient has a deep head or a long mandible, the entire atlas will not be shown. When the exactly superimposed shadows of the occlusal surface of the upper central incisors and the base of the skull are in line with those of the tips of the mastoid processes, the position cannot be improved. If the patient cannot open the mouth, tomography may be required (Fig. 9.35).

Evaluation Criteria

The following should be clearly seen:

- Evidence of proper collimation and presence of the side marker placed clear of anatomy of interest
- The dens, atlas, axis, and articulations between the first and second cervical vertebrae
- Entire articular surfaces of the atlas and axis (to check for lateral displacement)
- Mouth open wide
- Superimposed occlusal plane of the upper central incisors and the base of the skull, demonstrating proper neck flexion
  - If the upper incisors are projected over the dens, the neck is flexed too much toward the chest.
  - If the base of the skull is projected over the dens, the neck is extended too much.
- Shadow of the tongue not projected over the atlas and axis
- Mandibular rami equidistant from the dens, demonstrating proper head rotation
- Bony trabecular detail and surrounding soft tissues

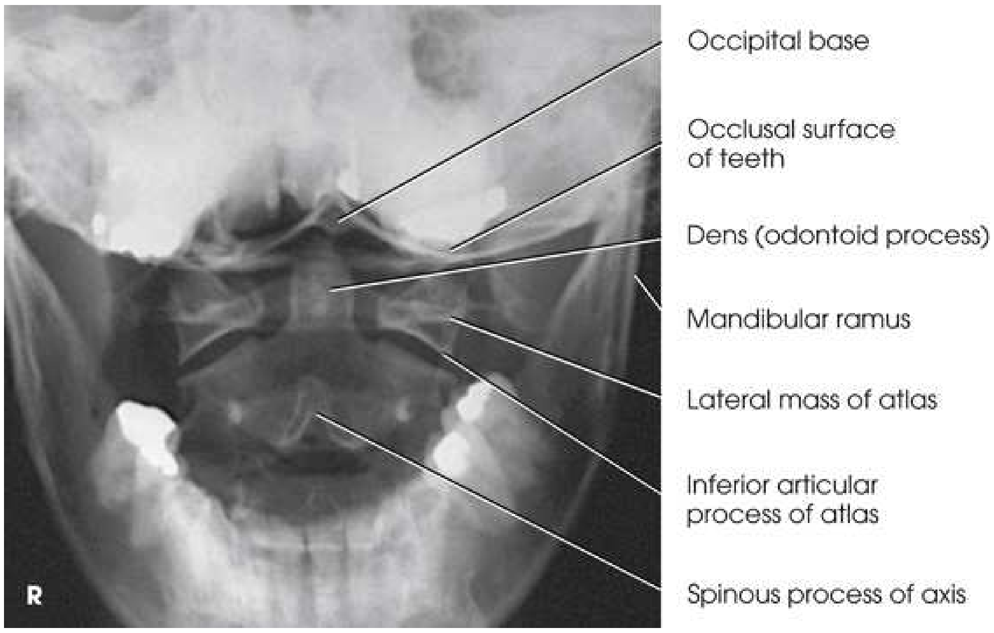


FIG. 9.33 Open-mouth atlas and axis.

An x-ray shows the atlas and axis through the open mouth. The upper region appears hazy. The parts labeled are marked from top to the bottom as follows: occipital base, occlusal surface of teeth, dens (odontoid process), mandibular ramus, lateral mass of atlas, inferior articular, process of atlas, and Spinous process of axis.

FIG. 9.34 Open-mouth atlas and axis, showing fracture of left lateral mass of axis *(arrow)*, performed at a 30-inch SID.

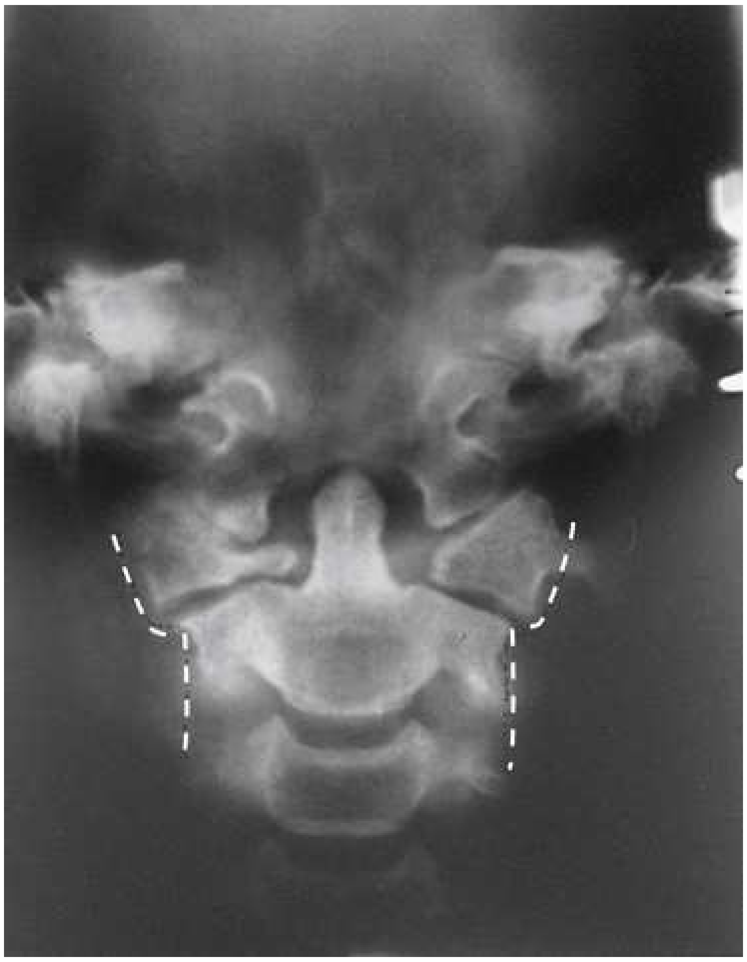


FIG. 9.35 AP upper cervical vertebrae tomogram of a patient who fell and landed on his head. A bursting-type Jefferson fracture caused outward displacement of both lateral masses of atlas. A tomogram is often necessary to show upper cervical area in trauma patients who cannot move their heads or open their mouths.

Lateral Projection

Right or left position

Image receptor + grid: Positioned by manufacturer or department protocol for proper anatomy display orientation; CR plate: 10 × 12 inches (24 × 30 cm).

Position of patient

- Place the patient in the supine position.
- Place the arms along the sides of the body and adjust the shoulders to lie in the same horizontal plane.
- Place a sponge or pad under the patient's head unless traumatic injury has been sustained, in which case the neck should not be moved.

Position of part

- With the IR in the vertical position and in contact with the upper neck, center it at the level of the atlantoaxial articulation (1 inch [2.5 cm] distal to the tip of the mastoid process).
- Adjust the IR so that it is parallel with the MSP of the neck, and then support the IR in position (Figs. 9.36 and 9.37).
- Extend the neck slightly so that the shadow of the mandibular rami does not overlap that of the spine.
- Adjust the head so that the MSP is perpendicular to the table.
- *Shield gonads.*
- *Respiration:* Suspend.

Central ray

- Perpendicular to a point 1 inch (2.5 cm) distal to the adjacent mastoid tip

Collimation

- Adjust radiation field to 5 × 5 inches (13 × 13 cm) on the collimator. Place the side marker in the collimated exposure field.

Structures shown

A lateral projection of the atlas and axis. The atlantooccipital articulations are also shown (Fig. 9.38).

Evaluation Criteria

The following should be clearly seen:

- Evidence of proper collimation and presence of the side marker placed clear of anatomy of interest
- Upper cervical vertebrae
- MSP of head and neck parallel to plane of IR, without tilt or rotation
    - Superimposed laminae of the axis and superimposed posterior arches of the atlas
    - Nearly superimposed rami of the mandible
- Neck extended so that the mandibular rami does not overlap the axis or atlas
- Bony trabecular detail and surrounding soft tissues

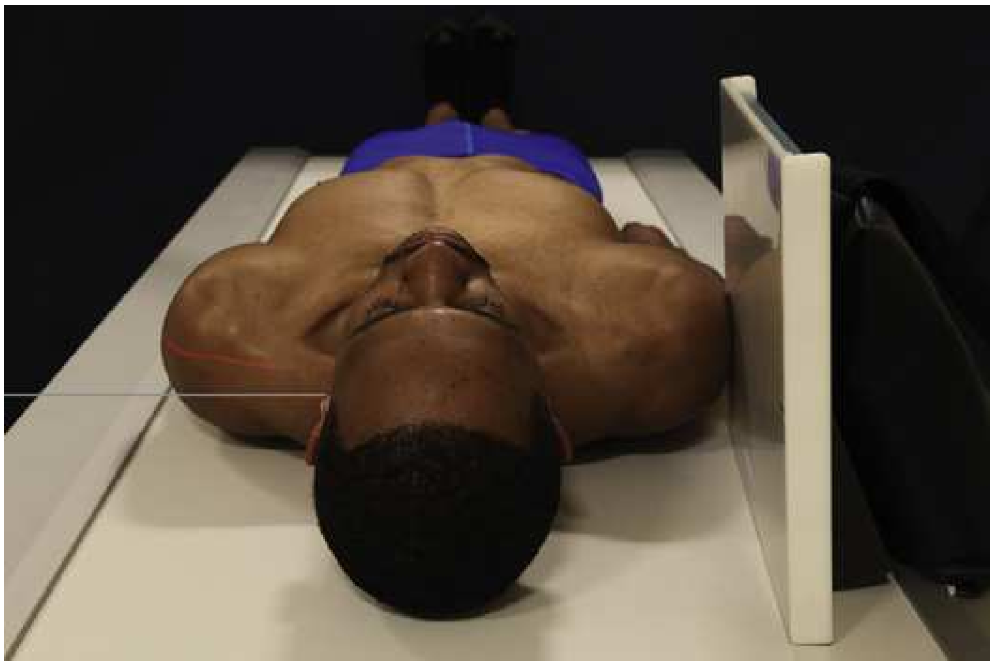


FIG. 9.36 Position for lateral atlas and axis.

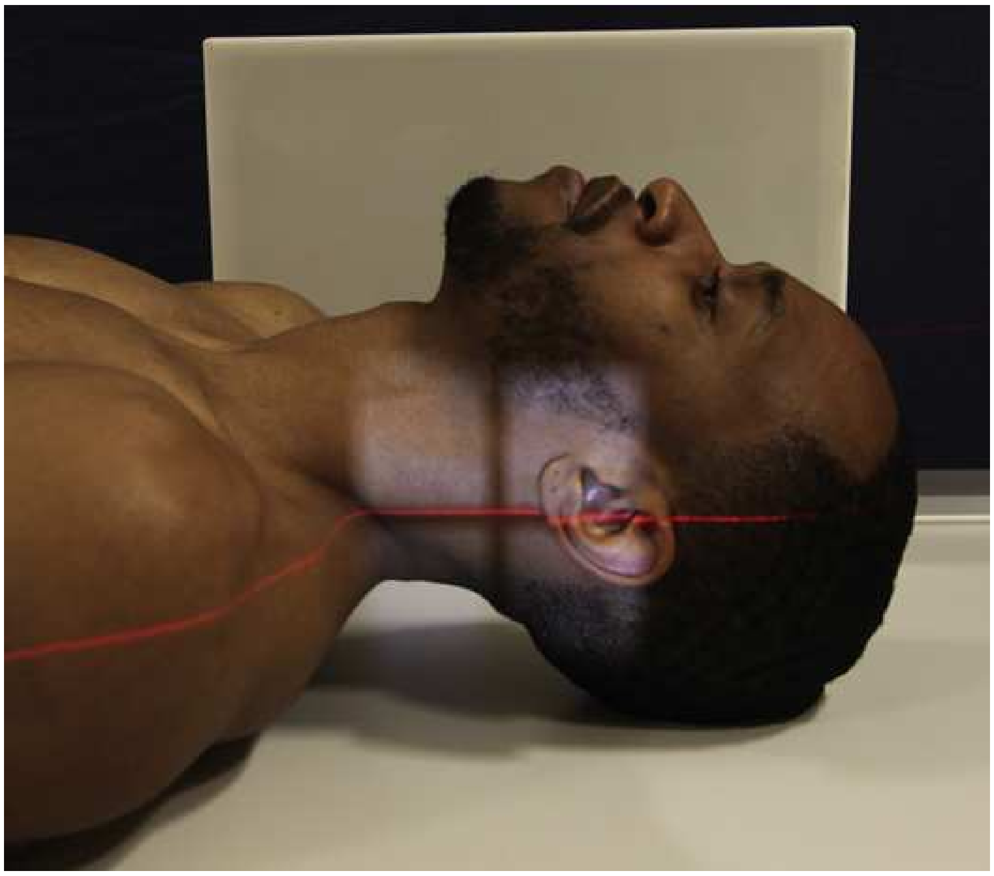


FIG. 9.37 Side view as seen for centering CR.

The side view of a patient lying in a supine position. The arms are placed along the sides of the body and the shoulders lie in the same horizontal plane. A horizontal red beam passes along the horizontal plane of the body.

FIG. 9.38 Lateral atlas and axis.

An x-ray shows the atlas, axis and atlantooccipital articulations. The parts labeled are marked from top to the bottom as follows: atlantooccipital articulation, posterior arch atlas, body of axis, and C 2 to C 3 zygapophyseal joint. The C 2 to C 3 zygapophyseal joint appears dark.

Cervical Vertebrae

Ap Axial Projection

Image receptor + grid: Positioned by manufacturer or department protocol for proper anatomy display orientation; CR plate: 10 × 12 inches (24 × 30 cm) lengthwise.

Position of patient

• Place the patient in the supine or upright position with the back against the IR holder.
• Adjust the patient's shoulders to lie in the same horizontal plane to prevent rotation.

Position of part

• Center the MSP of the patient's body to the midline of the table or vertical grid device.
• Extend the chin enough so that the occlusal plane is perpendicular to the tabletop. This prevents superimposition of the mandible and midcervical vertebrae (Figs. 9.39 and 9.40).
• Center the IR at the level of C4.
• Adjust the head so that the MSP is in straight alignment and perpendicular to the IR.
• Provide support for the head of any patient who has a pronounced lordotic curvature. This support helps compensate for the curvature and reduces image distortion.
• *Shield gonads.*
• *Respiration:* Suspend.

Central ray

• Directed through C4 at an angle of 15 to 20 degrees cephalad. The central ray enters at or slightly inferior to the most prominent point of the thyroid cartilage, commonly called the "Adam's apple."

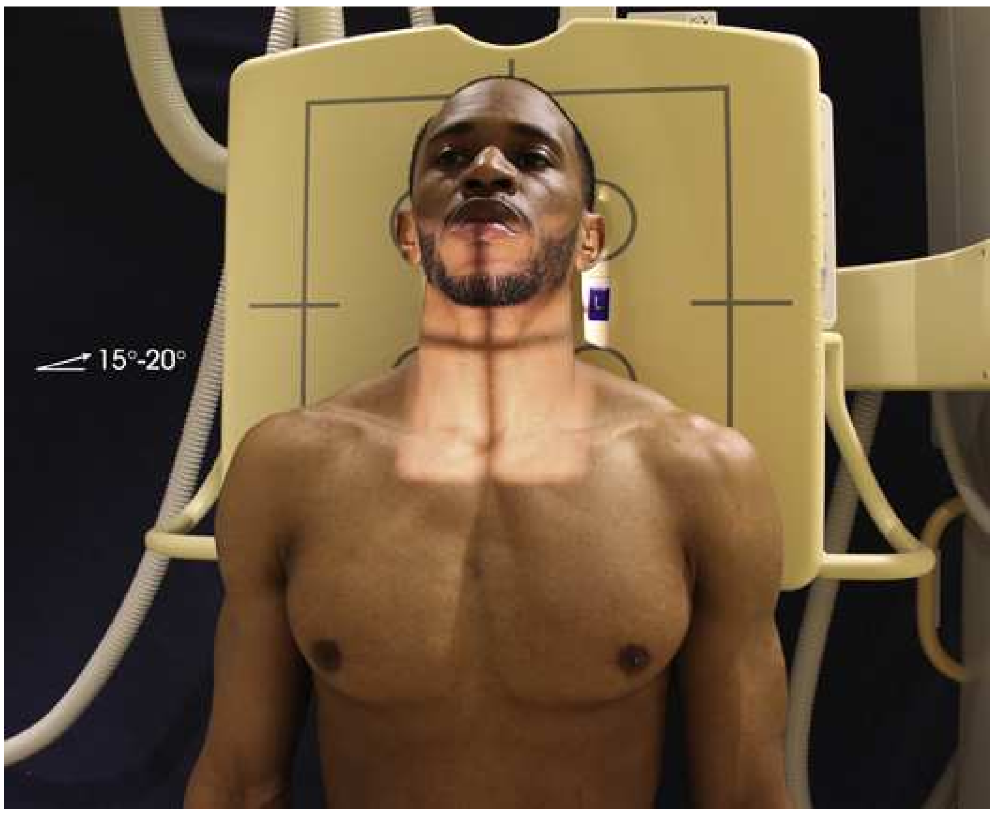


FIG. 9.39 AP axial cervical vertebrae: upright.

The patient is in an upright position with the back against the I R. The arms are placed along the sides of the body and the shoulders lie in the same horizontal plane. The side marker is in the collimated exposure field. The central ray is directed through C 4 at an angle of 15 to 20 degrees cephalad.

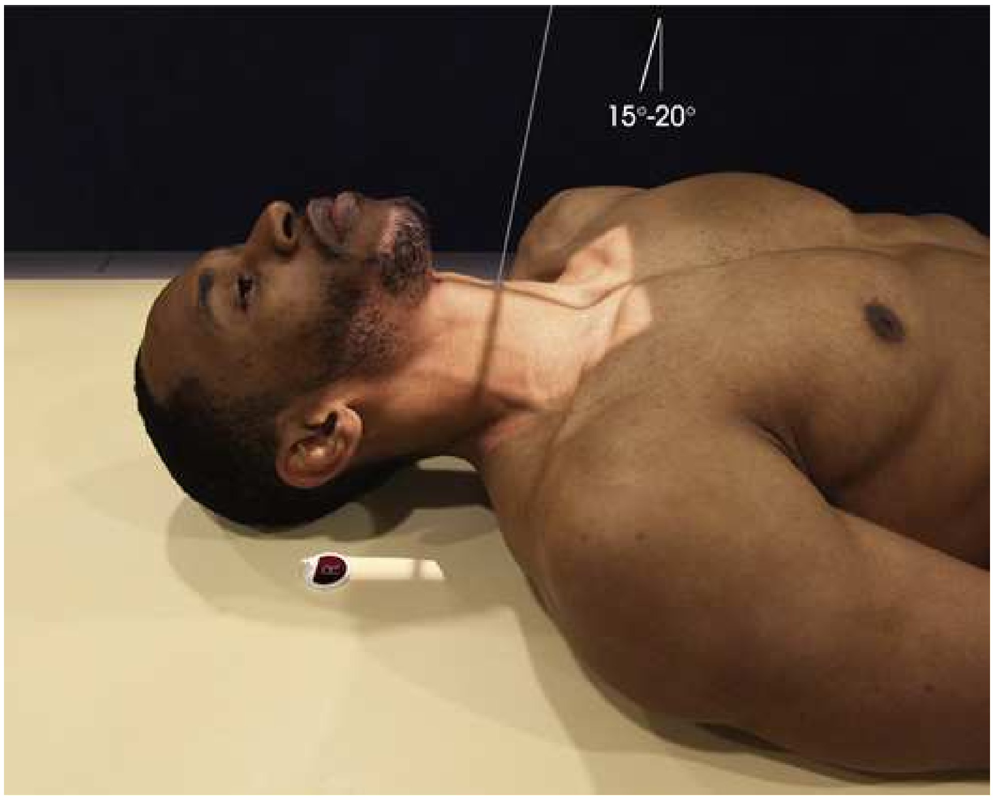


FIG. 9.40 AP axial cervical vertebrae: recumbent.

The patient is in a recumbent position. The arms are placed along the sides of the body and the shoulders lie in the same horizontal plane. The side marker is in the collimated exposure field. The central ray is directed through C 4 at an angle of 15 to 20 degrees cephalad.

Collimation

- Adjust radiation field to 10 inches (25 cm) lengthwise and 1 inch (2.5 cm) beyond the skin shadow on the sides. Place the side marker in the collimated exposure field.

Structures shown

The lower five cervical bodies and the upper two or three thoracic bodies, the interpediculate spaces, the superimposed transverse and articular processes, and the intervertebral disk spaces (Fig. 9.41). This projection is also used to show the presence or absence of cervical ribs.

Evaluation Criteria

The following should be clearly seen:

- Evidence of proper collimation and presence of the side marker placed clear of anatomy of interest
- Area from superior portion of C3 to T2 and surrounding soft tissue
- Shadows of the mandible and occiput superimposed over the atlas and most of the axis
- Open intervertebral disk spaces
- MSP of the head and neck perpendicular to the plane of the IR, without tilt or rotation
  - Spinous processes equidistant to the pedicles and aligned with the midline of the cervical bodies
  - Mandibular angles and mastoid processes equidistant to the vertebrae
- Bony trabecular detail and surrounding soft tissues

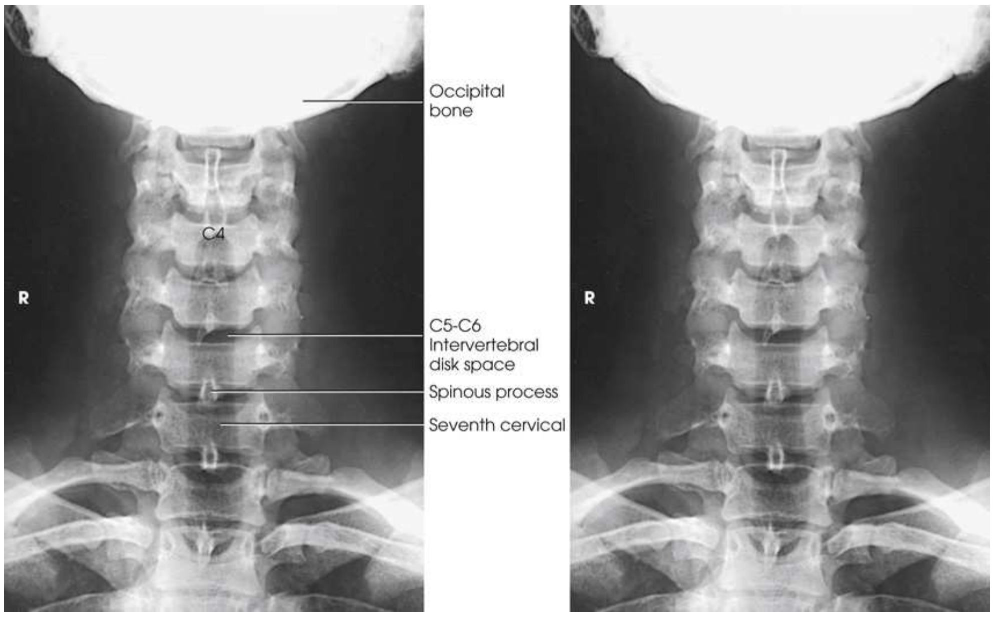


FIG. 9.41 AP axial cervical vertebrae.

Two x-ray shows the lower five cervical bodies and the upper two or three thoracic bodies. The parts labeled are marked from top to the bottom as follows: occipital bone, C 5 C 6 intervertebral disk space, spinous process, and seventh cervical. The cervical bone appears radiopaque.

Lateral Projection

Grandy Method [4]

Right or left position

Image receptor + grid: Positioned by manufacturer or department protocol for proper anatomy display orientation; CR plate: 10 × 12 inches (24 × 30 cm) lengthwise.

SID:

A 60- to 72-inch (152- to 183-cm) SID is recommended to compensate for the increased OID. A longer distance helps show C7.

Position of patient

- Place the patient in a true lateral position, either seated or standing, before a vertical grid device. The long axis of the cervical vertebrae should be parallel to the plane of the IR.
- Have the patient sit or stand straight then adjust the height of the IR so that it is centered at the level of C4. The top of the IR is about 1 inch (2.5 cm) above the external acoustic meatus (EAM).

Position of part

- Center the coronal plane that passes through the mastoid tips to the midline of the IR.
- Move the patient close enough to the vertical grid device to permit the adjacent shoulder to rest against the device for support (Fig. 9.42). (This projection may be performed using a grid.)
- Rotate the shoulders anteriorly or posteriorly according to the natural kyphosis of the back: If the patient is round-shouldered, rotate the shoulders anteriorly; otherwise, rotate them posteriorly.
- Adjust the shoulders to lie in the same horizontal plane, depress them as much as possible, and immobilize them by attaching one small sandbag to each *wrist*. The sandbags should be of equal weight.
- Be careful to ensure that the patient does not elevate the shoulder.
- Elevate the chin slightly, or have the patient protrude the mandible to prevent superimposition of the mandibular rami and the spine. At the same time and with the MSP of the head vertical, ask the patient to look steadily at one spot on the wall; this helps maintain the position of the head.
- *Shield gonads.*
- *Respiration:* Suspend respiration at the end of full expiration to obtain maximum depression of the shoulders.

NOTE: If cervical spine trauma is suspected, this projection must be performed **first** and "cleared" by the radiologist before additional images are performed. Refer to Chapter 12 in Volume 2 for details related to performing this projection on patients with suspected cervical spine trauma.

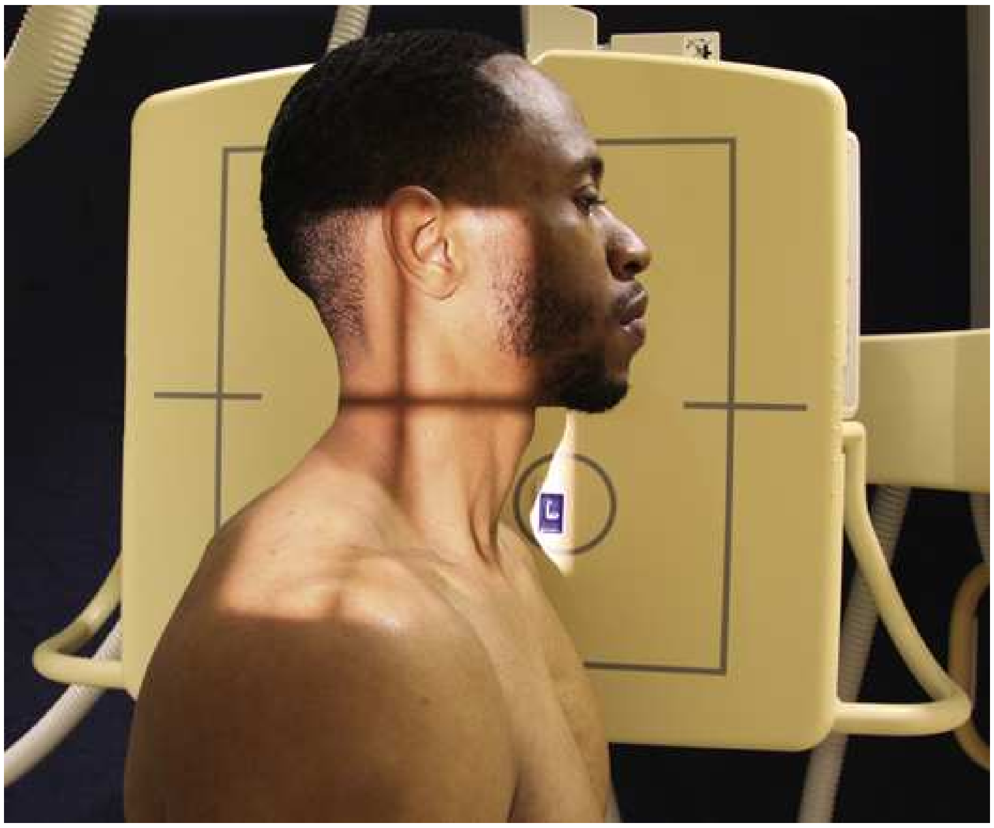


FIG. 9.42 Lateral cervical vertebrae: Grandy method.

The patient is in standing a true lateral position before a vertical grid device and is looking steadily in front. The adjacent shoulder is resting against the device. The chin is elevated slightly. The side marker is in the collimated exposure field. The central ray is horizontal and perpendicular to C4.

Central ray

- Horizontal and perpendicular to C4. With such centering, the magnified outline of the shoulder *farthest* from the IR is projected below the lower cervical vertebrae.

Collimation

- Adjust radiation field to 10 × 12 inches (24 × 30 cm) on the collimator. Place the side marker in the collimated exposure field.

Structures shown

The cervical bodies and their intervertebral disk spaces, the articular pillars, the lower five zygapophyseal joints, and the spinous processes (Figs. 9.43 and 9.44). Depending on how well the shoulders can be depressed, a good lateral projection must include C7; sometimes T1 and T2 can also be seen.

Evaluation Criteria

The following should be clearly seen:

- Evidence of proper collimation and presence of the side marker placed clear of anatomy of interest
- All seven cervical vertebrae and at least one-third of the T1 (otherwise a separate radiograph of the cervicothoracic region is recommended)
- C4 in the center of the radiograph
- Neck extended so that mandibular rami are not overlapping the atlas or axis
- No rotation or tilt of the cervical spine
  - Superimposed zygapophyseal joints and open intervertebral disk spaces
  - Superimposed or nearly superimposed rami of the mandible
  - Spinous processes shown in profile
- Bony trabecular detail and surrounding soft tissues

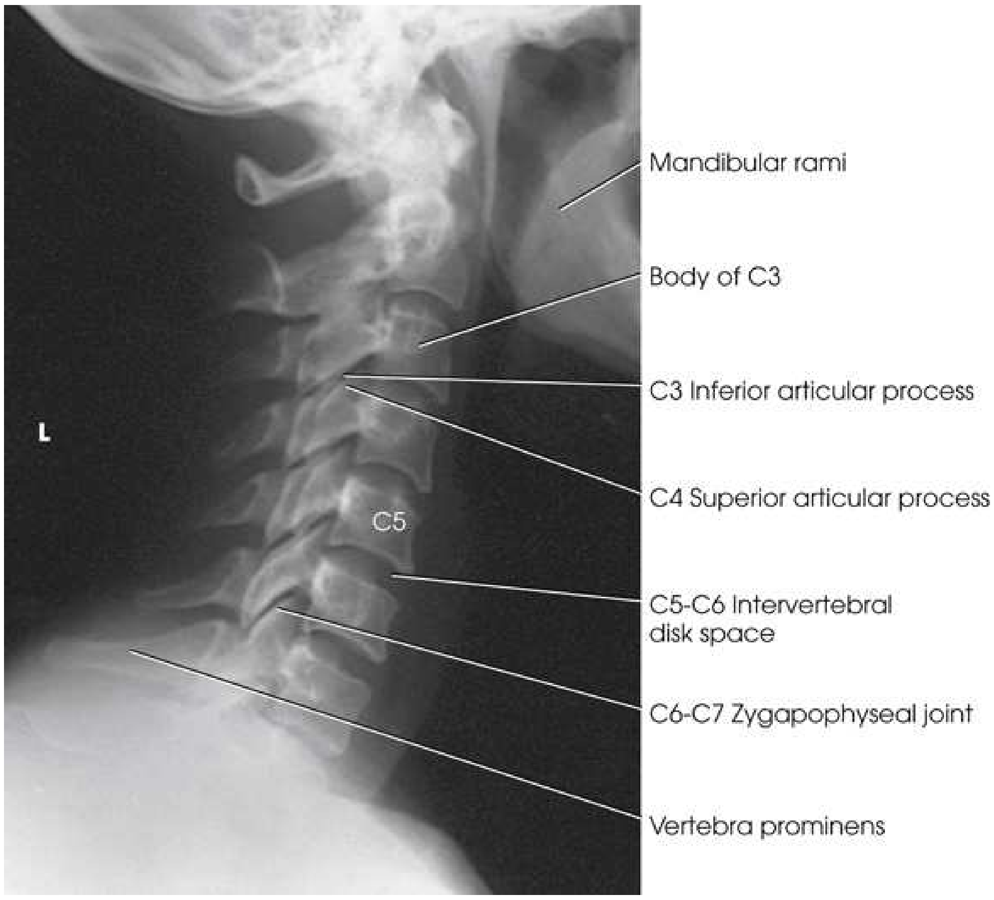


FIG. 9.43 Lateral cervical vertebrae: Grandy method.

An x-ray shows the cervical bodies and their intervertebral disk spaces, the articular pillars, the lower five zygapophyseal joints, and the spinous processes. The parts labeled on the diagram are marked from top to the bottom as follows: mandibular rami, body of C 3, C 3 inferior articular process, C 4 superior articular process, C 5 C 6 intervertebral, disk space, C 6 C 7 zygapophyseal joint, and vertebra prominens.

FIG. 9.44 Same projection as in Fig. 9.43 provides excellent visualization of all seven cervical vertebrae and T1.

Lateral Projection

Right or left position

Flexion and extension

NOTE: This procedure must not be attempted until a cervical spine pathology or fracture has been ruled out.

Functional studies of the cervical vertebrae in the lateral position are performed to show normal intersegmental movement or changes in intersegmental alignment resulting from trauma or disease. The spinous processes are elevated and widely separated in the flexion position and are depressed in close approximation in the extension position.

Image receptor + grid: Positioned by manufacturer or department protocol for proper anatomy display orientation; CR plate: 10 × 12 inches (24 × 30 cm) lengthwise.

SID:

A 60- to 72-inch (152- to 183-cm) SID is recommended to compensate for the increased OID. A longer distance helps show C7.

Position of patient

- Place the patient in a true lateral position, either seated or standing, before a vertical grid device.
- Have the patient sit or stand straight, then adjust the height of the IR so that it is centered at the level of C4. The top of the IR is about 2 inches (5 cm) above the EAM.

Position of part

- Move the patient close enough to the vertical grid device to permit the adjacent shoulder to rest against the grid for support.
- Keep the MSP of the patient's head and neck parallel to the plane of the IR.
- Alternatively, perform the projection without using a grid.

Flexion

• Ask the patient to drop the head forward and then draw the chin as close as possible to the chest, so that the cervical vertebrae are placed in a position of maximum flexion for the first exposure (Fig. 9.45).

Extension

• Ask the patient to elevate the chin as much as possible, so that the cervical vertebrae are placed in a position of maximum extension for the second exposure (Fig. 9.46).
• *Shield gonads.*
• *Respiration:* Suspend.

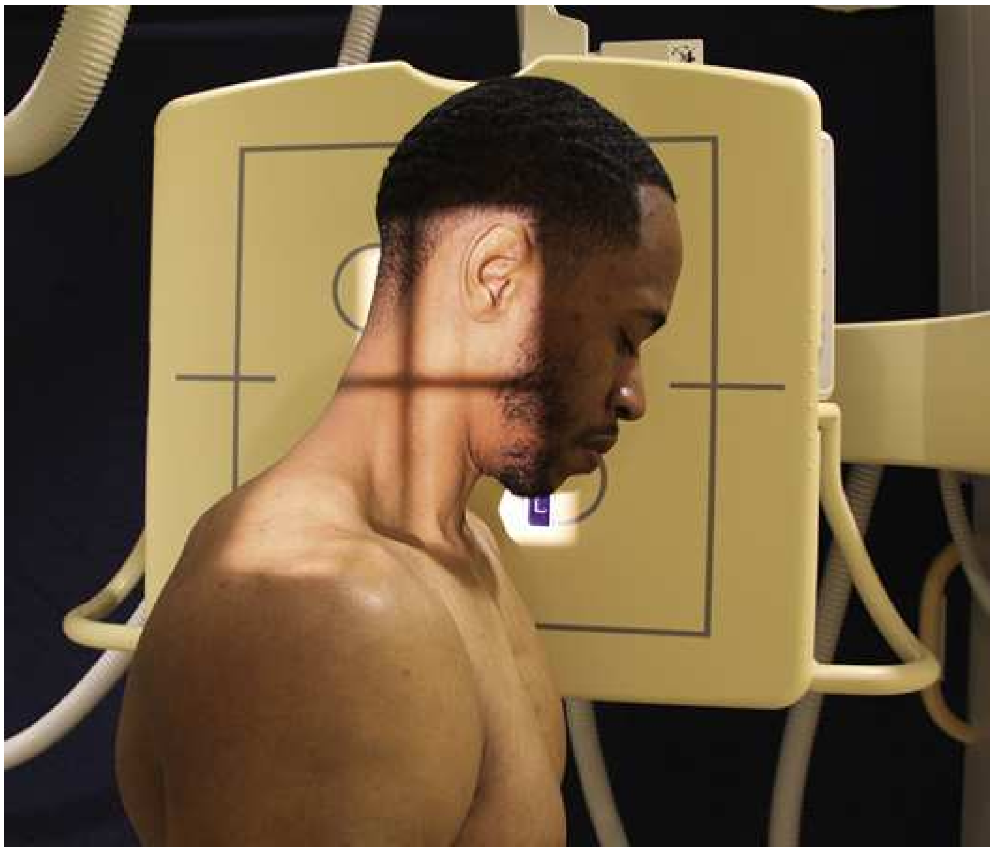


FIG. 9.45 Lateral cervical vertebrae: hyperflexion.

The patient is standing in a true lateral position before a vertical grid device. The adjacent shoulder is resting against the device. The patient's head is dropped forward and the chin is drawn as close as possible to the chest. The side marker is in the collimated exposure field. The central ray is horizontal and perpendicular to C 4.

FIG. 9.46 Lateral cervical vertebrae: hyperextension.

The patient is standing in a true lateral position. The adjacent shoulder is resting against the device. The patient's chin is elevated as much as possible. The side marker is in the collimated exposure field. The central ray is horizontal and perpendicular to C 4.

Central ray

- Horizontal and perpendicular to C4

Collimation

- Adjust radiation field to 10 × 12 inches (24 × 30 cm) on the collimator. For flexion, light should extend from EAC anteriorly to C7 spinous process posteriorly. For extension, light should extend from midmandible anteriorly to C7 spinous process posteriorly. Place the side marker in the collimated exposure field.

Structures shown

Intersegmental alignment of the cervical spine when flexed (Fig. 9.47) and extended (Fig. 9.48). The intervertebral disks and the zygapophyseal joints are also shown.

NOTE: The radiologist evaluates the posterior aspect of vertebral bodies for intersegmental alignment.

Evaluation Criteria

The following should be clearly seen:

- Evidence of proper collimation and presence of the side marker placed clear of anatomy of interest
- All seven cervical vertebrae in true lateral position
- No rotation or tilt of the cervical spine
  - Superimposed zygapophyseal joints and open intervertebral disk spaces
  - Superimposed or nearly superimposed rami of the mandible
  - Spinous processes shown in profile
- Bony trabecular detail and surrounding soft tissues

Flexion

- Body of the mandible almost vertical in a normal patient
- All seven spinous processes in profile, elevated and widely separated

Extension

- Body of the mandible almost horizontal in a normal patient
- All seven spinous processes in profile, depressed and closely spaced

FIG. 9.47 Lateral cervical spine: flexion. Note correct marking.

FIG. 9.48 Lateral cervical spine: extension. Note correct marking.

Cervical Intervertebral Foramina

Ap Axial Oblique Projection

RPO and LPO positions

Oblique projections for showing the cervical intervertebral foramina were first described by Barsóny and Koppenstein. [5, 6] Both sides are examined for comparison.

Image receptor + grid: Positioned by manufacturer or department protocol for proper anatomy display orientation; CR plate: 10 × 12 inches (24 × 30 cm) lengthwise.

SID:

A 60- to 72-inch (152- to 183-cm) SID is recommended to compensate for the increased OID.

Position of patient

- Place the patient in a supine or upright position facing the x-ray tube. The upright position (standing or seated) is preferable for the patient's comfort and makes it easier to position the patient.

Position of part

- Adjust the body (including the head) at a 45-degree angle, and center the cervical spine to the midline of the IR.
- Center the IR to the third cervical body (1 inch [2.5 cm] superior to the most prominent point of the thyroid cartilage) to compensate for the cephalic angulation of the central ray.

Upright posterior oblique position

- Ask the patient to sit or stand straight without strain and to rest the adjacent shoulder firmly against the vertical grid device for support.
- Ensure that the degree of body rotation is 45 degrees.
- While the patient looks straight ahead, elevate and, if needed, protrude the chin so that the mandible does not overlap the spine (Fig. 9.49). Turning the chin to the side causes slight rotation of the superior vertebrae and should be avoided.

Recumbent posterior oblique position

- Rotate the patient's head and body approximately 45 degrees.
- Center the cervical spine to the midline of the grid.
- Place suitable supports under the lower thorax and the elevated hip.
- Place a support under the patient's head and adjust it so that the cervical column is horizontal.
- Check and adjust the 45-degree body rotation.
- Elevate the patient's chin and protrude the jaw as for the upright study (Fig. 9.50). Turning the chin to the side causes slight rotation of the superior vertebrae and should be avoided.
- *Shield gonads.*
- *Respiration:* Suspend.

NOTE: See p. 440 for the Summary of Oblique Projections.

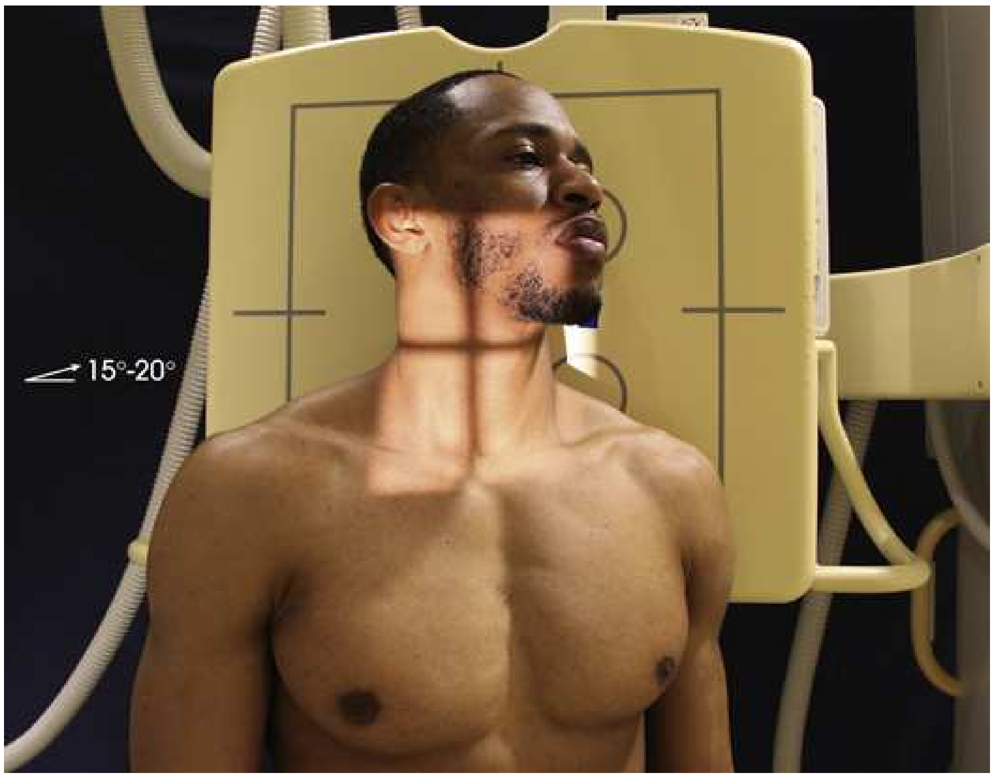


FIG. 9.49 Upright AP axial oblique right intervertebral foramina: LPO position.

The patient is standing straight and is resting the adjacent shoulder firmly against the vertical grid. The patient looks straight ahead and his chin is protruded. The side marker is in the collimated exposure field. The central ray is directed to C 4 at a cephalad angle of 15 to 20 degrees.

FIG. 9.50 Recumbent AP axial oblique left intervertebral foramina: RPO position.

The patient is in a supine position facing the x-ray tube. A support is placed under the patient's head. The patient's chin is elevated and the jaw is protruded. The side marker is in the collimated exposure field. The central ray is angled to 15 to 20 degrees.

Central ray

- Directed to C4 at a cephalad angle of 15 to 20 degrees so that the central ray coincides with the orientation of the foramina

Collimation

- Adjust radiation field to 10 × 12 inches (24 × 30 cm) on the collimator. Place the side marker in the collimated exposure field.

Structures shown

The intervertebral foramina and pedicles *farthest* from the IR and an oblique projection of the bodies and other parts of the cervical vertebrae (Fig. 9.51). (See the Summary of Oblique Projections, p. 440.)

Evaluation Criteria

The following should be clearly seen:

- Evidence of proper collimation and presence of the side marker placed clear of anatomy of interest
- All seven cervical and the first thoracic vertebrae
- Appropriate 45-degree rotation of body and neck
  - Open intervertebral foramina *farthest* from the IR, from C2–C3 to C7–T1
  - Uniform size and contour of the foramina
- Appropriately elevated chin
  - Mandible not overlapping the atlas and axis
  - Occipital bone not overlapping the atlas and axis
- Open intervertebral disk spaces
- Bony trabecular detail and surrounding soft tissues

Ap Oblique Projection

Flexion and extension

Boylston [7] suggested using functional studies of the cervical vertebrae in the oblique to show fractures of the articular processes and obscure dislocations and subluxations. When acute injury has been sustained, manipulation of the patient's head must be performed by a physician.

The patient is placed in a direct frontal body position facing the x-ray tube, with the shoulders held firmly against the grid device. The head is carefully rotated maximally to one side and is kept in that position while the neck is fully flexed for the first exposure and fully extended for the second exposure. Both sides are examined for comparison.

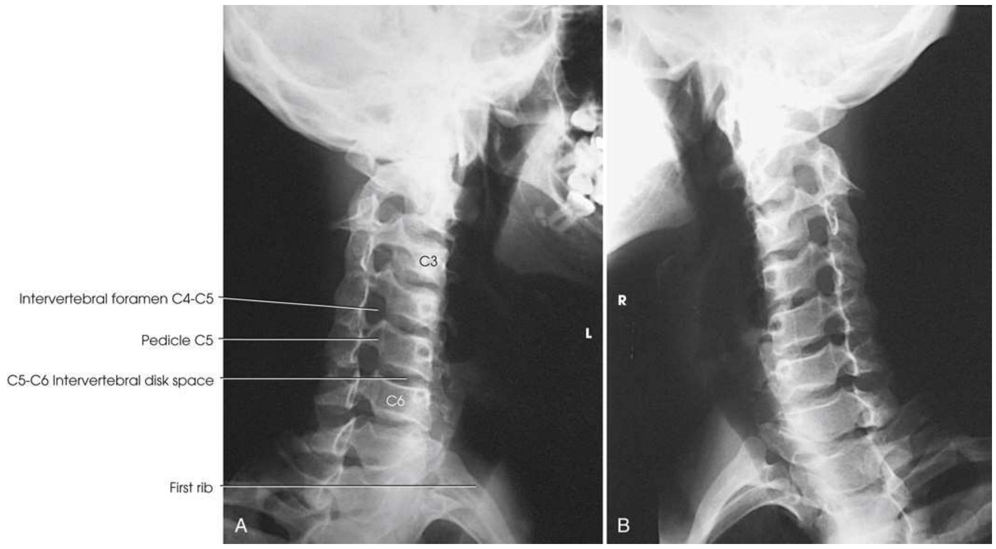


FIG. 9.51 AP axial oblique intervertebral foramina. (A) LPO position showing right side. (B) RPO position showing left side.

(A) An x-ray shows all seven cervical and the first thoracic vertebrae. The parts labeled are marked from top to the bottom as follows: intervertebral foramen C 4 to C 5, pedicle C 5, C 5 to C 6 intervertebral disk space, and first rib. (B) An x-ray shows open intervertebral foramina farthest from the I R, from C 2–C 3 to C 7–T 1. The intervertebral disk apces are open.

Pa Axial Oblique Projection

RAO and LAO positions

Image receptor + grid: Positioned by manufacturer or department protocol for proper anatomy display orientation; CR plate: 10 × 12 inches (24 × 30 cm) lengthwise.

SID:

A 60- to 72-inch (152- to 183-cm) SID is recommended to compensate for the increased OID.

Position of patient

- Place the patient prone or upright with the back toward the x-ray tube. For the patient's comfort and accurate adjustment of the part, the standing or seated-upright position is preferred.

Position of part

- *Upright anterior oblique position:* Ask the patient to sit or stand straight with the arms by the side and rest the shoulder against the grid device. Rotate the patient's entire body to a 45-degree angle. Center the cervical spine to the midline of the grid device (Fig. 9.52).
- *Recumbent anterior oblique position:* Place the patient's body at an angle of 45 degrees and the cervical spine centered to the midline of the grid. Have the patient use the forearm and flexed knee of the elevated side to support the body and maintain the position (Figs. 9.53 and 9.54). Place a suitable support under the patient's head to position the long axis of the cervical column parallel with the IR.
- To allow for the caudal angulation of the central ray, center the IR at the level of C5 (1 inch [2.5 cm] caudal to the most prominent point of the thyroid cartilage).
- Adjust the position of the patient's head so that the MSP is aligned with the plane of the spine.
- Elevate and protrude the patient's chin just enough to prevent superimposition of the mandible with the upper cervical vertebrae. Turning the chin to the side causes rotation of the superior vertebrae and should be avoided. (The chin has to be turned slightly for the recumbent anterior oblique position.)
- *Shield gonads.*
- *Respiration:* Suspend.

Central ray

- Directed to C4 at an angle of 15 to 20 degrees caudad so that it coincides with the orientation of the foramina.

Collimation

- Adjust radiation field to 10 × 12 inches (24 × 30 cm) in the collimator. Place the side marker in the collimated exposure field.

Structures shown

The intervertebral foramina and pedicles *closest* to the IR and an oblique projection of the bodies and other parts of the cervical column (Fig. 9.55). (See the Summary of Oblique Projections, p. 440.)

Evaluation Criteria

The following should be clearly seen:

- Evidence of proper collimation and presence of the side marker placed clear of anatomy of interest
- All seven cervical and the first thoracic vertebrae
- Appropriate 45-degree rotation of body and neck
  - Open intervertebral foramina *closest* to the IR, from C2–C3 to C7–T1
  - Uniform size and contour of the foramina
- Appropriately elevated chin
  - Mandible not overlapping the atlas and axis
  - Occipital bone not overlapping the atlas and axis
- Open intervertebral disk spaces
- Bony trabecular detail and surrounding soft tissues

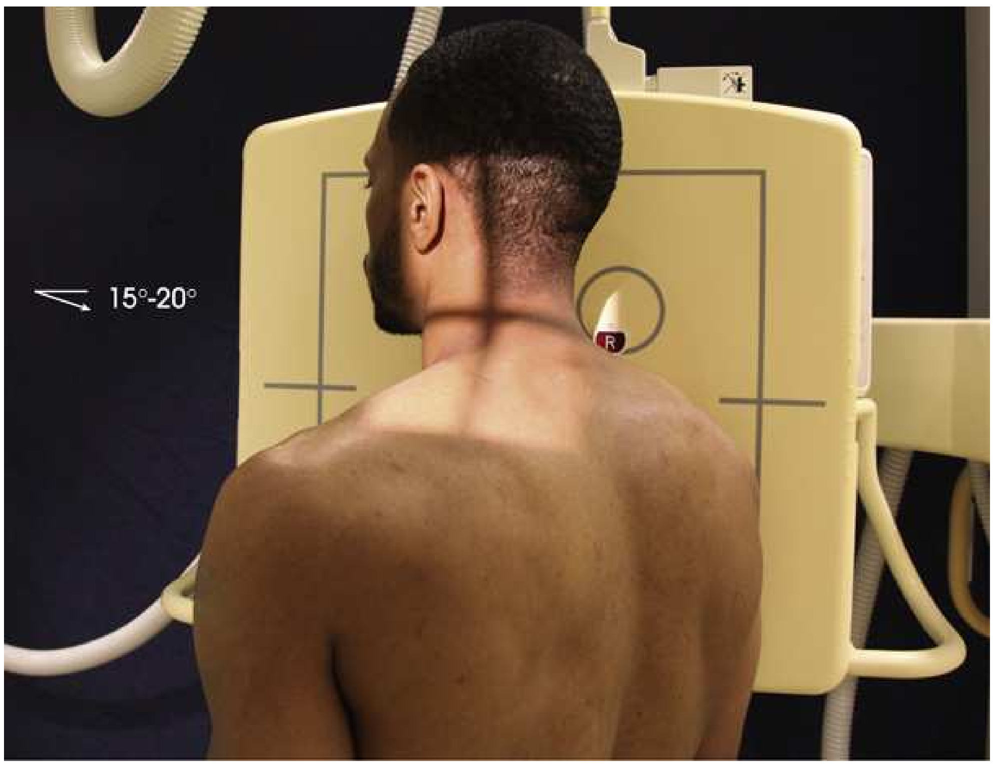


FIG. 9.52 PA axial oblique right intervertebral foramina: RAO position.

The patient is standing upright and arms are by the side with the shoulder resting against the grid device. The side marker is in the collimated exposure field. The central ray is directed to C 4 at an angle of 15 to 20 degrees caudad.

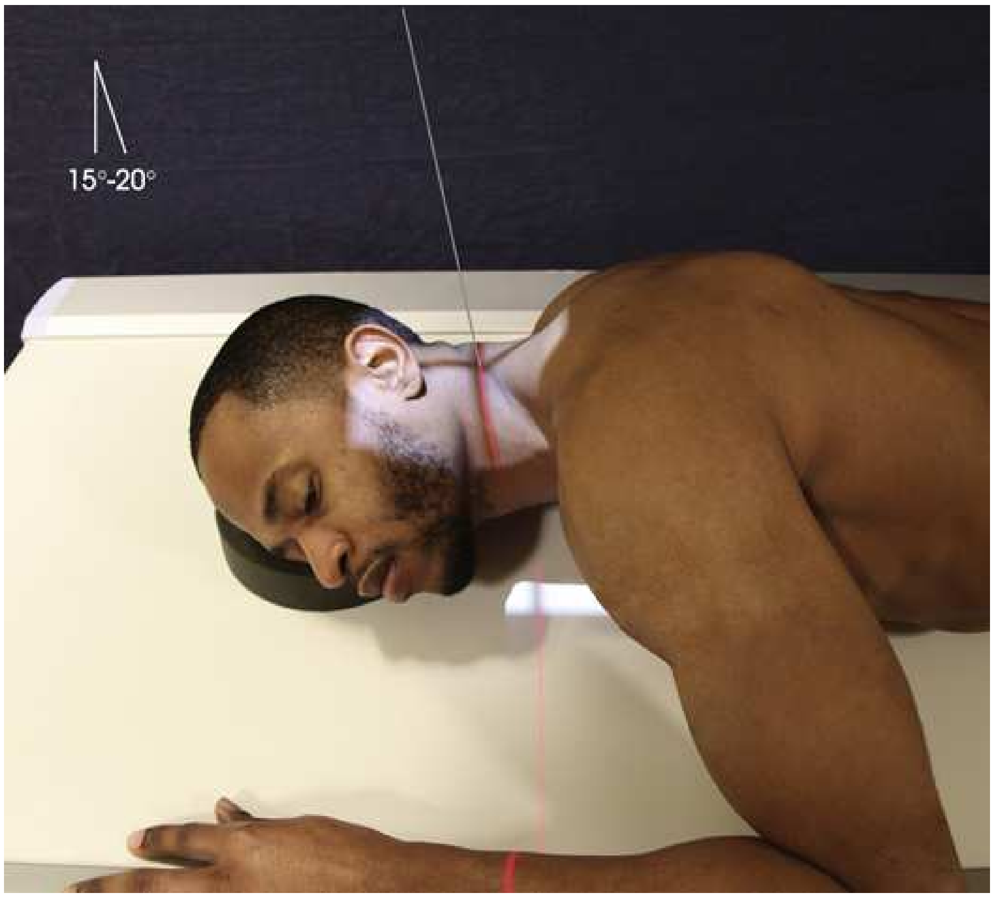


FIG. 9.53 PA axial oblique right intervertebral foramina: RAO position.

The patient is in a prone position and the body is placed at an angle of 45 degrees. The forearm is flexed and the cervical spine is centered to the midline of the grid. The side marker is in the collimated exposure field. The central ray is directed to C 4 at an angle of 15 to 20 degrees caudad.

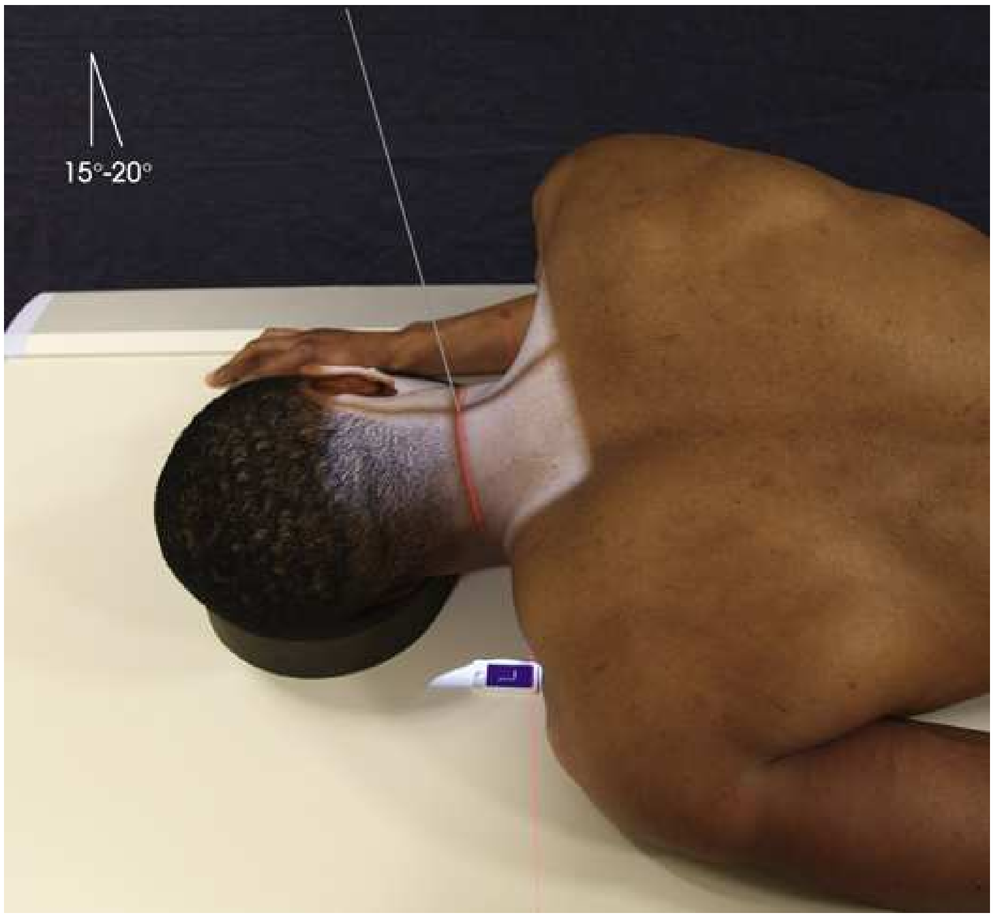


FIG. 9.54 PA axial oblique left intervertebral foramina: LAO position.

The patient is in a prone position and the body is placed at an angle of 45 degrees and the face is turned away. The forearm is flexed and the cervical spine is centered to the midline of the grid. The side marker is in the collimated exposure field. The central ray is directed to C 4 at an angle of 15 to 20 degrees caudad.

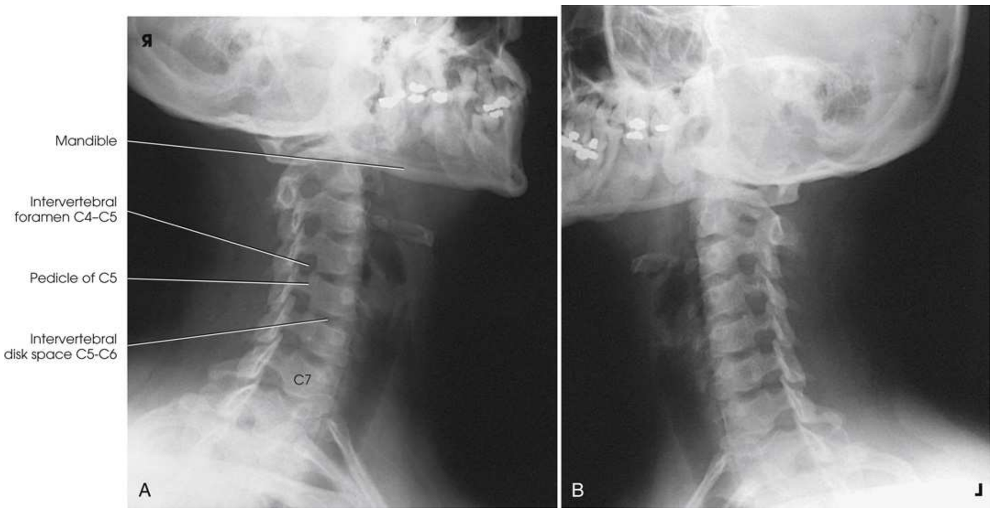


FIG. 9.55 PA axial oblique intervertebral foramina. (A) RAO position showing right side. (B) LAO position showing left side.

(A) An x-ray shows All seven cervical and the first thoracic vertebrae R A O position of the right side. The parts labeled are marked from top to the bottom as follows: mandible, intervertebral foramen C 4 to C 5, pedicle of C 5, and intervertebral disk space C 5 to C 6. (B) An x-ray shows All seven cervical and the first thoracic vertebrae of the L A O position of the left side. The intervertebral disk spaces are open.

Cervical Vertebrae

Ap Projection

Ottonello Method

With the Ottonello method, the mandibular shadow is blurred or obliterated by having the patient perform an even chewing motion of the mandible during the exposure. The patient's head must be rigidly immobilized to prevent movement of the vertebrae. The exposure time must be long enough to cover several complete excursions of the mandible. This projection is also referred to as the "wagging jaw."

Image receptor + grid: Positioned by manufacturer or department protocol for proper anatomy display orientation; CR plate: 10 × 12 inches (24 × 30 cm) lengthwise.

Position of patient

- Place the patient in the supine position.
- Center MCP of the body to the midline of the grid.
- Place the patient's arms along the sides of the body and adjust the shoulders to lie in the same horizontal plane.
- Place a support under the knees for the patient's comfort.

Position of part

- Adjust the patient's head so that the MSP is aligned with the lower body and is perpendicular to the table.
- Elevate the patient's chin enough to place the occlusal surface of the upper incisors and the mastoid tips in the same vertical plane.
- Immobilize the head and have the patient practice opening and closing the mouth until the mandible can be moved smoothly without striking the teeth together (Fig. 9.56).
- Place the IR in a Bucky tray, and center the IR at the level of C4.
- To blur the mandible, use an exposure technique with low milliamperage (mA) and long exposure time (minimum of 1 second).
- *Shield gonads.*
- *Respiration:* Suspend.

FIG. 9.56 AP cervical vertebrae: Ottonello method.

The patient is in a supine position and the chin is elevated. The side marker is in the collimated exposure field. The central ray is perpendicular to C 4 and enters at the most prominent point of the thyroid cartilage.

Central ray

- Perpendicular to C4; the central ray enters at the most prominent point of the thyroid cartilage.

Collimation

- Adjust radiation field to 10 × 12 inches (24 × 30 cm) on the collimator. Place the side marker in the collimated exposure field.

Structures shown

The entire cervical spine, with the mandible blurred or obliterated (Figs. 9.57 and 9.58).

Evaluation Criteria

The following should be clearly seen:

- Evidence of proper collimation and presence of the side marker placed clear of anatomy of interest
- All seven cervical vertebrae
- Blurred mandible with resultant visualization of the underlying atlas and axis
- Bony trabecular detail and surrounding soft tissues

FIG. 9.57 AP cervical spine: Ottonello method with chewing motion of mandible and use of perpendicular central ray.

An x-ray shows the entire cervical spine, with the mandible blurred with resultant visualization of the underlying atlas and axis. The parts labeled are marked from top to the bottom as follows: dens, C 1 lateral mass, spinous process of C 2, and first rib.

FIG. 9.58 Conventional AP axial cervical spine with stationary mandible and 15- to 20-degree cephalad angulation of central ray.

Cervical and Upper Thoracic Vertebrae

Vertebral Arch (Pillars)

Ap Axial Projection [8]

NOTE: The procedure must not be attempted until cervical spine pathology or fracture has been ruled out.

The vertebral arch projections, sometimes referred to as *pillar* or *lateral mass* projections, are used to show the posterior elements of the cervical vertebrae, the upper three or four thoracic vertebrae, the articular processes and their facets, the laminae, and the spinous processes. The central ray angulations that are employed project the vertebral arch elements free of the anteriorly situated vertebral bodies and transverse processes. When the central ray angulation is correct, the resultant image resembles a hemisection of the vertebrae. In addition to frontal plane delineation of the articular pillars and facets, vertebral arch projections are especially useful for showing the cervicothoracic spinous processes in patients with whiplash injury. [9]

Image receptor + grid: Positioned by manufacturer or department protocol for proper anatomy display orientation; CR plate: 10 × 12 inches (24 × 30 cm).

Position of patient

- Adjust the patient in the supine position with the MSP of the body centered to the midline of the grid.
- Depress the patient's shoulders and adjust them to lie in the same horizontal plane.

Position of part

- With the MSP of the head perpendicular to the table, fully *extend* the patient's neck (Figs. 9.59 and 9.60).
- If the patient cannot tolerate full extension without undue discomfort, the oblique projection described in the next section is recommended.

- *Shield gonads.*
- *Respiration:* Suspend.

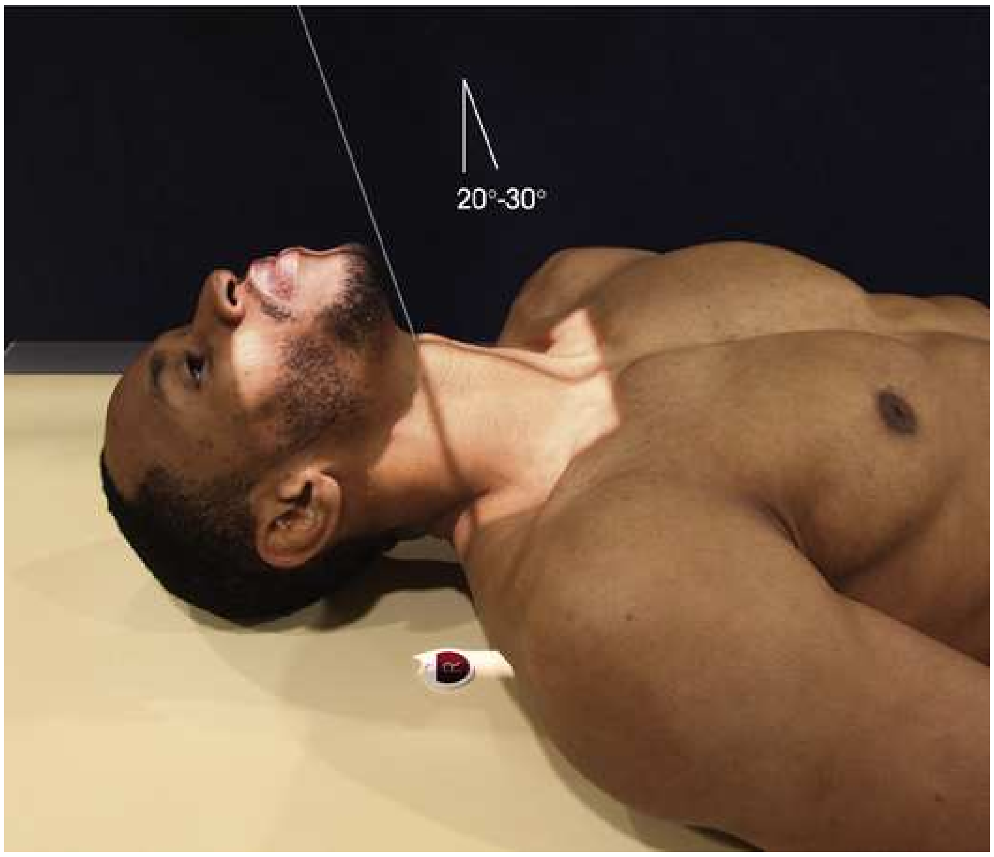


FIG. 9.59 AP axial vertebral arch.

The patient is lying in a supine position. The M S P of the head is perpendicular to the table and the patient's neck is fully extended. The side marker is in the collimated exposure field. The central ray is directed to C 7 at an average angle of 25 degrees caudad.

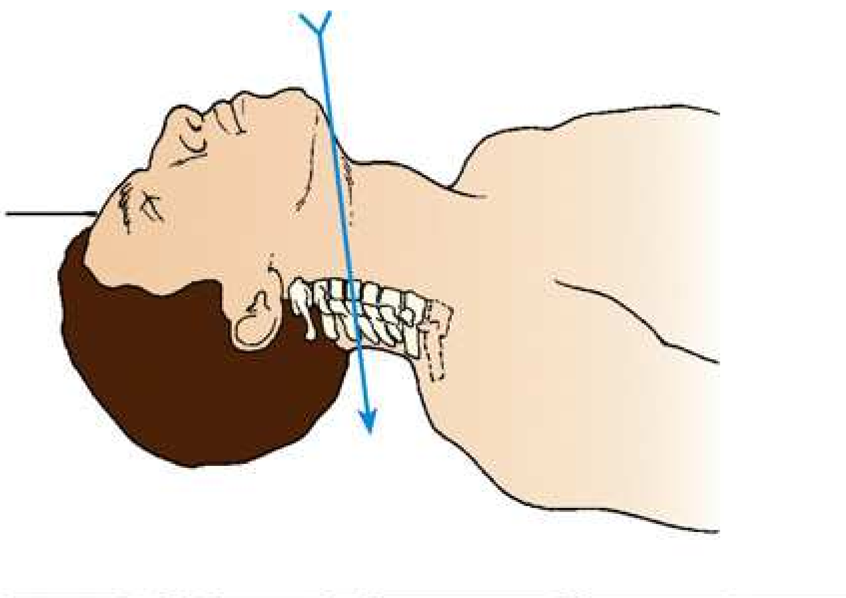


FIG. 9.60 AP axial vertebral arch.

Diagram shows a patient in a supine position. The M S P of the head is perpendicular to the table and the patient's neck is fully extended. The central ray is directed to C 7 at an average angle of 25 degrees caudad.

Central ray

- Directed to C7 at an average angle of 25 degrees caudad (range, 20 to 30 degrees). The central ray enters the neck in the region of the thyroid cartilage.

- The degree of the central ray angulation is determined by the cervical lordosis. The goal is to have the central ray coincide with the plane of the articular facets so that a greater angle is required when the cervical curve is accentuated, and a lesser angle is required when the curve is diminished.
- To reduce an accentuated cervical curve and place C3–C7 in the same plane as T1–T4, the originators [8] of this technique have suggested that a radiolucent wedge be placed under the patient's neck and shoulders, with the head extended over the edge of the wedge.

Collimation

- Adjust radiation field to 10 × 12 inches (24 × 30 cm) on the collimator. Place the side marker in the collimated exposure field.

Structures shown

The posterior portion of the cervical and upper thoracic vertebrae, including the articular and spinous processes (Fig. 9.61).

Evaluation Criteria

The following should be clearly seen:

- Evidence of proper collimation and presence of the side marker placed clear of anatomy of interest
- Vertebral arch structures, especially the superior and inferior articulating processes (pillars), without overlapping of the vertebral bodies and transverse processes
- Articular processes
- Open zygapophyseal joints between the articular processes
- Bony trabecular detail and surrounding soft tissues

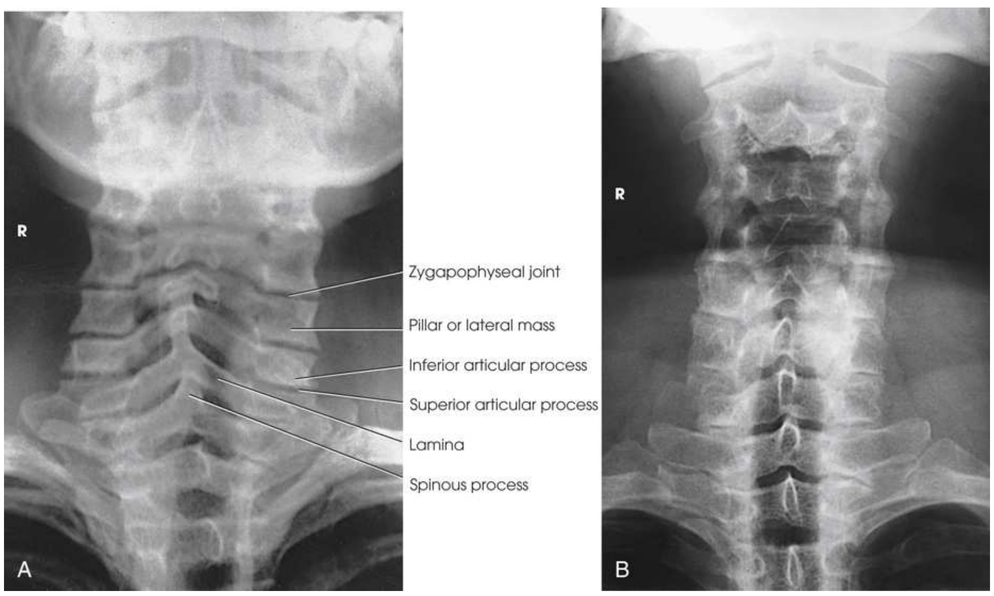


FIG. 9.61 AP axial. (A) Central ray parallel with plateau of articular processes. (B) Head fully extended but inadequate central ray angulation; central ray not parallel with zygapophyseal joints.

An x-ray shows the posterior portion of the cervical and upper thoracic vertebrae, including the articular and spinous processes. The parts labeled are marked from top to the bottom as follows: zygapophyseal joint, pillar or lateral mass, inferior articular process, superior articular process, lamina, and spinous process. (B) An x-ray shows the vertebral arch structure and the open zygapophyseal joints between the articular processes.

Vertebral Arch (Pillars)

Ap Axial Oblique Projection

Right and left head rotations [10]

These radiographic projections are used to show the vertebral arches or pillars when the patient cannot fully extend the head for the AP axial projection. Both sides are examined for comparison.

Image receptor + grid: Positioned by manufacturer or department protocol for proper anatomy display orientation; CR plate: 10 × 12 inches (24 × 30 cm).

Position of patient

- Place the patient in the supine position.

Position of part

- Rotate the patient's head 45 to 50 degrees, turning the jaw away from the side of interest. A 45- to 50-degree rotation of the head usually shows the articular processes of C2–C7 and T1. A rotation of 60 to 70 degrees is sometimes required to show the processes of C6 and T1–T4 (Fig. 9.62).
- Position the IR so that the top edge is at the level of the mastoid tip.
- *Shield gonads.*
- *Respiration:* Suspend.

Central ray

- Directed to exit the spinous process of C7 at an average angle of 35 degrees caudad (range, 30 to 40 degrees).

Collimation

- Adjust radiation field to 10 × 12 inches (24 × 30 cm) on the collimator. Place the side marker in the collimated exposure field.

Structures shown

The posterior arch and pillars of the cervical and upper thoracic vertebrae with open zygapophyseal joints (Fig. 9.63).

Evaluation Criteria

The following should be clearly seen:

- Evidence of proper collimation and presence of the side marker placed clear of anatomy of interest
- Vertebral arch structures, especially the superior and inferior articulating processes (pillars), without overlapping of the vertebral bodies and transverse processes
- Articular processes on the side of interest
- Open zygapophyseal joints between the articular processes
- Bony trabecular detail and surrounding soft tissues

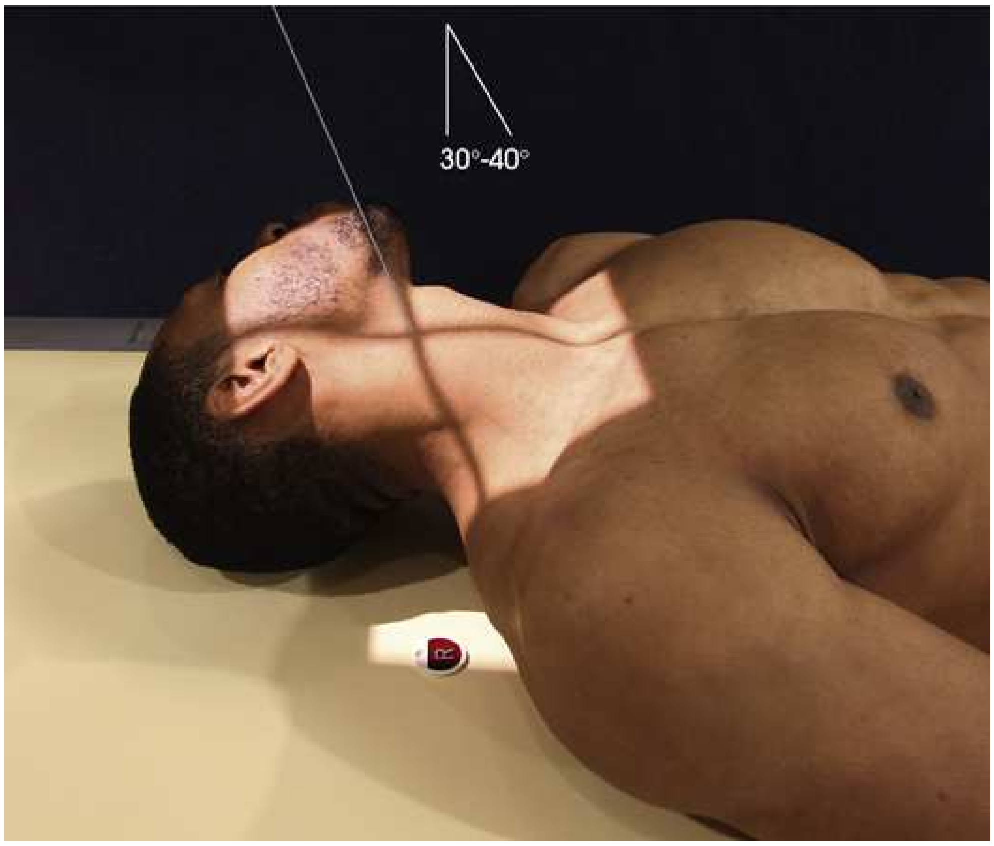


FIG. 9.62 AP axial oblique showing right vertebral arches.

The patient is lying in a supine position. The patient's head is rotated 45 to 50 degrees and the jaw is turned away. The side marker is in the collimated exposure field. The central ray is directed to exit the spinous process of C 7 at an average angle of 35 degrees caudad (range, 30 to 40 degrees).

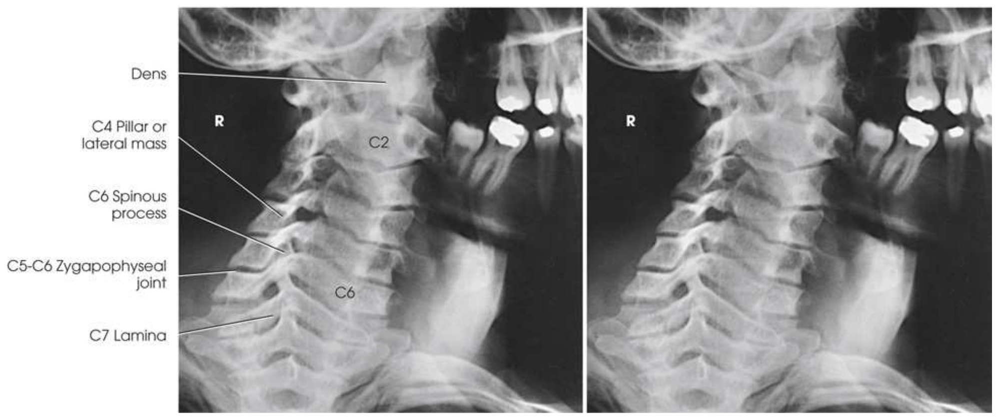


FIG. 9.63 AP axial oblique showing right vertebral arches.

Two x-ray shows the posterior arch and pillars of the cervical and upper thoracic vertebrae with open zygapophyseal joints. The enamel appears white and prominent. The parts labeled are marked from top to the bottom as follows: dens, C 4 pillar or lateral mass, C 6 spinous process, C 5 to C 6 zygapophyseal joint, and C 7 lamina.

Cervicothoracic Region

Lateral Projection

Swimmer's Technique

Right or left position

The *swimmer's technique* is performed when shoulder superimposition obscures C7 on a lateral cervical spine projection or when a lateral projection of the upper thoracic vertebra is needed. After reviewing the original publications of Twining [11] and Pawlow [12] and other pertinent publications,[13–15] the authors determined that the current technique descriptions are a combination of their recommendations. The following description identifies the historical origins and provides the authors' recommendations for the optimal positioning technique.

Image receptor + grid: Positioned by manufacturer or department protocol for proper anatomy display orientation; CR plate: 10 × 12 inches (24 × 30 cm) lengthwise.

Position of patient

- *Recumbent:* Place the patient in a lateral recumbent position with the head elevated on the patient's arm or other firm support (Fig. 9.64).
- *Upright:* Place the patient in a lateral position, either seated or standing, against a vertical grid device (Fig. 9.65).

Position of part

- Center MCP of the body to the midline of the grid.
- Extend the arm closest to the IR above the head. If the patient is upright, flex the elbow and rest the forearm on the patient's head (see Fig. 9.65).[11] In addition, the humeral head can be moved anteriorly[12] (recommended) or posteriorly.[13]
- Position the arm away from the IR down along the patient's side and depress the shoulder as much as possible.[11] In addition, the humeral head can be moved in the opposite direction to that of the other shoulder[12, 13] (posterior recommended).
- Adjust the head and body in a true lateral position, with the MSP parallel to the plane of the IR. If the patient is recumbent, a support may be placed under the lower thorax.
- Center the IR at the level of the C7–T1 intervertebral disk space, which is located 2 inches (5 cm) above the jugular notch.
- *Shield gonads.*
- *Respiration:* Suspend; or if patient can cooperate and can be immobilized, a breathing technique can be used to blur the lung anatomy.

Central ray

- Directed to the C7–T1 intervertebral disk space: perpendicular[12] if the shoulder away from the IR is well depressed or at a caudal angle of 3 to 5 degrees[14] when the shoulder is immobile and cannot be depressed sufficiently.
- Monda[15] recommended angling 5 to 15 degrees cephalad to show better the intervertebral disk spaces when the spine is tilted because of broad shoulders or a nonelevated lower spine. The proper angle results in a central ray perpendicular to the long axis of the tilted spine.

NOTE: See Chapter 12 in Volume 2 for a description of positioning used for patients with suspected cervical spine trauma.

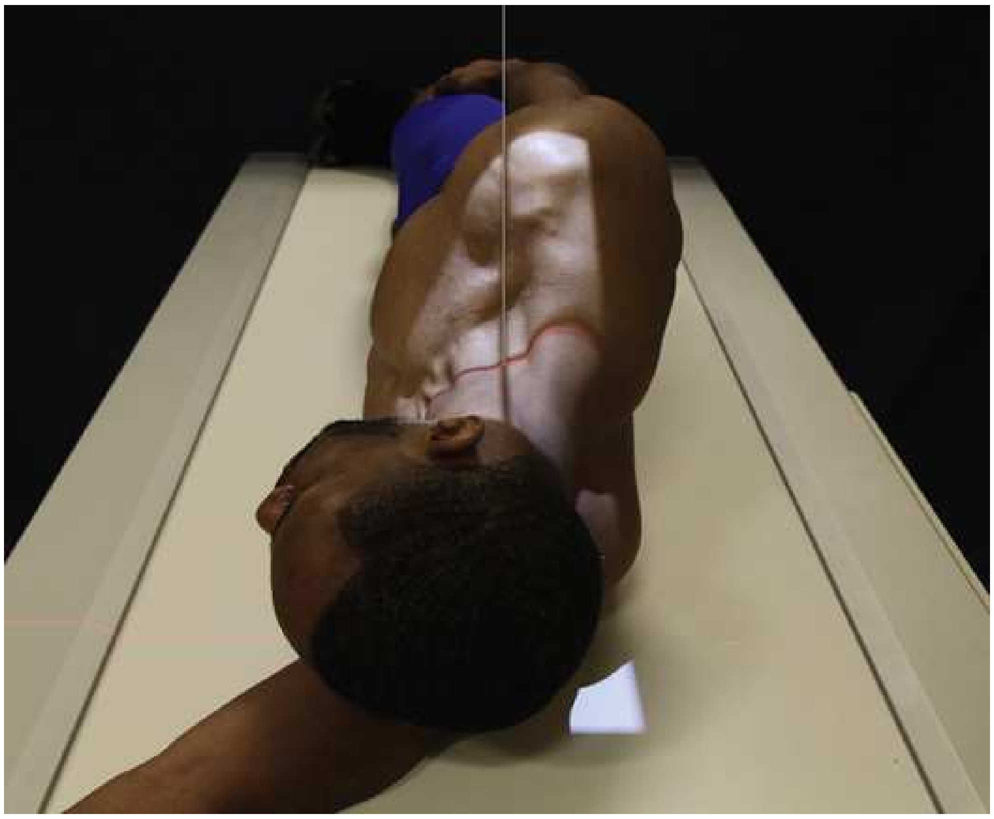


FIG. 9.64 Recumbent lateral cervicothoracic region: Pawlow method.

The patient is lying in a lateral recumbent position on the radiographic table with the head elevated on the patient's arm. The central ray is directed perpendicular to the C 7 to T 1 intervertebral disk space.

FIG. 9.65 Upright lateral cervicothoracic region: Twining method.

The patient is standing in a lateral position against a vertical grid device. The elbow and rest of the patient's forearm are flexed and it is resting on the patient’s head. The side marker is in the collimated exposure field. The central ray is directed perpendicular to the C 7 to T 1 intervertebral disk space.

Collimation

• Adjust radiation field to 10 × 12 inches (24 × 30 cm) on the collimator. Place the side marker in the collimated exposure field.

Compensating Filter

This projection may benefit from the use of a compensating filter because of the extreme difference between the thin lower neck and the very thick upper thoracic region. With the use of a specially designed filter, the C7–T1 area can be shown on one image.

Structures shown

The cervicothoracic vertebrae between the shoulders (Figs. 9.66 and 9.67).

Evaluation Criteria

The following should be clearly seen:

- Evidence of proper collimation and presence of the side marker placed clear of anatomy of interest
- Adequate x-ray penetration through the shoulder region demonstrating the lower cervical and upper thoracic vertebra, not appreciably rotated from lateral position
- Humeral heads minimally superimposed on vertebral column
- Bony trabecular detail and surrounding soft tissues

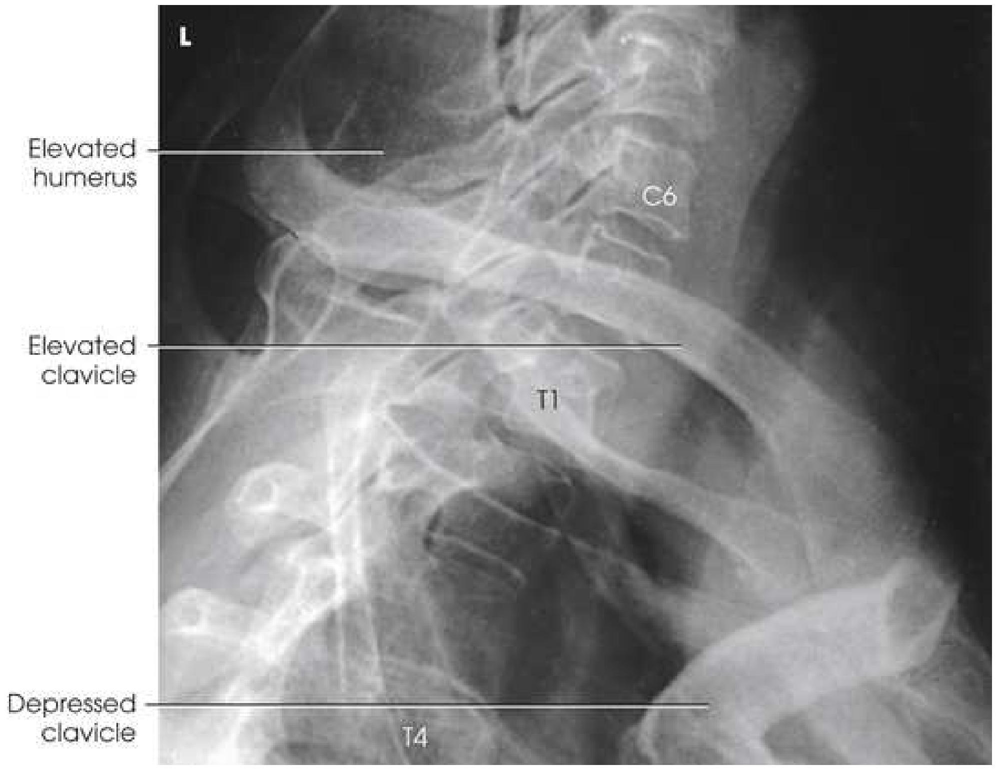


FIG. 9.66 Lateral cervicothoracic region: swimmer's technique with Ferlic filter.

An x-ray shows the cervicothoracic vertebrae between the shoulders. It appears blurry. The parts labeled are marked from top to the bottom as follows: elevated humerus, elevated clavicle, and depressed clavicle. The clavile is long and cylindrical.

FIG. 9.67 Lateral cervicothoracic region: swimmer's technique with Ferlic filter showing bony structures.

Thoracic Vertebrae

Ap Projection

Image receptor + grid: Positioned by manufacturer or department protocol for proper anatomy display orientation; CR plate: 14 × 17 inches (35 × 43 cm) lengthwise.

Position of patient

- Place the patient in the supine or upright position.
- Place the patient's arms along the sides of the body and adjust the shoulders to lie in the same horizontal plane.
- If the patient is supine, let the head rest directly on the table or on a thin pillow to avoid accentuating the thoracic kyphosis. If possible, orient the patient so the lower thorax is at the cathode end of the x-ray tube. This orientation takes advantage of the "anode heel effect" to ensure a more uniform exposure of the thoracic anatomy.
- If the upright position is used, ask the patient to sit or stand up as straight as possible.

Position of part

- Center the MSP of the body to the midline of the grid.
- For the *supine position,* to reduce kyphosis, flex the patient's hips and knees to place the thighs in vertical position. Immobilize the feet with sandbags (Fig. 9.68).
- If the patient's limbs cannot be flexed, support the knees to relieve strain.
- For the *upright position,* have the patient stand so that the patient's weight is equally distributed on the feet to prevent rotation of the vertebral column.
- If the patient's lower limbs are of unequal length, place a support of the correct height under the foot of the shorter side.
- Place the superior edge of the IR 1½ to 2 inches (3.8 to 5 cm) above the shoulders on an average patient. This positions the IR so that T7 appears near the center of the image and all thoracic vertebrae are shown.
- *Shield gonads.*
- *Respiration:* Suspended at the end of full expiration. This minimizes the air in the lungs, which results in less attenuation differences and more uniform exposure of the thoracic anatomy.

Central ray

- Perpendicular to the IR. The center of the central ray should be approximately halfway between the jugular notch and the xiphoid process (see Fig. 9.68).
- Collimate closely to the spine.

Collimation

- Adjust radiation field to 7 × 17 inches (18 × 43 cm) on the collimator. Place the side marker in the collimated exposure field.

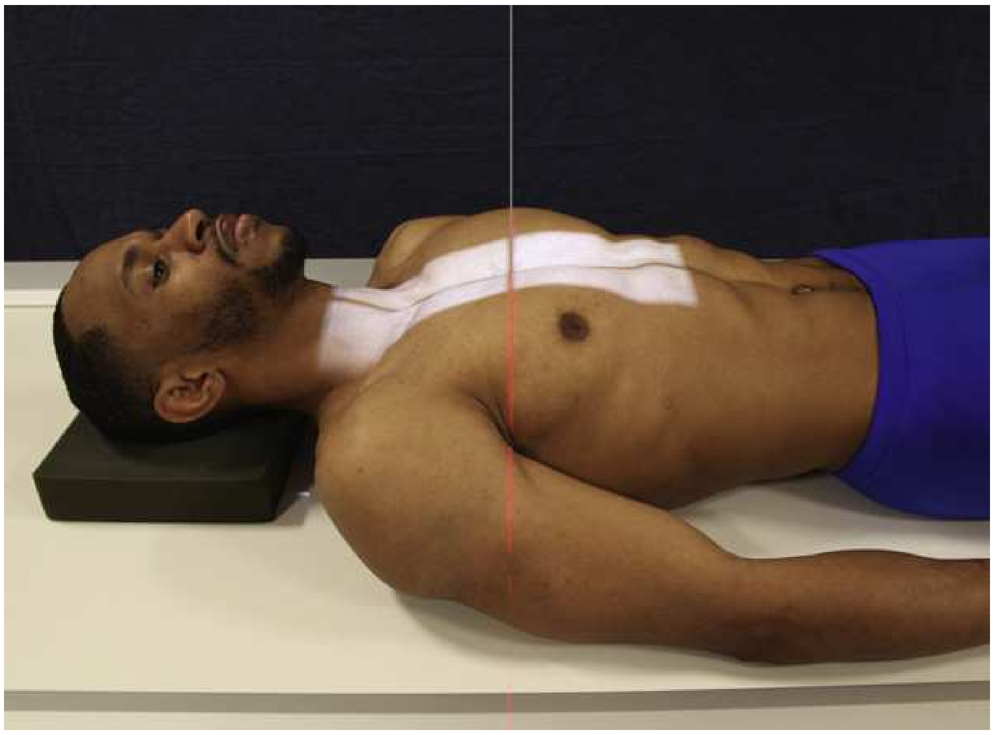


FIG. 9.68 AP thoracic vertebrae.

The patient is lying in a supine position. A support is placed under the head. The patient's arms are placed along the sides of the body and the shoulders lie in the same horizontal plane. The central ray is directed perpendicular to the I R.

NOTE: As suggested by Fuchs,[16] a more uniform exposure of the thoracic vertebrae can be obtained if the "heel effect" of the tube is used (Figs. 9.69 and 9.70). With the tube positioned so that the cathode end is toward the feet, the greatest percentage of radiation goes through the thickest part of the thorax.

Structures shown

The thoracic bodies, intervertebral disk spaces, transverse processes, costovertebral articulations, and surrounding structures (see Fig. 9.69). The thoracic spine can be difficult to evaluate with radiography for extremely large patients and those with a fluid-filled chest. CT is often used to see the vertebrae in detail (Fig. 9.71).

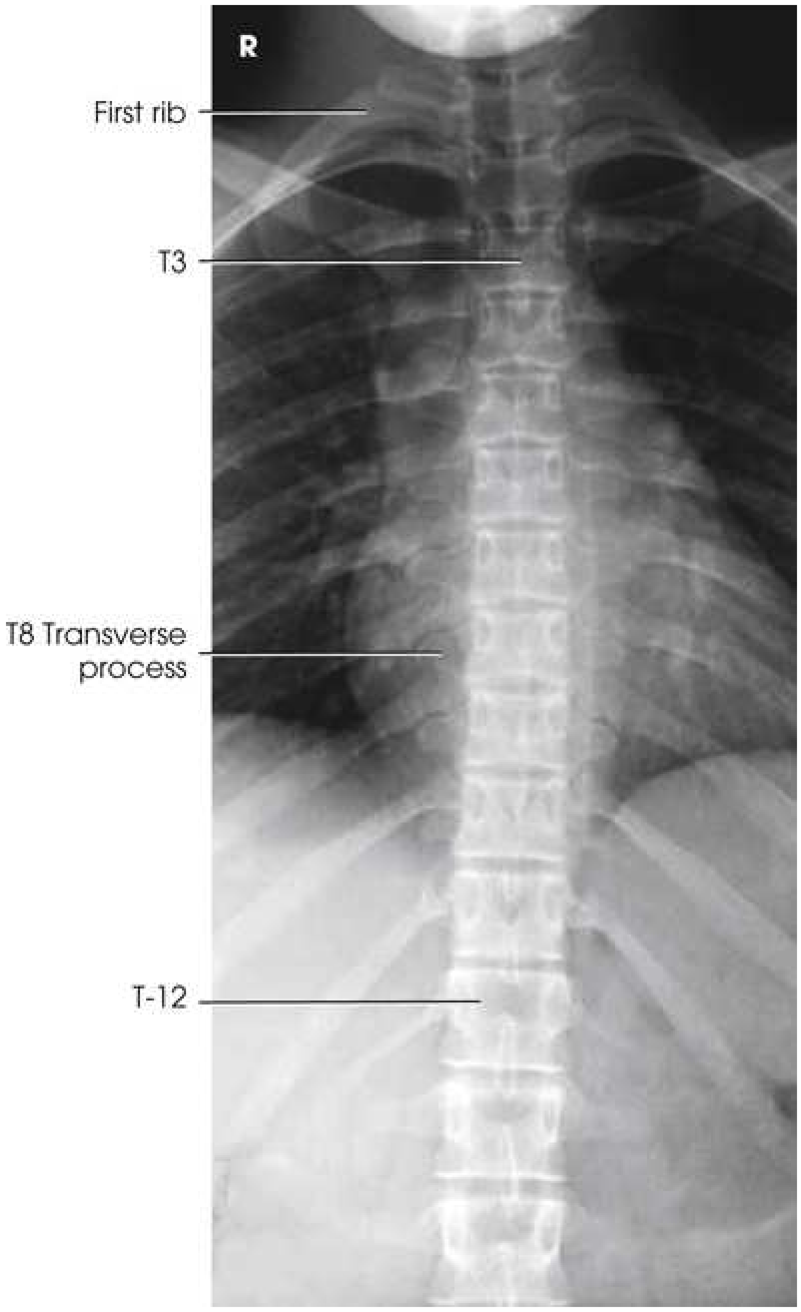


FIG. 9.69 Cathode end of x-ray tube over lower thorax (more uniform exposure).

An x-ray shows all 12 thoracic vertebrae. The vertebral column is aligned to the middle of the image. The parts labeled are marked from top to the bottom as follows: the first rib, T 3, the T 8 transverse process, and T 12.

FIG. 9.70 Cathode end of x-ray tube over upper thorax (nonuniform exposure).

Compensating Filter

This projection can be improved significantly with the use of a compensating filter. Various wedge filters are available to assist in providing an even exposure of the entire thoracic spine, without the need to window.

Evaluation Criteria

The following should be clearly seen:

- Evidence of proper collimation and presence of the side marker placed clear of anatomy of interest
- All 12 thoracic vertebrae
- No rotation as demonstrated by spinous processes at the midline of the vertebral bodies
- Vertebral column aligned to the middle of the image
- Bony trabecular detail and surrounding soft tissues

FIG. 9.71 CT thin-section scan thoracic spine shows unstable injury at T-5 after car accident. *Arrowheads* show various fractures.

Lateral Projection

Right or left position

Image receptor + grid: Positioned by manufacturer or department protocol for proper anatomy display orientation; CR plate: 14 × 17 inches (35 × 43 cm) lengthwise.

Position of patient

- Place the patient in the lateral recumbent position. (*Note:* Oppenheimer [17] also suggests the use of the upright position.)
- If possible, use the left lateral position to place the heart closer to the IR, which minimizes superimposition of the vertebrae by the heart.
- Have the patient dressed in an open-backed gown so that the vertebral column can be exposed for adjustment of the position.

Position of part

- Place a firm pillow under the patient's head to keep the long axis of the vertebral column horizontal.
- Flex the patient's hips and knees to a comfortable position.
- Place the superior edge of the IR 1½ to 2 inches (3.8 to 5 cm) above the relaxed shoulders. Center the posterior half of the thorax to the midline of the grid and at the level of T7 (Fig. 9.72). T7 is at the inferior angle of the scapulae.
- With the patient's knees exactly superimposed to prevent rotation of the pelvis, a small sponge or cloth may be placed between the knees.
- Adjust the patient's arms at right angles to the long axis of the body to elevate the ribs enough to clear the intervertebral foramina.
- If the long axis of the vertebral column is not horizontal, elevate the lower or upper thoracic region with a radiolucent support (Fig. 9.73). This is the *preferred method.*
- *Shield gonads.*
- *Respiration:* The exposure can be made while the patient continues to breathe normally, the "breathing technique," to blur the pulmonary vascular markings and ribs or after breathing is suspended at the end of expiration.

- When the breathing technique is used, the patient should be instructed not to move during the exposure. An increased exposure time, preferably 2 to 3 seconds (with a corresponding decrease in mA), is needed to ensure the pulmonary vasculature and ribs will be blurred.

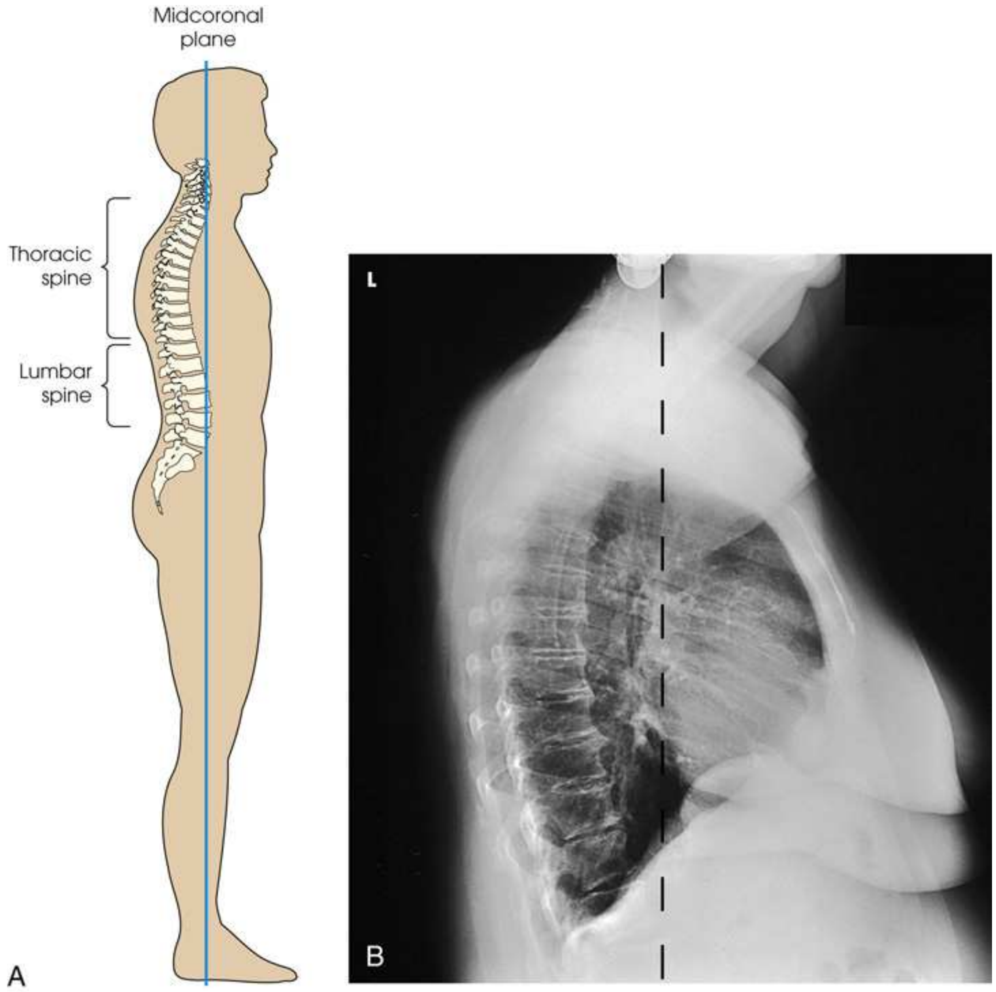


FIG. 9.72 (A) Lateral view of body showing midcoronal plane. The plane divides the thorax in half, and thoracic vertebrae lie in posterior half. Centering for lateral thoracic vertebrae is on posterior half of thorax. (B) Lateral chest showing entire thorax. Thoracic vertebrae are located in posterior half of thorax.

Diagram (A) shows the lateral view of the body showing the midcoronal plane. The plane divides the thorax in half, and thoracic vertebrae lie in the posterior half. Centering for lateral thoracic vertebrae is on the posterior half of the thorax. (B) shows the lateral chest with the entire thorax. It appears dark and the surrounding region appears radiopaque.

Central ray

- Perpendicular to the center of the IR at the level of T7 (inferior angles of the scapulae). The central ray enters the *posterior half* of the thorax.
- If the vertebral column is not elevated to a horizontal plane when the patient is in a recumbent position, angle the tube to direct the central ray perpendicular to the long axis of the thoracic column, and then center it at the level of T7. An average angle of 10 degrees cephalad is sufficient in most female patients; an average angle of 15 degrees is satisfactory in most male patients because of their greater shoulder width (Fig. 9.74). Fig. 9.75 shows positioning of the central ray for an upright lateral thoracic spine.

FIG. 9.73 Recumbent lateral thoracic spine. Support placed under lower thoracic region; perpendicular central ray. This is the preferred method of positioning.

The patient lying in the lateral recumbent position with his back facing front. A support is placed under the head to elevate it. A support is placed under the lower thoracic region. The side marker is in the collimated exposure field. The central ray is perpendicular to the center of the I R at the level of T 7.

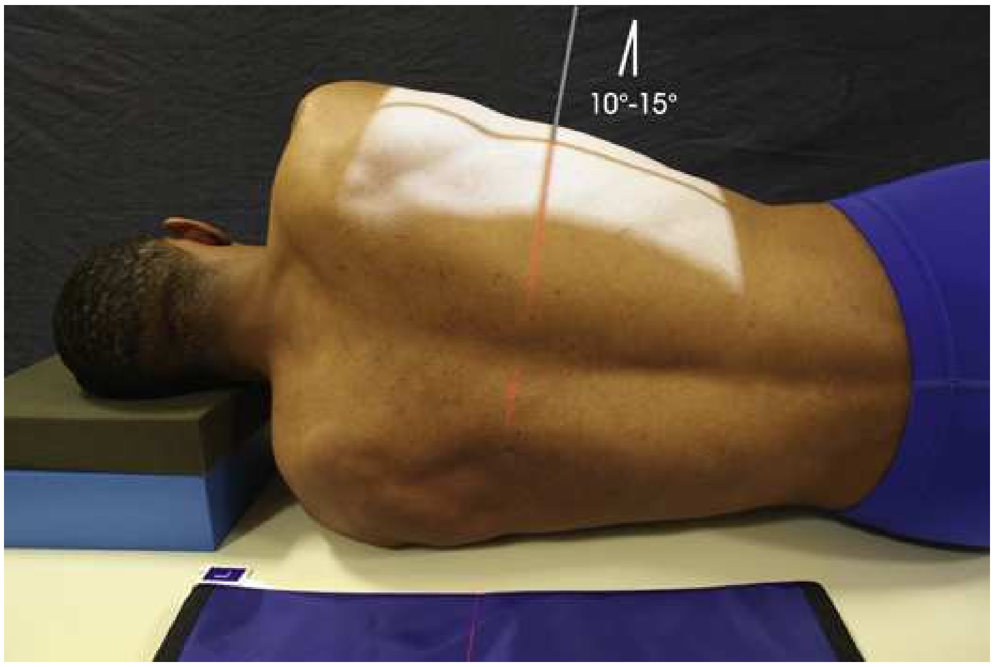


FIG. 9.74 No support under lower thoracic spine; central ray angled 10 to 15 degrees cephalad.

The patient lying in the lateral recumbent position with his back facing front. A support is placed under the head to elevate it. The side marker is in the collimated exposure field. The central ray is angled 10 to 15 degrees cephalad.

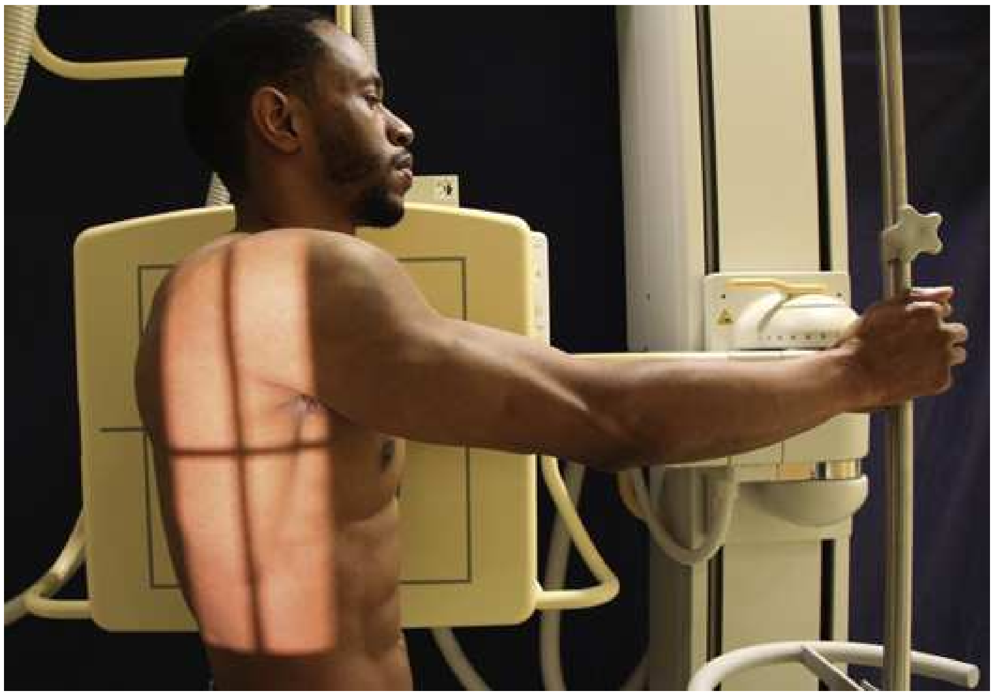


FIG. 9.75 Upright lateral thoracic spine.

The patient is standing with his lateral arm against the vertical grid facing left. The other arm is extended and is grasping the support in front of him. The central ray is directed perpendicular at the level of T 1.

Collimation

- Adjust the radiation field to 7 × 17 inches (18 × 43 cm) on the collimator. Place the side marker in the collimated exposure field.

Improving radiographic quality

In addition to close collimation, the quality of the radiographic image can be improved in several ways. A 48-inch (112-cm) or greater SID is recommended to reduce the magnification inherent in this image, because OID of the thoracic spine is significant in this projection. In addition, if a sheet of leaded rubber is placed on the table behind the patient (see Figs. 9.73 and 9.74), the lead absorbs the scatter radiation coming from the patient and prevents table scatter from affecting the image. Scatter radiation decreases the quality of the radiograph and darkens the image of the spinous processes. More important, with automatic exposure control (AEC), the scatter radiation coming from the patient is often sufficient to terminate the exposure prematurely. The resulting image may be underexposed because of the effect of the scatter radiation on the AEC device.

Structures shown

The thoracic bodies, intervertebral disk spaces, intervertebral foramina, and lower spinous processes. Because of the overlapping shoulders, the upper vertebrae may not be shown in this position (Figs. 9.76 and 9.77). If the upper thoracic area is of interest, a *swimmer's lateral* may be included with the examination. The younger the patient, the easier it is to show the upper thoracic bodies.

Evaluation Criteria

The following should be clearly seen:

- Evidence of proper collimation, posterior field shielding and presence of the side marker placed clear of anatomy of interest
- Vertebrae clearly seen through rib and lung shadows
- Twelve thoracic vertebrae centered on the IR. Superimposition of the shoulders on the upper vertebrae may cause underexposure in this area. The number of vertebrae visualized depends on the size and shape of the patient. T1 to T3 are not well seen.
- Ribs superimposed posteriorly to indicate that the patient was not rotated
- Open intervertebral disk spaces
- Bony trabecular detail and surrounding soft tissues

FIG. 9.76 Lateral thoracic spine. (A) Suspended respiration with exposure of 1⁄2 second. (B) Breathing technique with exposure of 11⁄2 seconds. Note that lung's vascular markings are blurred.

(A) An x-ray shows the thoracic bodies, intervertebral disk spaces, intervertebral foramina, and lower spinous processes. (B) An x-ray shows the thoracic bodies, intervertebral disk spaces, intervertebral foramina, and lower spinous processes. The outlines of the intervertebral discs appear white. The lung's vascular markings are blurred.

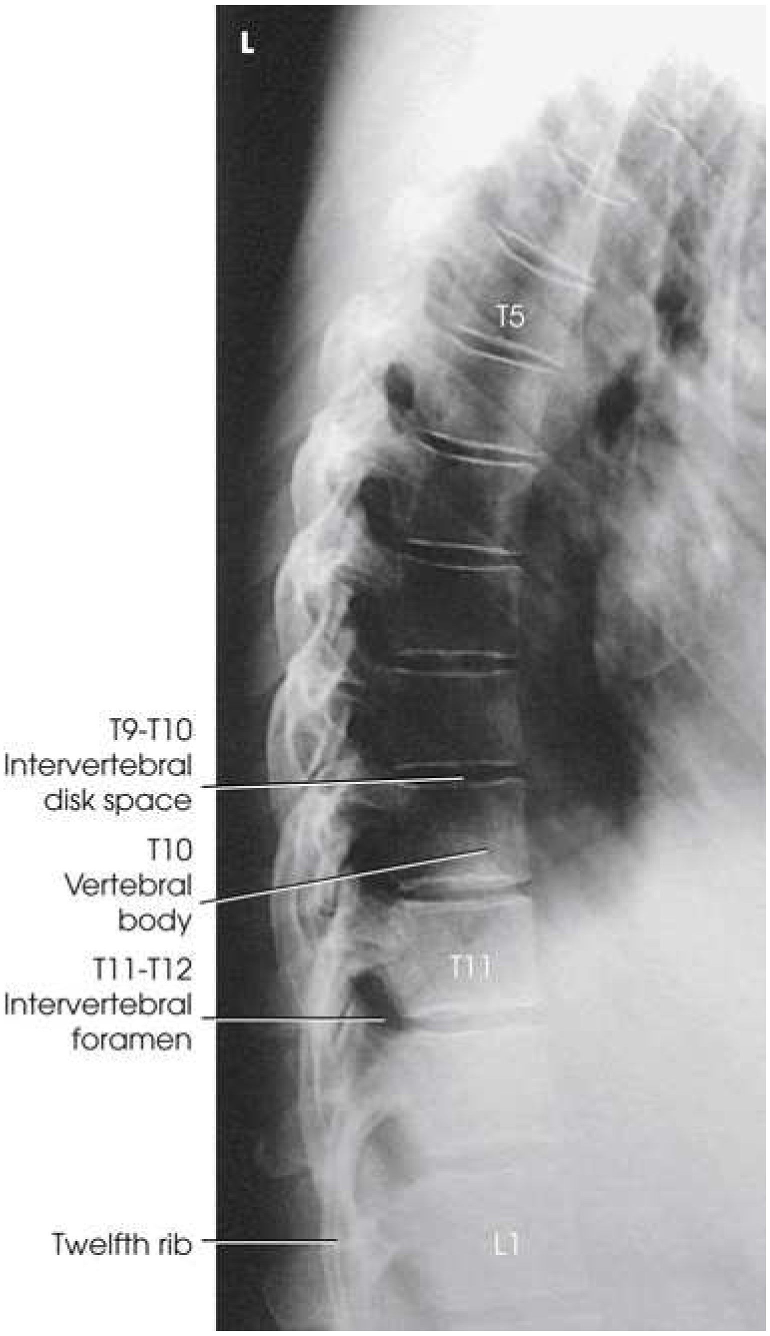


FIG. 9.77 Lateral thoracic spine with breathing technique.

An x-ray shows the Vertebrae that is clearly seen through rib and lung shadows. The parts labeled are marked from top to the bottom as follows: T 9 to T 10 intervertebral disk space, T 10 vertebral body, T 11 to T12 intervertebral foramen, and twelfth rib.

Thoracic Zygapophyseal Joints

Ap Or Pa Oblique Projection

RAO and LAO or RPO and LPO

Upright and recumbent positions

The thoracic zygapophyseal joints are examined using PA oblique projections, as recommended by Oppenheimer, [17] or using AP oblique projections, as recommended by Fuchs. [18] The joints are well shown with either projection. AP obliques show the joints *farthest* from the IR, and PA obliques show the joints *closest* to the IR. Although the difference in OID between the two projections is not great, the same rotation technique is used bilaterally.

Upright position

Image receptor + grid: Positioned by manufacturer or department protocol for proper anatomy display orientation; CR plate: 14 × 17 inches (35 × 43 cm) lengthwise.

Position of patient

- Place the patient, standing or sitting upright, in a lateral position before a vertical grid.

Position of part

- Rotate the body 20 degrees anterior (PA oblique) or posterior (AP oblique) so that the coronal plane forms an angle of 70 degrees from the plane of the IR.
- Center the patient's vertebral column to the midline of the grid, and have the patient rest the adjacent shoulder firmly against it for support.
- Adjust the height of the IR 1½ to 2 inches (3.8 to 5 cm) above the shoulders to center the IR to T7.
- For the PA oblique, flex the elbow of the arm adjacent to the grid and rest the hand on the hip. For the AP oblique, the arm adjacent to the grid is brought forward to avoid superimposing the humerus on the upper thoracic vertebrae.
- For the PA oblique, have the patient grasp the side of the grid device with the outer hand (Fig. 9.78). For the AP oblique, have the patient place the outer hand on the hip.
- Adjust the patient's shoulders to lie in the same horizontal plane.
- Have the patient stand straight to place the long axis of the vertebral column parallel with the IR.
- The weight of the patient's body must be equally distributed on the feet, and the head must not be turned laterally.
- *Shield gonads.*
- *Respiration:* Suspend at the end of expiration.

NOTE: See p. 440 for the Summary of Oblique Projections.

FIG. 9.78 PA oblique thoracic zygapophyseal joints: RAO for joints closest to the IR.

The patient sitting next to the vertical grid is grasping the side of the grid device with the outer hand. The patient's vertebral column is centered to the midline of the grid. The central ray is perpendicular to the IR entering the level of T 7.

Recumbent position

Image receptor + grid: Positioned by manufacturer or department protocol for proper anatomy display orientation; CR plate: 14 × 17 inches (35 × 43 cm) lengthwise.

Position of patient

- Place the patient in a lateral recumbent position.
- Elevate the head on a firm pillow so that its MSP is continuous with that of the vertebral column.
- Flex the patient's hips and knees to a comfortable position.

Position of part

- For the PA oblique, place the lower arm behind the back and the upper arm forward with the hand on the table for support (Fig. 9.79).
- For the AP oblique, adjust the lower arm at right angles to the long axis of the body, flex the elbow, and place the hand under or beside the head. Place the upper arm posteriorly and support it (Fig. 9.80).
- Rotate the body slightly, either anteriorly or posteriorly 20 degrees, so that the coronal plane forms an angle of 70 degrees with the horizontal.
- Center the vertebral column to the midline of the grid.
- Center the IR 1½ to 2 inches (3.8 to 5 cm) above the shoulders to center it at the level of T7.
- If needed, apply a compression band across the hips, but be careful not to change the position.
- *Shield gonads.*
- *Respiration:* Suspend at the end of expiration.

Central ray

- Perpendicular to the IR exiting or entering the level of T7

Collimation

- Adjust radiation field to 7 × 17 inches (18 × 43 cm) on the collimator. Place the side marker in the collimated exposure field.

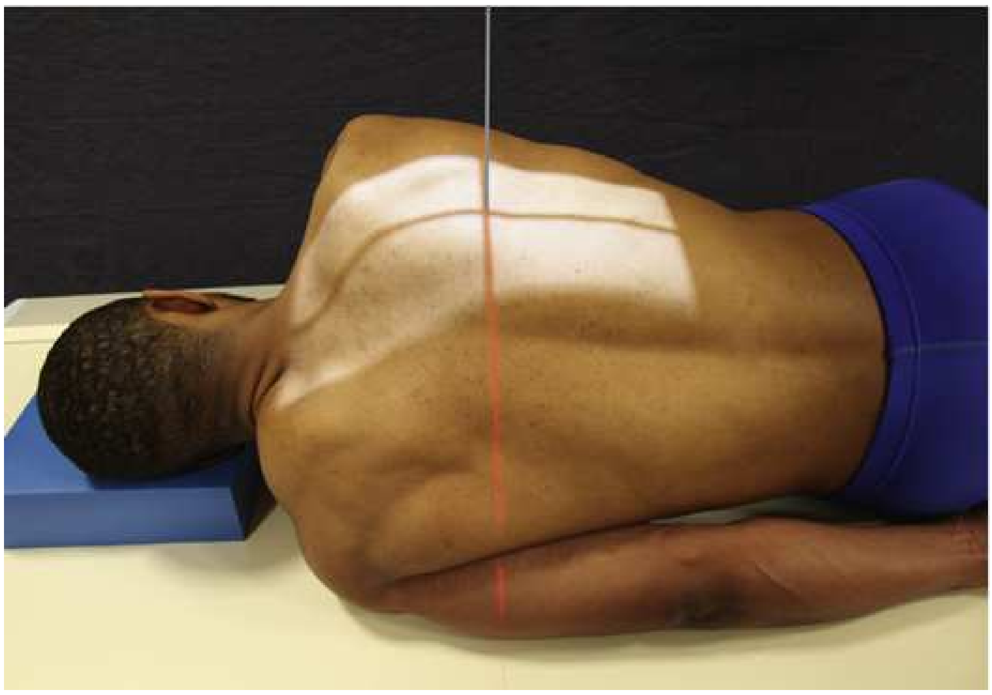


FIG. 9.79 PA oblique thoracic zygapophyseal joints: LAO for joints closest to the IR.

The patient is lying in a lateral recumbent position. The lower arm is behind the back and the upper arm is forward. A support is placed under the head. The central ray is perpendicular to the I R exiting or entering the level of T 7.

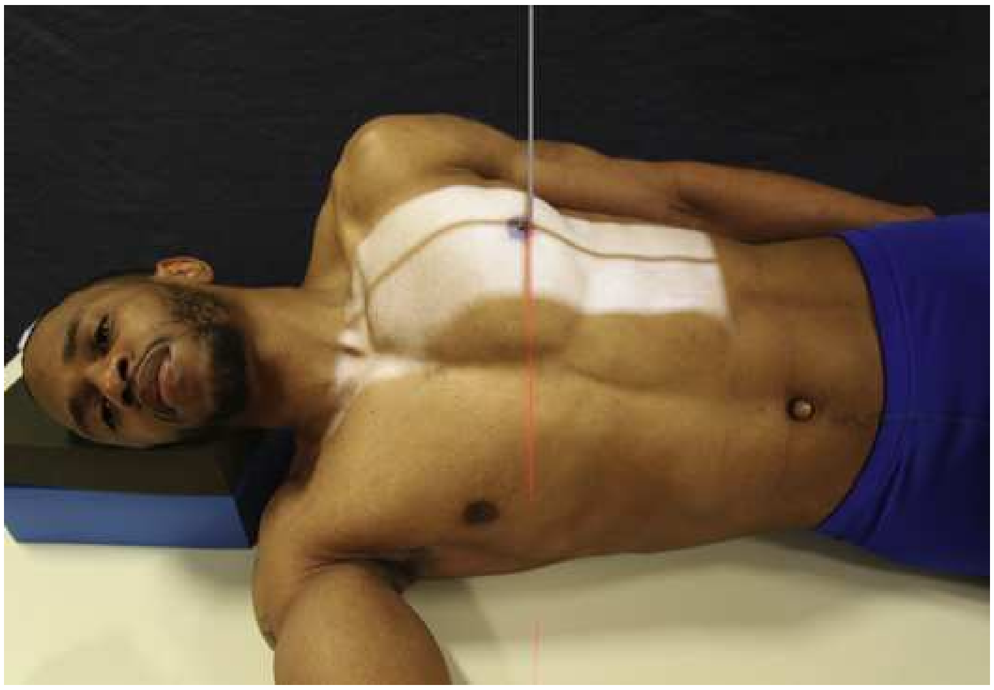


FIG. 9.80 AP oblique thoracic zygapophyseal joints: RPO for joints farthest from the IR.

The patient is lying in a lateral recumbent position. The elbow is flexed and the upper arm is placed posteriorly. A support is placed under the head. The central ray is perpendicular to the I R exiting or entering the level of T 7.

Structures shown

The thoracic zygapophyseal joints (*arrows* on Figs. 9.81 and 9.82). The number of joints shown depends on the thoracic curve. A greater degree of rotation from the lateral position is required to show the joints at the proximal and distal ends of the region in patients with an accentuated dorsal kyphosis. The inferior articular processes of T12, having an inclination of about 45 degrees, are not shown in this projection. (See the Summary of Oblique Projections on p. 440.)

Evaluation Criteria

The following should be clearly seen:

- Evidence of proper collimation and presence of the side marker placed clear of anatomy of interest
- All 12 thoracic vertebrae
- Zygapophyseal joints closest to the IR on PA obliques and the joints farthest from the IR on AP obliques
- Bony trabecular detail and surrounding soft tissues

NOTE: The AP oblique projection shows the cervicothoracic spinous processes well and is used for this purpose when the patient cannot be satisfactorily positioned for a direct lateral projection.

FIG. 9.81 Upright PA oblique thoracic zygapophyseal joints: LAO position. *Arrow* indicates articulation that is closest to the IR.

FIG. 9.82 Recumbent AP oblique thoracic zygapophyseal joints: RPO position. *Arrow* indicates articulation that is farthest from the IR.

An x-ray shows the thoracic zygapophyseal joints and all twelve vertebrae. The articulations appear radiopaque. It appears like a white dot on all intervertebral columns. It is indicated by a white arrow.

Lumbar-Lumbosacral Vertebrae

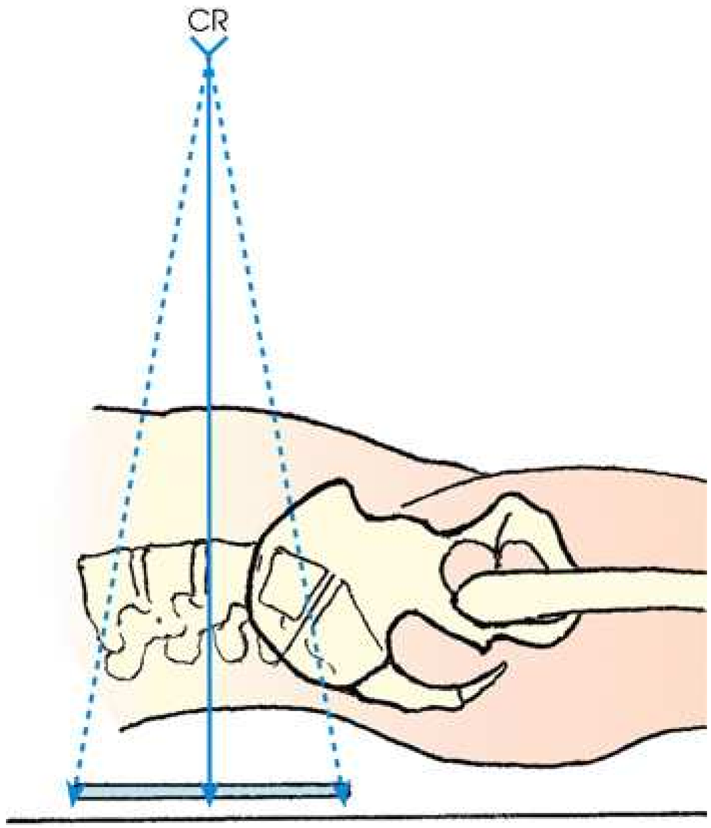


FIG. 9.83 Lumbar spine showing intervertebral disk spaces are not parallel; diverging CR.

Ap Projection

PA Projection (Optional)

If possible, gas and fecal material should be cleared from the intestinal tract for examination of bones lying within the abdominal and pelvic regions. The urinary bladder should be emptied just before the examination to eliminate superimposition caused by the secondary radiation generated within a filled bladder.

An AP or PA projection may be used, but the AP projection is more commonly employed. The AP projection is generally used for recumbent examinations. The extended limb position accentuates the lordotic curve, resulting in distortion of the bodies and poor delineation of the intervertebral disk spaces (Figs. 9.83 and 9.84). This curve can be reduced by flexing the patient's hips and knees enough to place the back in firm contact with the radiographic table (Figs. 9.85 and 9.86).

The PA projection places the intervertebral disk spaces at an angle closely paralleling the divergence of the beam of radiation (Fig. 9.87; also see Fig. 9.84C). This projection also reduces the dose to the patient by decreasing the abdominal thickness when prone, which requires less mAs, and by placing the gonads farther from the beam entrance to the body. However, this position does result in a slight increase in bone marrow dose in the spine. [19]

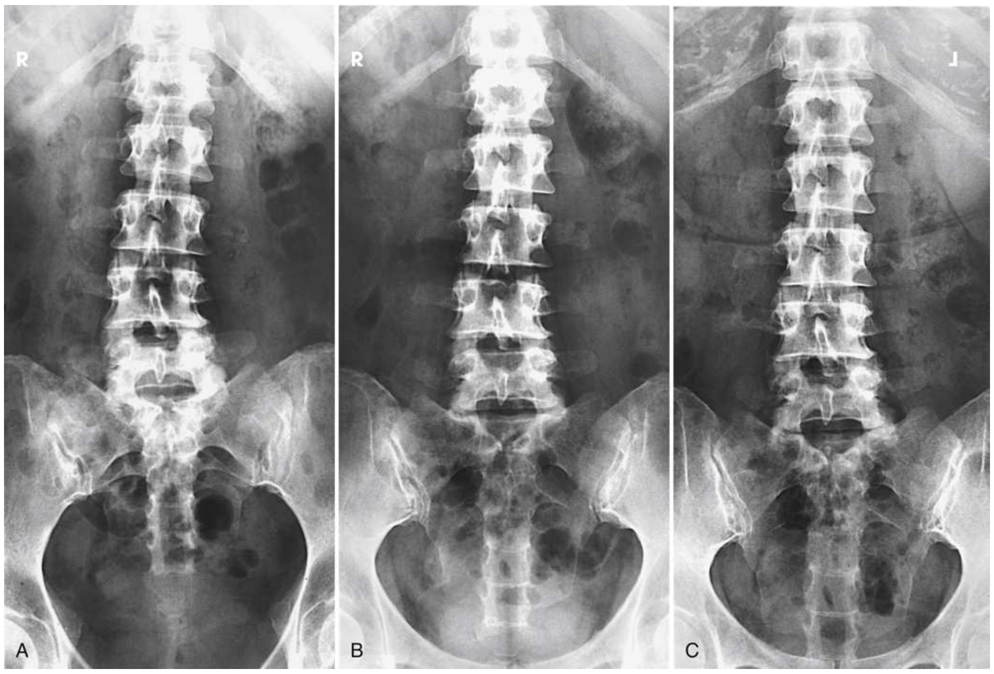


FIG. 9.84 Lumbar spine: AP and PA comparison on same patient. (A) AP with limbs extended. (B) AP with limbs flexed. (C) PA.

(A) An x-ray shows a curved lumbar spine. (B) An x-ray shows a less curved lumbar spine. (C) An x-ray shows a slight increase in bone marrow dose in the spine. The vascular structures appear radiolucent.

Special positioning

- If a patient is having *severe* back pain and a radiographic room with a tilting table is available, place a footboard on the radiographic table, and stand the table upright before beginning the examination.
- Have the patient stand on the footboard and position the part for the projection.
- Turn the table to the horizontal position for the exposure and return it to the upright position for the next projection.
- Although this procedure takes a few minutes, the patient appreciates the decrease in pain.

Image receptor + grid: Positioned by manufacturer or department protocol for proper anatomy display orientation; CR plate: 14 × 17 inches (35 × 43 cm) lengthwise.

SID:

48 inches (122 cm) is suggested to reduce distortion and open the intervertebral disk spaces more completely.

Position of patient

- Examine the lumbar or lumbosacral spine with the patient recumbent.

Position of part

- Center the MSP of the patient's body to the midline of the grid.
- Adjust the patient's shoulders and hips to lie in the same horizontal plane.
- Flex the patient's elbows and place the hands on the upper chest so that the forearms do not lie within the exposure field.
- A radiolucent support under the lower pelvic side can be used to reduce rotation when necessary.
- Reduce lumbar lordosis by flexing the patient's hips and knees enough to place the back in firm contact with table (see Fig. 9.86).
- To show the lumbar spine and sacrum, center the 14 × 17 inches (35 × 43 cm) IR at the level of the iliac crests (L4).
- To show the lumbar spine only, center the IR 1.5 inches (3.8 cm) above the iliac crest (L3).
- *Shield gonads.*
- *Respiration:* Suspend at the end of expiration.

Central ray

- Perpendicular to the IR at the level of the iliac crests (L4) for a *lumbosacral* examination or 1.5 inches (3.8 cm) above the iliac crest for the lumbar spine only

Collimation

- Adjust to 8 × 17 inches (18 × 43 cm) on the collimator for the lumbosacral spine. Ensure that the sacroiliac joints are included. For lumbar spine only, collimation can be reduced to 8 × 14 inches (18 × 35 cm). Place the side marker in the collimated exposure field.

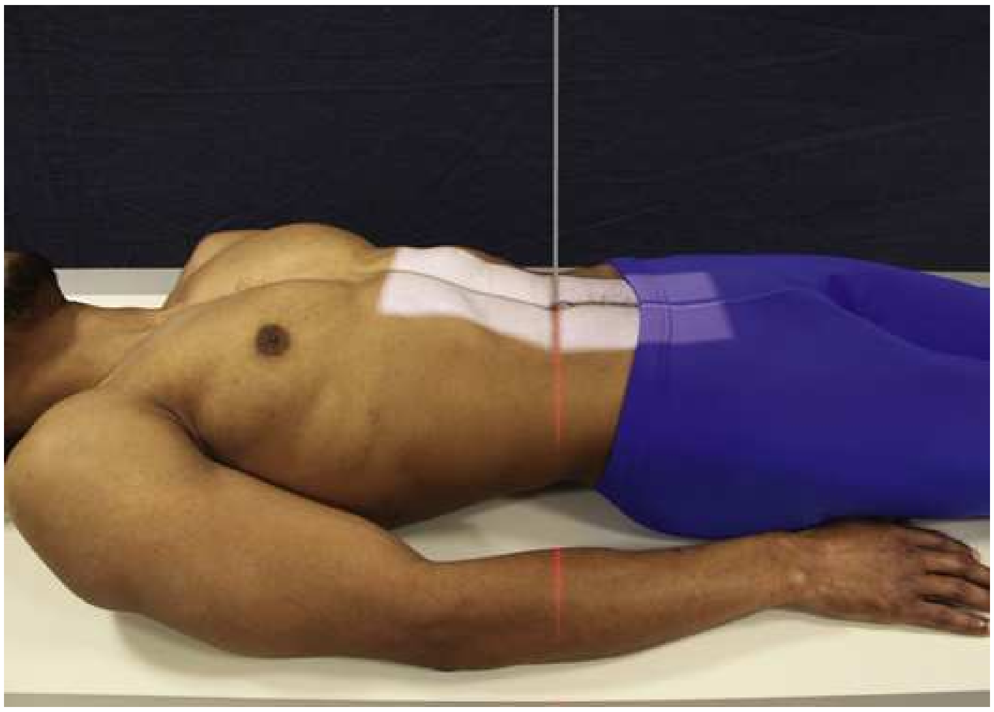


FIG. 9.85 AP lumbar spine with limbs extended, creating increased lordotic curve.

A patient is in a supine position. The back is placed in firm contact with the radiographic table. The patient's shoulders and hips lie in the same horizontal plane. The central ray is directed perpendicular to the I R at the level of the iliac crests.

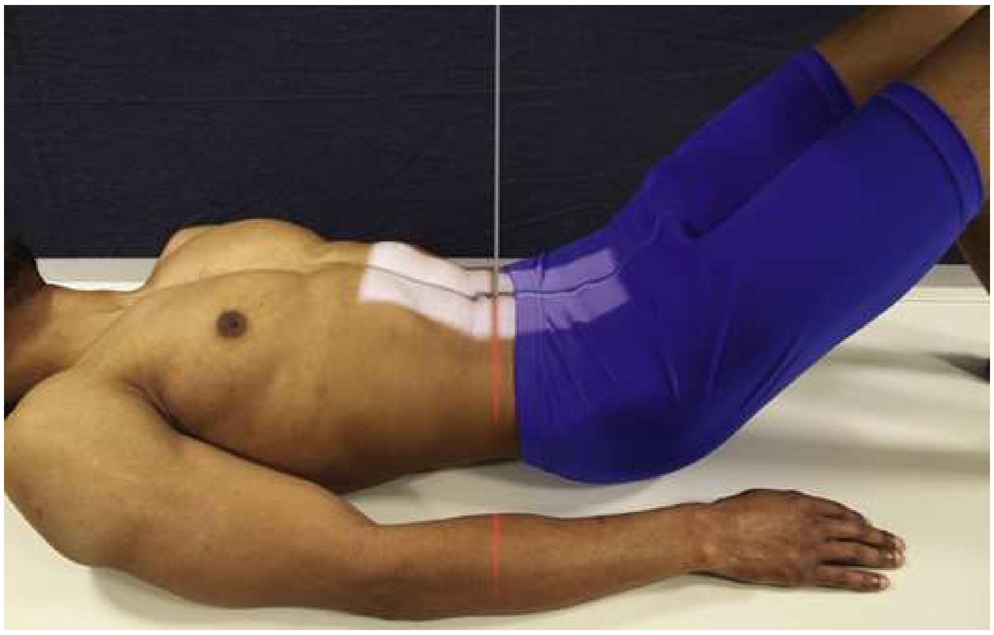


FIG. 9.86 AP lumbar spine with limbs flexed, decreasing lordotic curve.

A patient is in a supine position. The back of the patient is placed in firm contact with the radiographic table. The patient's hip and knee are flexed. The central ray is directed perpendicular to the I R at the level of the iliac crests.

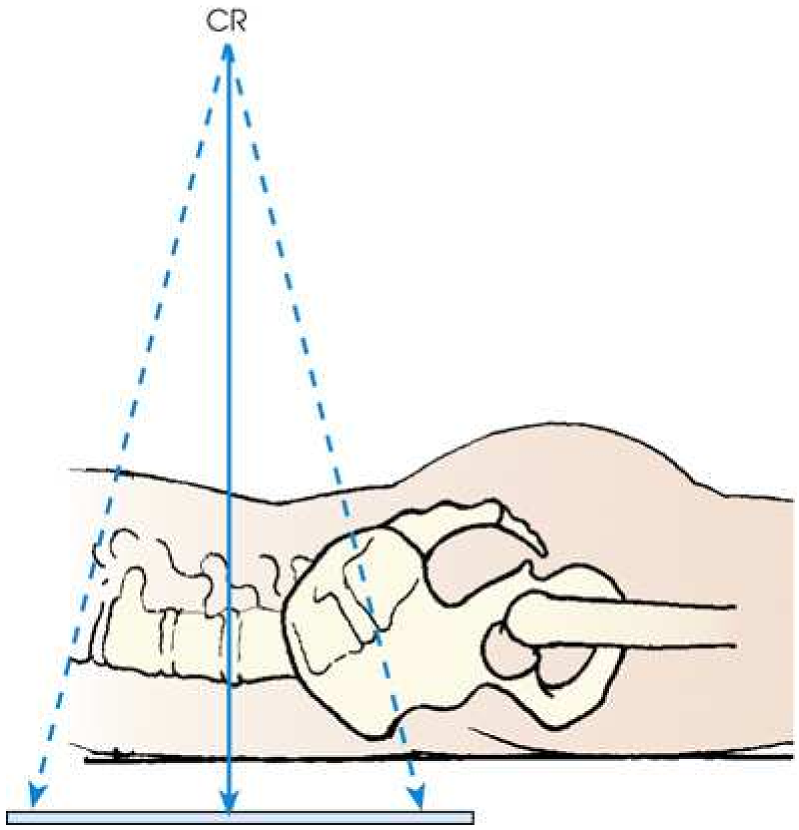


FIG. 9.87 Lumbar spine showing intervertebral disk spaces nearly parallel with divergent PA x-ray beam.

Structures shown, AP and PA

The lumbar bodies, intervertebral disk spaces, interpediculate spaces, laminae, and spinous and transverse processes (Fig. 9.88). The images may include one or two of the lower thoracic vertebrae, the sacrum, coccyx, and the pelvic bones. Because of the angle at which the last lumbar segment joins the sacrum, this lumbosacral disk space is not shown well in the AP projection. The projections used for this purpose are described later in this chapter.

CT (Fig. 9.89) and magnetic resonance imaging (MRI) are used often to identify pathology.

Evaluation Criteria

The following should be clearly seen:

- Evidence of proper collimation and presence of the side marker placed clear of anatomy of interest
- Area from the lower thoracic vertebrae to the sacrum
- X-ray beam collimated to the lateral margin of the psoas muscles
- No artifact across the midabdomen from any elastic in the patient's underclothing
- No rotation
  - Symmetric vertebrae, with spinous processes centered to the bodies
  - Sacroiliac joints equidistant from the vertebral column
- Open intervertebral disk spaces
- Bony trabecular detail and surrounding soft tissues

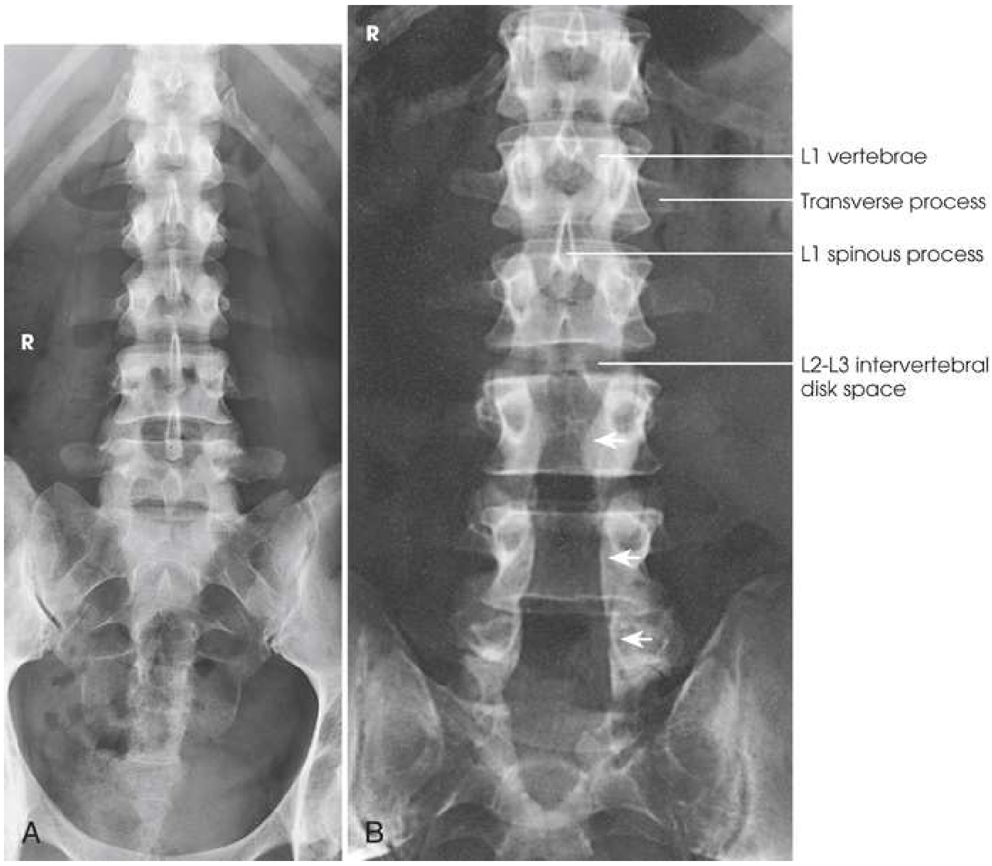


FIG. 9.88 AP lumbosacral spine. (A) Close collimation technique. (B) AP lumbar spine showing spina bifida *(arrows)*.

(A) An x-ray shows the lumbar bodies, intervertebral disk spaces, interpediculate spaces, laminae, and spinous and transverse processes. It appears hazy. (B) An x-ray shows a lumbar spine with spina bifida which are indicated by arrows. The lower part gets wider. The parts labeled are marked from top to the bottom as follows: L 1 vertebrae, transverse process, L 1 spinous process, and L 2 to L 3 intervertebral disk space.

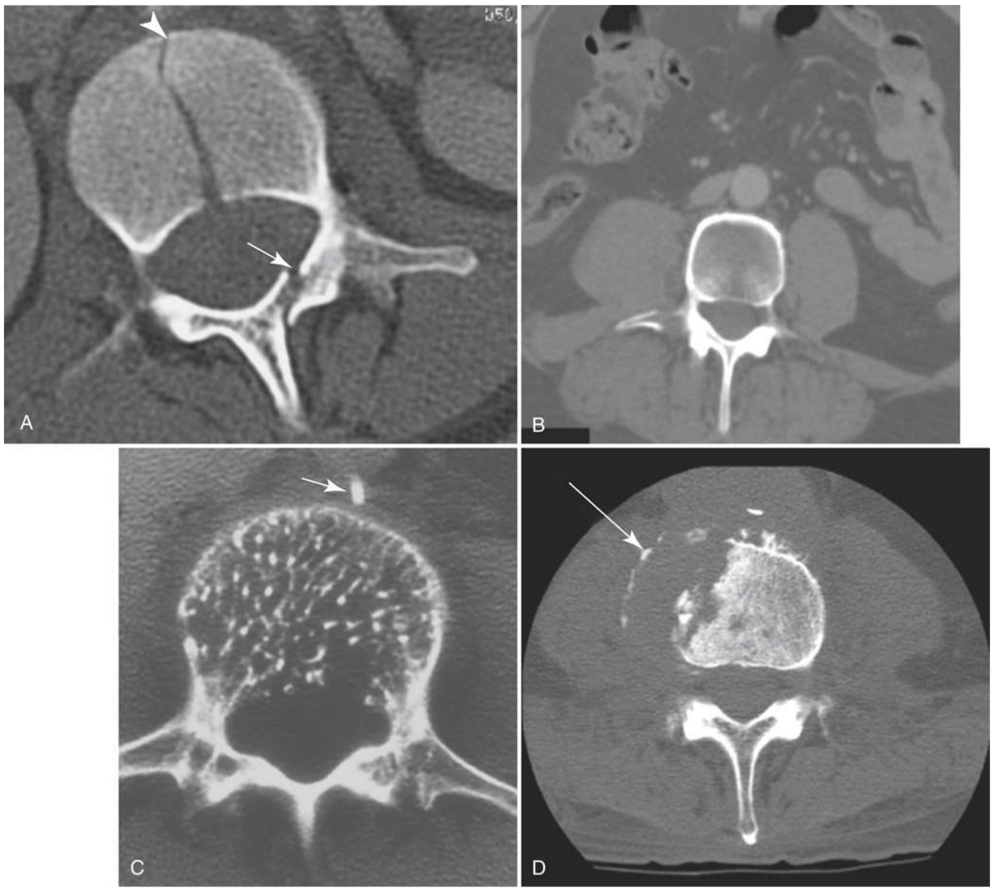


FIG. 9.89 Value of using CT for further evaluation of lumbar spine. Axial images. (A) Burst fracture of L2. Fracture of vertebral body *(arrowhead)* and fracture of left lamina *(arrow)*. (B) Fracture of transverse process of L4. (C) Hemangioma of L3 with no involvement of pedicles or laminae. *Arrow* points to catheter in common third artery for CT angiography. (D) Osteomyelitis seen in L3. *Arrow* points to tuberculous abscess with paravertebral calcification in wall.

(A) A C T image shows burst fracture of the ring-like structure. It is indicated by a white arrow. The fracture in the circular upper part is indicated by an arrowhead. (B) A C T image shows a fracture of the transverse process. Its outline appears white. The fracture site appears grey. (C) A C T image shows the hemangioma of L 3. An arrow points to a catheter. It is dome-shaped and has many white grainy dots on it. (D) A C T image shows a tuberculous abscess with paravertebral calcification in the wall. An arrow points at an irregular white curve on the left side.

Lateral Projection

Right or left position

Image receptor + grid: Positioned by manufacturer or department protocol for proper anatomy display orientation; CR plate: 14 × 17 inches (35 × 43 cm) lengthwise.

Position of patient

- For the lateral position, use the same body position (recumbent or upright) as for the AP or PA projection.
- Have the patient dressed in an open-backed gown so that the spine can be exposed for final adjustment of the position.

Position of part

- Ask the patient to turn onto the affected side and flex the hips and knees to a comfortable position.
- When examining a thin patient, adjust a suitable pad under the dependent hip to relieve pressure.
- Align MCP of the body to the midline of the grid and ensure that it is vertical. On most patients, the long axis of the bodies of the lumbar spine is situated in the midcoronal plane (Fig. 9.90).
- With the patient's elbow flexed, adjust the dependent arm at right angles to the body.
- To prevent rotation, superimpose the knees exactly, and place a small sponge or cloth between them.
- Place a suitable radiolucent support under the lower thorax, then adjust it so that the long axis of the spine is *horizontal* (Fig. 9.91A). This is the *preferred method* of positioning the spine.
- Center the IR at the level of the iliac crest (L4) for the lumbosacral spine.
- To show the lumbar spine only, center the IR 1.5 inches (3.8 cm) above the iliac crest (L3).
- *Shield gonads.*

- *Respiration:* Suspend at the end of expiration.

Central ray

- Perpendicular; at the level of the iliac crest (L4) for the lumbosacral spine or 1.5 inches (3.8 cm) above the iliac crest (L3) for the lumbar spine only. The central ray enters the midcoronal plane (see Fig. 9.91A).
- When the spine cannot be adjusted so that it is horizontal, angle the central ray caudad so that it is perpendicular to the long axis (see Fig. 9.91B). The degree of central ray angulation depends on the angulation of the lumbar column and the breadth of the pelvis. In most instances, an average caudal angle of 5 degrees for men and 8 degrees for women with a wide pelvis is used. CR placement must be adjusted slightly based on the angle used.

Collimation

- Adjust radiation field to 8 × 17 inches (18 × 43 cm) on the collimator. For lumbar spine only, collimation can be reduced to 8 × 14 inches (18 × 35 cm). Place the side marker in the collimated exposure field.

Structures shown

The lumbar bodies and their intervertebral disk spaces, the spinous processes, and the lumbosacral junction (Fig. 9.92). This projection gives a profile image of the intervertebral foramina of L1–L4. The L5 intervertebral foramina (right and left) are not usually well seen in this projection because of their oblique direction. Consequently, oblique projections are used for these foramina.

Evaluation Criteria

The following should be clearly seen:

- Evidence of proper collimation and presence of the side marker placed clear of anatomy of interest
- Area from the lower thoracic vertebrae to the coccyx for lumbosacral spine procedure
- Area from the lower thoracic vertebrae to proximal sacrum for lumbar only
- Vertebrae aligned down the middle of the image
- No rotation
  - Superimposed posterior margins of each vertebral body
  - Nearly superimposed crests of the ilia when the x-ray beam is not angled
  - Spinous processes in profile
- Open intervertebral disk spaces and intervertebral foramina (L1–L4)
- Bony trabecular detail and surrounding soft tissues

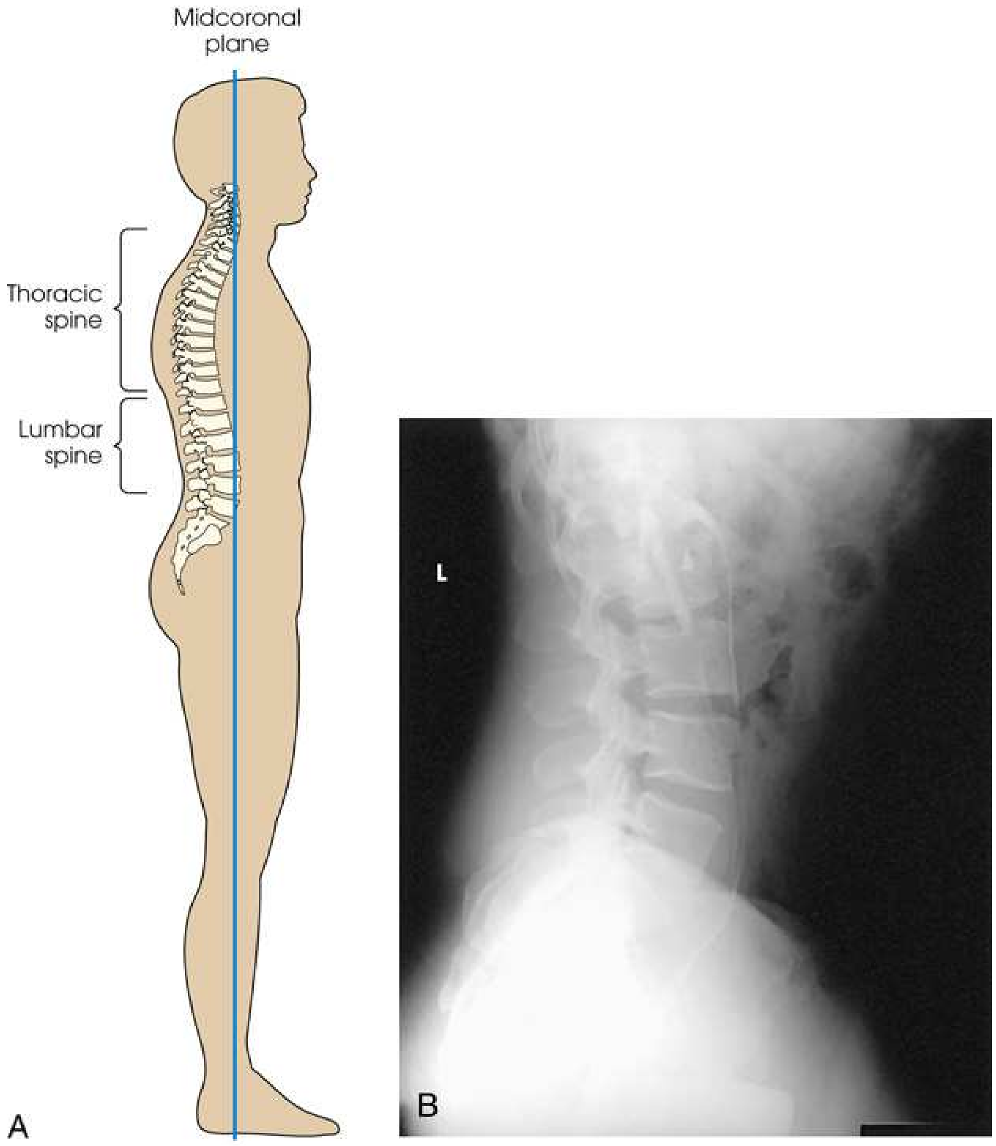


FIG. 9.90 (A) Lateral view of body showing midcoronal plane. The plane goes through lumbar bodies. (B) Lateral abdomen showing lumbar bodies located near midcoronal plane.

Diagram (A) shows the lateral view of the body showing the midcoronal plane. The plane divides the thorax in half, and thoracic vertebrae lie in the posterior half. Centering for lateral thoracic vertebrae is on the posterior half of the thorax. (B) An x-ray shows lumbar bodies located near the midcoronal plane. It appears radiopaque and hazy.

Improving radiographic quality

In addition to close collimation, the quality of the radiographic image can be improved in several ways. A 48-inch (112-cm) or greater SID is recommended to reduce the magnification inherent in this image, because OID of the lumbar spine is significant in this projection. In addition, if a sheet of leaded rubber is placed on the table behind the patient (see Fig. 9.91), the lead absorbs scatter radiation coming from the patient and prevents table scatter. Scatter radiation decreases the quality of the radiograph and darkens the image of the spinous processes. More important, with AEC, scatter radiation coming from the patient is often sufficient to terminate the exposure prematurely. As a result, the image may be underexposed.

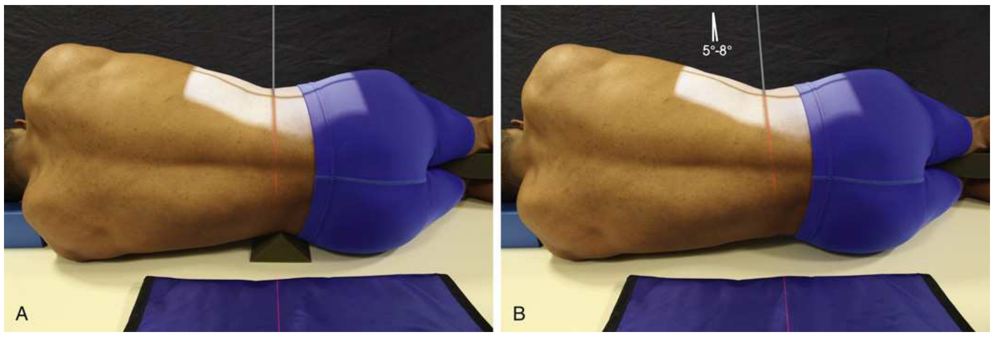


FIG. 9.91 Lateral lumbar spine. (A) Horizontal spine and perpendicular central ray. This is the preferred method of positioning. (B) Spine is angled and central ray is directed caudad to be perpendicular to long axis of spine.

(A) The patient is lying on the affected side. The hips and knees are flexed. A support is placed under the lower thorax. The central ray is perpendicular at the level of the iliac crest. (B) The patient is lying on the affected side. The hips and knees are flexed. The central ray is directed caudad at an angle of 5 to 8 degrees perpendicular to the long axis of the spine.

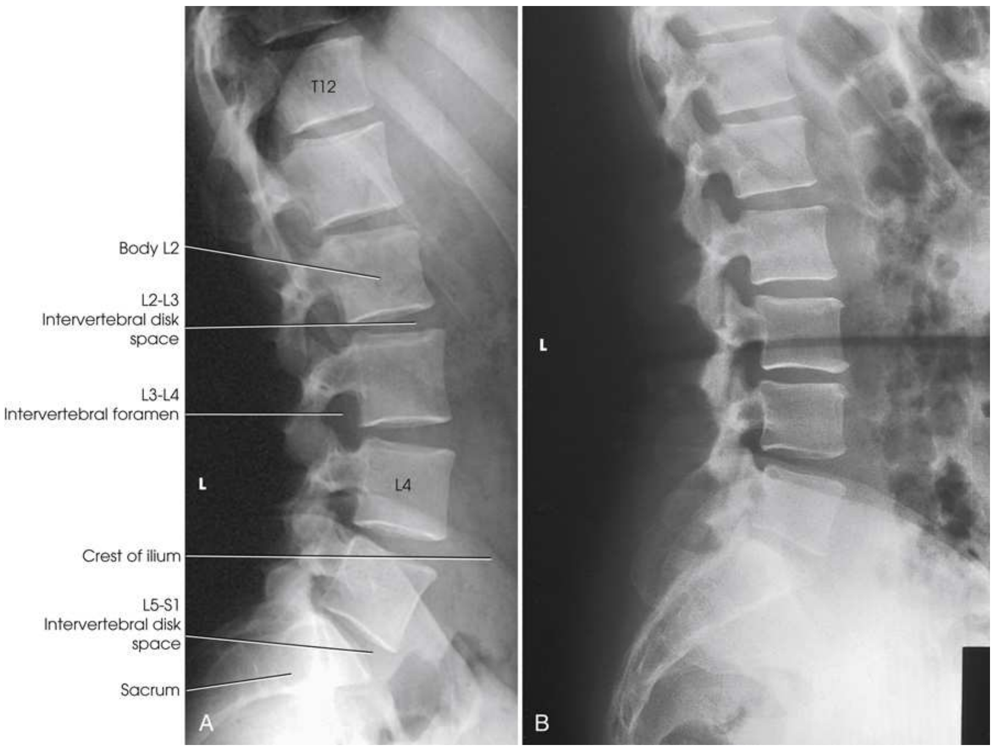


FIG. 9.92 (A) Lateral lumbar spine, 11 × 14 inches (28 × 35 cm) IR. (B) Lateral lumbosacral spine, 14 × 17 inches (35 × 43 cm) IR.

(A) An x-ray shows the lateral lumbar spine. The parts labeled are marked from top to the bottom as follows: body L 2, L 2 to L 3 intervertebral disk space, T 12, L 4 L3 to L4 intervertebral foramen, crest of ilium, L 5 to S 1 intervertebral disk space, and sacrum. (B) An x-ray shows the lumbar bodies and their intervertebral disk spaces, the spinous processes, and the lumbosacral junction. The intervertebral disk spaces are open. The lower region appears radiopaque.

L5–S1 Lumbosacral Junction

Lateral Projection

Right or left position

Image receptor + grid: Positioned by manufacturer or department protocol for proper anatomy display orientation; CR plate: 10 × 12 inches (24 × 30 cm) lengthwise.

Position of patient

- Examine the L5–S1 lumbosacral region with the patient in the lateral recumbent position.

Position of part

- With the patient in the recumbent position, adjust the pillow to place the MSP of the head in the same plane with the spine.
- Adjust MCP of the body (passing through the hips and shoulders) aligned perpendicular to the IR.
- Flex the patient's elbow and adjust the dependent arm in a position at right angles to the body (Fig. 9.93A).
- Flex the patient's hips and knees, superimpose the knees, and place a support between them.
- As described for the lateral projection, place a radiolucent support under the lower thorax and adjust it so that the long axis of the spine is *horizontal* (see Fig. 9.93A). This is the *preferred method.*
- *Shield gonads.*
- *Respiration:* Suspend.

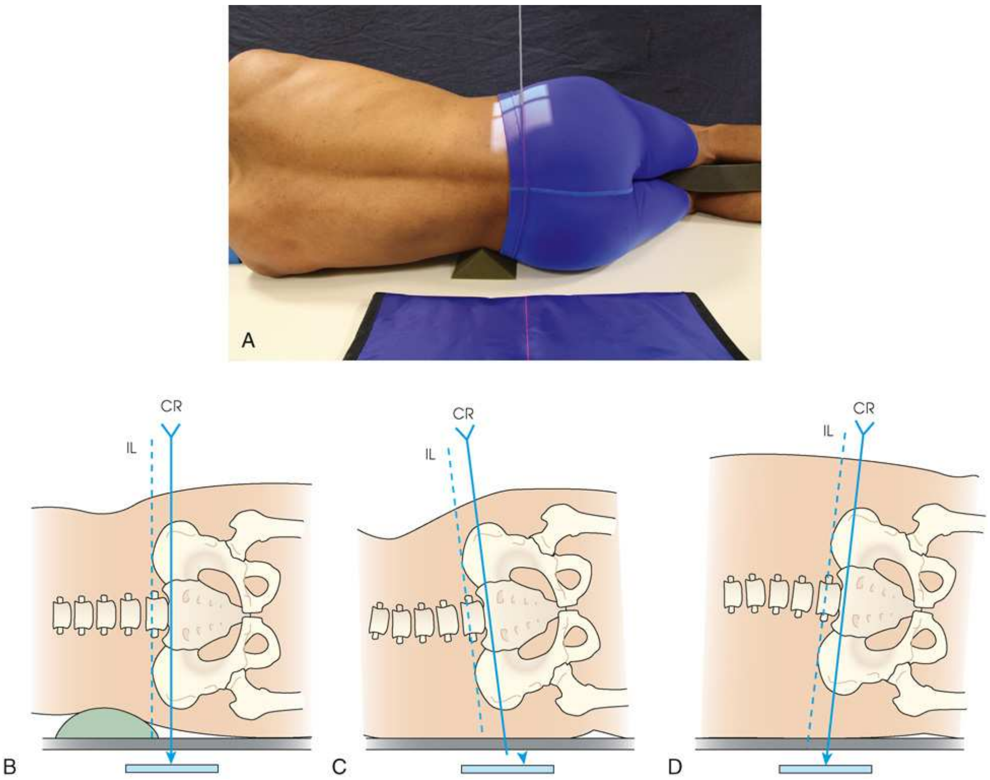


FIG. 9.93 (A) Lateral L5–S1. (B) Optimal L5–S1 joint position. Lower abdomen is blocked to place spine parallel with the IR. Interiliac *(IL)* line is perpendicular, and CR is perpendicular. (C) Typical lumbar spine curvature. If blocking cannot be used, angle CR caudad and parallel to IL. (D) Typical lumbar spine position in a patient with a large waist. IL shows that CR must be angled cephalad to open joint space.
Modified from Francis C. Method improves consistency in L5–S1 joint space films. *Radiol Technol.* 1992;63:302.

(A) The patient is in the recumbent position. The hips and knees are flexed. A support is placed under the lower thorax. The central ray is perpendicular and is centered to the I R. Diagram (B) shows the patient is in the recumbent position. A support is placed under the lower thorax. The central ray is perpendicular and is centered to the I R. Diagram (C) shows the patient is in the recumbent position. The C R is angled caudad and parallel to the iliac crest. Diagram (D) shows the patient with a large waist in the recumbent position. The C R is angled cephalad to the open joint space.

Central ray

- The elevated anterior superior iliac spine (ASIS) is easily palpated and found in all patients when lying on the side. The ASIS provides a standardized and accurate reference point from which to center the L5–S1 junction.
- Center on a coronal plane 2 inches (5 cm) posterior to the ASIS and 1.5 inches (3.8 cm) inferior to the iliac crest.
- Center the IR to the central ray.
- When the spine cannot be positioned horizontal, the central ray is angled 5 degrees caudally for male patients and 8 degrees caudally for female patients.
- Francis [20] identified an alternative technique to show the open L5–S1 intervertebral disk space when the spine is not horizontal:
    1. With the patient in the lateral position, locate both iliac crests.
    2. Draw an imaginary line between the two points (interiliac plane).
    3. Adjust central ray angulation to be parallel with the interiliac line (see Fig. 9.93B–D).

Collimation

• Adjust radiation field to 6 × 8 inches (15 × 20 cm) on the collimator. This is a high-scatter projection. Close collimation is essential. Place the side marker in the collimated exposure field.

Structures shown

The lumbosacral junction, the lower one or two lumbar vertebrae, and the upper sacrum (Fig. 9.94).

Evaluation Criteria

The following should be clearly seen:

- Evidence of proper collimation and presence of the side marker placed clear of anatomy of interest
- Lumbosacral joint in the center of the image
- Open lumbosacral intervertebral disk space
- Crests of the ilia closely superimposing each other when the x-ray beam is not angled
- Bony trabecular detail and surrounding soft tissues

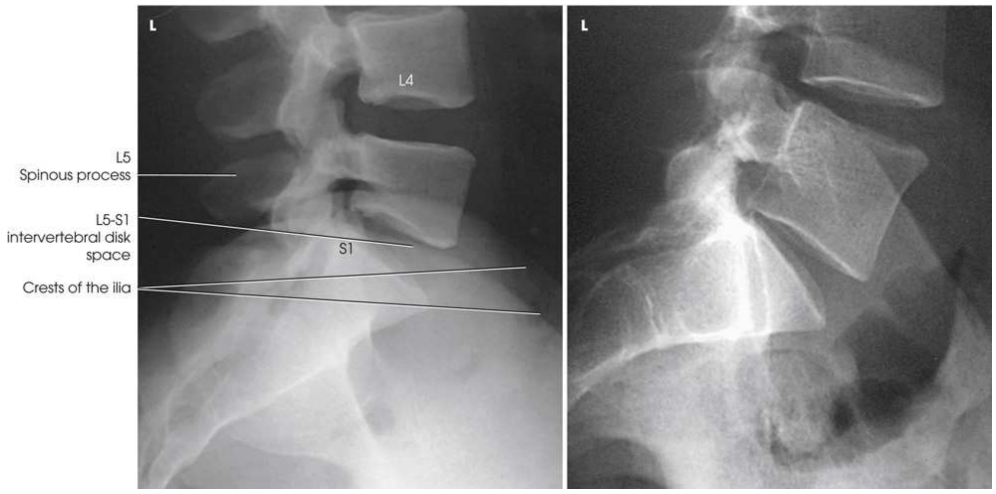


FIG. 9.94 Lateral L5–S1.

Two x-ray shows the Lumbosacral joint in the center of the image. The parts labeled are marked from top to the bottom as follows: L 5 spinous process, L 5 to S 1 intervertebral disk space, and crests of the ilia. The lumbosacral disk space is open. A radiolucent region is on the right of the x-ray on the right.

Lumbar Zygapophyseal Joints

Ap Oblique Projection

RPO and LPO positions

The plane of the zygapophyseal joints of the lumbar vertebrae forms an angle of 30 to 60 degrees to the MSP in most patients. The angulation varies from patient to patient, however, and from cephalad to caudad in the same patient (see Table 9.3). For comparison, both oblique radiographs are obtained.

Image receptor + grid: Positioned by manufacturer or department protocol for proper anatomy display orientation; CR plate: 10 × 12 inches (24 × 30 cm) or 14 × 17 inches (35 × 43 cm) lengthwise.

Position of patient

- When oblique projections are indicated, they are generally performed immediately after the AP projection and in the same body position (recumbent or upright).

Position of part

- Have the patient turn from the supine position toward the side of interest approximately 45 degrees to show the joints *closest* to the IR. An oblique body position 60 degrees from the plane of the IR may be needed to show the L5–S1 zygapophyseal joints.
- Adjust the patient's body so that the long axis of the patient is parallel with the long axis of the radiographic table.
- Center the patient's spine to the midline of the grid. In the oblique position, the lumbar spine lies in the longitudinal plane that passes 2 inches (5 cm) medial to the elevated ASIS.
- Ask the patient to place the arms in a comfortable position. A support may be placed under the elevated shoulder, hip, and knee to avoid patient motion (Figs. 9.95 and 9.96).
- *Shield gonads.*
- *Respiration:* Suspend at the end of expiration.

NOTE: Although the customary 45-degree oblique body position shows most L3–S1 zygapophyseal joint spaces, 25% of L1–L2 and L2–L3 joints are shown on an AP projection, and a small percentage of L4–L5 and L5–S1 joints are seen on a lateral projection. [21]

Central ray

Lumbar region

- Perpendicular to enter 2 inches (5 cm) medial to the elevated ASIS and 1 to 1.5 inches (2.5 to 3.8 cm) above the iliac crest (L3)

L5–S1 zygapophyseal joint

- Perpendicular to enter 2 inches (5 cm) medial to the elevated ASIS and to a point midway between the iliac crest and the ASIS
- Center the IR to the central ray.

Collimation

- Adjust radiation field to:
- 9 × 12 inches (23 × 30 cm) on the collimator for 10 × 12 inches (24 × 30 cm) IR
- 9 × 14 inches (23 × 35 cm) on the collimator for 14 × 17 inches (35 × 43 cm) IR
- 8 × 10 inches (18 × 24 cm) on the collimator for L5–S1 zygapophyseal joint
- Place the side marker in the collimated exposure field.

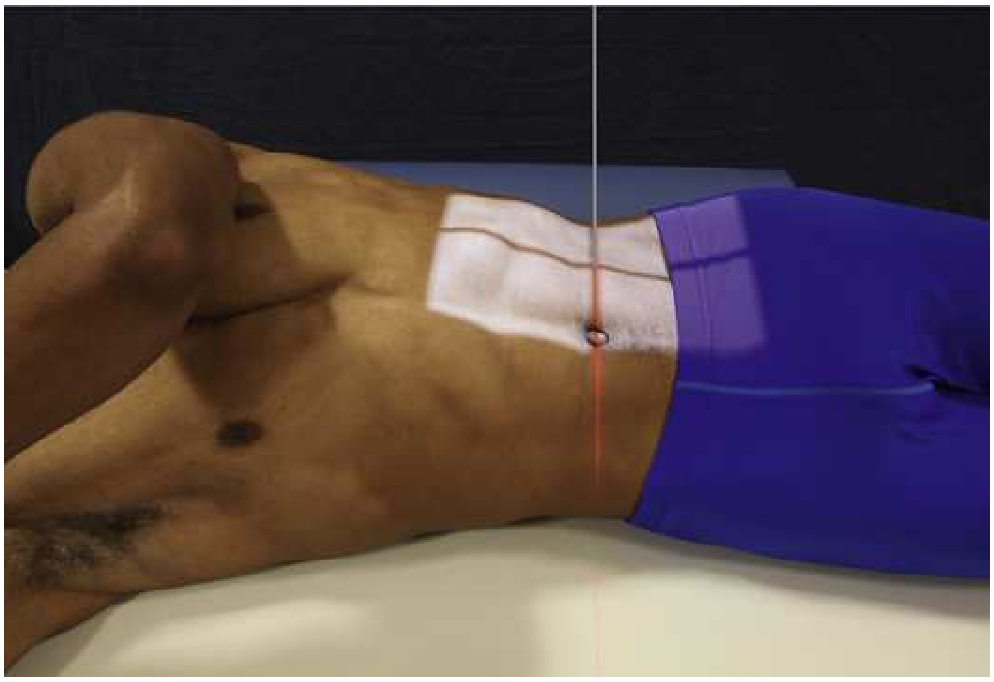


FIG. 9.95 AP oblique lumbar spine: RPO for right zygapophyseal joints.

The patient is turned from the supine position to the side. The long axis of the patient is parallel with the long axis of the radiographic table. The arms are placed away from the body. The central ray is perpendicular to the iliac crest.

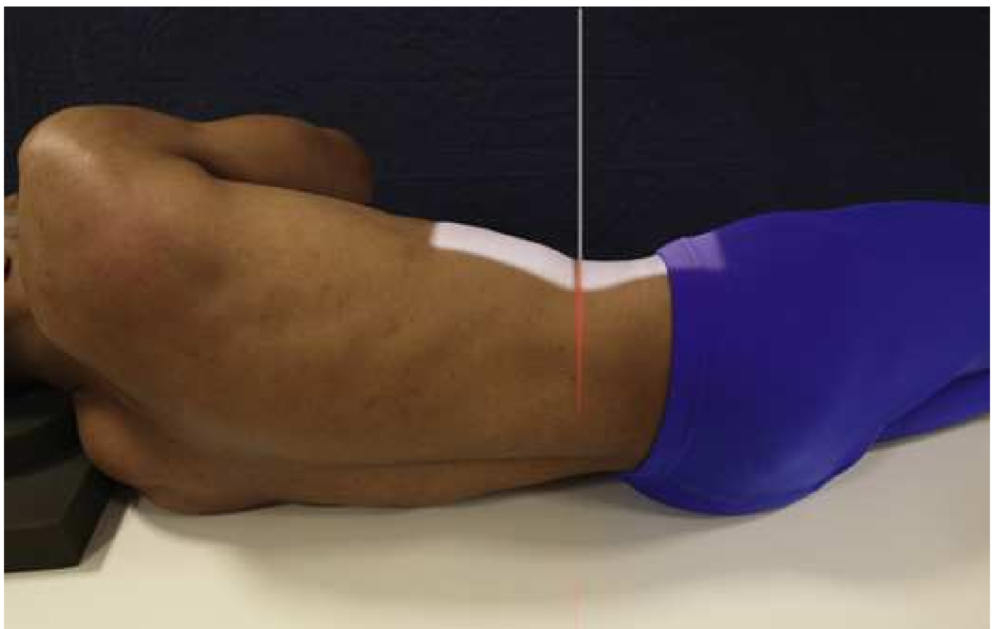


FIG. 9.96 AP oblique lumbar spine: LPO for left zygapophyseal joints.

The patient is turned from the supine position to the side facing the other side. The long axis of the patient is parallel with the long axis of the radiographic table. A support is placed under the head. The arms are placed away from the body. The central ray is perpendicular to the iliac crest.

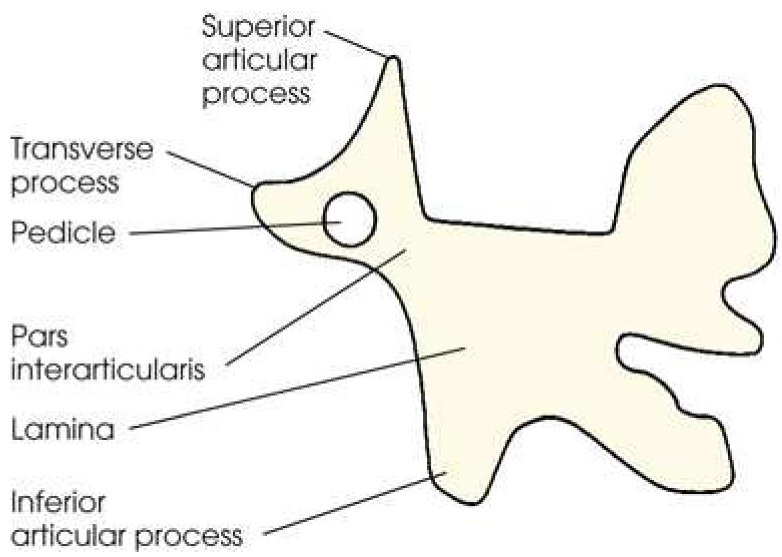


FIG. 9.97 Parts of Scottie dog.

Diagram shows the Scottie dog, the transverse process is the nose. The parts labeled on the diagram are marked from top to the bottom as follows: superior articular process, transverse process, pedicle, pars interarticularis, lamina, and inferior articular process.

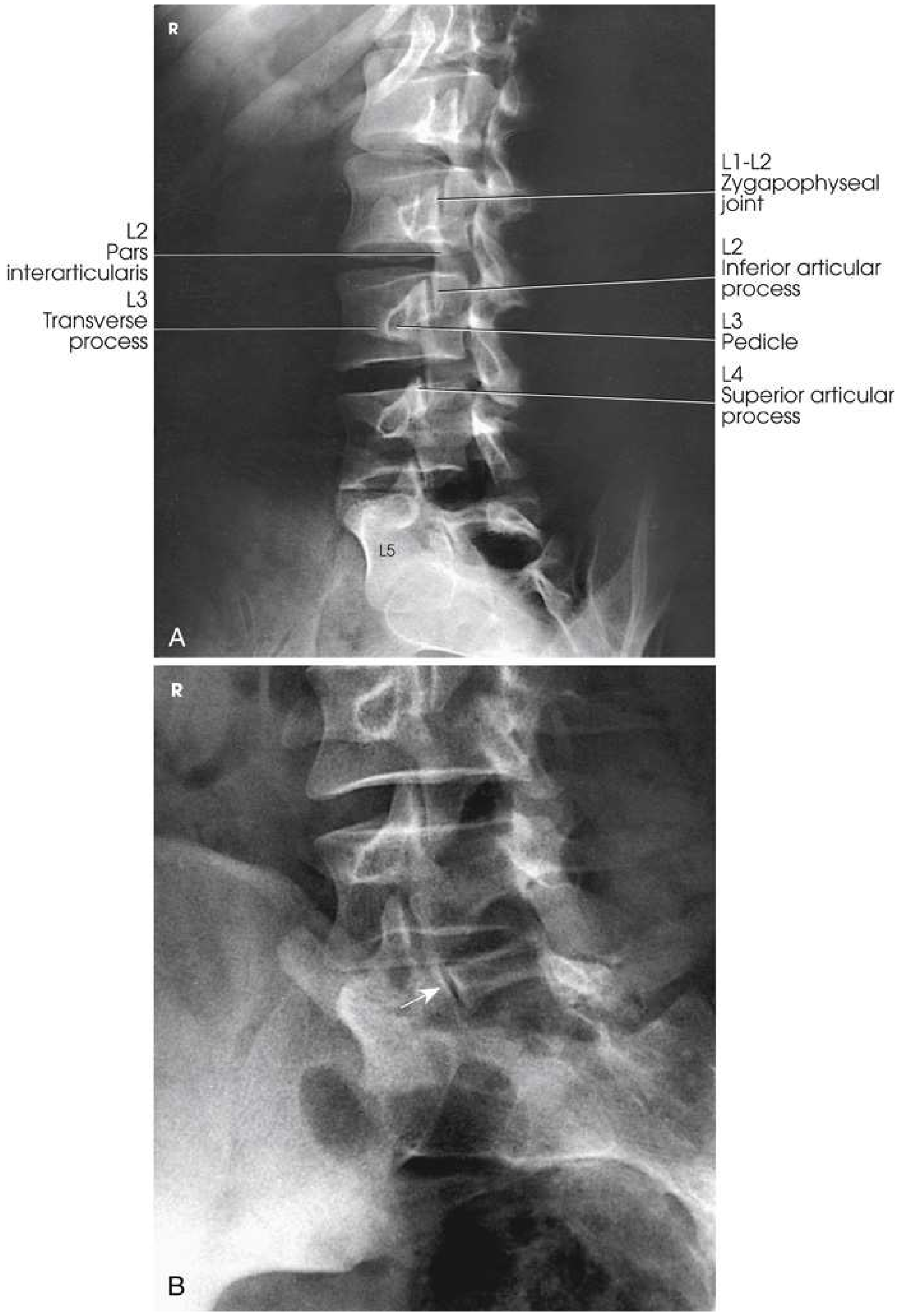


FIG. 9.98 (A) AP oblique lumbar spine: RPO for right zygapophyseal joints. (Note Scottie dogs.) (B) AP oblique lumbar spine: RPO showing L5–S1 zygapophyseal joint *(arrow)* using a 60-degree position.

(A) An x-ray shows the area from the lower thoracic vertebrae to the sacrum. The parts labeled are marked clockwise as follows: L 2 pars interarticularis, L 3 transverse process, L 1 to L 2 zygapophyseal joint, L 2 inferior articular process, L 3 pedicle, and L 4 superior articular process. (B) An x-ray shows the zygapophyseal joints space. It appears dark and is indicated by a white arrow.

Structures shown

The lumbar or lumbosacral spine or both, showing the articular processes of the side *closest* to the IR. Both sides are examined for comparison (Figs. 9.97 and 9.98).

When the body is placed in a 45-degree oblique position and the lumbar spine is radiographed, the articular processes and the zygapophyseal joints are shown. When the patient has been properly positioned, images of the lumbar vertebrae have the appearance of Scottie dogs. See Fig. 9.97 shows the vertebral structures that compose the Scottie dog. (See the Summary of Oblique Projections, p. 440.)

Evaluation Criteria

The following should be clearly seen:

- Evidence of proper collimation and presence of the side marker placed clear of anatomy of interest
- Area from the lower thoracic vertebrae to the sacrum
- Zygapophyseal joints *closest* to the IR—open and uniformly visible through the vertebral bodies
- When the joint is not well seen, and the pedicle is *anterior* on the vertebral body, the patient is not rotated enough (Fig. 9.99A).
- When the joint is not well seen, and the pedicle is *posterior* on the vertebral body, the patient is rotated too much (see Fig. 9.99B).
- Vertebral column parallel with the tabletop so that T12–L1 and L1–L2 intervertebral joint spaces remain open
- Bony trabecular detail and surrounding soft tissues

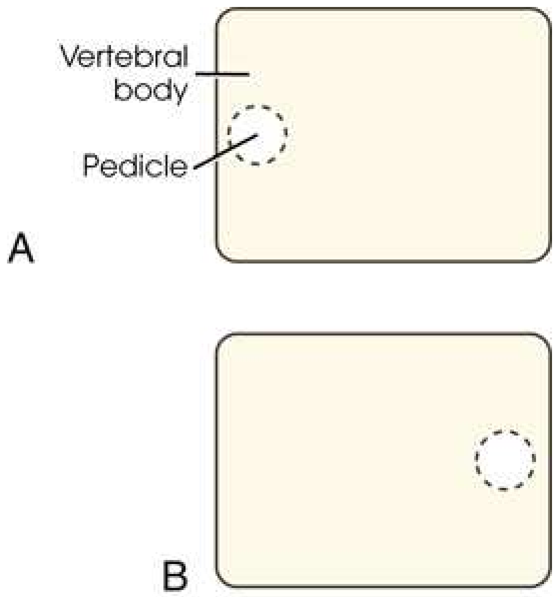


FIG. 9.99 *Box* represents vertebral body, and *circle* represents pedicle. (A) Pedicle is anterior on vertebral body, which means that the patient is not rotated enough. (B) Pedicle is posterior on vertebral body, which means that the patient is rotated too much.

Two diagrams (A) and (B) shows a box representing a vertebral body each, and the circle representing a pedicle each. Box (A) shows a pedicle anterior on the vertebral body. The parts labeled are vertebral body and pedicle. Box (B) shows a pedicle posterior on the vertebral body.

Pa Oblique Projection

RAO and LAO positions

Image receptor + grid: 10 × 12 inches (24 × 30 cm) or 14 × 17 inches (35 × 43 cm) lengthwise.

Position of patient

- Examine the patient in the upright or recumbent prone position. The recumbent position is generally used because it facilitates immobilization.
- Greater ease in positioning the patient and a resultant higher percentage of success in duplicating results make the semiprone position preferable to the semisupine position. The OID is increased, however, which can affect resolution.

Position of part

- From the prone position, have the patient turn away from the side of interest approximately 45 degrees to show the zygapophyseal joints *farthest* from the IR and support the body on the forearm and flexed knee. An oblique body position 60 degrees from the plane of the IR may be needed to show the L5–S1 zygapophyseal joints.
- Adjust the patient's body so that the long axis of the patient is parallel with the long axis of the radiographic table.
- Center the patient's spine to the midline of the grid. In the oblique position, the lumbar spine lies in the longitudinal plane that passes 2 inches (5 cm) lateral to the spinous processes (Fig. 9.100).
- *Shield gonads.*
- *Respiration:* Suspend at the end of expiration.

Central ray

Lumbar region

• Perpendicular to enter the elevated side approximately 2 inches (5 cm) lateral to the palpable spinous process and 1 to 1.5 inches (2.5 to 3.8 cm) above the iliac crest.

L5–S1 zygapophyseal joint

• Perpendicular to enter the elevated side 2 inches (5 cm) lateral to the spinous process and to a point midway between the iliac crest and the ASIS.
• Center the IR to the central ray.

Collimation

• Adjust radiation field to:
• 9 × 12 inches (23 × 30 cm) on the collimator for 10 × 12 inches (24 × 30 cm) IR
• 9 × 14 inches (23 × 35 cm) on the collimator for 14 × 17 inches (35 × 43 cm) IR
• 8 × 10 inches (18 × 24 cm) on the collimator for L5–S1 zygapophyseal joint
• Place the side marker in the collimated exposure field.

Structures shown

The lumbar or lumbosacral vertebrae, showing the articular processes of the side *farther* from the IR (Figs. 9.101–9.103). The T12–L1 articulation between the twelfth thoracic and first lumbar vertebrae, having the same direction as those in the lumbar region, is shown on the larger IR. The fifth lumbosacral joint is usually well shown in oblique positions (see Fig. 9.103).

When the body is placed in a 45-degree oblique position, and the lumbar spine is radiographed, the articular processes and zygapophyseal joints are shown. When the patient has been properly positioned, images of the lumbar vertebrae have the appearance of Scottie dogs. Fig. 9.101 identifies the vertebral structures that compose the Scottie dog. (See the Summary of Oblique Projections, p. 440.)

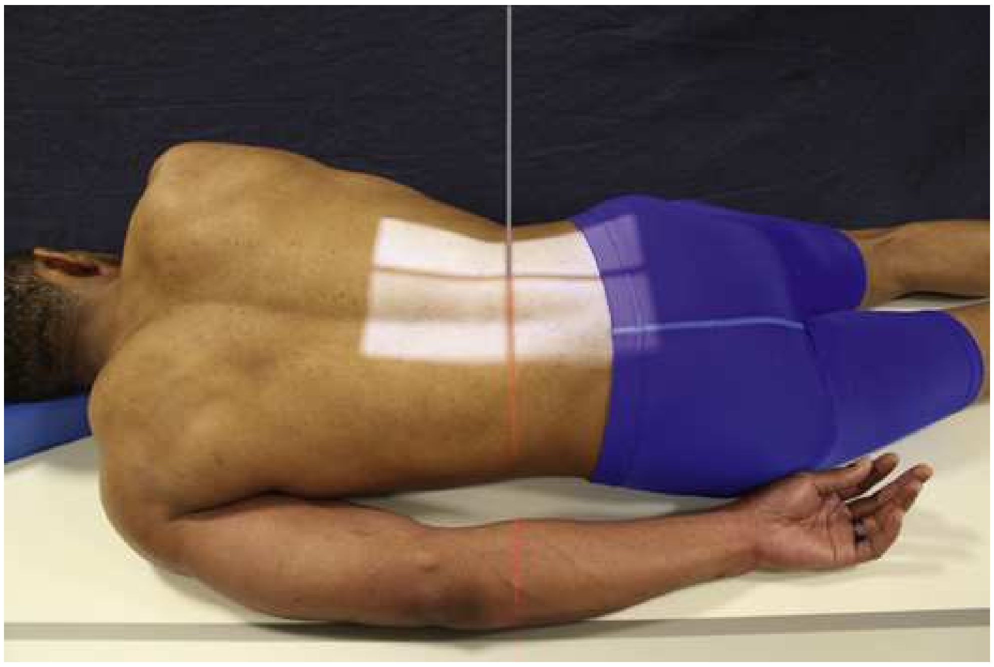


FIG. 9.100 PA oblique lumbar spine: LAO for right zygapophyseal joint.

The patient is in a prone position and the patient is turned away from the side of interest. The body is supported on the forearm and the knee is flexed. The long axis of the patient is parallel with the long axis of the radiographic table. The central ray is perpendicular to the illiac crest.

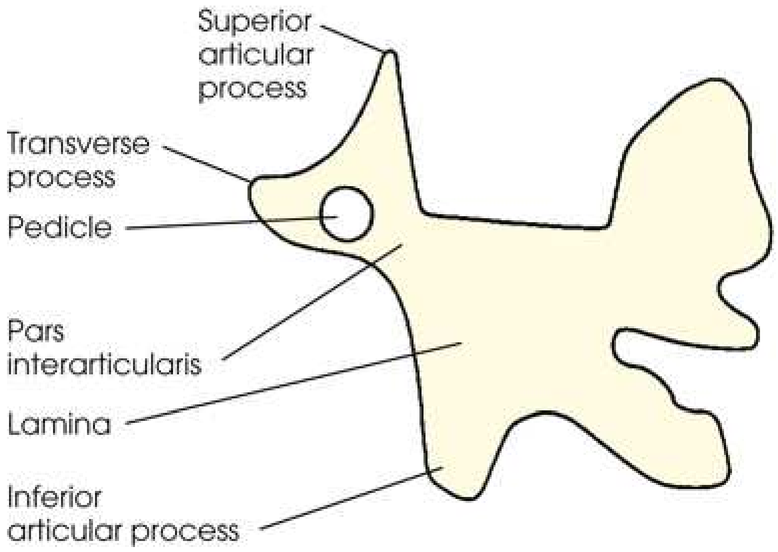


FIG. 9.101 Parts of Scottie dog.

Diagram shows the Scottie dog, the transverse process is the nose. The parts labeled on the diagram are marked from top to the bottom as follows: superior articular process, transverse process, pedicle, pars interarticularis, lamina, and inferior articular process.

Evaluation Criteria

The following should be clearly seen:

- Evidence of proper collimation and presence of the side marker placed clear of anatomy of interest
- Area from the lower thoracic vertebrae to the sacrum
- Zygapophyseal joints *farthest* from the IR
  - When the joint is not well seen and the pedicle is quite anterior on the vertebral body, the patient is not rotated enough.
  - When the joint is not well seen and the pedicle is quite posterior on the vertebral body, the patient is rotated too much.
- Vertebral column parallel with the tabletop so that the T12–L1 and L1–L2 intervertebral joint spaces remain open
- Bony trabecular detail and surrounding soft tissues

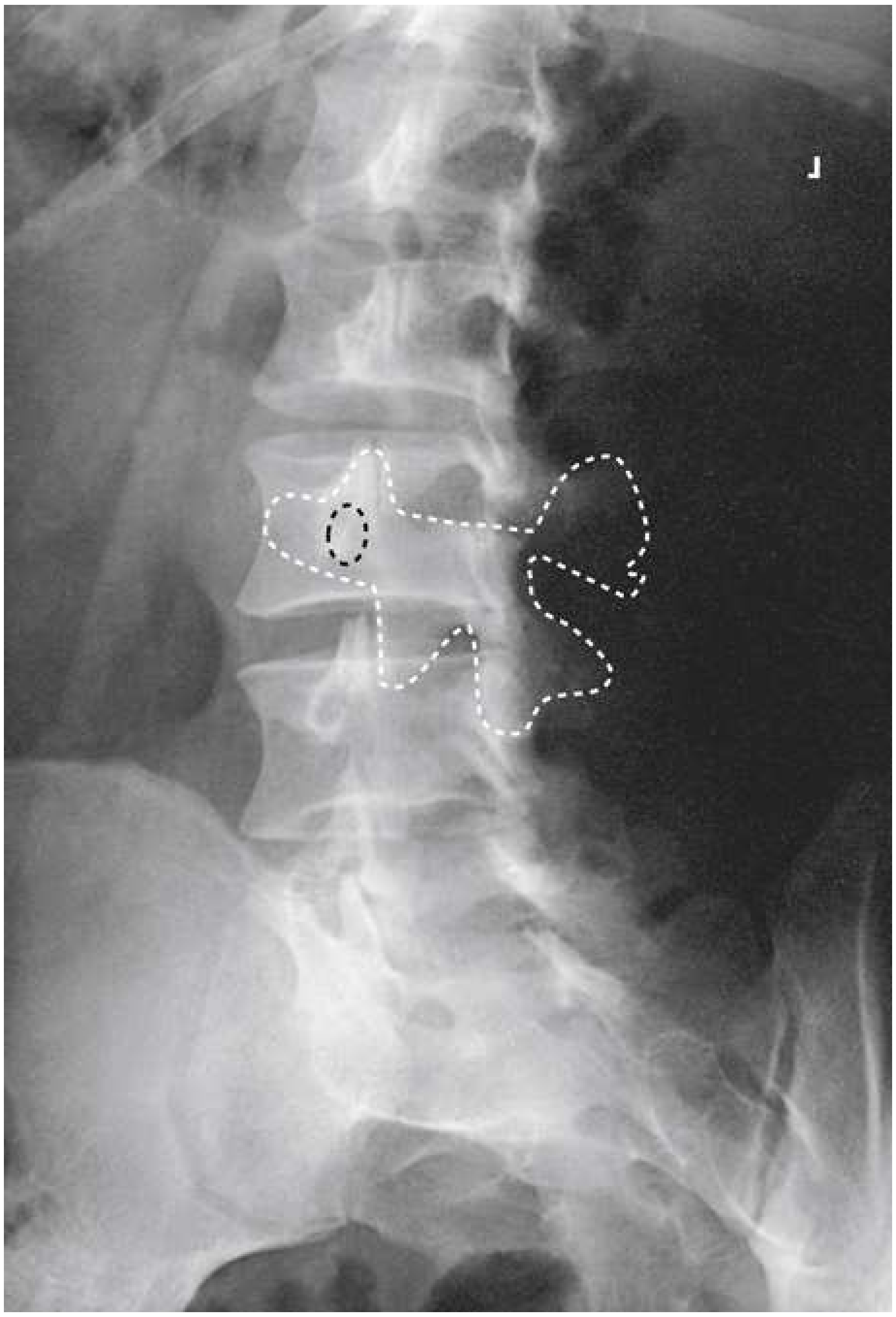


FIG. 9.102 PA oblique lumbar spine: LAO for right zygapophyseal joints. (Note Scottie dog.)

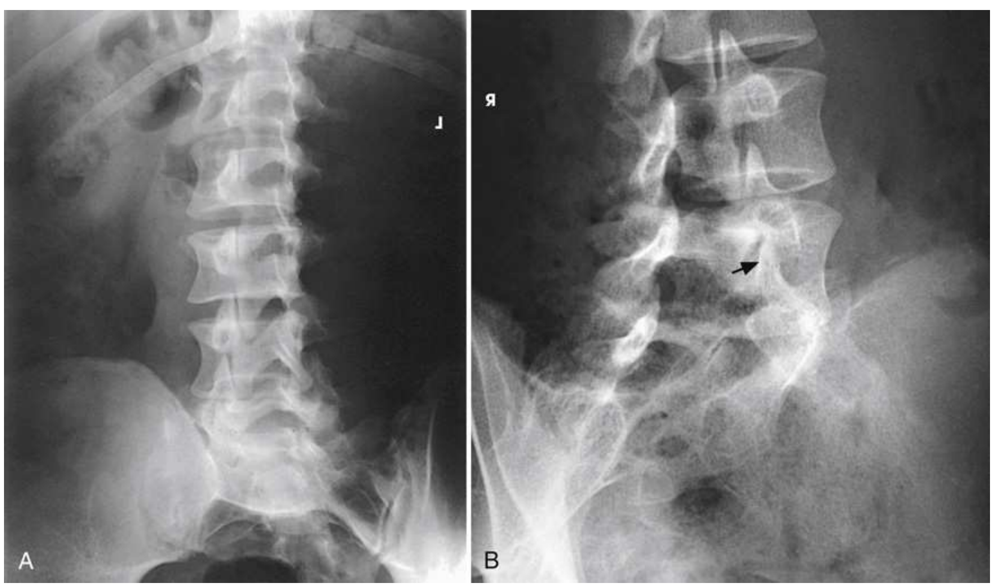


FIG. 9.103 PA oblique lumbar spine. (A) LAO for right zygapophyseal joints. (B) RAO for left L5 zygapophyseal joint *(arrow)*.

Lumbosacral Junction and Sacroiliac Joints

Ap or Pa Axial Projection

Ferguson Method [22]

Image receptor + grid: Positioned by manufacturer or department protocol for proper anatomy display orientation; CR plate: 10 × 12 inches (24 × 30 cm) lengthwise.

Position of patient

- For the AP axial projection of the lumbosacral and sacroiliac joints, position the patient in the supine position.

Position of part

- With the patient supine and the MSP centered to the grid, extend the patient's lower limbs or abduct the thighs and adjust in the vertical position (Fig. 9.104).
- Ensure that the pelvis is not rotated.
- *Shield gonads.*
- *Respiration:* Suspend.

Central ray

- Directed through the lumbosacral joint at an average angle of 30 to 35 degrees cephalad. [23]
- An angulation of 30 degrees in male patients and 35 degrees in female patients is usually satisfactory. By noting the contour of the lower back, unusual accentuation or diminution of the lumbosacral angle can be estimated, and the central ray angulation can be varied accordingly.
- The central ray enters the MSP at a point about 1.5 inches (3.8 cm) superior to the pubic symphysis or 2 to 2.5 inches (5 to 6.5 cm) inferior to the ASIS (Fig. 9.105).
- Ferguson originally recommended an angle of 45 degrees.
- Center the IR to the central ray.

Collimation

- Adjust radiation field to 8 × 10 inches (18 × 24 cm) on the collimator. Place the side marker in the collimated exposure field.

Structures shown

The lumbosacral joint and a symmetric image of both sacroiliac joints free of superimposition (Fig. 9.106).

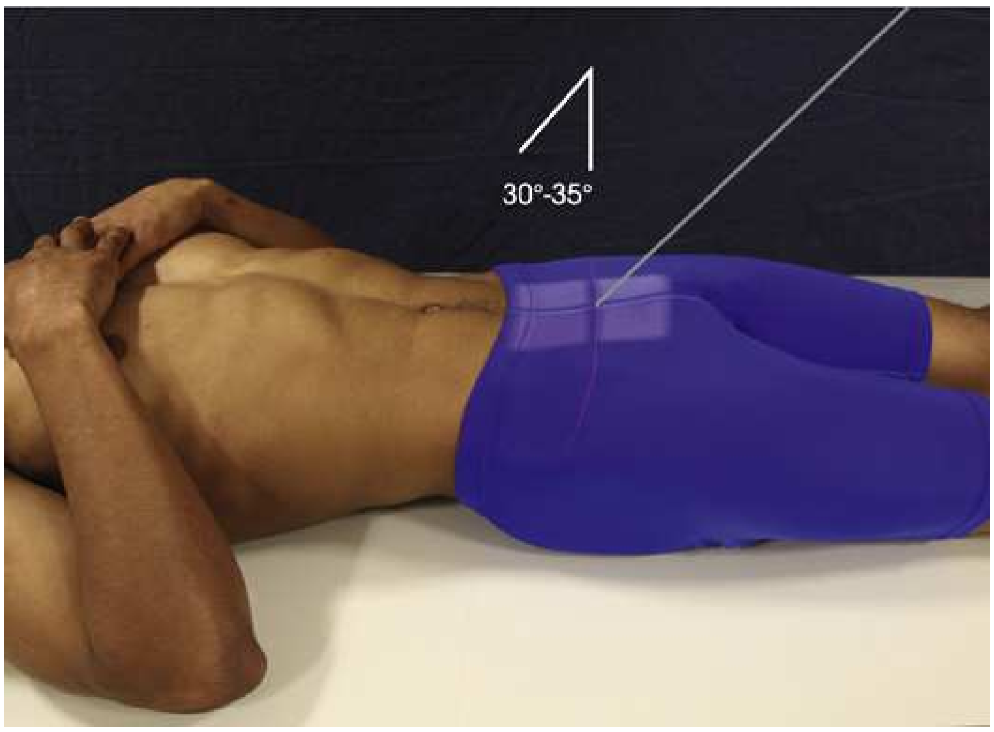


FIG. 9.104 AP axial lumbosacral junction and sacroiliac joints: Ferguson method.

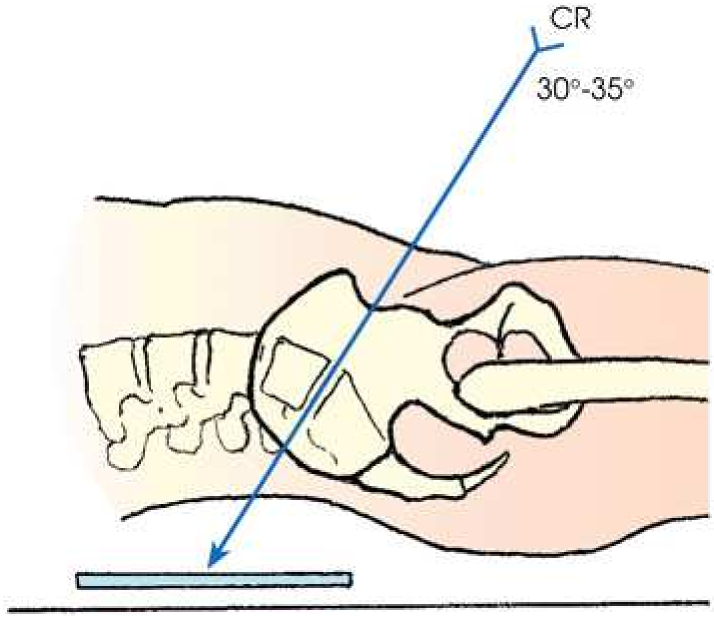


FIG. 9.105 AP axial sacroiliac joints: Ferguson method.

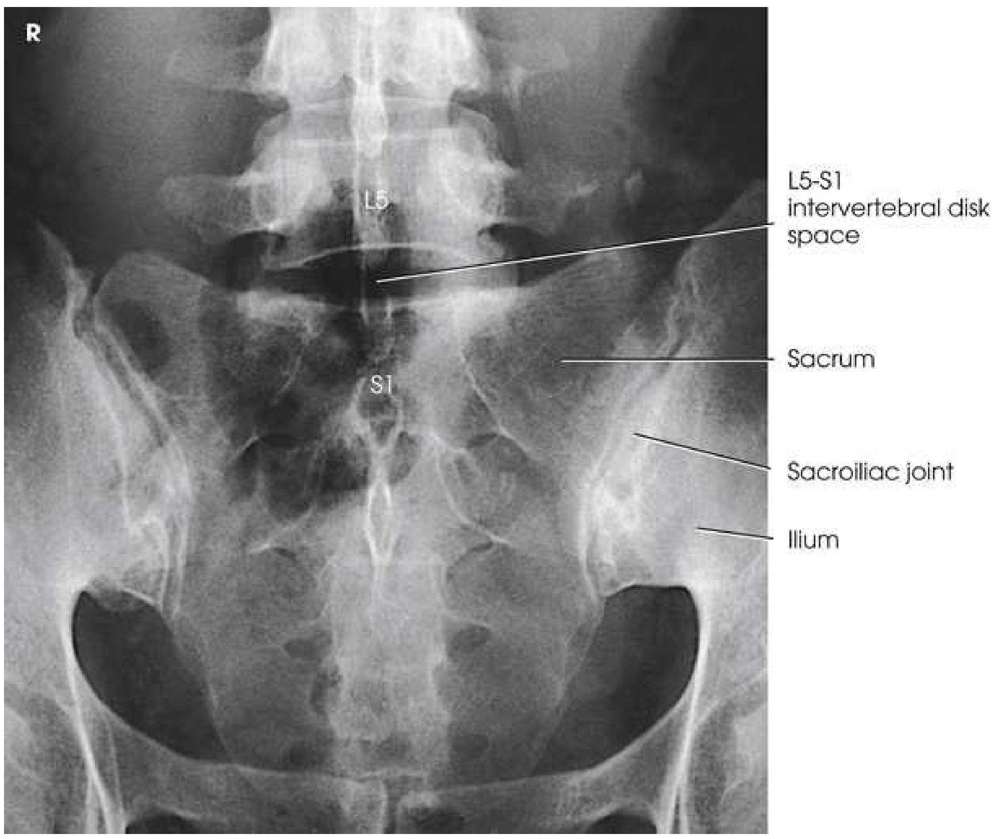


FIG. 9.106 AP axial lumbosacral junction and sacroiliac joints: Ferguson method.

An x-ray shows the lumbosacral joint and a symmetric image of both sacroiliac joints free of superimposition. The parts labeled are marked from top to the bottom as follows: L 5 to S 1 intervertebral disk space, sacrum, sacroiliac joint, and ilium. The L 5 to S 1 intervertebral disk space appears dark.

Evaluation Criteria

The following should be clearly seen:

- Evidence of proper collimation and presence of the side marker placed clear of anatomy of interest
- Lumbosacral junction and sacrum
- Open intervertebral disk space between L5 and S1
- Both sacroiliac joints
- Bony trabecular detail and surrounding soft tissues

NOTE: The PA axial projection for the lumbosacral junction can be modified in accordance with the AP axial projection just described. With the patient in the prone position, the central ray is directed through the lumbosacral joint to the midpoint of the IR at an average angle of 35 degrees caudad. The central ray enters the spinous process of L4 (Figs. 9.107 and 9.108).

Meese [24] recommended the prone position for examinations of the sacroiliac joints because their obliquity places them in a position more nearly parallel with the divergence of the beam of radiation. The central ray is directed perpendicularly and is centered at the level of the ASIS. It enters the midline of the patient about 2 inches (5 cm) distal to the spinous process of L5 (Fig. 9.109).

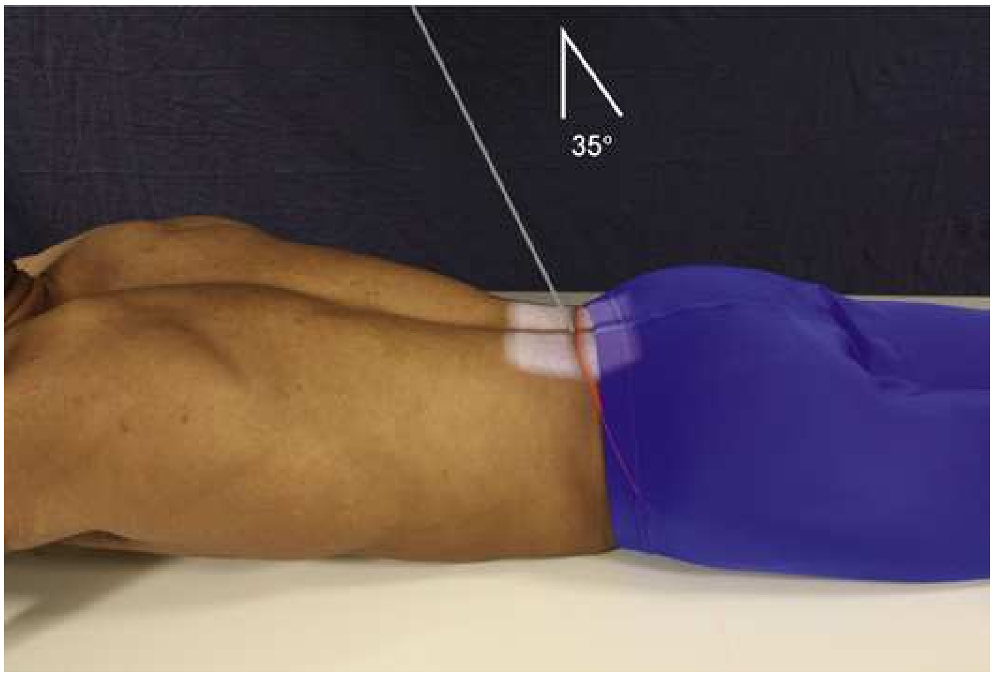


FIG. 9.107 PA axial lumbosacral junction and sacroiliac joints.

The patient is lying in a prone position on the radiographic table. The central ray is directed through the lumbosacral joint to the midpoint of the I R at an average angle of 35 degrees caudad entering the spinous process of L 4.

FIG. 9.108 PA axial lumbosacral junction and sacroiliac joints.

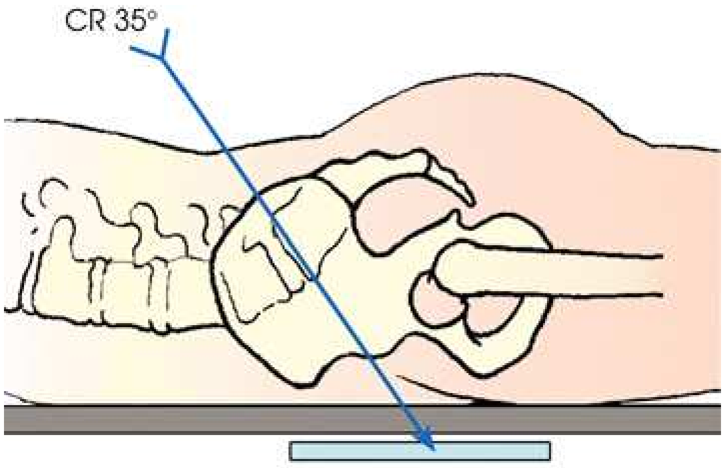


FIG. 9.109 PA axial lumbosacral junction and sacroiliac joints.

Diagram shows the patient lying in a prone position on the radiographic table. The central ray is directed through the lumbosacral joint to the midpoint of the I R at an average angle of 35 degrees caudad entering the spinous process of L 4.

Sacroiliac Joints

Ap Oblique Projection

RPO and LPO positions

Image receptor + grid: Positioned by manufacturer or department protocol for proper anatomy display orientation; CR plate: 10 × 12 inches (24 × 30 cm) lengthwise. Both obliques are usually obtained for comparison.

Position of patient

- Place the patient in the supine position and elevate the head on a firm pillow.

Position of part

- Elevate the side of interest approximately 25 to 30 degrees, and support the shoulder, lower thorax, and upper thigh (Figs. 9.110 and 9.111).
- The side being examined is *farther* from the IR. Use the LPO position to show the right joint and the RPO position to show the left joint.
- Adjust the patient's body so that its long axis is parallel with the long axis of the radiographic table.
- Align the body so that a sagittal plane passing 1 inch (2.5 cm) medial to the ASIS of the elevated side is centered to the midline of the grid.
- Check the rotation at several points along the back.
- Center the IR at the level of the ASIS.
- *Shield gonads.* Collimating close to the joint may shield the gonads in male patients. It may be difficult to use contact shielding in female patients.
- *Respiration:* Suspend.

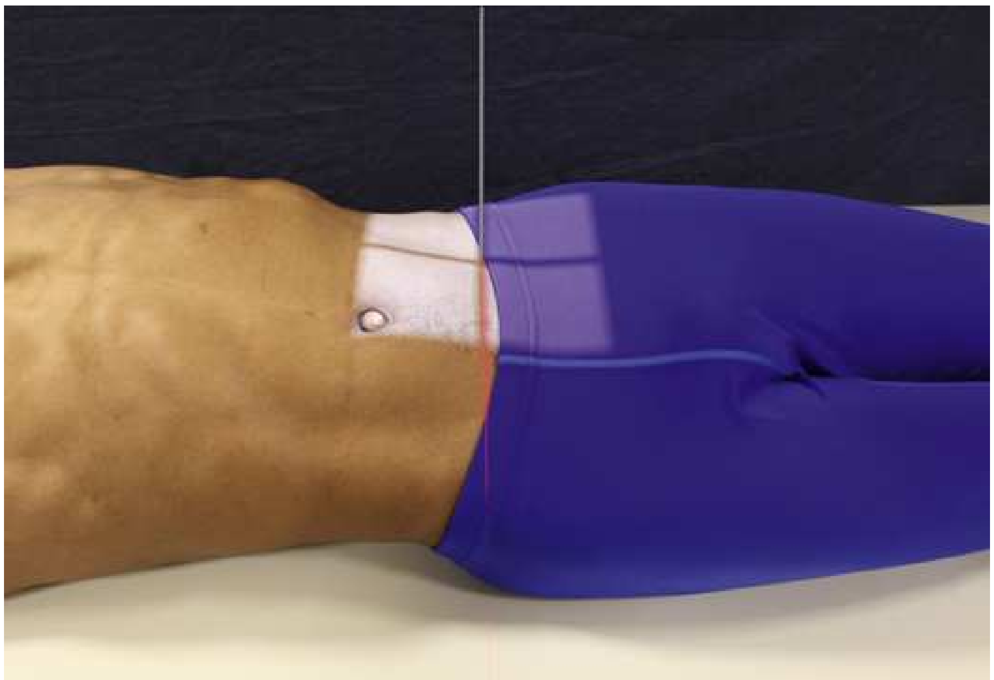


FIG. 9.110 AP oblique sacroiliac joint. RPO shows left joint.

The patient is lying in a supine position. The side of interest is elevated to approximately 25 to 30 degrees. The long axis of the body is parallel with the long axis of the radiographic table. The central ray is perpendicular to the center of the IR and medial to the elevated A S I S.

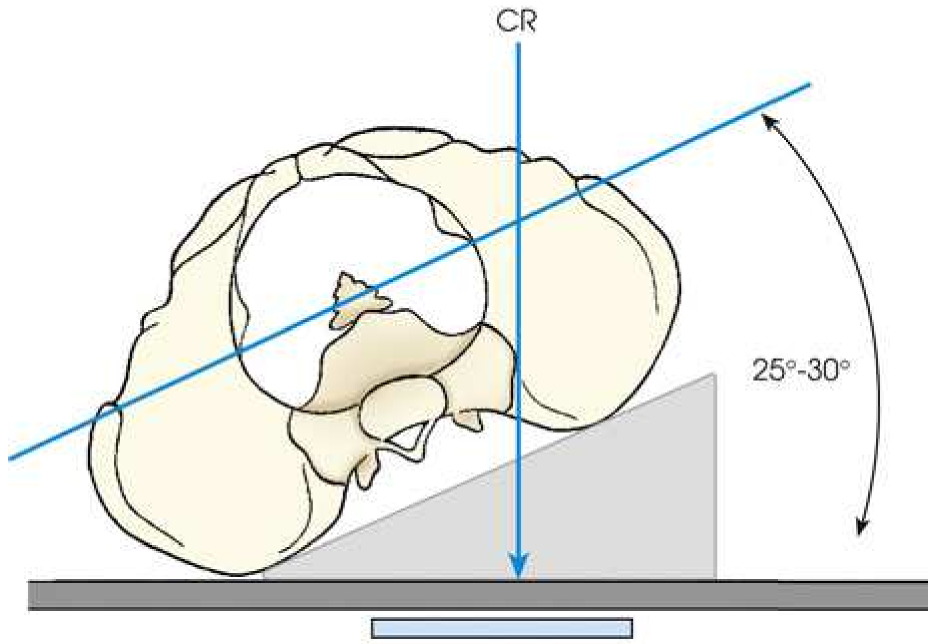


FIG. 9.111 Degree of obliquity required to show sacroiliac joint for AP oblique projection.

Diagram shows the patient is lying in a supine position. The side of interest is elevated to approximately 25 to 30 degrees. The long axis of the body is parallel with the long axis of the radiographic table. The central ray is perpendicular to the center of the IR and medial to the elevated A S I S.

Central ray

- Perpendicular to the center of the IR, entering 1 inch (2.5 cm) medial to the elevated ASIS

Collimation

- Adjust radiation field to 6 × 10 inches (15 × 24 cm) on the collimator. Place the side marker in the collimated exposure field.

Structures shown

The sacroiliac joint *farthest* from the IR and an oblique projection of the adjacent structures. Both sides are examined for comparison (Fig. 9.112). (See the Summary of Oblique Projections, p. 440.)

Evaluation Criteria

The following should be clearly seen:

- Evidence of proper collimation and presence of the side marker placed clear of anatomy of interest
- Open sacroiliac joint space *farthest* from IR with minimal overlapping of the ilium and sacrum
- Joint centered on the radiograph
- Bony trabecular detail and surrounding soft tissues

NOTE: An AP axial oblique can be obtained by positioning the patient as described. For the AP axial oblique, the central ray is directed at an angle of 20 to 25 degrees cephalad, entering 1 inch (2.5 cm) medial and 1½ inches (3.8 cm) distal to the elevated ASIS (Fig. 9.113).

NOTE: Brower and Kransdorf [25] summarized difficulties in imaging the sacroiliac joints because of patient positioning and variability.

FIG. 9.112 AP oblique sacroiliac joint. RPO shows left joint *(arrows)*.

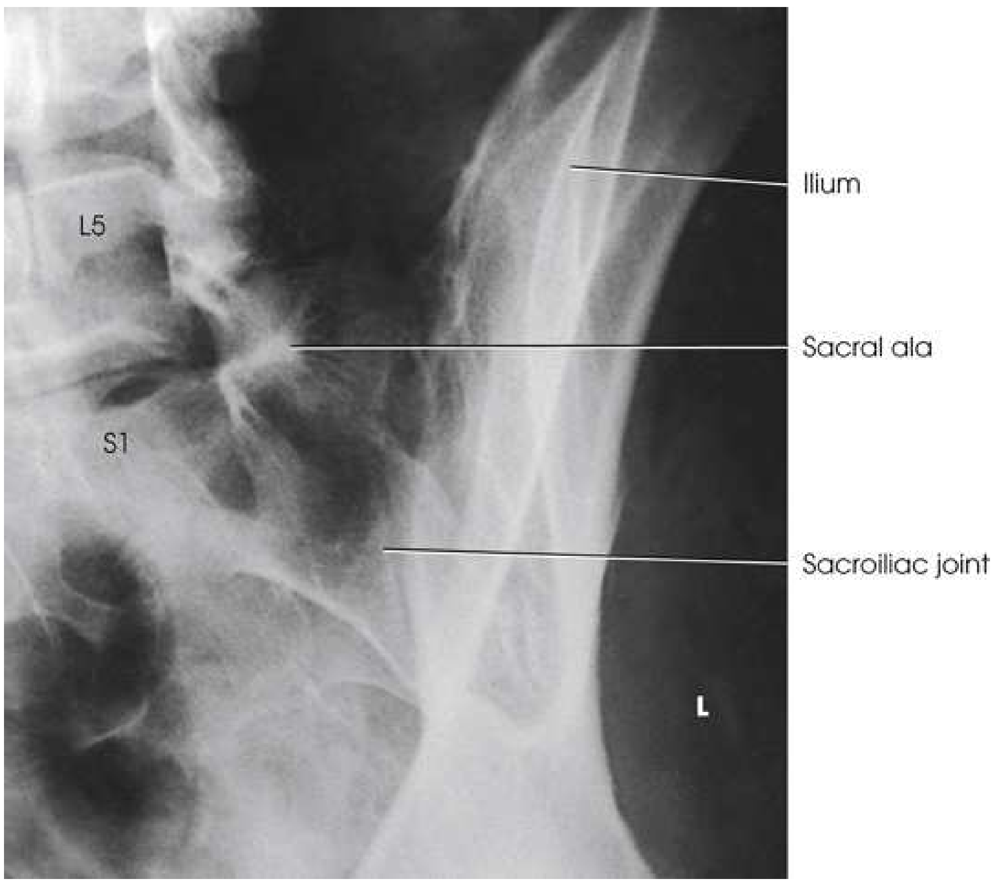


FIG. 9.113 AP axial oblique sacroiliac joint. RPO with 20-degree cephalad angulation shows left joint.

PA Oblique Projection

RAO and LAO positions

Image receptor + grid: Positioned by manufacturer or department protocol for proper anatomy display orientation; CR plate: 10 × 12 inches (24 × 30 cm) lengthwise. Both obliques are usually obtained for comparison.

Position of patient

- Place the patient in a prone position.
- Place a small, firm pillow under the head.

Position of part

- Adjust the patient by rotating the side of interest toward the radiographic table until a body rotation of 25 to 30 degrees is achieved. Have the patient rest on the forearm and flexed knee of the elevated side.
- The side being examined should be *closer* to the IR. Use the RAO position to show the right joint and the LAO position to show the left joint.
- Check the degree of rotation at several points along the anterior surface of the patient's body.
- Adjust the patient's body so that its long axis is parallel with the long axis of the table.
- Center the body so that a point 1 inch (2.5 cm) medial to the ASIS closest to the IR is centered to the grid (Figs. 9.114 and 9.115).
- Center the IR at the level of the ASIS.
- *Shield gonads.* Collimating close to the joint may shield the gonads in male patients. It may be difficult to use contact shielding in female patients.
- *Respiration:* Suspend.

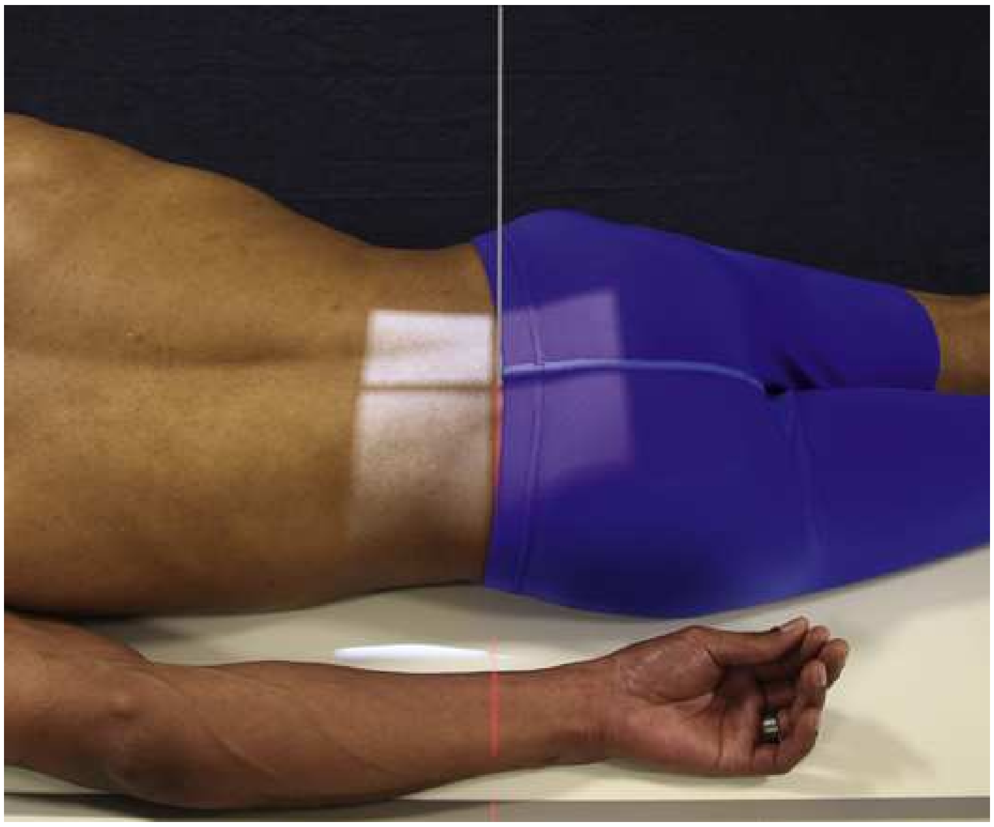


FIG. 9.114 PA oblique sacroiliac joint. LAO shows left joint.

The patient is lying in a prone position on the radiographic table. The patient is resting on the forearm and the flexed knee of the elevated side. The central ray is perpendicular to the I R and centered medial to the A S I S closest to the I R.

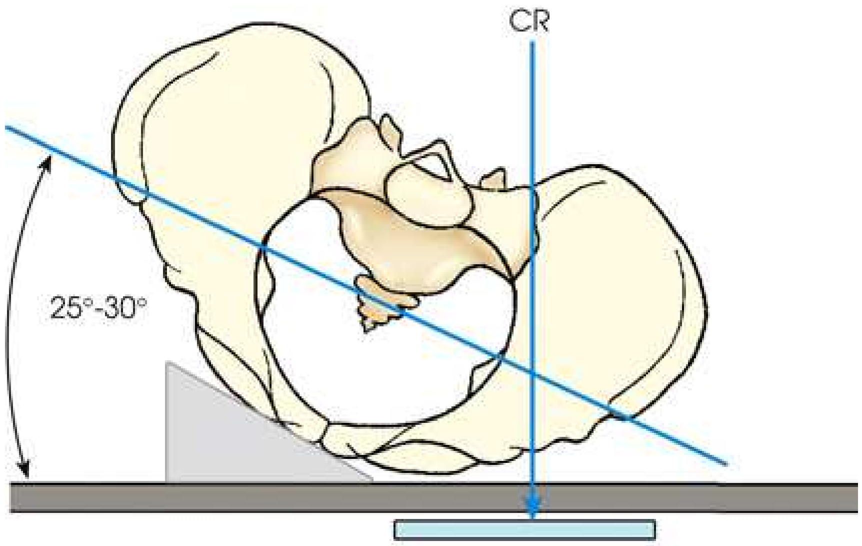


FIG. 9.115 Degree of obliquity required to show sacroiliac joint for PA oblique projection.

The patient is lying in a prone position. The position of the patient is adjusted by rotating the side of interest toward the radiographic table until a body rotation of 25 to 30 degrees. The central ray is perpendicular to the I R and centered medial to the A S I S closest to the I R.

Central ray

- Perpendicular to the IR and centered 1 inch (2.5 cm) medial to the ASIS closest to the IR

Collimation

- Adjust radiation field to 6 × 10 inches (15 × 24 cm) on the collimator. Place the side marker in the collimated exposure field.

Structures shown

The sacroiliac joint *closest* to the IR (Fig. 9.116). (See the Summary of Oblique Projections, p. 440.)

Evaluation Criteria

The following should be clearly seen:

- Evidence of proper collimation and presence of the side marker placed clear of anatomy of interest
- Open sacroiliac joint space *closest* to the IR or minimal overlapping of the ilium and sacrum
- Joint centered on the radiograph
- Bony trabecular detail and surrounding soft tissues

NOTE: A PA axial oblique can be obtained by positioning the patient as described previously. For the PA axial oblique, the central ray is directed 20 to 25 degrees caudad to enter the patient at the level of the transverse plane, pass 1½ inches (3.8 cm) distal to the L5 spinous process, and exit at the level of the ASIS (Fig. 9.117).

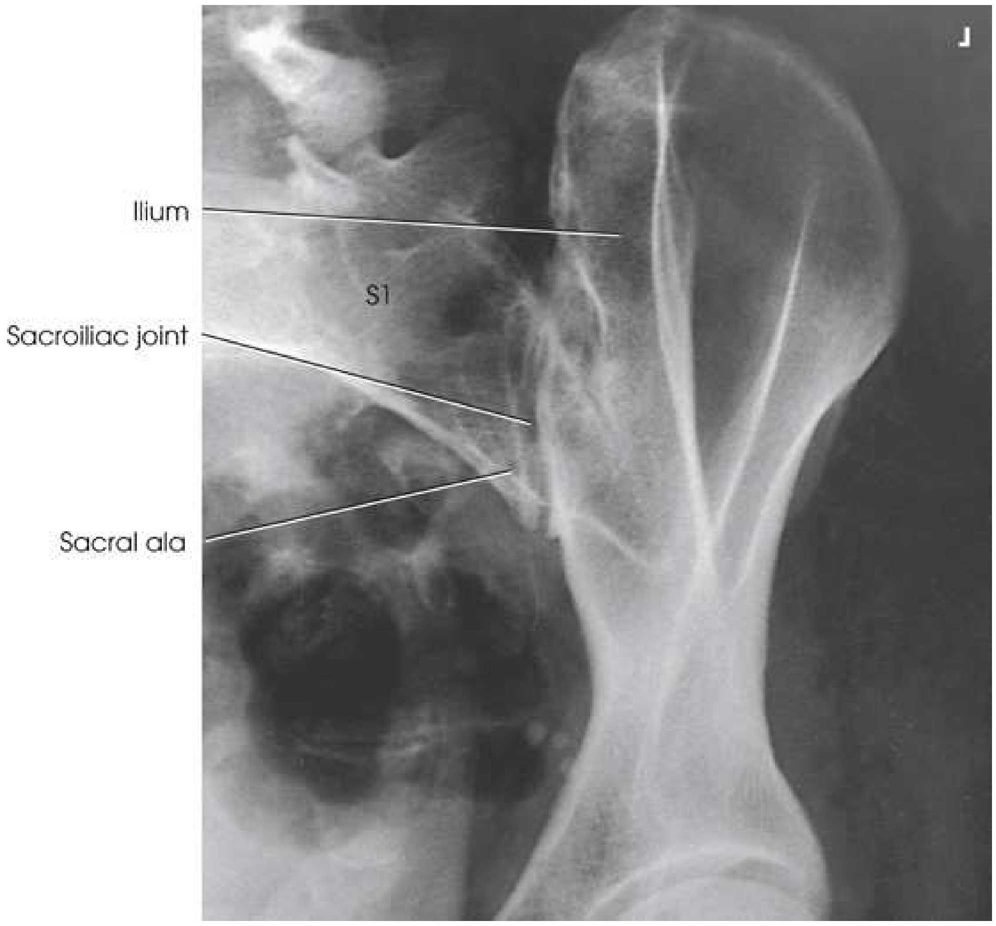


FIG. 9.116 PA oblique sacroiliac joint. LAO shows left joint.

An x-ray shows the open sacroiliac joint space. The parts labeled are marked from top to the bottom as follows: ilium, sacroiliac joint, and sacral ala. There are a few slightly vertical lines on the right.

FIG. 9.117 PA axial oblique sacroiliac joint. LAO with 20-degree caudal central ray shows left joint *(arrows)*.

Sacrum and Coccyx

Ap And Pa Axial Projections

Bowel content may interfere with radiography of the sacrum and coccyx. The urinary bladder should be emptied before the examination.

Image receptor + grid: Positioned by manufacturer or department protocol for proper anatomy display orientation; CR plate: 10 × 12 inches (24 × 30 cm) lengthwise.

Position of patient

- Place the patient in the supine position. The prone position can be used without appreciable loss of detail and is particularly appropriate for patients with a painful injury or destructive disease.

Position of part

- With the patient either supine or prone, center the MSP of the body to the midline of the table grid.
- Adjust the patient so that the ASIS are equidistant from the grid.
- Have the patient flex the elbows and place the arms in a comfortable, bilaterally symmetric position.
- When the supine position is used, place a support under the patient's knees.
- *Shield gonads* on men. Women cannot be shielded for this projection.
- *Respiration:* Suspend.

Central ray

Sacrum

- With the patient supine, direct the central ray 15 degrees cephalad and center it to a point 2 inches (5 cm) superior to the pubic symphysis (Figs. 9.118–9.120).
- With the patient prone, angle the central ray 15 degrees caudad and center it to the clearly visible sacral curve (Fig. 9.121).

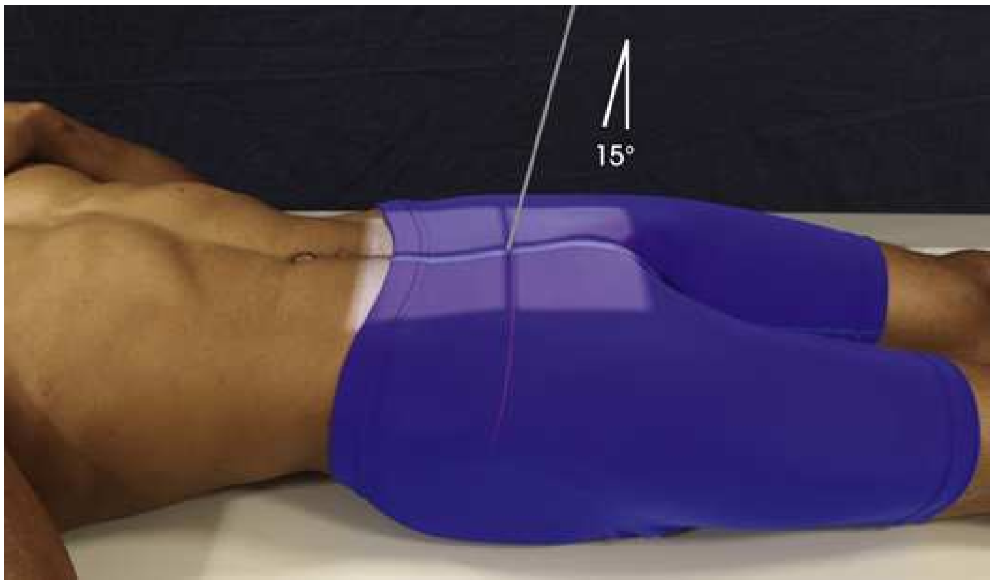


FIG. 9.118 AP axial sacrum.

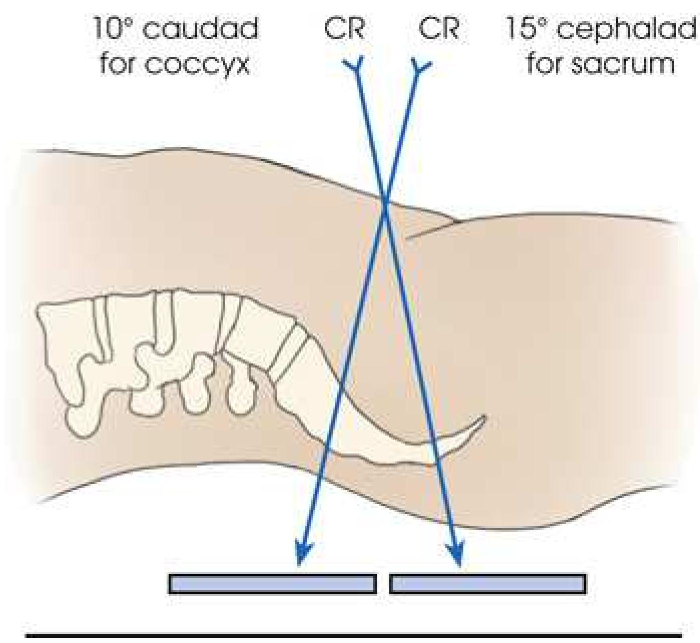


FIG. 9.119 CR angles for AP axial sacrum and coccyx.

FIG. 9.120 AP axial sacrum.

Coccyx

- With the patient *supine*, direct the central ray 10 degrees caudad and center it to a point about 2 inches (5 cm) superior to the pubic symphysis (see Figs. 9.121 and 9.122).
- With the patient *prone*, angle the central ray 10 degrees cephalad and center it to the easily palpable coccyx.
- Center the IR to the central ray.

Collimation

- Adjust radiation field to:
- *Sacrum:* 10 × 12 inches (24 × 30 cm) on the collimator
- *Coccyx:* 8 × 10 inches (18 × 24 cm) on the collimator
- Place the side marker in the collimated exposure field.

Structures shown

The sacrum or coccyx free of superimposition (see Figs. 9.120 and 9.123; see also Fig. 9.121).

Evaluation Criteria

The following should be clearly seen:

- Evidence of proper collimation and presence of the side marker placed clear of anatomy of interest
- Bony trabecular detail and surrounding soft tissues

Sacrum

- Sacrum centered and seen in its entirety
- Sacrum free of foreshortening, with the sacral curvature straightened
- Pubic bones not overlapping the sacrum
- No rotation of the sacrum, as demonstrated by symmetric alae

Coccyx

- Coccyx centered and seen in its entirety

- Coccygeal segments not superimposed by pubic bones
- No rotation of coccyx, as demonstrated by distal segment in line with pubic symphysis

Radiation protection

- Because the reproductive organs lie within the exposure area, use close collimation to limit the irradiated area and the amount of scatter radiation.

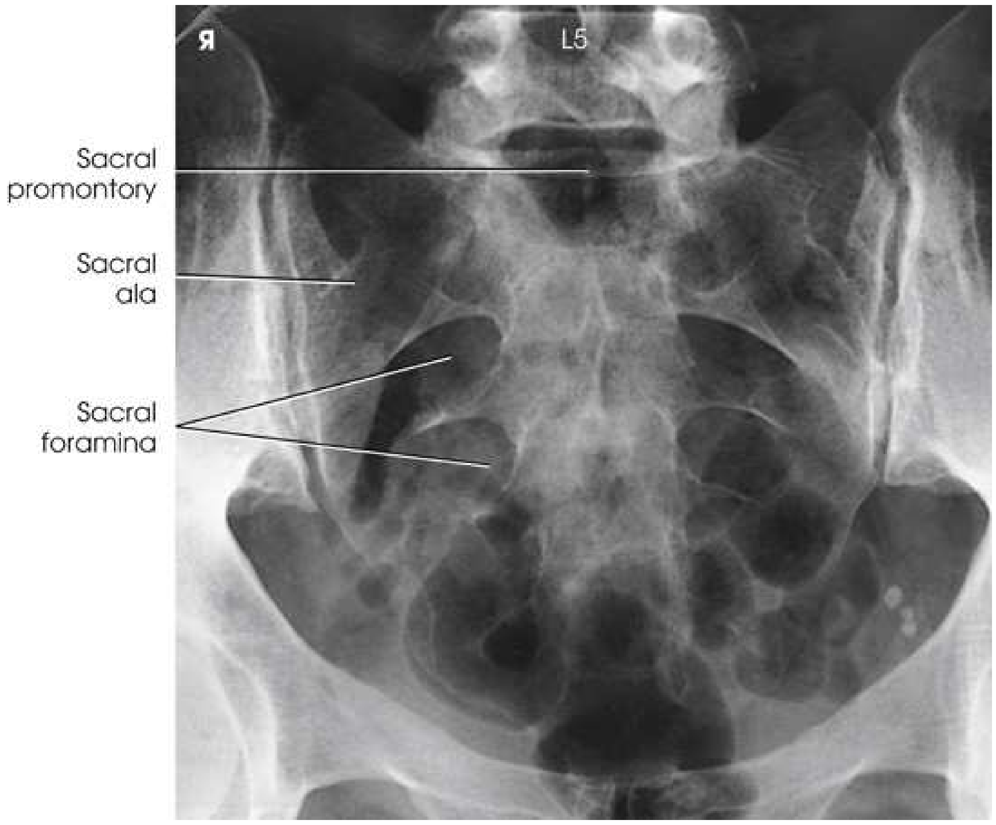


FIG. 9.121 PA axial sacrum.

An x-ray shows a radiolucent area in the center of the sacrum called the sacral promontory. The sacral formina also appears radiolucent and hazy. The parts labeled are listed as follows: sacral promontory, sacral ala, and sacral foramina.

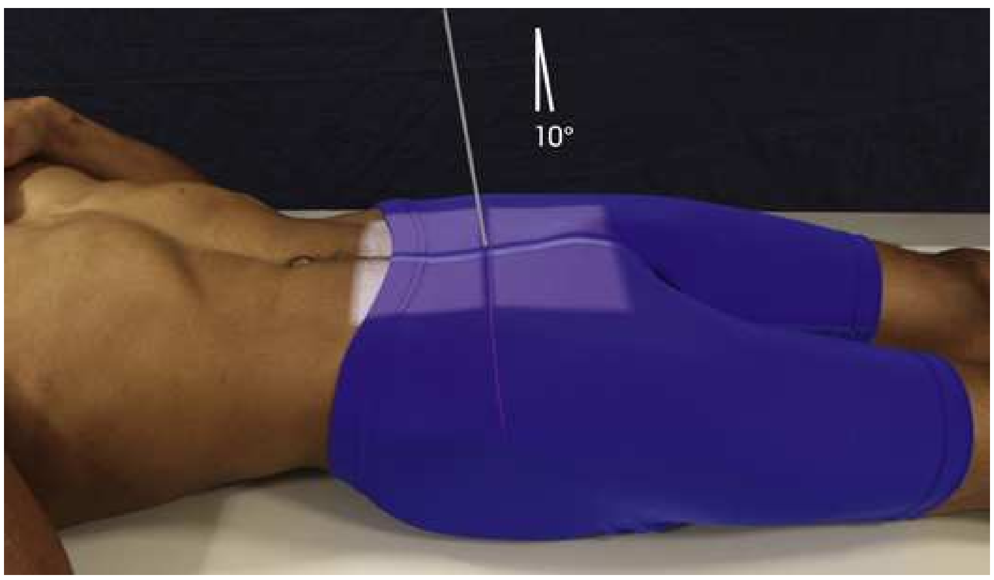


FIG. 9.122 AP axial coccyx.

FIG. 9.123 AP axial coccyx.

Lateral Projection

Right or left position

Image receptor + grid: Positioned by manufacturer or department protocol for proper anatomy display orientation; CR plate: 10 × 12 inches (24 × 30 cm) lengthwise.

Position of patient

- Ask the patient to turn onto the indicated side and flex the hips and knees to a comfortable position.

Position of part

- Adjust the arms in a position at right angles to the body.
- Superimpose the knees, and, if needed, place positioning sponges under and between the ankles and between the knees.
- Adjust a support under the body to place the long axis of the spine horizontal. The interiliac plane should be perpendicular to the IR.
- Adjust the pelvis and shoulders so that the true lateral position is maintained (i.e., no rotation) (Figs. 9.124 and 9.125).
- To prepare for accurate positioning of the central ray, center the sacrum or coccyx to the midline of the grid.
- *Shield gonads.*
- *Respiration:* Suspend.

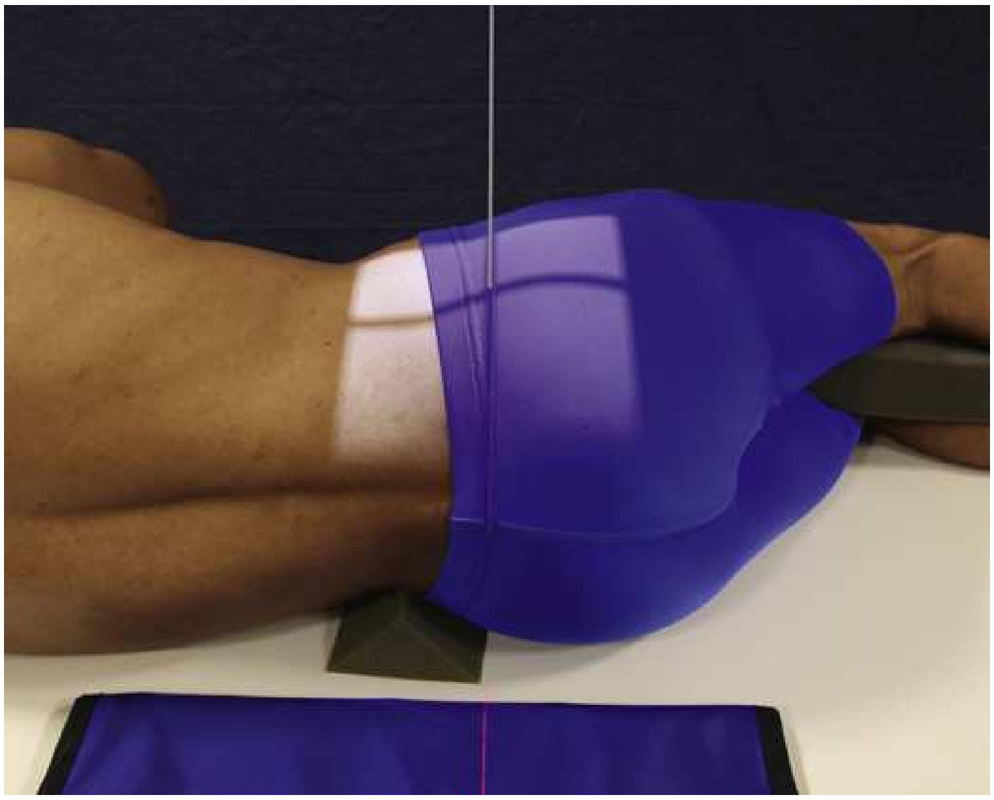


FIG. 9.124 Lateral sacrum.

The patient is lying on the side. The hips and knees are flexed. The arms are in a position at right angles to the body. A support is placed under the body to place the long axis of the spine horizontal. The central ray is perpendicular and directed to the level of the A S I S.

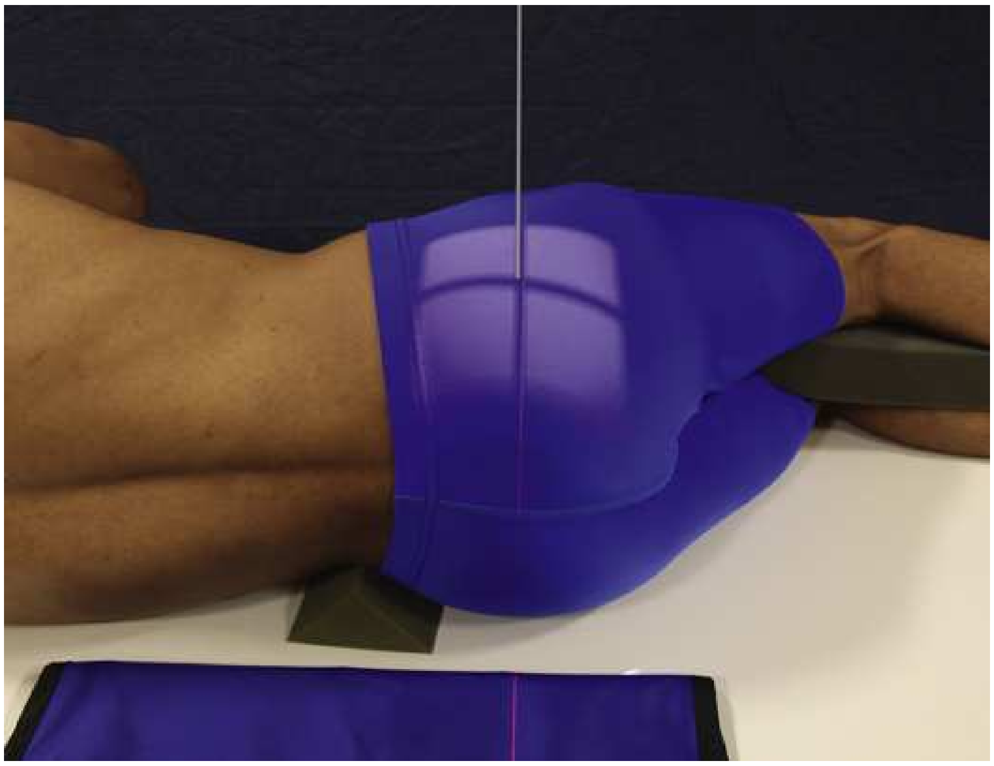


FIG. 9.125 Lateral coccyx.

The patient is lying on the side. The hips and knees are flexed. The arms are in a position at right angles to the body. A support is placed under the body to place the long axis of the spine horizontal. The central ray is perpendicular and directed posterior to the A S I S.

Central ray

- The elevated ASIS is easily palpated and found on all patients when they are lying on their side and provides a standardized reference point from which to center the sacrum and coccyx (Fig. 9.126).

Sacrum

- Perpendicular and directed to the level of the ASIS and to a point 3.5 inches (9 cm) posterior. This centering should work with most patients. The exact position of the sacrum depends on the pelvic curve.

Coccyx

- Perpendicular and directed toward a point 3.5 inches (9 cm) posterior to the ASIS and 2 inches (5 cm) inferior. This centering should work for most patients. The exact position of the coccyx depends on the pelvic curve.
- Center the IR to the central ray.

Collimation

- Adjust radiation field to:
- *Sacrum:* 10 × 12 inches (24 × 30 cm) on the collimator.
- *Coccyx:* 6 × 8 inches (15 × 20 cm) on the collimator.
- Place the side marker in the collimated exposure field.

Structures shown

The sacrum or coccyx (Figs. 9.127 and 9.128).

Evaluation Criteria

The following should be clearly seen:

- Evidence of proper collimation, presence of a lead rubber absorber behind the sacrum and presence of the side marker placed clear of anatomy of interest
- Sacrum and coccyx
- Closely superimposed posterior margins of the ischia and ilia, demonstrating no rotation
- Bony trabecular detail and surrounding soft tissues

Improving radiographic quality

The quality of the radiograph can be improved if a sheet of leaded rubber is placed on the table behind the patient (see Figs. 9.124 and 9.125). The lead absorbs the scatter radiation coming from the patient. Scatter radiation decreases the quality of the radiograph. More importantly, with AEC, the scatter radiation coming from the patient is often sufficient to terminate the exposure prematurely, resulting in an underexposed radiograph. For the same reason, close collimation is necessary for lateral sacrum and coccyx images.

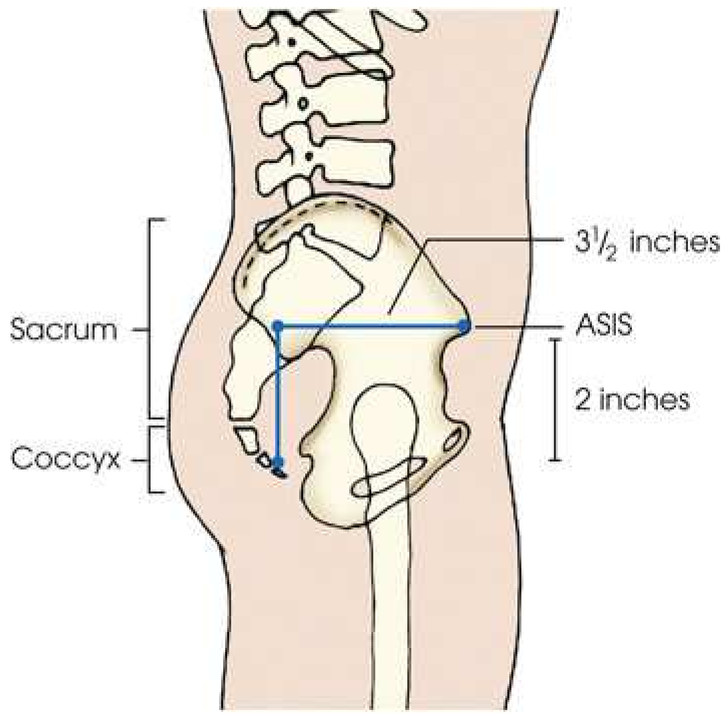


FIG. 9.126 Lateral sacrum, coccyx, and ilium *(dashed outline)* showing centering points. ASIS provides a standardized reference point for central ray positioning.

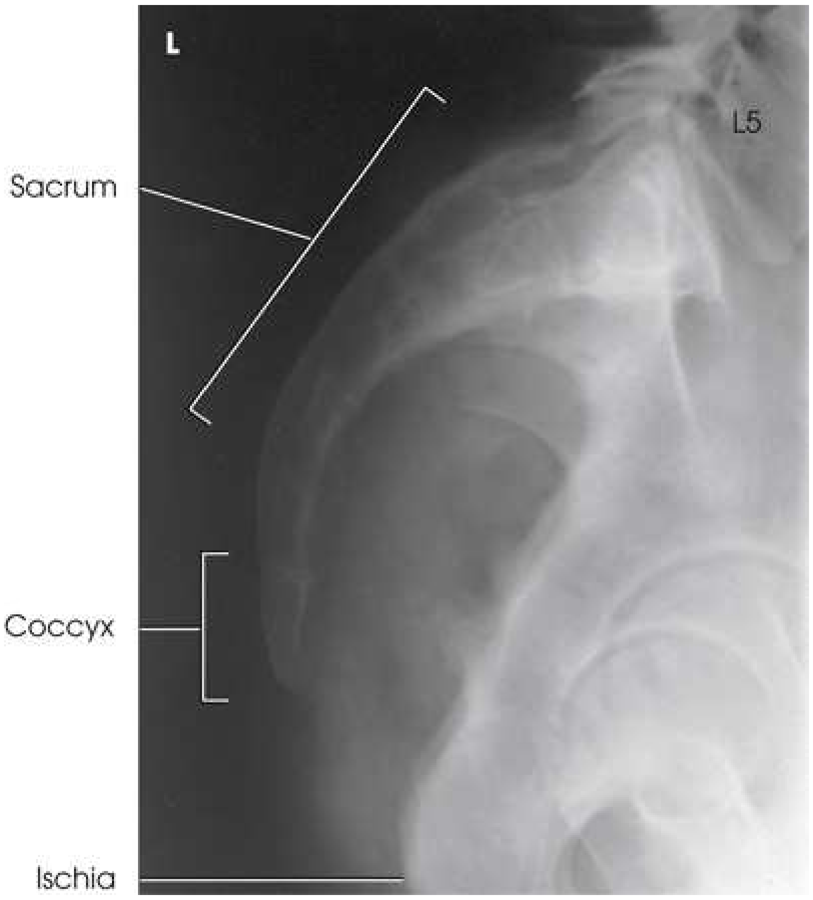


FIG. 9.127 Lateral sacrum.

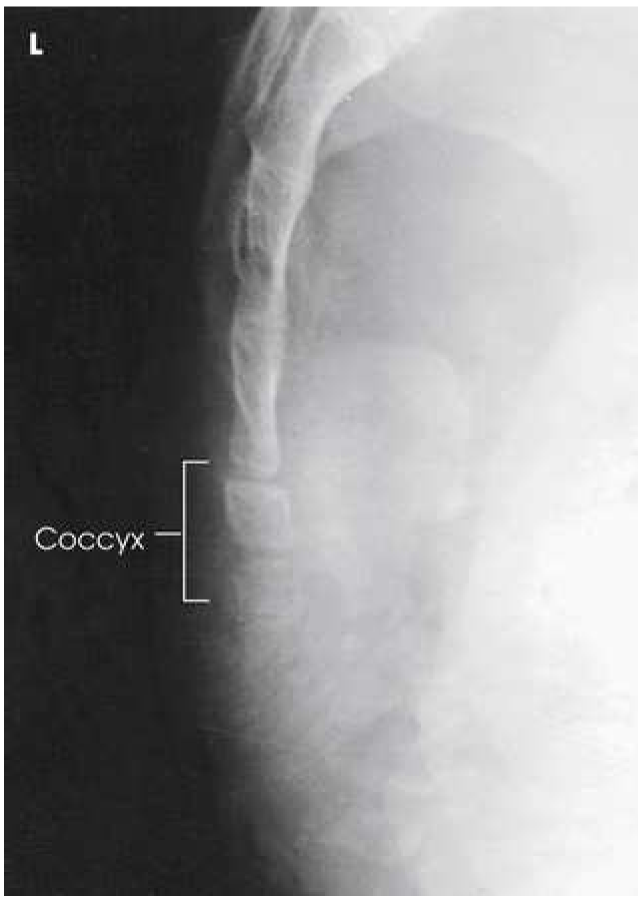


FIG. 9.128 Lateral coccyx.

Lumbar Intervertebral Joints

PA Projection

Weight-Bearing Method

Right and left bending

Image receptor + grid: Positioned by manufacturer or department protocol for proper anatomy display orientation; CR plate: 14 × 17 inches (35 × 43 cm) lengthwise.

Position of patient

- Perform this examination with the patient in the standing position. Duncan and Hoen [26] recommended that the PA projection be used because, in this direction, the divergent rays are more nearly parallel with the intervertebral disk spaces.

Position of part

- With the patient facing the vertical grid device, adjust the height of the IR to be centered at the level of L3.
- Adjust the patient's pelvis for rotation by ensuring that the ASIS are equidistant from the IR.
- Center the MSP of the patient's body to the midline of the vertical grid device (Fig. 9.129).
- Let the patient's arms hang unsupported by the sides.
- Make one radiograph with the patient bending to the right and one with the patient bending to the left (Fig. 9.130).
- Have the patient lean directly lateral as far as possible without rotation and without elevation of the foot. The degree of bending must not be forced, and the patient must not be supported in position.
- Ensure that the MSP of the lower lumbar spine and sacrum remains centered to the grid device as the upper portion moves laterally.
- *Shield gonads.*
- *Respiration:* Suspend.

Central ray

- Directed perpendicular to L3 or through the L4–L5 or L5–S1 intervertebral disk spaces, if these are the areas of interest

FIG. 9.129 PA lumbar intervertebral disks with right bending.

FIG. 9.130 PA lumbar radiograph. Note that the pelvis is straight and only the lumbar spine is bent.

Collimation

- Adjust radiation field to 8 × 17 inches (20 × 43 cm) on the collimator. Place the side marker in the collimated exposure field.

Structures shown

The lower thoracic region and the lumbar region for demonstration of the mobility of the cartilaginous intervertebral joints (see Fig. 9.130). In patients with disk protrusion, this type of examination is used to localize the involved joint, as shown by limitation of motion at the site of the lesion.

Evaluation Criteria

The following should be clearly seen:

- Evidence of proper collimation and presence of the side marker placed clear of anatomy of interest
- Area from the lower thoracic intervertebral disk spaces to all of the sacrum
- No rotation of the patient in the bending position
- Bending direction correctly identified on the image with appropriate lead markers
- Bony trabecular detail and surrounding soft tissues

Radiation protection

The PA projection is recommended instead of the AP projection whenever the clinical information provided by the examination is not compromised. With the PA projection, the patient's gonad area and breast tissue receive significantly less radiation than when the AP projection is used. In addition, proper collimation reduces the radiation dose to the patient.

Thoracolumbar Spine: Scoliosis

Pa And Lateral Projection

Frank et al. Method [27–29]

The method described has been endorsed by the American College of Radiology, the Academy of Orthopedic Physicians, and the Center for Development and Radiation Health of the Department of Health and Human Services. Endorsement includes use of the PA projection, compensating filters, and lateral breast protection, and nonuse of graduated screens.

Scoliosis is an abnormal lateral curvature of the vertebral column with some associated rotation of the vertebral bodies at the curve. This condition may be caused by disease, surgery, or trauma, but it is frequently idiopathic. Scoliosis is commonly detected in the adolescent years. If not detected and treated, it may progress to the point of debilitation.

Radiographic diagnosis and monitoring of scoliosis usually consist of PA (or AP) and lateral images taken in the upright position with a special ruler placed adjacent to the spine to allow accurate measurements to be made. Some of the newer scoliosis radiography systems do not require use of a ruler because software allows accurate measurements to be made from the digital data sets. Supine and bending studies may be included when dictated by patient condition. The PA (or AP) and lateral upright projections show the amount or degree of curvature that occurs with the force of gravity acting on the body and allow precise measurements to be taken. Spinal fixation devices, such as Harrington rods, may also be evaluated. Bending studies may be included to differentiate between primary and compensatory curves. Primary curves do not change when the patient bends, whereas secondary curves do change with bending.

Radiation protection

In 1983, Frank et al. [27] described the use of the PA projection for radiography of scoliosis. Also in 1983, Frank and Kuntz [30] described a simple method of protecting the breasts during radiography of scoliosis. By 1986, in an article by Butler et al., the federal government had endorsed the use of these techniques. [31]

Radiation protection is crucial. Collimation must be closely limited to irradiate only the thoracic and lumbar spine. The gonads should be shielded by placing a lead apron at the level of the ASIS between the patient and the x-ray tube. The breasts should be shielded with leaded rubber or leaded acrylic, or the breast radiation exposure should be decreased by performing PA projections.

Image receptor + grid: Positioned by manufacturer or department protocol for proper anatomy display orientation. A variety of devices and IR holders have been developed for both CR and DR systems. All systems allow multiple images encompassing the entire spine to be captured without the need for repositioning of the patient. The acquired images are combined, or “stitched,” by the computer system into a composite image that demonstrates the entire spine in one image.

Position of patient

- This procedure is usually performed with the patient in the upright position.

Position of part

PA (or AP)

- Patient faces the vertical grid device for the PA or rests the back against the device for the AP.
- Adjust the patient’s pelvis for rotation by ensuring that the ASIS are equidistant from the IR.
- Center the MSP of the patient’s body to the midline of the vertical grid device (Fig. 9.131A).
- Let the patient’s arms hang by the sides.
- Position the special ruler adjacent to the spine, if needed.
- *Shield gonads and breasts as appropriate.*
- *Respiration:* Suspend.

Lateral

- Place the patient’s side against the vertical grid device.
- Adjust the position of the patient so that the MSP of the body is parallel with the IR and the adjacent shoulder is touching the grid device.
- Center the thorax to the grid; MCP should be perpendicular and centered to the midline of the grid (see Fig. 9.131B).
- Position the special ruler adjacent to the spine, if needed.
- Have the patient extend the arms upward to prevent superimposition over the spine.
- *Shield gonads and breasts as appropriate.*
- *Respiration:* Suspend.

FIG. 9.131 Standing full-spine radiography for evaluation of scoliosis. (A) PA projection: Frank et al. method. (B) Lateral projection.

(A) A patient is standing upright and is facing the vertical grid device. The body is centered to the midline of the vertical grid device. The central ray is perpendicular to the center of the I R. Diagram (B) A patient is standing upright with the adjacent shoulder touching the vertical grid device. The thorax is centered to the midline of the grid device. The body is centered to the midline of the vertical grid device. The central ray is perpendicular to the center of the I R.

Central ray

- Perpendicular to the center of the IR. The centering points for each radiograph in the sequence will be dictated by the system used.
- A two- (or three-) image sequence is performed for both the PA and lateral projections (Figs. 9.132 and 9.133).

Collimation

- Extent of collimation depends on the type of imaging system used, as well as the extent of the patient's scoliosis. Care should be taken to include only the anatomy of interest. If possible, the width of the collimated field should be less than the width of the IR. Always check previous examination images to determine extent of curvature.

FIG. 9.132 Standing full-spine radiography for evaluation of scoliosis. (A) PA projection to include the cervical spine. (B) PA projection to include the thoracic spine. (C) PA projection to include the lumbar spine and sacroiliac joints.

(A) A patient is standing upright and is facing the vertical grid device. The central ray is perpendicular to the cervical spine. (B) A patient is standing upright and is facing the vertical grid device. The central ray is perpendicular to the thoracic spine. (C) A patient is standing upright and is facing the vertical grid device. The central ray is perpendicular to the lumbar spine and sacroiliac joints.

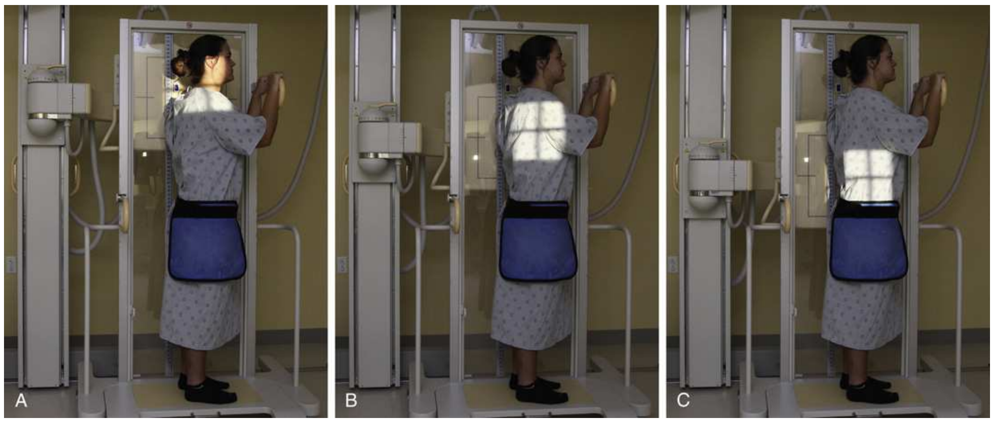


FIG. 9.133 Standing full-spine radiography for evaluation of scoliosis. (A) Lateral projection to include the cervical spine. (B) Lateral projection to include the thoracic spine. (C) Lateral projection to include the lumbar spine and sacroiliac joints.

(A) A patient is standing upright with the adjacent shoulder touching the vertical grid device. The central ray is perpendicular to the cervical spine. (B) A patient is standing upright with the adjacent shoulder touching the vertical grid device. The central ray is perpendicular to the thoracic spine. (C) A patient is standing upright with the adjacent shoulder touching the vertical grid device. The central ray is perpendicular to the lumbar spine and sacroiliac joints.

Structures shown

The entire spine from base of skull to tip of coccyx (Fig. 9.134).

Evaluation Criteria

The following should be clearly seen:

- Evidence of proper collimation, presence of special ruler if used, and presence of the side marker placed clear of anatomy of interest
- Entire cervical, thoracic, and lumbosacral spines
- Vertebral column aligned down the center of the image
- Bony trabecular detail and surrounding soft tissues

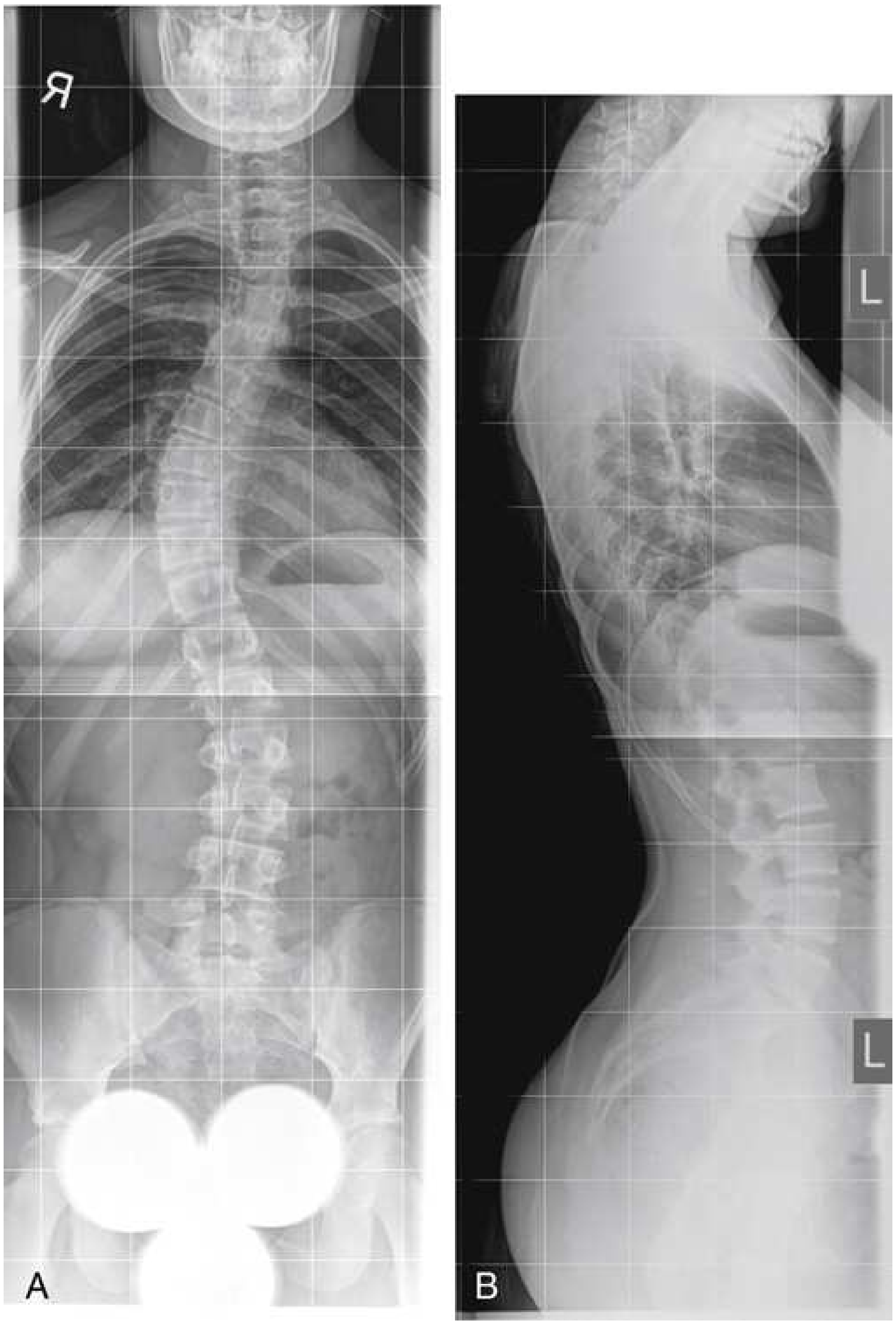


FIG. 9.134 Standing full-spine radiography. Multiple images were combined digitally to create these composite images. (A) PA projection. (B) Lateral projection.

(A) shows an x-ray view of the entire cervical, thoracic, and lumbosacral spines. The vertebral column is aligned down the center of the image. The gonad shield is at the bottom. (B) shows an x-ray view of the lateral cervical, thoracic, and lumbosacral spines. It appears blurry.

Microdose procedure

Large children's hospitals may have a low-dose slit scanning system (Fig. 9.135) that allows upright PA and lateral images (Fig. 9.136) to be acquired simultaneously. These systems are capable of delivering microdose exposures for repeat procedures where less detail is needed.

FIG. 9.135 Standing full-spine radiography using a microdose slit-scanning unit. Both PA and lateral projections can be acquired simultaneously.

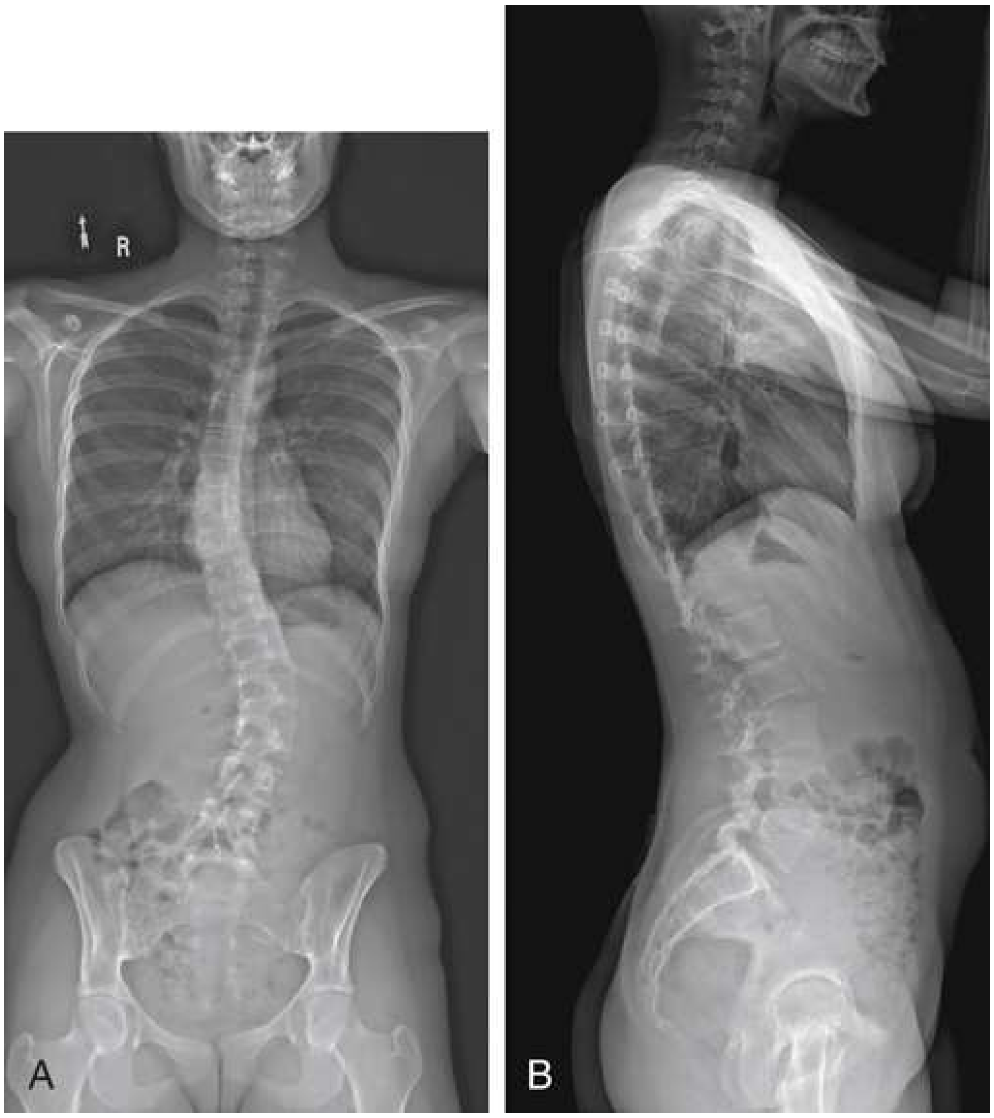


FIG. 9.136 Standing full-spine radiographs acquired by the microdose unit in Fig. 9.135. (A) PA projection. (B) Lateral projection.

(A) An x-ray shows the entire cervical, thoracic, and lumbosacral spines. The vertebral column is aligned down the center of the image. The lungs appear radiolucent. (B) An x-ray shows the lateral cervical, thoracic, and lumbosacral spines. It appears blurry.

PA Projection

Ferguson Method [32]

The patient should be positioned to obtain a PA projection (in lieu of the AP projection) to reduce radiation exposure [27] to selected radiosensitive organs. The decision whether to use a PA or AP projection is often determined by the physician or institutional policy.

Image receptor + grid: Positioned by manufacturer or department protocol for proper anatomy display orientation. A variety of devices and IR holders have been developed for both CR and DR systems. All systems allow multiple images encompassing the entire spine to be captured without the need for repositioning of the patient. The acquired images are combined, or "stitched," by the computer system into a composite image that demonstrates the entire spine in one image.

Position of patient

- For a PA projection, place the patient in a seated or standing position in front of a vertical grid device (Fig. 9.137).

Position of part

First radiograph

- Adjust the patient in a normally seated or standing position to check the spinal curvature.
- Center the MSP of the patient's body to the midline of the grid.
- Allow the patient's arms to hang relaxed at the sides. If the patient is seated, flex the elbows and rest the hands on the lap (Fig. 9.138).
- Do not support the patient.
- *Shield gonads.*

- *Respiration:* Suspend.

Second radiograph

- Elevate the patient's hip or foot on the convex side of the primary curve approximately 3 or 4 inches (7.6 to 10.2 cm) by placing a block, a book, or sandbags under the buttock or foot (Fig. 9.139). Ferguson [32] specified that the elevation must be sufficient to make the patient expend some effort in maintaining the position.
- Do not support the patient.
- *Shield gonads.*
- *Respiration:* Suspend.
- Obtain additional radiographs (if needed) with elevation of the hip on the side opposite the major or primary curve (Fig. 9.140), or with the patient in a recumbent position (Fig. 9.141).

Central ray

- Perpendicular to the midpoint of the IR. The centering points for each radiograph in the sequence will be dictated by the system used.

Collimation

- Extent of collimation depends on the type of imaging system used, as well as the severity of the patient's scoliosis. Care should be taken to include only the anatomy of interest. The width of the collimated field must be less than the width of the IR. Always check previous examination images to determine the extent of curvature.

Structures shown

The thoracic and lumbar vertebrae, for comparison to distinguish the deforming or primary curve from the compensatory curve in patients with scoliosis (see Figs. 9.138–9.141).

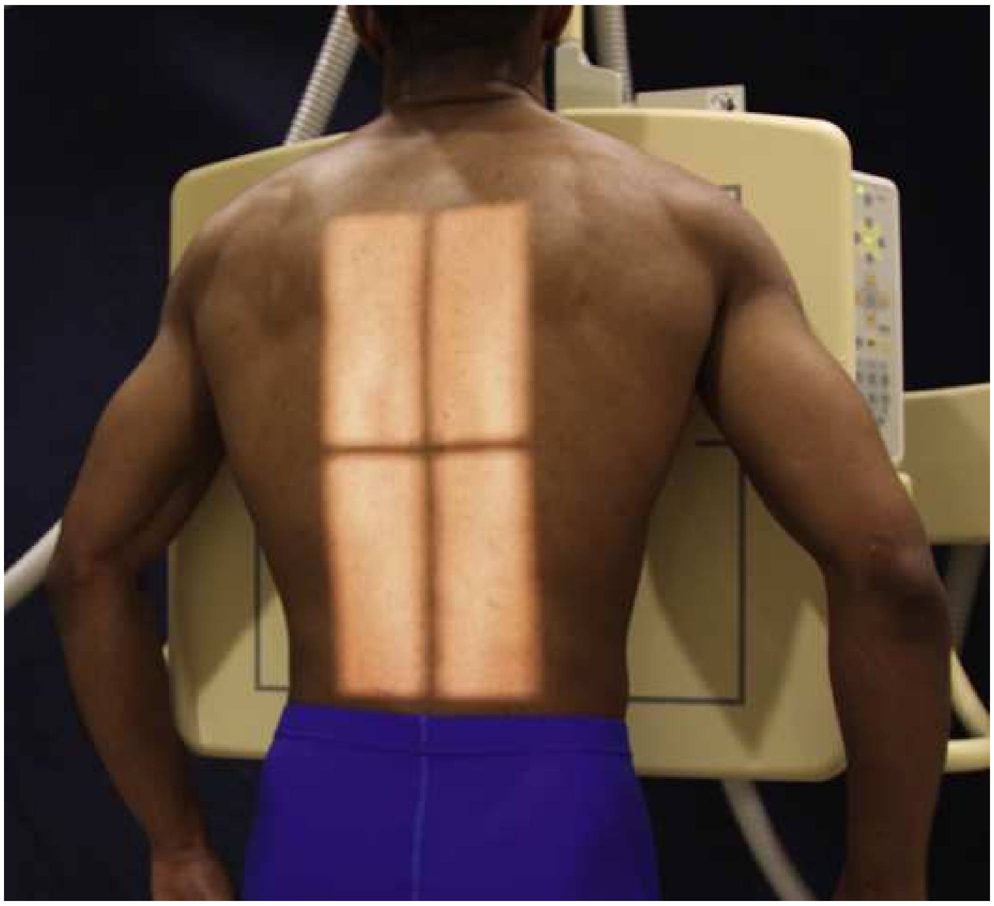


FIG. 9.137 PA thoracic and lumbar spine for scoliosis, upright.

The patient is in a standing position in front of the grid. The patient's arms are relaxed on the sides. The M S P is centered to the patient's body to the midline of the grid. The central ray is perpendicular to the midpoint of the I R.

FIG. 9.138 PA thoracic and lumbar spine for scoliosis, upright, showing structural (major or primary) curve *(arrow)*.

Evaluation Criteria

The following should be clearly seen:

- Evidence of proper collimation and presence of the side marker placed clear of anatomy of interest
- Thoracic and lumbar vertebrae to include about 1 inch (2.5 cm) of the iliac crests
- Vertebral column aligned down the center of the image
- Bony trabecular detail and surrounding soft tissues

NOTE: Another widely used scoliosis series consists of four images of the thoracic and lumbar spine: a direct PA projection with the patient standing, a direct PA projection with the patient prone, and PA projections with alternate right and left lateral flexion in the prone position. The right and left bending positions are described in the next section.

NOTE: Young et al. [33] described their application of this scoliosis procedure in detail. They recommended the addition of a lateral position, made with the patient standing upright, to show spondylolisthesis or to show exaggerated degrees of kyphosis or lordosis. Kittleson and Lim [34] described the Ferguson and Cobb methods of measurement of scoliosis.

FIG. 9.139 PA thoracic and lumbar spine with left hip elevated.

FIG. 9.140 PA thoracic and lumbar spine with right hip elevated.

FIG. 9.141 PA thoracic and lumbar spine for scoliosis, prone.

Lumbar Spine: Spinal Fusion

Ap Projection

Right and left bending

Image receptor + grid: Positioned by manufacturer or department protocol for proper anatomy display orientation; CR plate: 10 × 12 inches (24 × 30 cm) or 14 × 17 inches (35 × 43 cm) lengthwise for each exposure. IR size is determined by number of vertebral segments to be imaged.

Position of patient

- Place the patient in the supine position and center the MSP of the body to the midline of the grid. These bending positions can also be performed with the patient upright.

Position of part

- Take the first radiograph with maximum right bending. Take the second radiograph with maximum left bending.
- To obtain equal bending force throughout the spine when the patient is supine, cross the patient's leg on the opposite side to be flexed over the other leg. A right bending requires the left leg to be crossed over the right.
- Move the patient's heels toward the side that is flexed. Immobilize the heels with sandbags.
- Move the shoulders directly lateral as far as possible without rotating the pelvis (Fig. 9.142).
- *Shield gonads.*
- *Respiration:* Suspend.

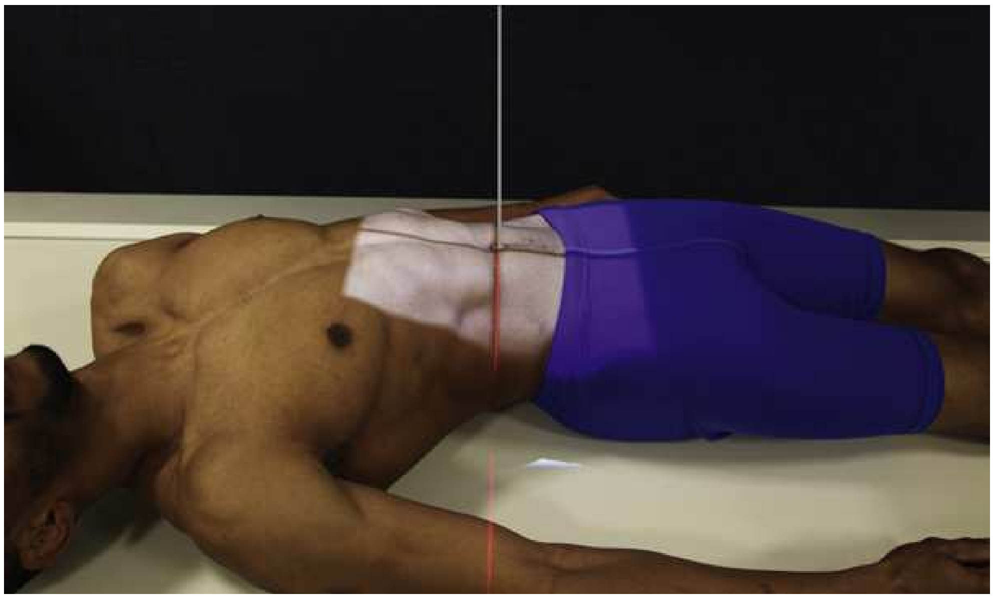


FIG. 9.142 AP lumbar spine, right bending.

The patient is lying in the supine position on the radiographic table and is bent to the right. The patient's shoulders are moved directly and placed laterally as far as possible without rotating the pelvis. The central ray is perpendicular to the level of the third lumbar vertebra.

Central ray

- Perpendicular to the level of the third lumbar vertebra, 1 to 1.5 inches (2.5 to 3.8 cm) above the iliac crest on the MSP
- Center the IR to the central ray.

Collimation

- Adjust radiation field to 10 × 12 inches (24 × 30 cm) or 14 × 17 inches (35 × 43 cm) on the collimator. Place the side marker in the collimated exposure field.

Structures shown

The lumbar vertebrae, in maximum right and left bending (lateral flexion) (Figs. 9.143 and 9.144). These studies are used to evaluate the integrity of a spinal fusion and are usually performed 6 months after the fusion procedure. This procedure may also be used in patients with early scoliosis to determine the presence of structural change when bending to the right and left. The studies may be used to localize a herniated disk, as shown by limitation of motion at the site of the lesion.

Evaluation Criteria

The following should be clearly seen:

- Evidence of proper collimation and presence of the side marker placed clear of anatomy of interest
- Site of the spinal fusion centered and including the superior and inferior vertebrae
- No rotation of the pelvis (symmetric ilia)
- Bending directions correctly identified with appropriate lead markers
- Bony trabecular detail and surrounding soft tissues

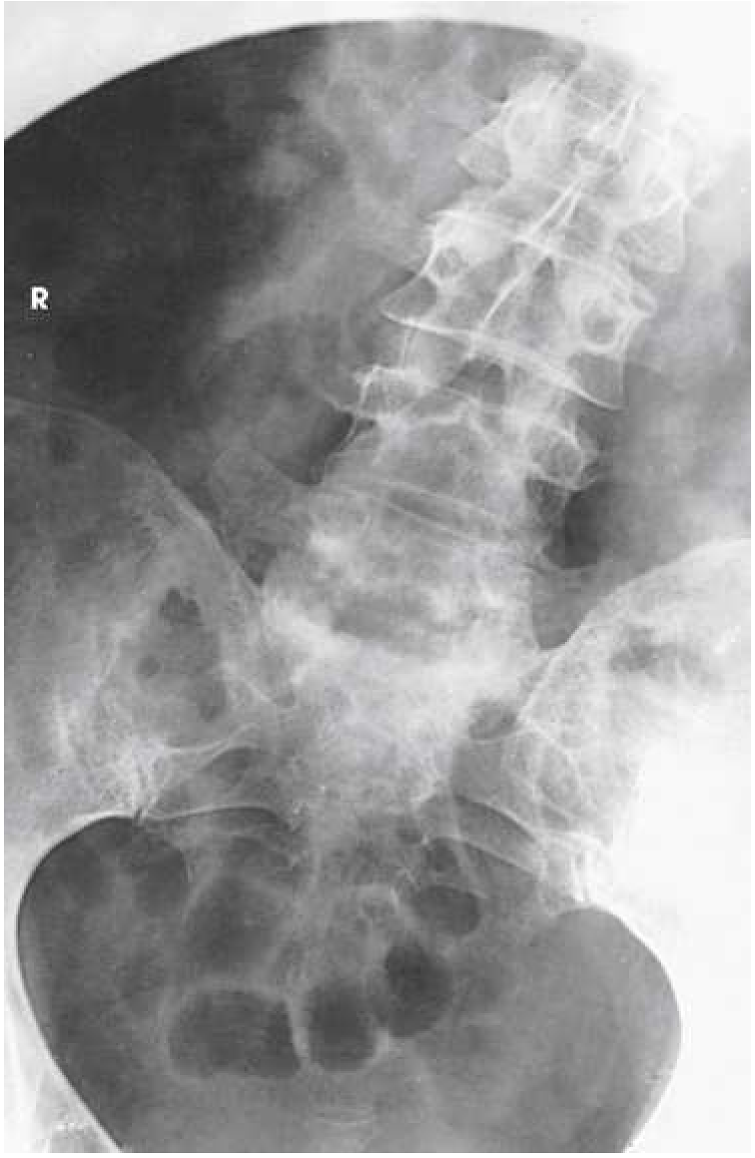


FIG. 9.143 AP lumbar spine, right bending spinal fusion series.

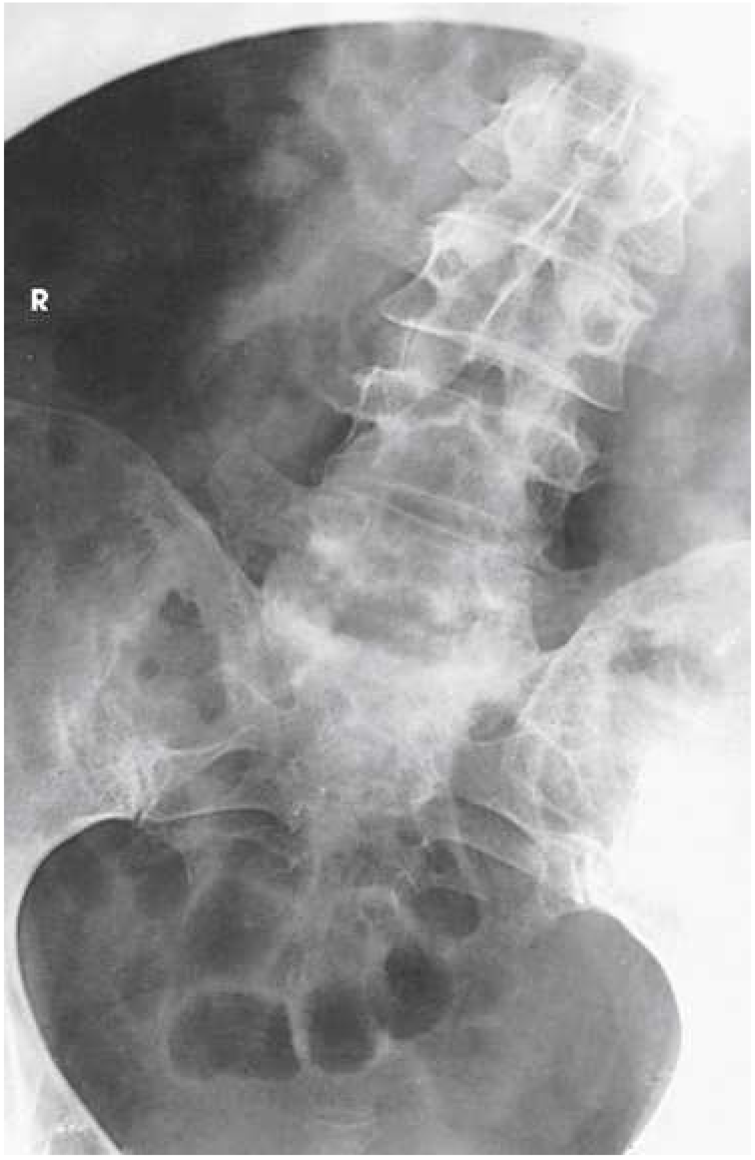


FIG. 9.144 AP lumbar spine, left bending spinal fusion series.

Lateral Projection

Right or left position

Flexion and extension

Image receptor + grid: Positioned by the manufacturer or department protocol for proper anatomy display orientation; CR plate: 14 × 17 inches (35 × 43 cm) lengthwise for each exposure.

Position of patient

- Adjust the patient in the upright or lateral recumbent position.
- Center the midcoronal plane to the midline of the grid.

Position of part

Flexion

- Ask the patient to bend forward, to flex the spine as much as possible (Fig. 9.145).

Extension

- Ask the patient to bend backward, to extend the spine as much as possible (Fig. 9.146).
- Immobilize the patient to prevent movement, if needed.
- Center the IR at the level of the spinal fusion.
- *Shield gonads.*
- *Respiration:* Suspend.

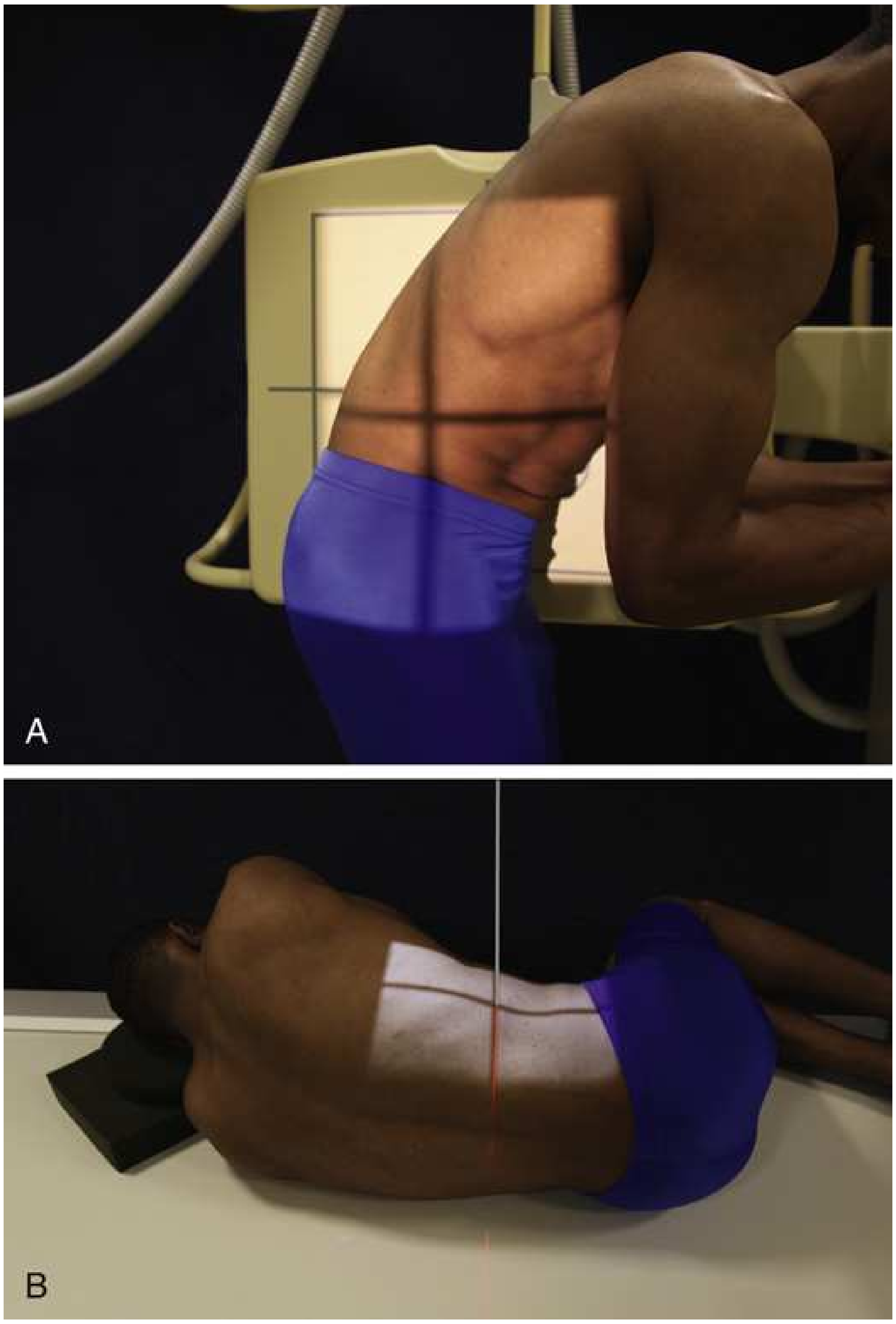


FIG. 9.145 Lateral lumbar spine in flexion. (A) Upright position. (B) Recumbent position.

(A) shows the patient in the upright position against the vertical grid. The patient is bent forward and the spine is flexed. The central ray is perpendicular to the spinal fusion area or L 3. (B) shows the patient in a recumbent position on the radiographic table. The patient is bent forward and the spine is flexed. The central ray is perpendicular to the spinal fusion area or L 3.

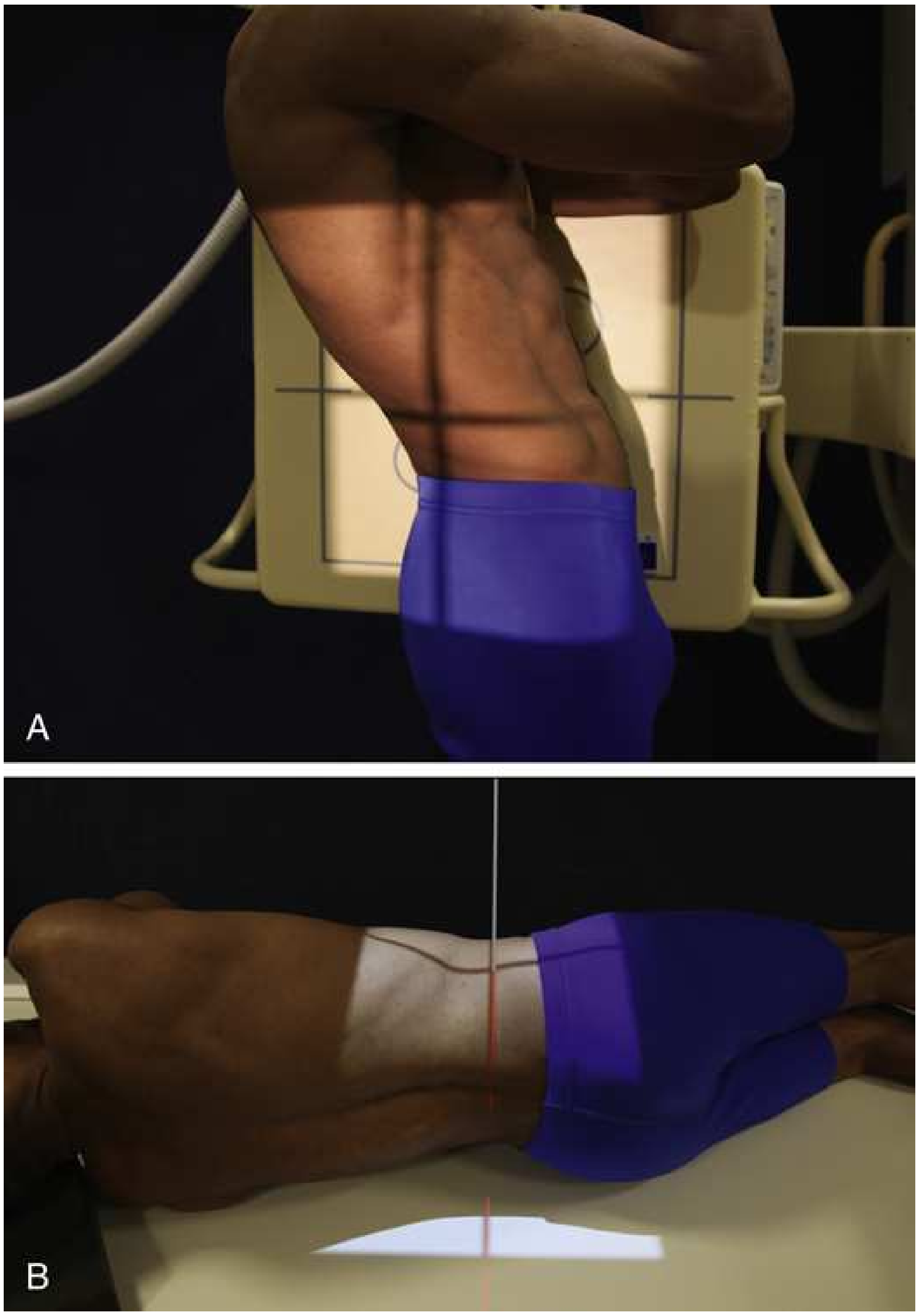


FIG. 9.146 Lateral lumbar spine in extension. (A) Upright position. (B) Recumbent position.

(A) shows the patient in the upright position against the vertical grid. The patient is bent backward and the spine is extended. The central ray is perpendicular to the spinal fusion area or L 3. (B) shows the patient in a recumbent position on the radiographic table. The patient is bent backward and the spine is extended. The central ray is perpendicular to the spinal fusion area or L 3.

Central ray

- Perpendicular to the spinal fusion area or L3.

Collimation

- Adjust radiation field to 14 × 17 inches (35 × 43 cm) on the collimator. Place the side marker in the collimated exposure field.

Structures shown

Two lateral projections of the spine are taken in flexion (Fig. 9.147A) and extension (see Fig. 9.147B), to determine whether motion is present in the area of a spinal fusion, indicating a nonunion, or to localize a herniated disk as shown by limitation of motion at the site of the lesion.

Evaluation Criteria

The following should be clearly seen:

- Evidence of proper collimation and presence of the side marker placed clear of anatomy of interest
- Site of the spinal fusion in the center of the radiograph
- No rotation of the vertebral column (posterior margins of the vertebral bodies are superimposed)
- Hyperflexion and hyperextension identification markers correctly used for each respective projection
- Bony trabecular detail and surrounding soft tissues

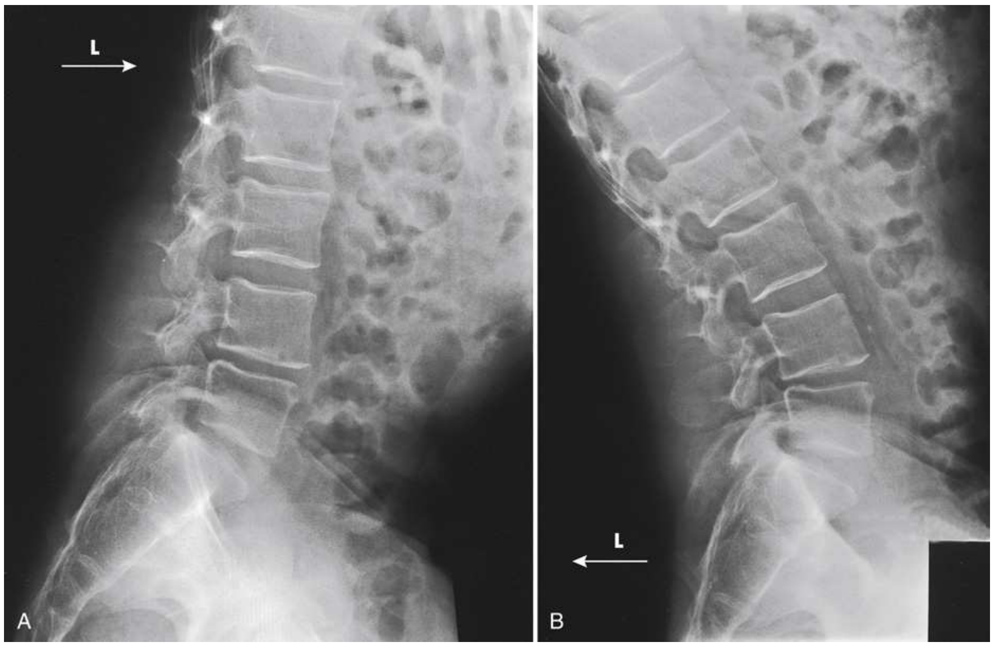


FIG. 9.147 (A) Lateral with hyperflexion. (B) Lateral with hyperextension. Note position of markers and accurate use of *arrows*.

(A) An x-ray shows hyperflexion of the spine. The site of the spinal fusion is in the center of the radiograph. An arrow pointing to the line is labeled L. (B) An x-ray shows the hyperextension of the spine. The site of the spinal fusion is in the center of the radiograph. An arrow pointing to the line is labeled R.

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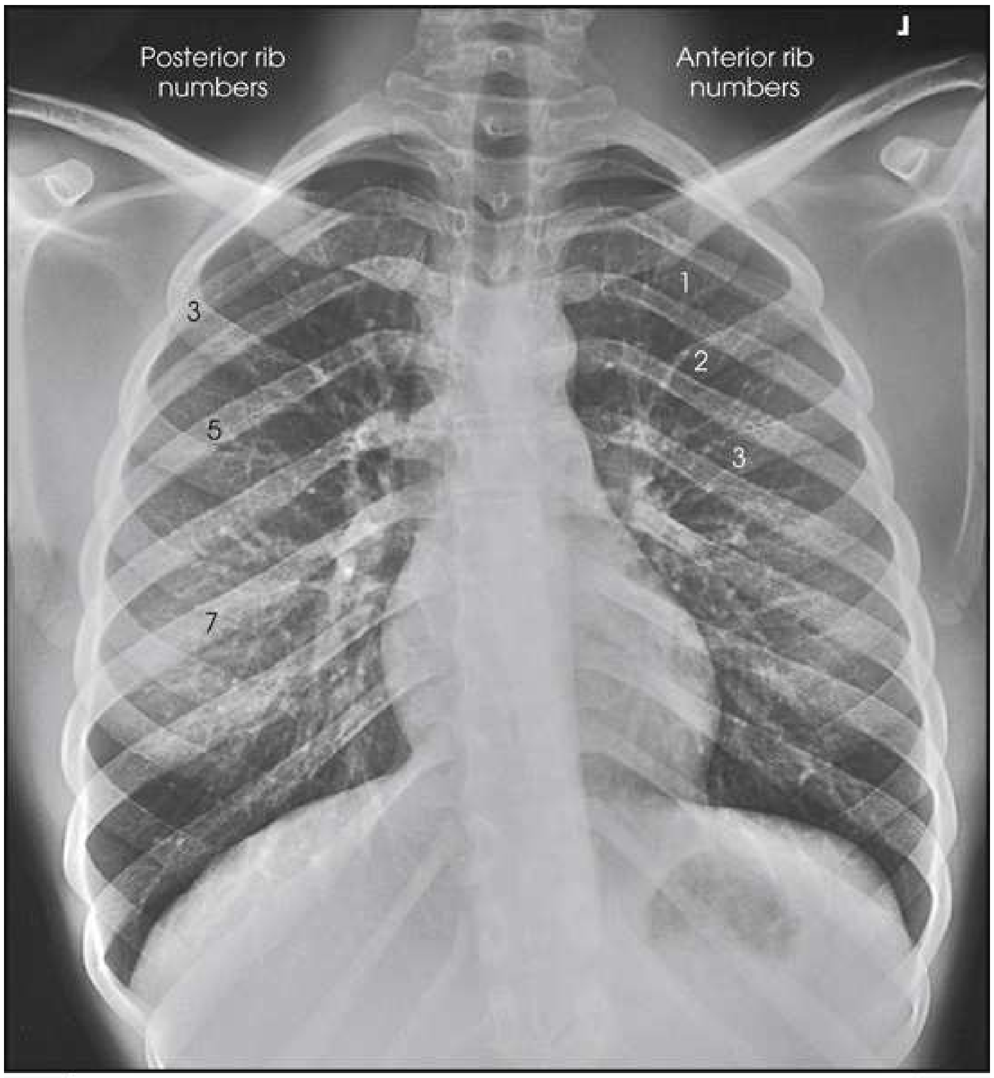
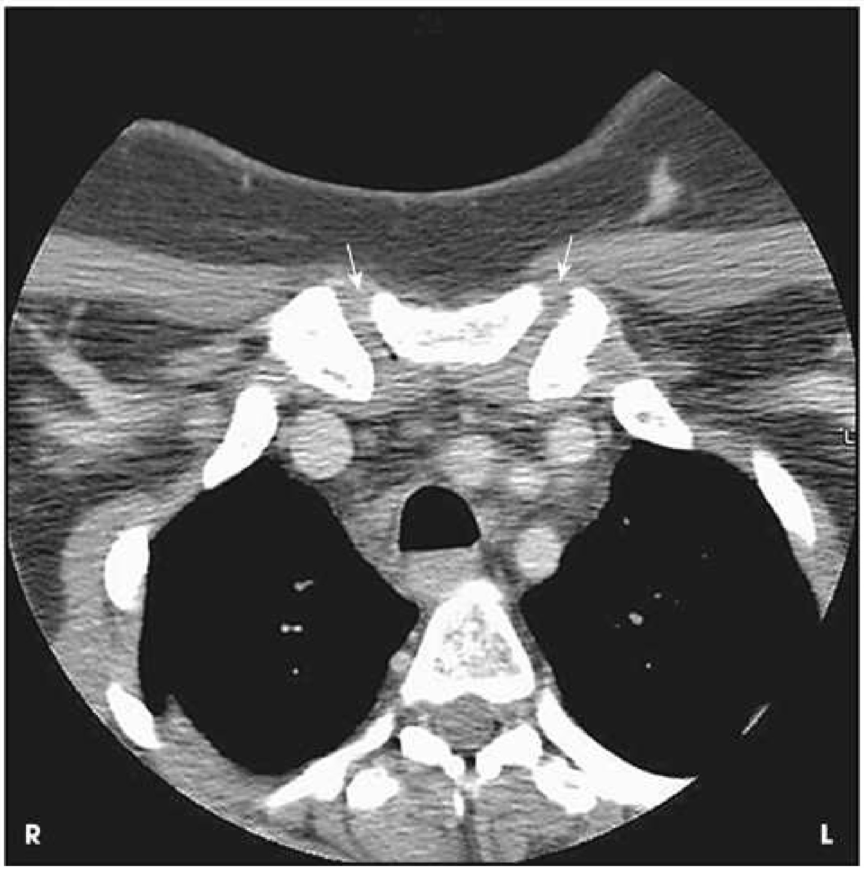
10: Bony Thorax





OUTLINE

Summary of Projections

PROJECTIONS, POSITIONS, AND METHODS					
Page	Essential	Anatomy	Projection	Position	Method
520		Sternum	PA oblique	RAO	
522		Sternum	PA oblique	Modified prone	MOORE
524		Sternum	Lateral	R or L	
526		Sternoclavicular articulations	PA		
527		Sternoclavicular articulations	PA oblique	RAO or LAO	BODY ROTATION
528		Sternoclavicular articulations	PA oblique	RAO or LAO	CENTRAL RAY ANGULATION
531		Upper anterior ribs	PA		
533		Posterior ribs	AP		
535		Axillary ribs	AP oblique	RPO or LPO	
537		Axillary ribs	PA oblique	RAO or LAO	

The icons in the Essential column indicate projections that are frequently performed in the United States and Canada. Students should be competent in these projections.

AP, Anteroposterior; *L,* left; *LAO,* left anterior oblique; *LPO,* left posterior oblique; *PA,* posteroanterior; *R,* right; *RAO,* right anterior oblique; *RPO,* right posterior oblique.

Anatomy

Bony Thorax

The *bony thorax* supports the walls of the pleural cavity and diaphragm used in respiration. The thorax is constructed so that the volume of the thoracic cavity can be varied during respiration. The thorax also protects the heart and lungs.

The bony thorax is formed by the sternum, 12 pairs of ribs, and 12 thoracic vertebrae. The bony thorax protects the heart and lungs. Conical in shape, the bony thorax is narrower above than below, more wide than deep, and longer posteriorly than anteriorly.

Sternum

The *sternum*, or breastbone, is directed anteriorly and inferiorly and is centered over the midline of the anterior thorax (Figs. 10.1 through 10.3). A narrow, flat bone approximately 6 inches (15 cm) in length, the sternum consists of three parts: manubrium, body, and xiphoid process. The sternum supports the clavicles at the superior manubrial angles and provides attachment to the costal cartilages of the first seven pairs of ribs at the lateral borders.

The *manubrium*, the superior portion of the sternum, is quadrilateral in shape and is the widest portion of the sternum. At its center, the superior border of the manubrium has an easily palpable concavity termed the *jugular notch*. In the upright position, the jugular notch of the average person lies anterior to the interspace between the second and third thoracic vertebrae. The manubrium slants laterally and posteriorly on each side of the jugular notch, and an oval articular facet called the *clavicular notch* articulates with the sternal extremity of the clavicle. On the lateral borders of the manubrium, immediately below the articular notches for the clavicles, are shallow depressions for attachment of the cartilages of the first pair of ribs.

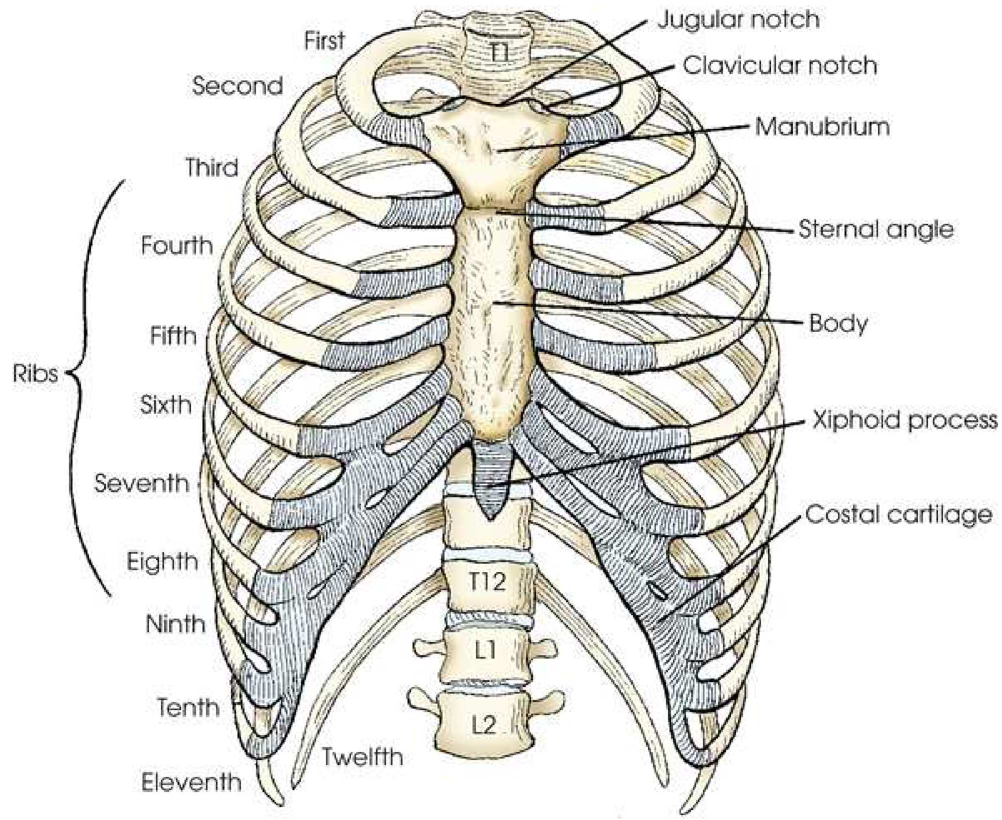


FIG. 10.1 Anterior aspect of bony thorax.

Diagram shows the anterior aspect of the bony thorax. The sternum is directed anteriorly and inferiorly and is centered over the midline of the anterior thorax. The sternum is narrow and flat. The parts labeled in the diagram are as follows. the first, second, third, fourth, fifth, sixth, seventh, eighth, ninth, tenth, eleventh, twelfth ribs, jugular notch, clavicular notch, manubrium, sternal angle, body, xiphoid process, and costal cartilage.

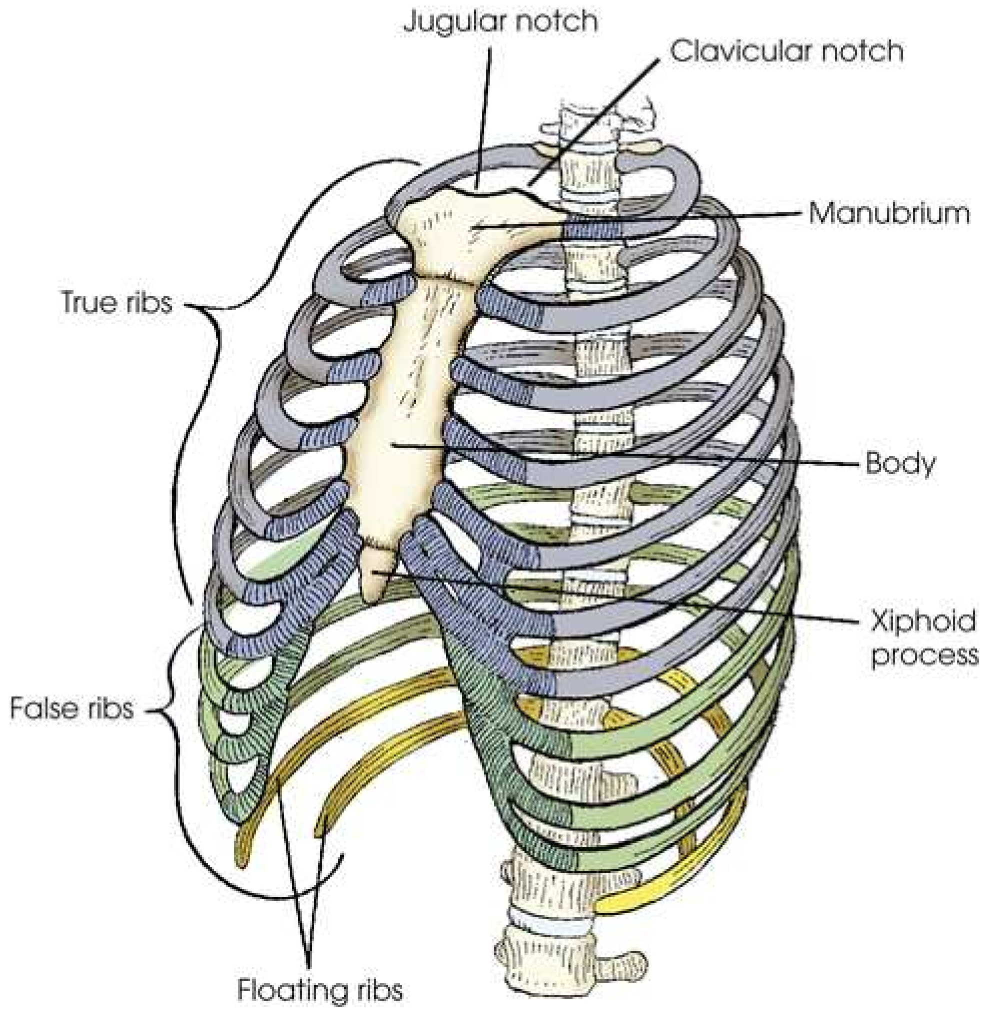


FIG. 10.2 Color-coded anterolateral oblique aspect of bony thorax. *blue*, True ribs; *green*, false ribs; *yellow*, floating ribs.

Diagram shows the color-coded anterolateral oblique aspect of the bony thorax. Blue is the true ribs, green is the false ribs, yellow outline with green shading are the floating ribs. The parts labeled are as follows: jugular notch, clavicular notch, manubrium, body, xiphoid process.

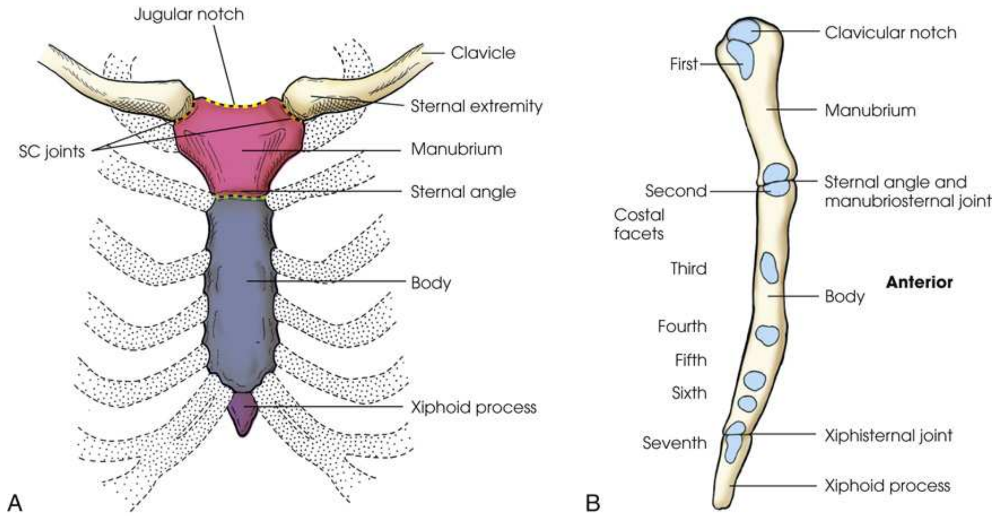


FIG. 10.3 (A) Color-coded anterior aspect of sternum and sternoclavicular joints. *Blue*, body; *green (outline),* sternal angle; *orange (outline)*, sternoclavicular joints; *pink*, manubrium; *purple*, xiphoid process; *yellow (outline)*, jugular notch. (B) Lateral sternum.

Diagram (A) shows the color-coded anterior aspect of the sternum and sternoclavicular joints. The sternum is narrow and flat. Blue is the body, green (outline) is the sternal angle, orange (outline) is the sternoclavicular joints, pink is the manubrium, purple is the xiphoid process, yellow (outline) is the jugular notch. Diagram (B) shows the lateral sternum. It is long and narrow. The parts labeled in the diagram are marked as follows: first, second, third, fourth, fifth, sixth, seventh costal facets, clavicular notch, manubrium, sternal angle, and manubriosternal joint, body, xiphisternal joint, and xiphoid process.

The *body* is the longest part of the sternum (4 inches [10.2 cm]) and is joined to the manubrium at the *sternal angle*, an obtuse angle that lies at the level of the junction of the second costal cartilage. The manubrium and the body contribute to the attachment of the second costal cartilage. The succeeding five pairs of costal cartilages are attached to the lateral borders of the body. The sternal angle is palpable; in the normally formed thorax, it lies anterior to the interspace between the fourth and fifth thoracic vertebrae when the body is upright.

The *xiphoid process*, the distal and smallest part of the sternum, is cartilaginous in early life and partially or completely ossifies, particularly the superior portion, in later life. The xiphoid process is variable in shape and often deviates from the midline of the body. In the normal thorax, the xiphoid process lies over the tenth thoracic vertebra and serves as a useful bony landmark for locating the superior portion of the liver and the inferior border of the heart.

Ribs

The 12 pairs of ribs are numbered consecutively from superiorly to inferiorly (Fig. 10.4; also see Figs. 10.1 and 10.2). The rib number corresponds to the thoracic vertebra to which it attaches. Each rib is a long, narrow, curved bone with an anteriorly attached piece of hyaline cartilage, the *costal cartilage*. The costal cartilages of the first through seventh ribs attach directly to the sternum. The costal cartilages of the eighth through tenth ribs attach to the costal cartilage of the seventh rib. The ribs are situated in an oblique plane slanting anteriorly and inferiorly so that their anterior ends lie 3 to 5 inches (7.6 to 12.5 cm) below the level of their vertebral ends. The degree of obliquity gradually increases from the first to the ninth rib and then decreases to the twelfth rib. The first seven ribs are called *true ribs* because they attach directly to the sternum. Ribs 8 to 12 are called *false ribs* because they do not attach directly to the sternum. The last two ribs (eleventh and twelfth ribs) are often called *floating ribs* because they are attached only to the vertebrae. The spaces between the ribs are referred to as the *intercostal spaces*.

The number of ribs may be increased by the presence of cervical or lumbar ribs, or both. *Cervical ribs* articulate with the C7 vertebra but rarely attach to the sternum. Cervical ribs may be free or may articulate or fuse with the first rib. Lumbar ribs are less common than cervical ribs. *Lumbar ribs* can lend confusion to images. They can confirm the identification of the vertebral level, or they can be erroneously interpreted as a fractured transverse process of the L1 vertebra.

Ribs vary in breadth and length. The first rib is the shortest and broadest; the breadth gradually decreases to the twelfth rib, the narrowest rib. The length increases from the first to the seventh rib and then gradually decreases to the twelfth rib.

A typical rib consists of a *head*, a flattened *neck*, a *tubercle*, and a *body* (Figs. 10.5 and 10.6). The ribs have *facets* on their heads for articulation with the vertebrae. The facet is divided on some ribs into superior and inferior portions for articulation with demifacets on the vertebral bodies. The tubercle also contains a facet for articulation with the transverse process of the vertebra. The eleventh and twelfth ribs do not have a neck or tubercular facets. The two ends of a rib are termed the *vertebral end* and the *sternal end*.

From the point of articulation with the vertebral body, the rib projects posteriorly at an oblique angle to the point of articulation with the transverse process. The rib turns laterally to the *angle* of the body, where the bone arches anteriorly, medially, and inferiorly in an oblique plane. Located along the inferior and internal border of each rib is the *costal groove*, which contains costal arteries, veins, and nerves. Trauma to the ribs can damage these neurovascular structures, causing pain and hemorrhage.

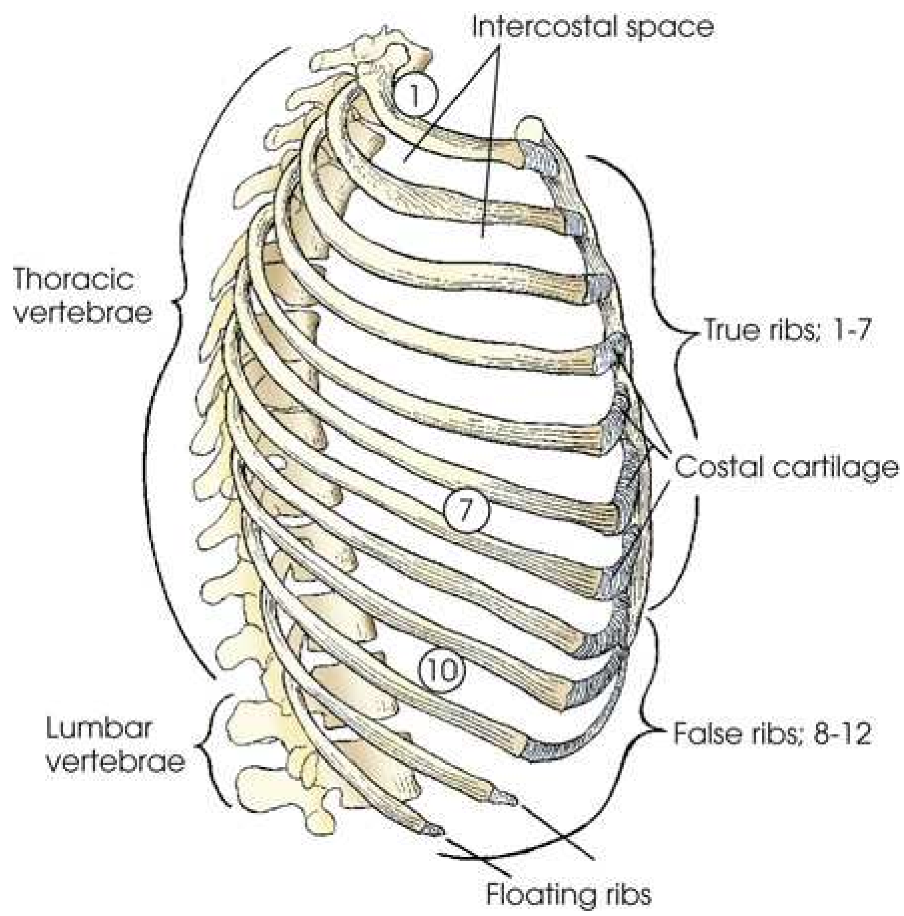


FIG. 10.4 Lateral aspect of bony thorax.

Diagram shows 12 pairs of ribs that are numbered consecutively from superiorly to inferiorly. The parts labeled in the diagram are marked as follows: the thoracic vertebrae, lumbar vertebrae, intercostal space, true ribs: 1 to 7, false ribs: 8 to 12, floating ribs, and the costal cartilage. The ribs vary in breadth and length.

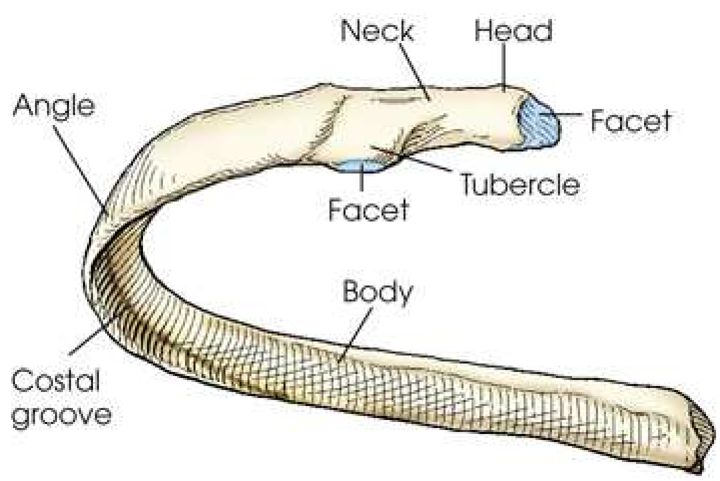


FIG. 10.5 Typical rib viewed from posterior.

Diagram shows the typical rib viewed from the posterior. The parts labeled in the diagram are marked as follows. angle neck head, facet, tubercle, body, costal, groove, and facet. The facets are shaded in blue.

Bony Thorax Articulations

The eight joints of the bony thorax are summarized in Table 10.1. A detailed description follows.

The *sternoclavicular* joints are the only points of articulation between the upper limbs and the trunk (see Fig. 10.3). Formed by the articulation between the sternal extremity of the clavicles and the clavicular notches of the manubrium, these *synovial gliding* joints permit free movement (the gliding of one surface on the other). A circular disk of fibrocartilage is interposed between the articular ends of the bones in each joint, and the joints are enclosed in articular capsules.

TABLE 10.1

Joint	Structural classification Tissue	Type	Movement
Sternoclavicular	Synovial	Gliding	Freely movable
Costovertebral			
1st–12th ribs	Synovial	Gliding	Freely movable
Costotransverse			
1st–10th ribs	Synovial	Gliding	Freely movable
Costochondral			
1st–10th ribs	Cartilaginous	Synchondroses	Immovable
Sternocostal			
1st rib	Cartilaginous	Synchondroses	Immovable
2nd–7th ribs	Synovial	Gliding	Freely movable
Interchondral			
6th–9th ribs	Synovial	Gliding	Freely movable
9th–10th ribs	Fibrous	Syndesmoses	Slightly movable
Manubriosternal	Cartilaginous	Symphysis	Slightly movable
Xiphisternal	Cartilaginous	Synchondroses	Immovable

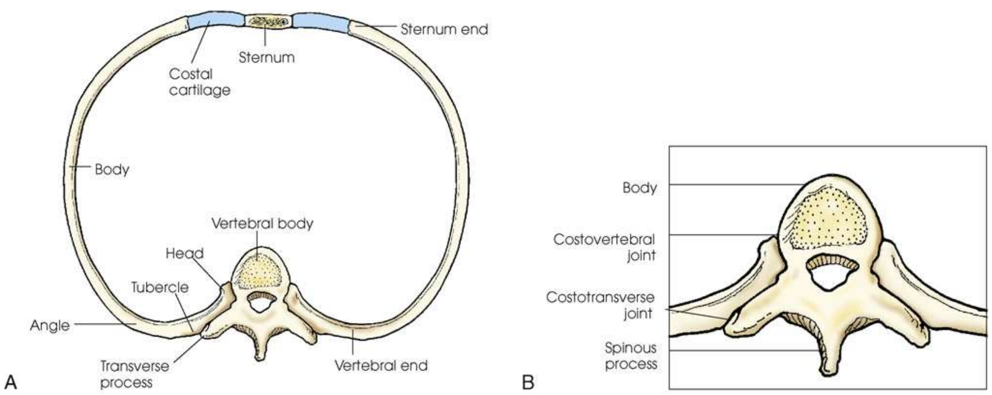


FIG. 10.6 (A) Superior aspect of rib articulating with thoracic vertebra and sternum. (B) Enlarged image of costovertebral and costotransverse articulations.

Diagram (A) shows the superior aspect of the rib articulating with the thoracic vertebra and the sternum. The parts labeled in the diagram are marked as follows. body, angle, transverse process, tubercle, head, vertebral body, vertebral end, costal cartilage, sternum, and sternum end. Diagram (B) shows the enlarged image of costovertebral and costotransverse articulations. The parts labeled in the diagram are marked as follows: body, costovertebral joint, costotransverse joint, and spinous process. The body has a triangular part in the middle and it appears grainy. There is a small hollow hole below it.

Posteriorly, the head of a rib is closely bound to the demifacets of two adjacent vertebral bodies to form a synovial gliding articulation called the *costovertebral joint* (Figs. 10.6 and 10.7A). The first, tenth, eleventh, and twelfth ribs all articulate with only one vertebral body.

The tubercle of a rib articulates with the anterior surface of the transverse process of the lower vertebra at the *costotransverse joint*, and the head of the rib articulates at the costovertebral joint. The head of the rib also articulates with the body of the same vertebra and articulates with the vertebra directly above. The costotransverse articulation is also a *synovial gliding* articulation. The articulations between the tubercles of the ribs and the transverse processes of the vertebrae permit only superior and inferior movements of the first six pairs. Greater freedom of movement is permitted in the succeeding four pairs.

Costochondral articulations are found between the anterior extremities of the ribs and the costal cartilages (see Fig. 10.7B). These articulations are *cartilaginous synchondroses* and allow no movement. The articulations between the costal cartilages of the true ribs and the sternum are called *sternocostal* joints. The first pair of ribs, rigidly attached to the sternum, forms the first sternocostal joint. This is a *cartilaginous synchondrosis* type of joint, which allows no movement. The second through seventh sternocostal joints are considered synovial gliding joints and are freely movable. *Interchondral* joints are found between the costal cartilages of the sixth and seventh, seventh and eighth, and eighth and ninth ribs (see Fig. 10.7C). These interchondral joints are *synovial gliding* articulations. The interchondral articulation between the ninth and tenth ribs is a *fibrous syndesmosis* and is only slightly movable.

The *manubriosternal* joint is a *cartilaginous symphysis* joint, and the *xiphisternal* joints are *cartilaginous synchondrosis* joints that allow little or no movement (see Figs. 10.3B and 10.7B and C).

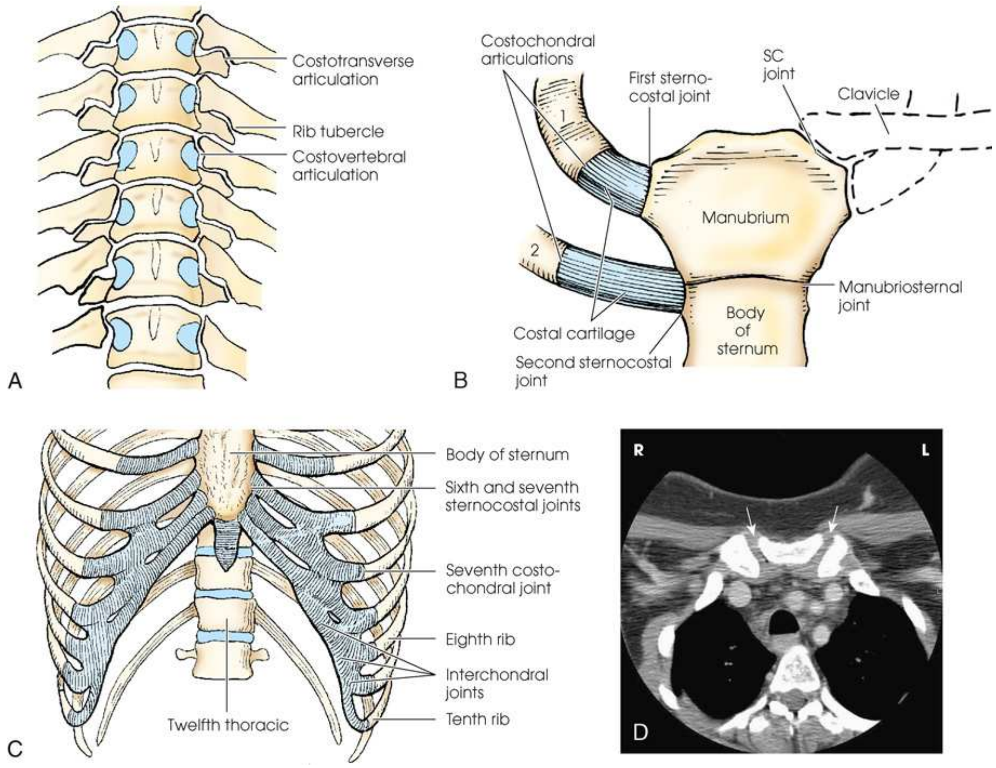


FIG. 10.7 Rib articulations. (A) Anterior aspect of thoracic spine, showing costovertebral articulations. (B) Anterior aspect of manubrium, sternum, and first two ribs, showing articulations. (C) Lower sternum and ribs, showing intercostal, costochondral, and sternocostal joints. (D) Computed tomography (CT) cross-section image of upper thorax showing manubrium and angulation of sternoclavicular joints *(arrows)*.

Diagram (A) shows the anterior aspect of the thoracic spine, with costovertebral articulations. The parts labeled in the diagram are marked as follows: costotransverse articulation, costovertebral articulation, and rib tubercle. Diagram. (B) shows the anterior aspect of the manubrium, sternum, and first two ribs, showing articulations. The parts labeled in the diagram are marked as follows: costochondral articulations, costal cartilage, clavicle, first sternocostal joint, second sternocostal joint, s c joint, manubriosternal joint, manubrium, and body of the sternum. The manubrium is shaped like a hexagon and the body of the sternum attaches itself to the manubrium. Diagram (C) shows the lower sternum and ribs, showing intercostal, costochondral, and sternocostal joints. The parts labeled in the diagram are marked as follows. body of sternum, interchondral joints, sixth and seventh sternocostal joints, seventh costochondral joint, eighth rib, twelfth thoracic, and tenth rib. The costal cartilages are shaded in blue. (D) shows a C T image of the upper thorax showing manubrium and angulation of sternoclavicular joints which is marked by two white arrows. The sternoclavicular joints appear white. The open sternoclavicular joint space appears dark.

Respiratory Movement

The normal oblique orientation of the ribs changes little during quiet respiratory movements; however, the degree of obliquity *decreases* with deep *inspiration* and *increases* with deep *expiration*. The first pair of ribs, which are rigidly attached to the manubrium, rotates at its vertebral end and moves with the sternum as one structure during respiratory movements.

On deep inspiration, the anterior ends of the ribs are carried anteriorly, superiorly, and laterally while the necks are rotated inferiorly (Fig. 10.8A). On deep expiration, the anterior ends are carried inferiorly, posteriorly, and medially, while the necks are rotated superiorly (see Fig. 10.8B). The last two pairs of ribs are depressed and are held in position by the action of the diaphragm when the anterior ends of the upper ribs are elevated during respiration.

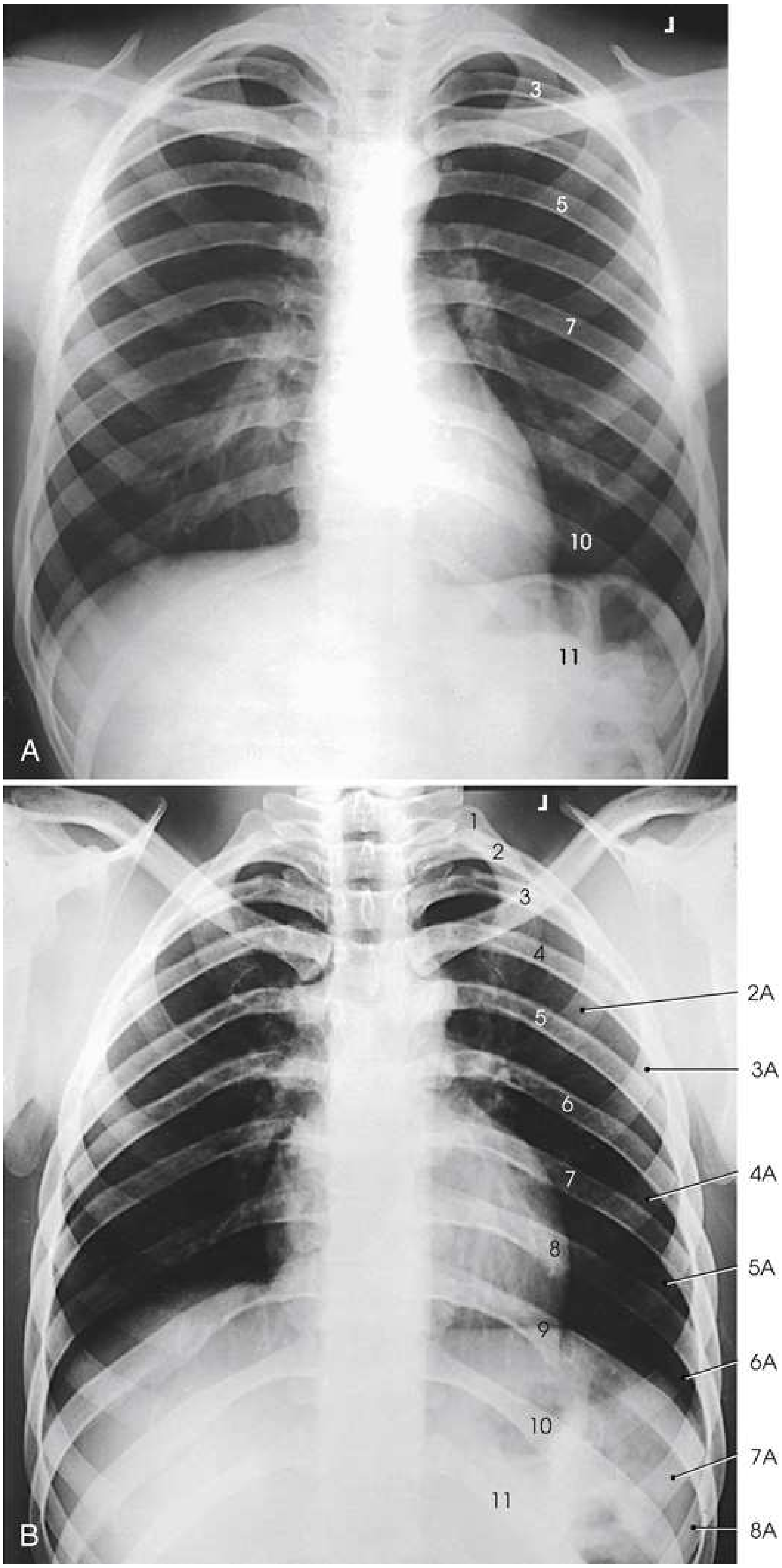


FIG. 10.8 Respiratory lung movement. (A) Full inspiration with posterior ribs numbered. (B) Full expiration with ribs numbered. Anterior ribs are labeled with *A*.

(A) An x-ray shows the lungs in full inspiration. The posterior ribs are numbered as 1, 3, 6, 7, 10, and 11. The lungs filled with air appear radiolucent. The heart and the region below the diaphragm appear radiopaque. (B) An x-ray shows the lungs in full expiration. The anterior ribs are labeled as 2 A, 4 A, 5 A, 6 A, 7 A, and 8 A. The lungs appear darker than in (A). The diaphragm is depressed.

Diaphragm

The ribs located above the diaphragm are best examined radiographically through the air-filled lungs, whereas the ribs situated below the diaphragm must be examined through the upper abdomen. Because of the difference in penetration required for the two regions, the position and respiratory excursion of the diaphragm play a large role in radiography of the ribs.

The position of the diaphragm varies with body habitus: it is at a higher level in hypersthenic patients and at a lower level in asthenic patients (Fig. 10.9). In sthenic patients of average size and shape, the right side of the diaphragm arches posteriorly from the level of about the sixth or seventh costal cartilage to the level of the ninth or tenth thoracic vertebra when the body is in the upright position. The left side of the diaphragm lies at a slightly lower level. Because of the oblique location of the ribs and the diaphragm, several pairs of ribs appear on radiographs to lie partly above and partly below the diaphragm.

The position of the diaphragm changes considerably with the body position, reaching its lowest level when the body is upright and its highest level when the body is supine. For this reason, it is desirable to place the patient in an upright position for examination of the ribs above the diaphragm and in a recumbent position for examination of the ribs below the diaphragm.

The respiratory movement of the diaphragm averages approximately 1½ inches (3.8 cm) between deep inspiration and deep expiration. The movement is less in hypersthenic patients and more in hyposthenic patients. Deeper inspiration or expiration and greater depression or elevation of the diaphragm are achieved on the second respiratory movement than on the first. This greater movement should be taken into consideration when the ribs that lie at the diaphragmatic level are examined.

When the body is placed in the supine position, the anterior ends of the ribs are displaced superiorly, laterally, and posteriorly. For this reason, the anterior ends of the ribs are less sharply visualized when the patient is radiographed in the supine position.

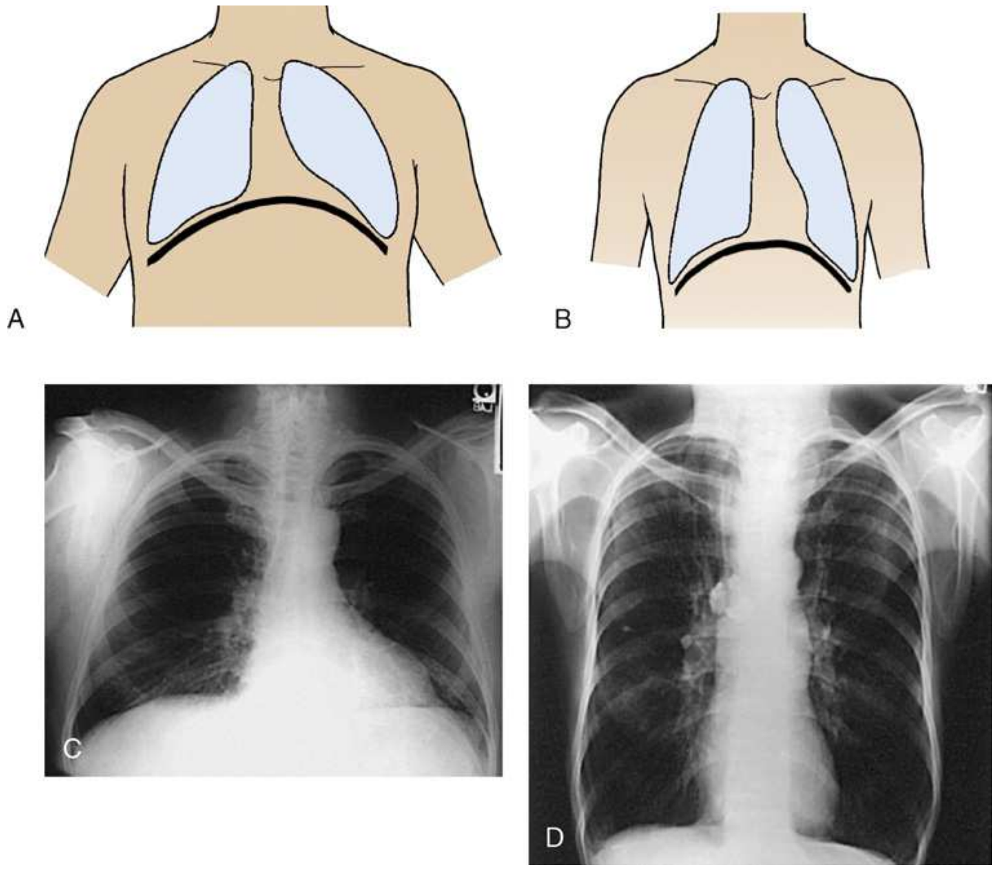


FIG. 10.9 Diaphragm position and body habitus. (A) A hypersthenic patient has a diaphragm positioned higher. (B) An asthenic patient has a diaphragm positioned lower. (C) Chest radiograph of a hypersthenic patient. (D) Chest radiograph of an asthenic patient. Note position of diaphragm on these extremely different body types.

(A) A diagram shows the anterior view of the human body with lungs highlighted. The diaphragm is positioned higher and arches posteriorly. An x-ray view below shows the anterior view of the human body and the lungs appear radiolucent. The diaphragm arches posteriorly from the level of about the sixth or seventh costal cartilage to the level of the ninth or tenth thoracic vertebra. The left side of the diaphragm lies at a slightly lower level (B) A diagram shows the anterior view of the human body with lungs highlighted. The diaphragm is positioned lower. An x-ray view below shows the anterior view of the human body and the lungs appear radiolucent. The diaphragm is positioned lower. The anterior ends of the ribs are less sharply visualized.

Body Position

Although in rib examinations it is desirable to take advantage of the effect that body position has on the position of the diaphragm, the effect is not of sufficient importance to justify subjecting a patient to a painful change from the upright position to the recumbent position or vice versa. Even minor rib injuries are painful, and slight movement frequently causes the patient considerable distress. Unless the change in position can be affected by a tilting radiographic table, patients with recent rib injury should be examined in the position in which they arrive in the radiology department. An ambulatory patient can be positioned for recumbent images with minimal discomfort by bringing the tilt table to the vertical position for each positioning change. The patient stands on the footboard, is comfortably adjusted, and is then lowered to the horizontal position.

Trauma Patients

The first and usually the only requirement in the initial radiographic examination of a patient who has sustained severe trauma to the rib cage is the need to take anteroposterior (AP) and lateral projections of the chest. These projections are obtained not only to show the site and extent of rib injury but also to investigate the possibility of injury to underlying structures by depressed rib fractures. Patients are examined in the position in which they arrive, usually recumbent on a stretcher. If it is deemed necessary to show the presence of air or fluid levels in the chest, the dorsal decubitus position is preferred.

Summary of Anatomy

Bony thorax

- Sternum
- Ribs (12)
- Thoracic vertebrae (12)

Sternum

- Manubrium
- Jugular notch
- Clavicular notch
- Body
- Sternal angle
- Xiphoid process

Ribs

- Costal cartilage
- True ribs
- False ribs
- Floating ribs
- Cervical ribs
- Lumbar ribs
- Intercostal spaces
- Head
- Neck
- Tubercle
- Body
- Facets
- Vertebral end
- Sternal end
- Angle
- Costal groove

Bony thorax articulations

- Sternoclavicular
- Costovertebral
- Costotransverse
- Costochondral
- Sternocostal
- Interchondral
- Manubriosternal
- Xiphisternal

Summary of Pathology

Condition	Definition
Fracture	Disruption of the continuity of bone
Metastasis	Transfer of a cancerous lesion from one area to another
Osteomyelitis	Inflammation of bone due to a pyogenic infection
Osteopetrosis	Increased density of atypically soft bone
Osteoporosis	Loss of bone density
Paget disease	Thick, soft bone marked by bowing and fractures
Tumor	New tissue growth where cell proliferation is uncontrolled
Chondrosarcoma	Malignant tumor arising from cartilage cells
Multiple myeloma	Malignant neoplasm of plasma cells involving the bone marrow and causing destruction of bone

Eponymous (named) pathologies are listed in nonpossessive form to conform to the *AMA manual of style: a guide for authors and editors*, ed 10, Oxford, 2009, Oxford University Press.

These techniques were accurate for the equipment used to produce each exposure. However, use caution when applying them in your department because “there is considerable variability in image receptor response owing to varying scatter sensitivity, the use of grids with different grid ratios, collimation, beam filtration, the choice of kilovoltage, source-to-image distance, and IR size.”[a]

This chart was created in collaboration with Dennis Bowman, AS, RT(R), Clinical Instructor, Community Hospital of the Monterey Peninsula, Monterey, CA. http://digitalradiographysolutions.com/.

Bony Thorax

Part	cm	kVp[b]	SID[c]	Collimation	CR[d]		DR[e]	
					mAs	Dose (mGy)[f]	mAs	Dose (mGy)[f]
Sternum—*PA oblique*[g]	20	81	30″	6″ × 11″ (15 × 28 cm)	6.3[h]	0.76.5	3.2[h]	0.383
Sternum—*lateral*[g]	29	81	40″	5″ × 11″ (13 × 28 cm)	20[h]	2.790	10[h]	1.395
Sternoclavicular articulations—*PA*[g]	17	81	40″	6″ × 4″ (15 × 10 cm)	7.1[h]	0.670	3.6[h]	0.337
Sternoclavicular articulations—*PA oblique*[g]	18	81	40″	6″ × 4″ (15 × 10 cm)	10[h]	0.963	5[h]	0.479
Upper anterior ribs—*PA*[g]	21	81	72″	9″ × 17″ (23 × 43 cm)	20[h]	0.625	10[h]	0.312
Posterior ribs—*AP upper*[g]	21	81	72″	9″ × 17″ (23 × 43 cm)	20[h]	0.625	10[h]	0.312
Posterior ribs—*AP lower*[g]	21	85	40″	9″ × 12″ (23 × 30 cm)	25[h]	3.540	12.5[h]	1.779
Ribs: axillary—*AP oblique*[g]	23	81	72″	11″ × 17″ (28 × 43 cm)	36[h]	1.180	16[h]	0.522
Ribs: axillary—*PA oblique*[g]	23	81	72″	11″ × 17″ (28 × 43 cm)	36[h]	1.181	16[h]	0.523

[a] ACR-AAPM-SIMM Practice Parameter for Digital Radiography, revised 2017.

[b] kVp values are for a high-frequency generator.

[c] 40-inch minimum; 44 to 48 inches recommended to improve spatial resolution (mAs increase needed, but no increase in patient dose will result).

[d] AGFA CR MD 4.0 General IP, CR 75.0 reader, 400 speed class, with 6:1 (178LPI) grid when needed.

[e] GE Definium 8000, with 13:1 grid when needed.

[f] All doses are skin entrance for average adult (160 to 200 pounds male, 150 to 190 pounds female) at part thickness indicated.

[g] Bucky/Grid.

[h] Small focal spot.

Radiography

Sternum

The position of the sternum with respect to the denser bony and soft tissue thoracic structures makes it difficult to radiograph. Few problems are involved in obtaining a lateral projection. However, in a posteroanterior (PA) or an AP projection, the sternum would be projected directly over the thoracic spine, so little useful diagnostic information could be obtained from these projections. To separate the thoracic vertebrae and sternum, rotate the body from the prone position or medially angle the CR. The exact degree of required rotation or angulation depends on the depth of the chest; deep chests require less rotation or angulation than shallow chests (Fig. 10.10 and Table 10.2).

Rotation of the body or angulation of the CR to project the sternum to the right of the thoracic vertebrae clears the sternum of the vertebrae but superimposes it over the posterior ribs and the lung markings (Fig. 10.11). If the sternum is projected to the left of the thoracic vertebrae, it is projected over the heart and other mediastinal structures (Fig. 10.12). The superimposition of the homogeneous density of the heart can be used to advantage (compare Figs. 10.11 and 10.12). For this reason, the PA oblique projection in the right anterior oblique (RAO) position is recommended.

The pulmonary structures, particularly in elderly persons and heavy smokers, can cast confusing markings over the sternum, unless the motion of *shallow* breathing is used to eliminate them. If motion is desired, the exposure time should be long enough to cover several phases of shallow respiration (Figs. 10.13 and 10.14). The milliampere (mA) must be relatively low to achieve the desired milliampere-second (mAs).

When female patients with large, pendulous breasts are imaged, the inferior portion of the sternum may be obscured. To prevent larger breasts from overlapping the sternum, instruct the patient to separate the breasts laterally, where the breasts can be held in place with a wide bandage. This positioning maneuver will also place the sternum closer to the IR. This positioning strategy for patients with pendulous breasts is also suggested for chest radiography. Pendulous breasts can also obscure the inferior portion of the sternum on the lateral projection and may need to be repositioned.

Radiation Protection

Protection of the patient from unnecessary radiation is a professional responsibility of the radiographer (see Chapter 1 for specific guidelines). In this chapter, the *Shield gonads* statement indicates that the patient is to be protected from unnecessary radiation by restricting the radiation beam using proper collimation. In addition, placement of lead shielding between the gonads and the radiation source may be used if requested by the patient or caregiver and when the clinical objectives of the examination are not compromised.

TABLE 10.2

Sternum: thickness versus rotation/CR angulation

Depth of thorax (cm)	Amount of rotation or CR angulation
15	22
16.5	21
18	20
19.5	19
21	18
22.5	17
24	16
25.5	15
27	14
28.5	13
30	12

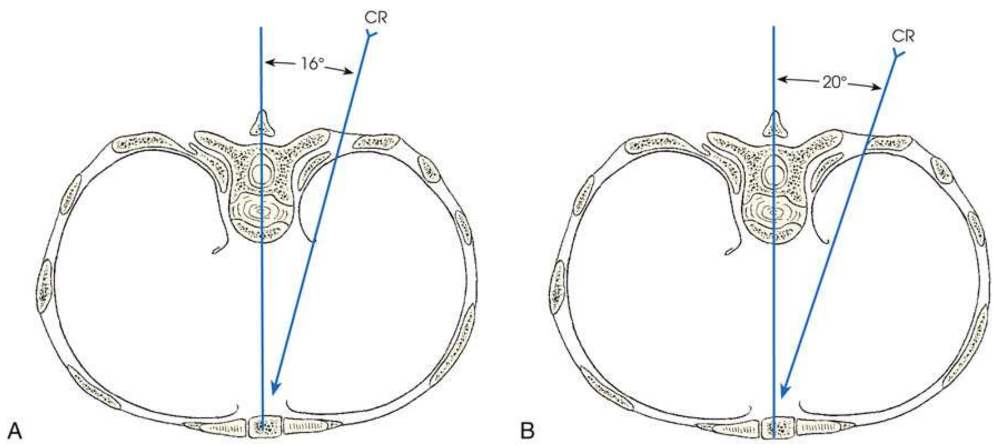


FIG. 10.10 (A) Drawing of 24-cm chest. (B) Drawing of 18-cm chest.

(A) A drawing of a chest shows s the central ray is at a 15-degree angle to the sternum. The line drawn next to it is the axial view of the right anterior oblique position and it passes through the sternum. (B) A drawing of a chest shows s the central ray is at a 20-degree angle to the sternum. The line drawn next to it is the axial view of the right anterior oblique position and it passes through the sternum

FIG. 10.11 PA oblique sternum, LAO position.

FIG. 10.12 PA oblique sternum, RAO position.

FIG. 10.13 Suspended respiration.

FIG. 10.14 Shallow breathing during exposure.

PA Oblique Projection

RAO position

Image receptor + grid: Positioned by manufacturer or department protocol for proper anatomy display orientation; CR plate: 10 × 12 inches (24 × 30 cm) lengthwise.

NOTE: This position may be difficult to perform on trauma patients. Use an upright position if possible.

SID:

A 30-inch (76-cm) SID is recommended to blur the posterior ribs. See p. 28, Chapter 1, for information on use of a 30-inch (76-cm) SID.

Position of patient

- With the patient prone or upright facing the IR, adjust the body into RAO position to use the heart for contrast as previously described.
- Have the patient support the body on the forearm and flexed knee, if recumbent.

Position of part

- Adjust the elevation of the left shoulder and hip so that the thorax is rotated just enough to prevent superimposition of the vertebrae and sternum.

- Estimate the amount of rotation with sufficient accuracy by placing one hand on the patient's sternum and the other hand on the thoracic vertebrae to act as guides while adjusting the degree of obliquity. The average rotation is approximately 15 to 20 degrees (Fig. 10.15).
- Align the patient's body so that the long axis of the sternum is centered to the midline of the grid.
- Place the top of the IR approximately 1½ inches (3.8 cm) above the jugular notch.
- *Shield gonads.*
- *Respiration:* When a breathing technique is to be used, instruct the patient to take slow, shallow breaths during the exposure. When a short exposure time is to be used, instruct the patient to suspend breathing at the end of expiration to minimize the visibility of the pulmonary vasculature.

NOTE: For trauma patients who are recumbent and unable to lie prone, obtain this projection with the patient in the left posterior oblique (LPO) position, resulting in an AP oblique projection.

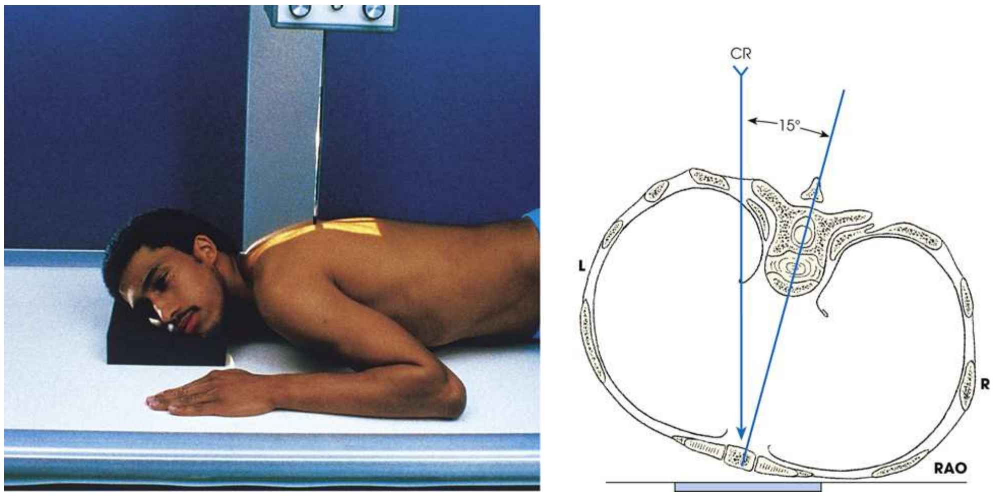


FIG. 10.15 PA oblique sternum, RAO position. Line drawing is an axial view (from feet upward).

The patient is in a prone position supporting his body with his forearm. A support is placed under the patient's head. The central ray is directed to the elevated side of the posterior thorax perpendicularly. The diagram next to it shows the central ray is at a 15-degree angle to the sternum. The line drawn next to it is the axial view of the right anterior oblique position.

Central ray

- Perpendicular to IR. The CR enters the *elevated side* of the posterior thorax at the level of T7 and approximately 1 inch (2.5 cm) lateral to the MSP.

Collimation

- Adjust radiation field to 10 × 12 inches (24 × 30 cm) on the collimator. Place side marker in the collimated exposure field.

Structures shown

A slightly oblique projection of the sternum (Fig. 10.16). The detail depends largely on the technical procedure used. If a breathing technique is used, the pulmonary markings are obliterated.

Evaluation Criteria

The following should be clearly seen:

- Evidence of proper collimation and presence of side marker placed clear of anatomy of interest
- Entire sternum from jugular notch to tip of xiphoid process
- Sternum projected over the heart, but free of superimposition from the thoracic spine
- Minimally rotated sternum and thorax, as shown by the following:
  - Sternum projected just free of superimposition from vertebral column
  - Minimally obliqued vertebrae to prevent excessive rotation of the sternum
  - Lateral portion of manubrium and sternoclavicular joint free of superimposition by the vertebrae
- Blurred pulmonary markings, if a breathing technique was used
- Bony trabecular detail and surrounding soft tissues

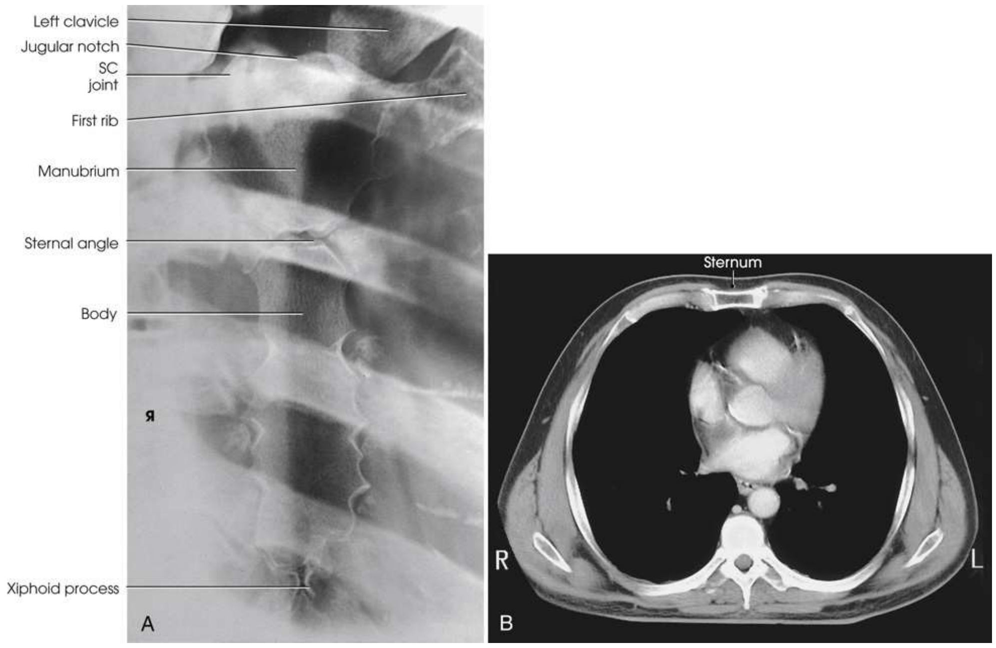


FIG. 10.16 (A) PA oblique sternum, RAO position. (B) CT is often used today to image the sternum. Image shows sternum in axial plane. B, Modified from Kelley LL, Petersen CM. *Sectional anatomy for imaging professionals,* 2nd ed. St. Louis: Mosby; 2007.

(A) An x-ray shows the entire sternum from the jugular notch to the tip of the xiphoid process. It appears hazy. The parts labeled in the x-ray on the left are marked from top to the bottom as follows: left clavicle, jugular notch, s c joint, first rib, manubrium, sternal angle, body, xiphoid process. (B) The C T shows the sternum in axial plane. The sternum is rectangular and is labeled on the top. The lungs appear dark and the outline of the sternum appears white and prominent.

PA Oblique Projection

Moore Method

Modified prone position

Image receptor + grid: Positioned by manufacturer or department protocol for proper anatomy display orientation; CR plate: 10 × 12 inches (24 × 30 cm) lengthwise.

SID:

A 30-inch (76-cm) SID is recommended. This short distance assists in blurring the posterior ribs.

Radiography of the sternum can be difficult to perform on an ambulatory patient who is having acute pain. The alternative positioning method described by Moore [1] uses a modified prone position, which makes it possible to produce a high-quality sternum image in a more comfortable manner for the patient.

Position of patient

- Before positioning the patient, place the IR crosswise in the Bucky tray. Place the x-ray tube at a 30-inch (76-cm) SID, angle it 25 degrees, and direct the CR to the center of the IR. The x-ray tube is positioned over the patient's right side.
- Place a marker on the tabletop near the patient's head to indicate the exact center of the IR.
- Have the patient stand at the side of the radiographic table directly in front of the Bucky tray.
- Ask the patient to bend at the waist, and place the sternum in the center of the table directly over the previously positioned IR.

Position of part

- Place the patient's arms above the shoulders and the palms down on the table. The arms act as a support for the side of the head (Fig. 10.17).
- Ensure that the patient is in a true prone position and that the midsternal area is at the center of the radiographic table.
- *Shield gonads.*
- *Respiration:* A shallow breathing technique produces the best results. Instruct the patient to take slow, shallow breaths during the exposure. A low mA setting and an exposure time of 1 to 3 seconds are recommended. When a low mA setting and long exposure time cannot be employed, instruct the patient to suspend respiration at the end of expiration to minimize the visibility of the pulmonary vasculature.

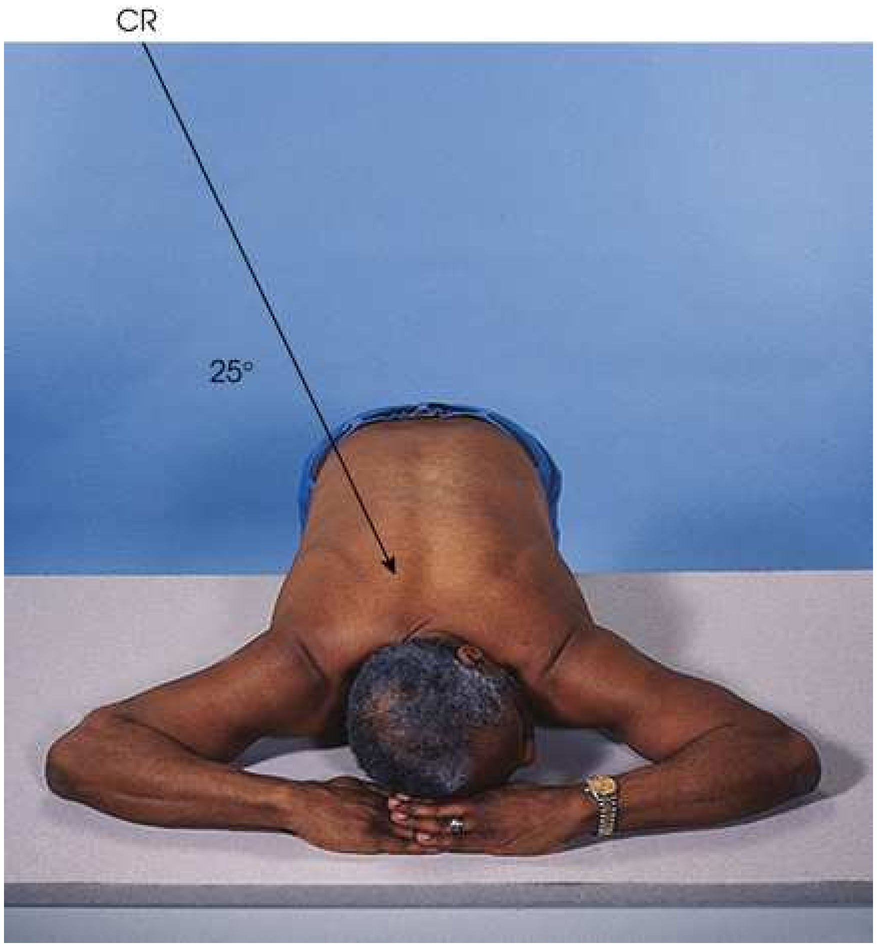


FIG. 10.17 PA oblique projection: Moore method.

The patient is standing at the side of the radiographic table and bending his hips over the table with the sternum positioned at the center of the table. The patient's hands are supporting his head. The central ray is directed at a 25-degree angle to the sternum.

Central ray

- The CR is already angled 25 degrees and centered to the IR. If patient positioning is accurate, the CR enters at the level of T7 and approximately 2 inches (5 cm) to the right of the spine. This angulation places the sternum over the lung to maintain maximum contrast of the sternum.
- The x-ray tube angulation can be adjusted for extremely large or small patients. Large patients require *less* angulation and thin patients require *more* angulation than the standard 25-degree angle.

Collimation

- Adjust radiation field to 10 × 12 inches (24 × 30 cm) on the collimator. Place side marker in the collimated exposure field.

Structures shown

A slightly oblique projection of the sternum (Fig. 10.18). The degree of detail shown depends largely on the technique used. If a breathing technique is used, the pulmonary markings are obliterated.

Evaluation Criteria

The following should be clearly seen:

- Evidence of proper collimation and presence of side marker placed clear of anatomy of interest
- Entire sternum from the jugular notch to the tip of the xiphoid process
- Sternum projected free of superimposition from the thoracic spine
- Blurred pulmonary markings if a breathing technique was used
- Blurred posterior ribs if a reduced SID was used
- Bony trabecular detail and surrounding soft tissues

FIG. 10.18 PA oblique projection: Moore method.

Lateral Projection

Right or left position

Image receptor + grid: Positioned by manufacturer or department protocol for proper anatomy display orientation; CR plate: 10 × 12 inches (24 × 30 cm) lengthwise.

SID:

72-inch (183-cm) SID to reduce magnification and distortion of the sternum.

Position of patient

- Place the patient in a lateral position, either upright (seated or standing) or recumbent. A dorsal decubitus position may be necessary due to the patient's condition.

Position of part

- Center the sternum to the midline of the grid.

Upright

- Adjust the patient in a true lateral position so that the broad surface of the sternum is perpendicular to the plane of the IR (Fig. 10.19).
- Rotate the shoulders posteriorly, and have the patient lock the hands behind the back.
- Being careful to keep the MSP of the body vertical, and place the patient close enough to the grid that the shoulder can be rested firmly against it.
- Large breasts on female patients should be drawn to the sides and held in position with a wide bandage so that their shadows do not obscure the lower portion of the sternum.

Recumbent

- Extend the patient's arms over the head to prevent them from overlapping the sternum (Fig. 10.20).
- Rest the patient's head on the arms or on a pillow.
- Place a support under the lower thoracic region to position the long axis of the sternum horizontally.
- *Shield gonads.*

• *Respiration:* Suspend deep inspiration. This provides sharper contrast between the posterior surface of the sternum and the adjacent structures.

Central ray

• Perpendicular to the center of the IR and entering the lateral border of the midsternum

Collimation

• Adjust radiation field to 10 × 12 inches (24 × 30 cm) on the collimator. Place side marker in the collimated exposure field.

Structures shown

A lateral image of the entire length of the sternum shows the superimposed sternoclavicular joints and medial ends of the clavicles (Fig. 10.21).

Evaluation Criteria

The following should be clearly seen:

- Evidence of proper collimation and presence of side marker placed clear of anatomy of interest
- Sternum in its entirety
- Manubrium free of superimposition by the soft tissue of the shoulders
- Sternum free of superimposition by the ribs
- Lower portion of the sternum unobscured by the breasts of a female patient
- Bony trabecular detail and surrounding soft tissues

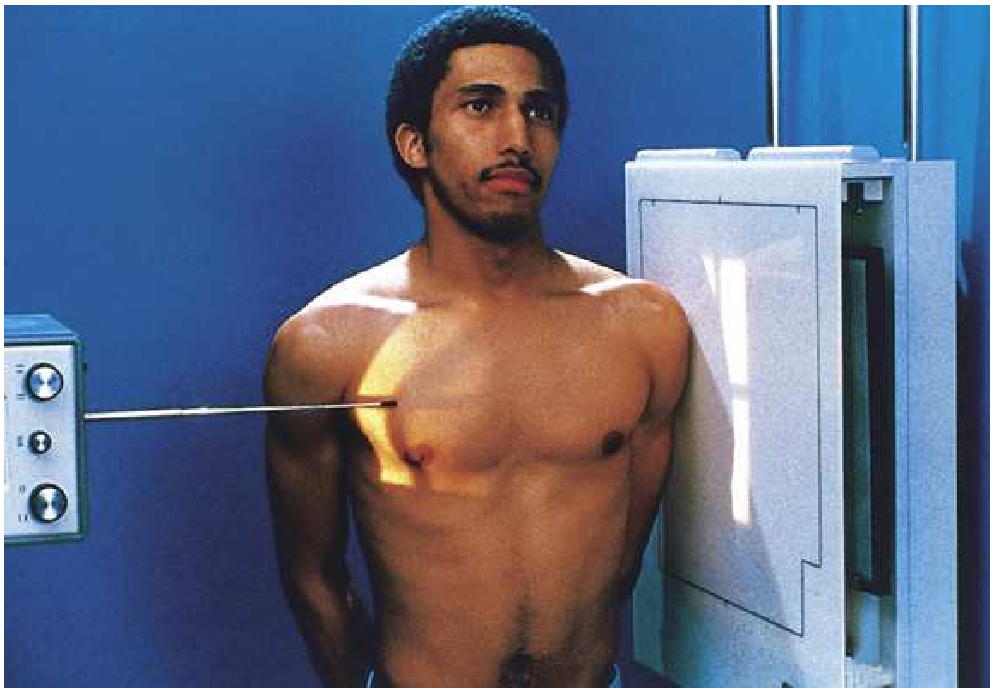


FIG. 10.19 Lateral sternum.

The patient is standing in an upright position, lateral to the vertical grid. His hands are held behind his back. The central ray is perpendicular to the vertical grid and directed to the lateral border of the mid sternum.

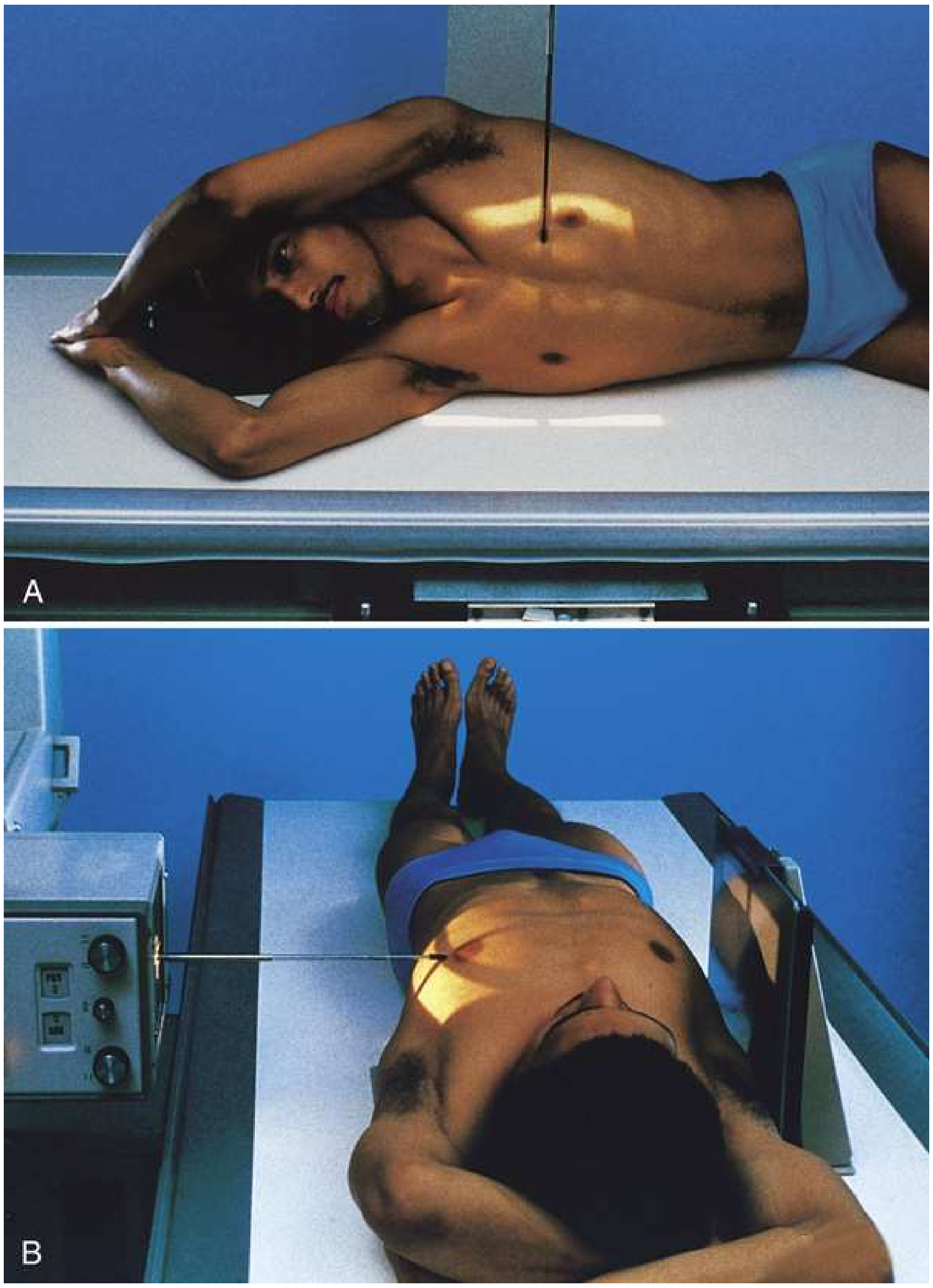


FIG. 10.20 (A) Lateral sternum. (B) Dorsal decubitus position for lateral sternum.

(A) The patient is lying in a right lateral recumbent position with his arms extended over his head. The central ray is directed to the lateral border of the midsternum. (A)The patient is lying in a supine position. The patient's arms are extended over his head. The central ray is directed to the lateral border of the midsternum.

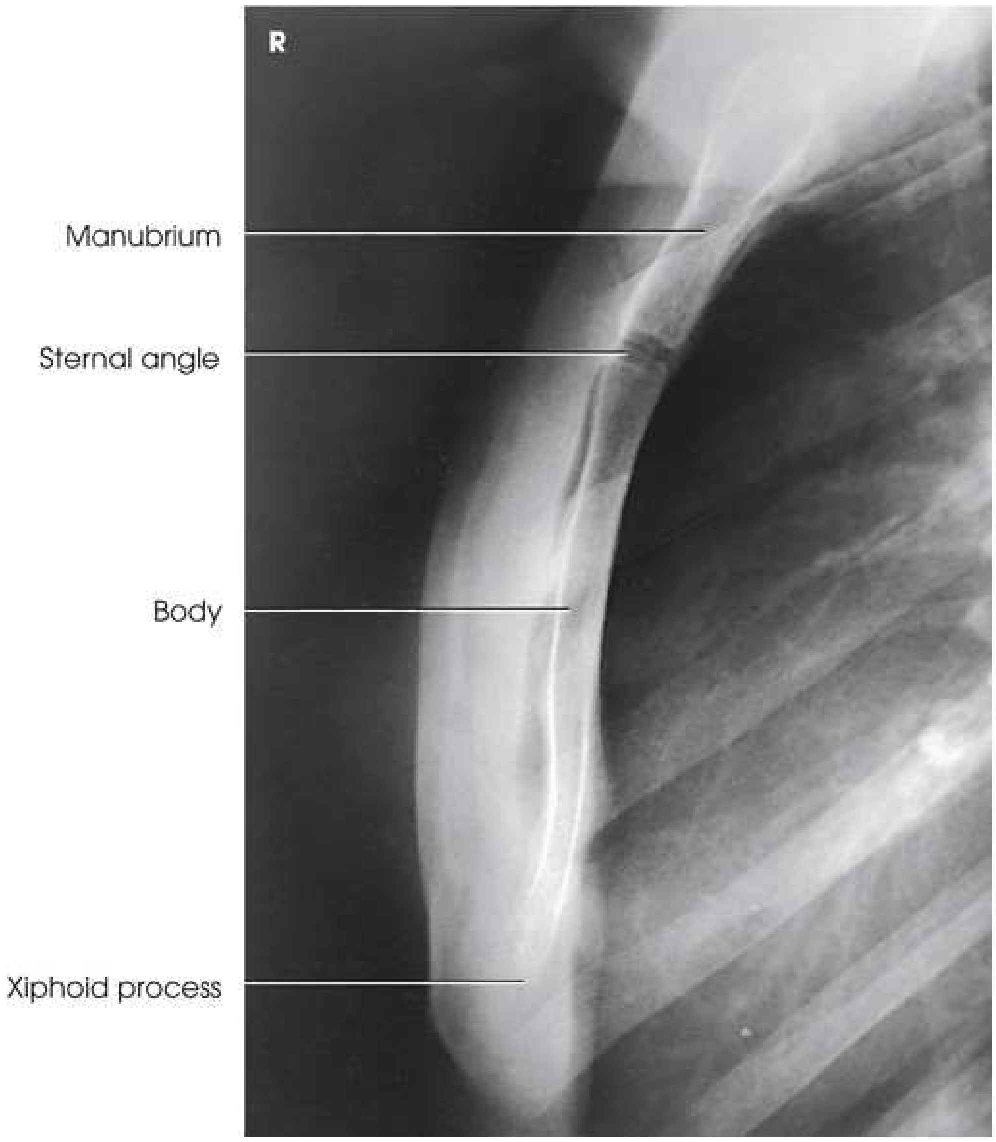


FIG. 10.21 Lateral sternum.

An x-ray shows the lateral sternum. The parts labeled in the x-ray on the left are marked from top to the bottom as follows: the manubrium, sternal angle, body, xiphoid process. The xiphoid process has a white outline and is long and narrow. The sternal angle appears dark.

Sternoclavicular Articulations

PA Projection

NOTE: This position may be difficult to perform on trauma patients. Use the upright position if the patient is able.

Image receptor + grid: Positioned by manufacturer or department protocol for proper anatomy display orientation; CR plate: 10 × 12 inches (24 × 30 cm) lengthwise.

Position of patient

- Place the patient in the prone (or upright) position.
- Center the MSP of the patient's body to the midline of the grid.
- Adapt the same procedure for use with a patient who is standing or seated upright.

Position of part

- Center the IR at the level of the spinous process of the third thoracic vertebra, which lies posterior to the jugular notch.
- Place the patient's arms along the sides of the body with the palms facing upward.
- Adjust the shoulders to lie in the same transverse plane.
- For a bilateral examination, rest the patient's head on the chin and adjust it so that the MSP is vertical.
- For a unilateral projection, ask the patient to turn the head to face the affected side and rest the cheek on the table (Fig. 10.22). Turning the head rotates the spine slightly away from the side being examined and provides better visualization of the lateral portion of the manubrium.
- *Shield gonads.*
- *Respiration:* Suspend at the end of expiration.

Central ray

- Perpendicular to the center of the IR and entering T3

Collimation

- Adjust radiation field to 6 × 8 inches (15 × 20 cm) on the collimator. Place side marker in the collimated exposure field.

Structures shown

The sternoclavicular joints and the medial portions of the clavicles (Figs. 10.23 and 10.24).

Evaluation Criteria

The following should be clearly seen:

- Evidence of proper collimation and presence of side marker placed clear of anatomy of interest
- Both sternoclavicular joints and the medial ends of the clavicles
- No rotation present on bilateral examination; slight rotation present on unilateral examination
- Bony trabecular detail and surrounding soft tissues

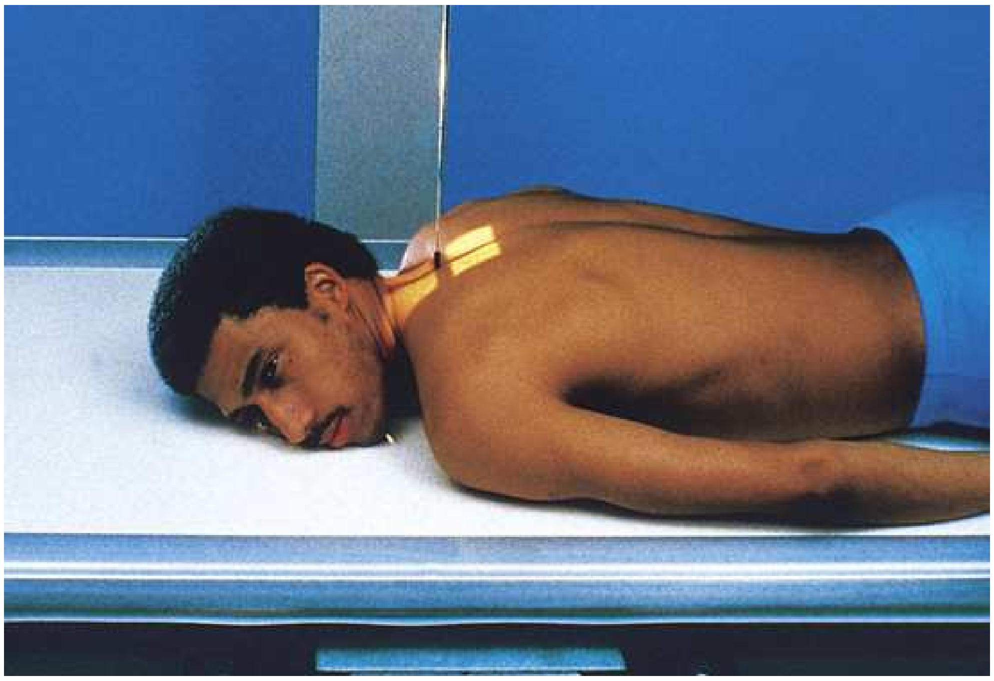


FIG. 10.22 Unilateral examination to show left sternoclavicular articulation.

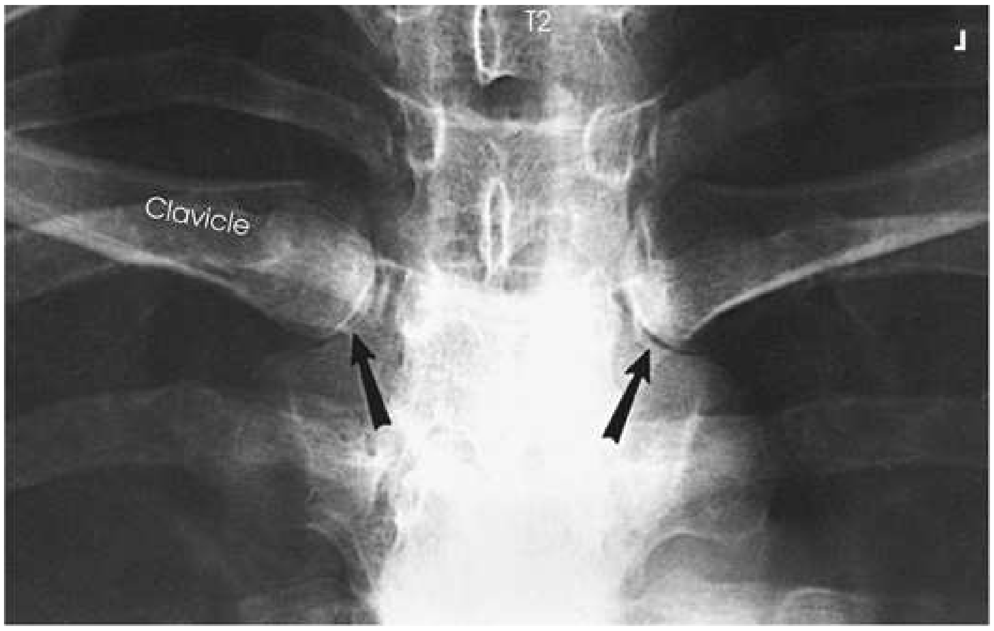


FIG. 10.23 Bilateral sternoclavicular joints *(arrows)*.

An x-ray shows both sternoclavicular joints and the medial ends of the clavicles. The sternum appears radiopaque. There are oval patches with white outlines on the upper portion of the sternum. Two black arrows indicate the bilateral sternoclavicular joints. The clavicle is labeled.

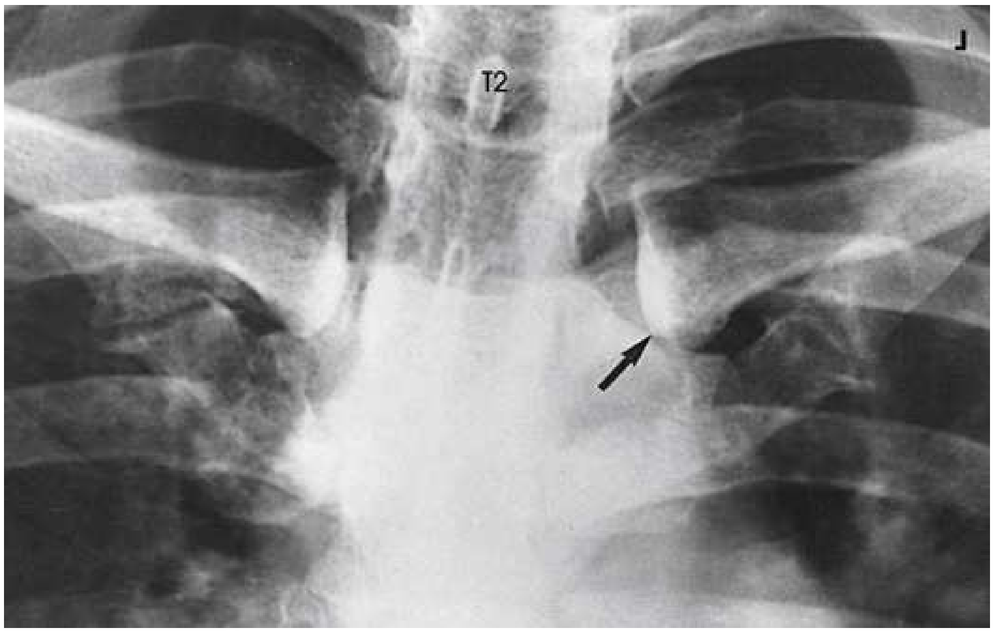


FIG. 10.24 Unilateral sternoclavicular joint *(arrow)*.

PA Oblique Projection

Body Rotation Method

RAO or LAO position

NOTE: This position may be difficult in trauma patients. Use the upright position if the patient is able.

Image receptor + grid:

Positioned by manufacturer or department protocol for proper anatomy display orientation; CR plate: 10 × 12 inches (24 × 30 cm) lengthwise.

Position of patient

- Place the patient in a prone or seated-upright position.

Position of part

- Keeping the affected side adjacent to the IR, position the patient at enough of an oblique angle to project the vertebrae well behind the sternoclavicular joint closest to the IR. The angle is usually approximately 10 to 15 degrees.

- Adjust the patient's position to center the joint to the midline of the grid.
- Adjust the shoulders to lie in the same transverse plane (Fig. 10.25A and B).
- *Shield gonads.*
- *Respiration:* Suspend at the end of expiration.

Central ray

- Perpendicular to the sternoclavicular joint closest to the IR. The CR enters at the level of T2-3 (approximately 3 inches [7.6 cm] distal to the vertebral prominens) and 1 to 2 inches (2.5 to 5 cm) lateral from the MSP. If the CR enters the right side, the left sternoclavicular joint is shown, and vice versa (see Fig. 10.25B).
- Center the IR to the CR.

Collimation

- Adjust radiation field to 6 × 8 inches (15 × 20 cm) on the collimator. Place side marker in the collimated exposure field.

Structures shown

A slightly oblique sternoclavicular joint (see Fig. 10.25C).

Evaluation Criteria

The following should be clearly seen:

- Evidence of proper collimation and presence of side marker placed clear of anatomy of interest
- Sternoclavicular joint of interest in the center of the radiograph, with the manubrium and the medial end of the clavicle included
- Open sternoclavicular joint space
- Sternoclavicular joint of interest immediately adjacent to the vertebral column with minimal obliquity
- Bony trabecular detail and surrounding soft tissues

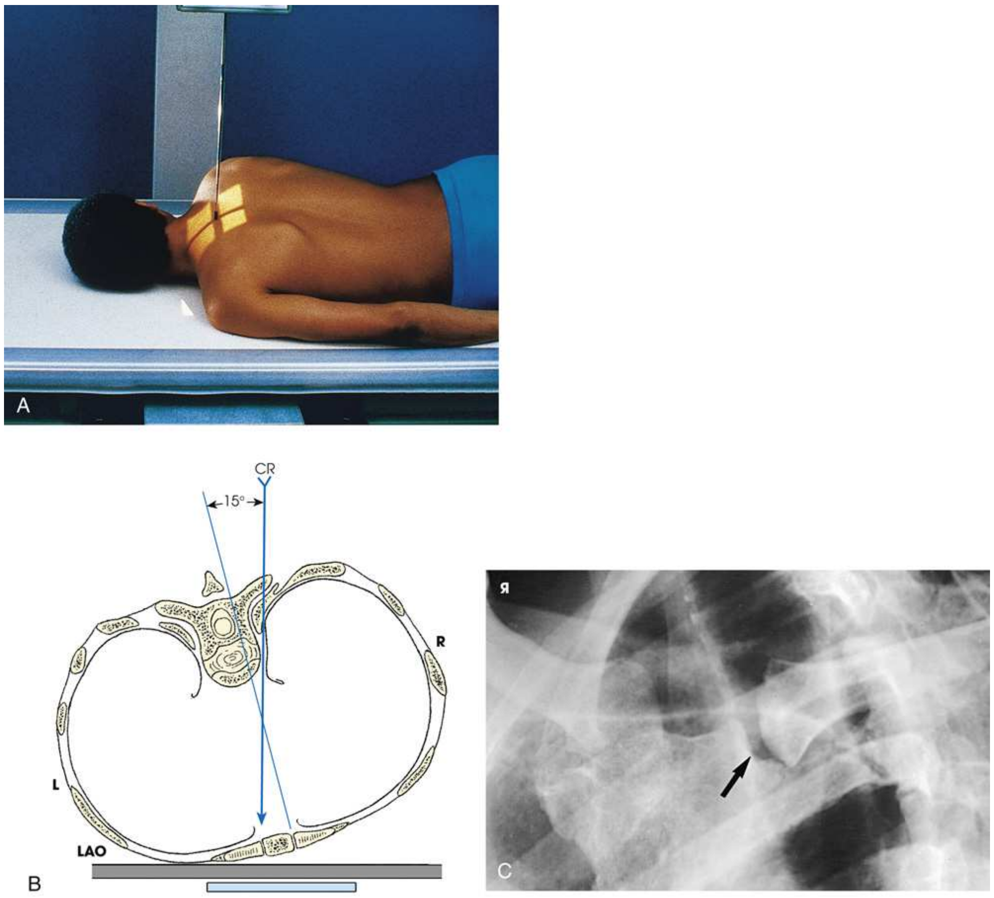


FIG. 10.25 (A) PA oblique sternoclavicular joint, LAO position: Body rotation method. (B) Axial view (from feet upward) of central ray position in relation to spine and sternoclavicular joint. (C) PA oblique sternoclavicular joint, LAO position. The joint closest to the IR is shown *(arrow)*.

(A) The patient is lying on the radiographic table in the prone position with his arms along the sides of his body. The patient is positioned at an oblique angle of about 10 to 15 degrees. The central ray is directed perpendicular to the sternoclavicular joint. (B) shows the central ray is at a 15-degree angle to the spine. The line is drawn in the axial view of the right anterior oblique position. (c) The x-ray view of the oblique sternoclavicular joint has an arrow pointing at the point.

PA Oblique Projection

CR Angulation Method

Image receptor: Positioned by manufacturer or department protocol for proper anatomy display orientation; CR plate: 10 × 12 inches (24 × 30 cm) lengthwise.

NOTE: For this projection, the joint is closer to the IR, and less distortion is obtained than when the previously described body rotation method is used. A grid IR placed on the tabletop enables the joint to be projected with minimal distortion. This position may be difficult to perform on trauma patients. Use the upright position if the patient is able.

Position of patient

- Place the patient in the prone position on a grid IR positioned directly under the upper chest.
- Center the grid to the level of the sternoclavicular joints.
- To avoid grid cutoff, place the grid on the radiographic table with its long axis running *perpendicular* to the long axis of the table.

Position of part

- Extend the patient's arms along the sides of the body with the palms of the hands facing upward.
- Adjust the shoulders to lie in the same transverse plane.
- Ask the patient to rest the head on the chin or to rotate the chin toward the side of the joint being radiographed (Fig. 10.26).

Central ray

- From the side opposite the side being examined, direct to the midpoint of the IR at an angle of 15 degrees toward the MSP. A small angle is satisfactory in examinations of sternoclavicular articulations because only slight anteroposterior overlapping of the vertebrae and these joints occurs.

• The CR should enter at the level of T2-3 (approximately 3 inches [7.6 cm] distal to the vertebral prominens) and 1 to 2 inches (2.5 to 5 cm) lateral to the MSP. If the CR enters the left side, the right side is shown, and vice versa.

Collimation

• Adjust radiation field to 6 × 8 inches (15 × 20 cm) on the collimator. Place side marker in the collimated exposure field.

Structures shown

A slightly oblique sternoclavicular joint (Figs. 10.27 and 10.28).

Evaluation Criteria

The following should be clearly seen:

- Evidence of proper collimation and presence of side marker placed clear of anatomy of interest
- Sternoclavicular joint of interest in the center of the radiograph, with the manubrium and the medial end of the clavicle included
- Open sternoclavicular joint space
- Sternoclavicular joint of interest immediately adjacent to the vertebral column with minimal obliquity
- Bony trabecular detail and surrounding soft tissues

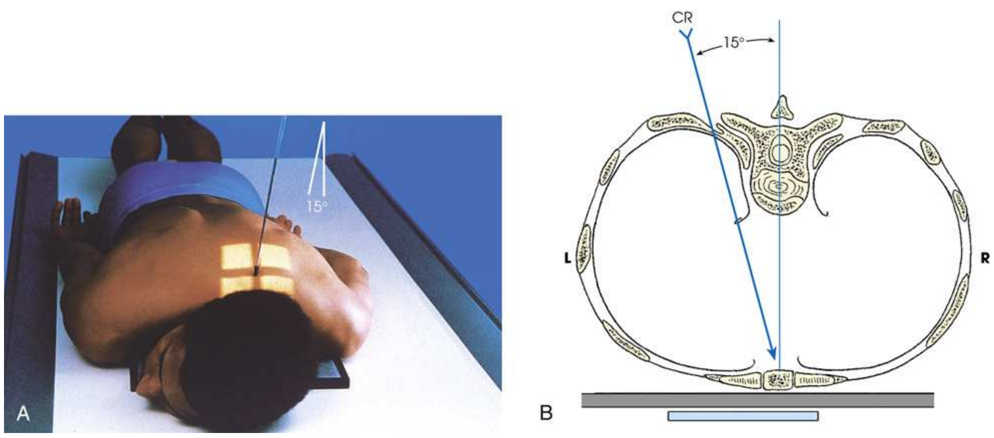


FIG. 10.26 PA oblique sternoclavicular joint: CR angulation method. CR enters left side to show right joint.

(A) The patient is lying on the radiographic table in the prone position with his arms along the sides of his body. The central ray is directed at a 15-degree angle at the M S P. (B) shows the line drawing of the axial view of the sternum that illustrates the central ray is at a 15-degree angle to the spine and sternum.

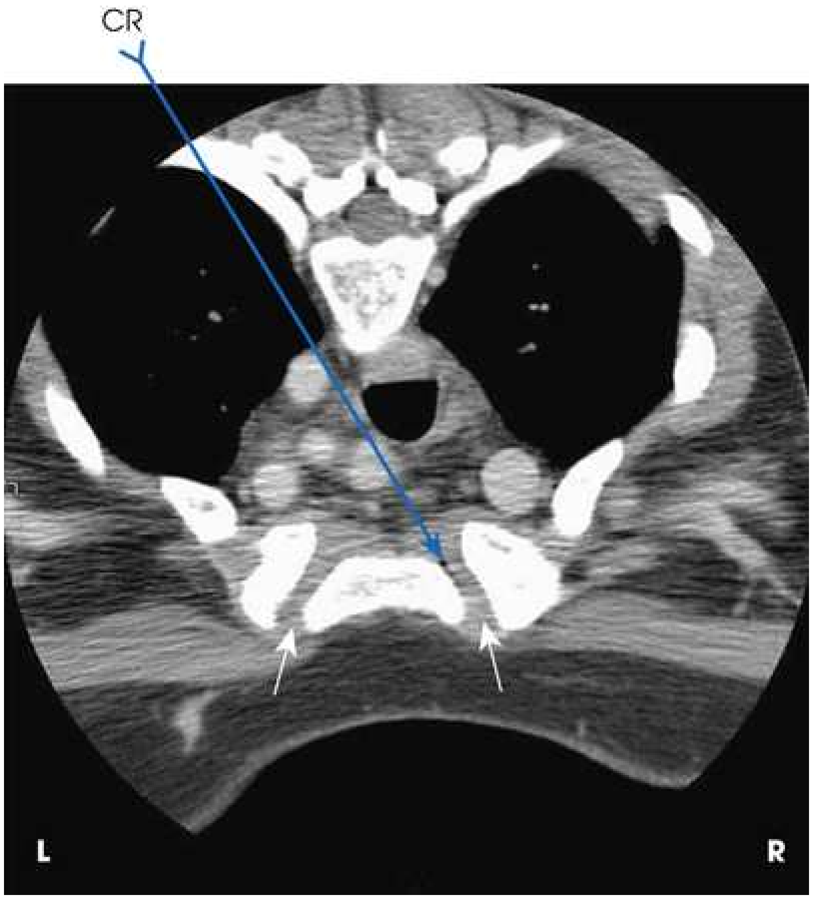


FIG. 10.27 CT axial image with patient prone, showing sternoclavicular joints *(white arrows)* and path of CR. View is from feet looking upward.

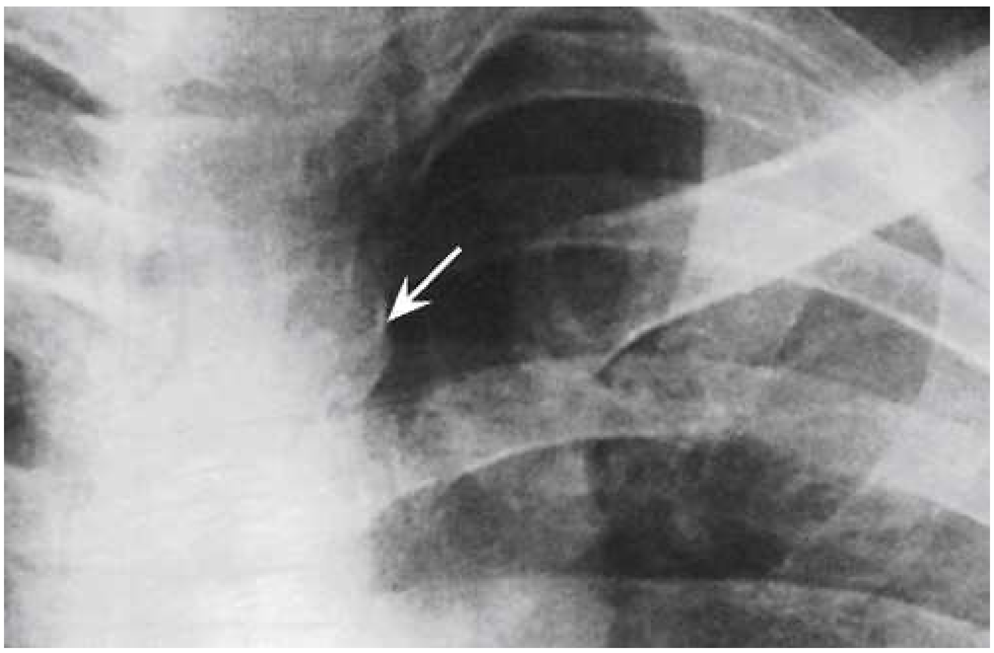


FIG. 10.28 Central ray angulation method for sternoclavicular joint *(arrow)*. From Kurzbauer R. The lateral projection in the roentgenography of the sternoclavicular articulation, *AJR Am J Roentgenol.* 1946;56:104.

Ribs

In radiography of the ribs, an IR 14 × 17 inches (35 × 43 cm) should be used to identify the ribs involved and to determine the extent of trauma or the pathologic condition. Projections can be made in recumbent and upright positions.

After the lesion is localized, the next step is to determine (1) the position required to place the affected rib region parallel with the plane of the IR, and (2) whether the radiograph should be made to include the ribs above or below the diaphragm.

The anterior portion of the ribs, usually referred to simply as the *anterior ribs*, is often examined with the patient facing the IR for a PA projection. The posterior portion of the ribs—the *posterior ribs*—is more commonly radiographed with the patient facing the x-ray tube in the same manner as for an AP projection.

The axillary portion of the ribs is best shown using an oblique projection. Because the lateral projection results in superimposition of the two sides, it is generally used only when fluid or air levels are evaluated after rib fractures.

When the ribs superimposed over the heart are involved, the body must be rotated to obtain a projection of the ribs free of the heart, or the radiographic exposure must be increased to compensate for the density of the heart. Although the anterior and posterior ends are superimposed, the left ribs are cleared of the heart when the LAO position or the right posterior oblique (RPO) position is used. These two body positions place the right-sided ribs parallel with the plane of the IR and are reversed to obtain comparable projections of the left-sided ribs. Lower kVp, compared with that used for chest radiography, should be used to increase beam attenuation in the ribs. The kVp chosen will vary based on expected rib mineralization of the patient.

Respiration

In radiography of the ribs, the patient is usually examined with respiration suspended in either full inspiration or full expiration. Occasionally, shallow breathing may be used to obliterate lung markings. If this technique is used, breathing must be shallow enough to ensure that the ribs are not elevated or depressed, as described in the anatomy portion of this chapter.

Rib fractures can cause a great deal of pain and hemorrhage because of the closely related neurovascular structures. This situation commonly makes it difficult for the patient to breathe deeply for the required radiograph. Deeper inspiration is attained if the patient fully understands the importance of expanding the lungs, and if the exposure is taken after the patient takes the second deep breath.

SID

SID protocol varies by department. Some may require 40 inches (100 cm), whereas others prefer 72 inches (180 cm) to reduce distortion and improve spatial resolution.

Upper Anterior Ribs

PA Projection

Image receptor + grid: Positioned by manufacturer or department protocol for proper anatomy display orientation; CR plate: 14 × 17 inches (35 × 43 cm) lengthwise.

Position of patient

- Position the patient either upright or recumbent, facing the IR.
- Because the diaphragm descends to its lowest level in the upright position, use the standing or seated-upright position for projections of the upper ribs when the patient's condition permits (Fig. 10.29). The upright position is also valuable for showing fluid levels in the chest.

Position of part

- Center the MSP of the patient's body to the midline of the grid for bilateral ribs.
- For unilateral ribs, center the affected side on a longitudinal plane drawn midway between the MSP and the lateral surface of the body to the midline of the grid.
- Adjust the IR position to project approximately 1½ inches (3.8 cm) above the upper border of the shoulders. Less may be required for hypersthenic patients and for those with very muscular shoulders.
- Rest the patient's hands against the hips with the palms turned outward to rotate the scapulae away from the rib cage.
- Adjust the shoulders to lie in the same transverse plane.
- If the patient is prone, rest the head on the chin and adjust the MSP to be vertical (Fig. 10.30).
- For hypersthenic patients with wide rib cages, it may be necessary to move the patient laterally to include the entire lateral surface of the affected rib area on the radiograph.
- *Shield gonads.*
- *Respiration:* Suspend at full inspiration to depress the diaphragm as much as possible.

FIG. 10.29 PA ribs, upright position.

The patient is standing in an upright position, facing the vertical grid. The patient's hands are resting on his hips with his palm turned outward. The central ray is perpendicular to the center of the I R at the level of T 7.

FIG. 10.30 PA ribs, recumbent position.

The patient is lying on the radiographic table in the prone position with his arms along the sides of his body. The central ray is directed perpendicular to the third thoracic vertebrae. The central ray is directed at the seventh thoracic vertebrae perpendicularly.

Central ray

- Perpendicular to the center of IR. If the IR is positioned correctly, the CR is at the level of T7.
- A useful option for showing the seventh, eighth, and ninth ribs is to angle the x-ray tube approximately 10 to 15 degrees caudad. This angulation aids in projecting the diaphragm below the affected ribs.

Collimation

- Adjust radiation field to 14 × 17 inches (35 × 43 cm) on the collimator for bilateral ribs. For unilateral exams, collimate the width to 1 inch beyond MSP and the lateral border of the side of interest. Place side marker in the collimated exposure field.

Structures shown

The anterior ribs above the diaphragm (Figs. 10.31 and 10.32). Although the posterior ribs are seen, the anterior ribs are shown with greater detail because they are closer to the IR.

Evaluation Criteria

The following should be clearly seen:

- Evidence of proper collimation and presence of side marker placed clear of anatomy of interest
- First through ninth ribs in their entirety, with posterior portions lying above the diaphragm
- First through seventh anterior ribs from both sides, in their entirety and above the diaphragm
- In a unilateral examination, ribs from the opposite side possibly not included in their entirety
- Bony trabecular detail and surrounding soft tissues

FIG. 10.31 PA ribs, normal centering.

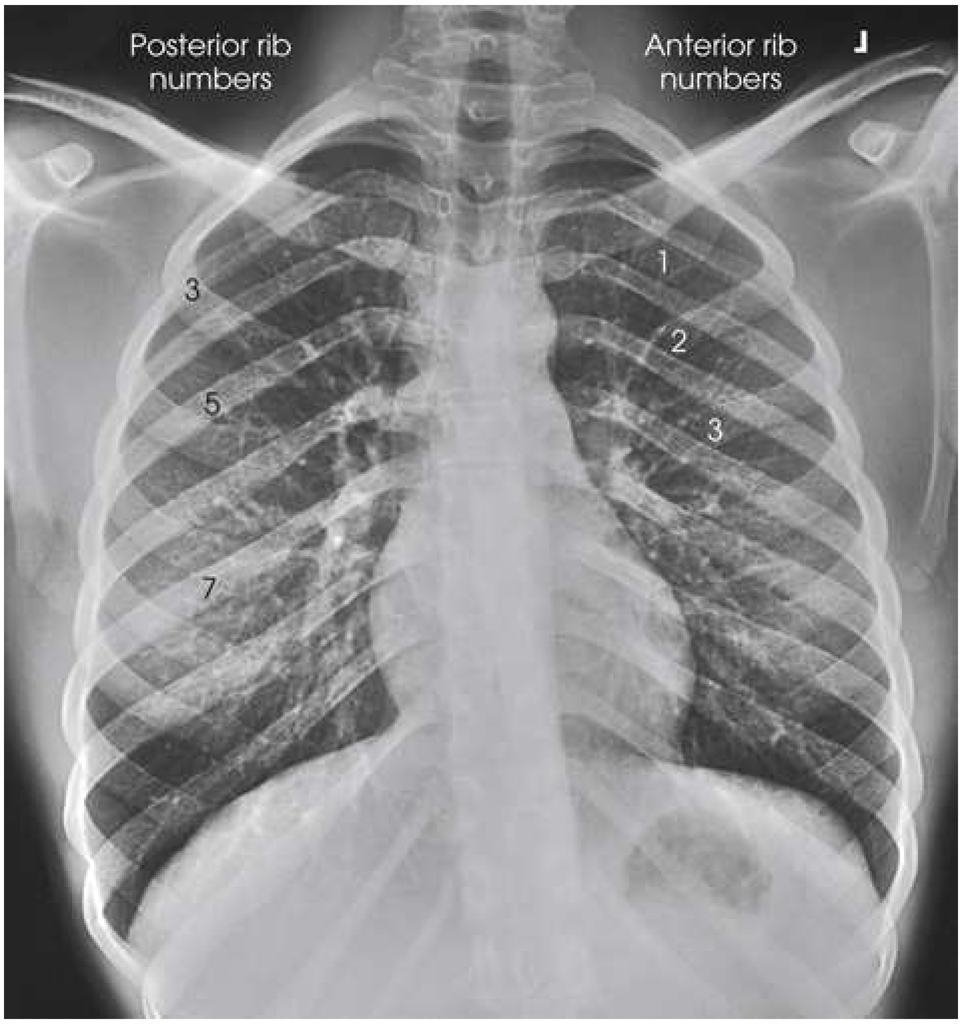


FIG. 10.32 PA ribs, with 10- to 15-degree caudal angulation.

An x-ray shows the anterior ribs above the diaphragm. The left side is labeled posterior rib numbers and the right side is labeled anterior rib numbers. A radiopaque area is aligned towards the right side of the radiograph towards the bottom.

Posterior Ribs

AP Projection

Image receptor + grid: Positioned by manufacturer or department protocol for proper anatomy display orientation; CR plate: 14 × 17 inches (35 × 43 cm) lengthwise.

Position of patient

- Have the patient face the x-ray tube in either an upright or a recumbent position.
- When the patient's condition permits, use the upright position to image ribs above the diaphragm and the supine position to image ribs below the diaphragm to permit gravity to assist in moving the patient's diaphragm.

Position of part

- Center the MSP of the patient's body to the midline of the grid for bilateral ribs.
- For unilateral ribs, center the affected side on a longitudinal plane drawn midway between the MSP and the lateral surface of the body.

Ribs above diaphragm

- Place the IR lengthwise 1½ inches (3.8 cm) above the upper border of the *relaxed* shoulders. Less may be needed for patients with very muscular shoulders.
- Rest the patient's hands, palms outward, against the hips. This position moves the scapula off the ribs. Alternatively, extend the arms to the vertical position with the hands under the head (Fig. 10.33).
- Adjust the patient's shoulders to lie in the same transverse plane, and rotate them forward to draw the scapulae away from the rib cage.
- *Shield gonads.*
- *Respiration:* Suspend at *full inspiration* to *depress* the diaphragm.

Ribs below diaphragm

- Place the IR crosswise in the Bucky tray, centered to a point halfway between the xiphoid process and the lower rib margin. The lower edge of the IR will be near the level of the iliac crests. This positioning ensures inclusion of the lower ribs because of the divergent x-rays.
- Adjust the patient's shoulders to lie in the same transverse plane.
- Place the patient's arms in a comfortable position (Fig. 10.34).
- *Shield gonads.*
- *Respiration:* Suspend at *full expiration* to *elevate* the diaphragm.

FIG. 10.33 AP ribs above diaphragm.

The patient is lying in a supine position. The patient's arms are extended to the vertical position, supporting his head. The central ray is directed to 3.8 centimeters above the upper border of the shoulders.

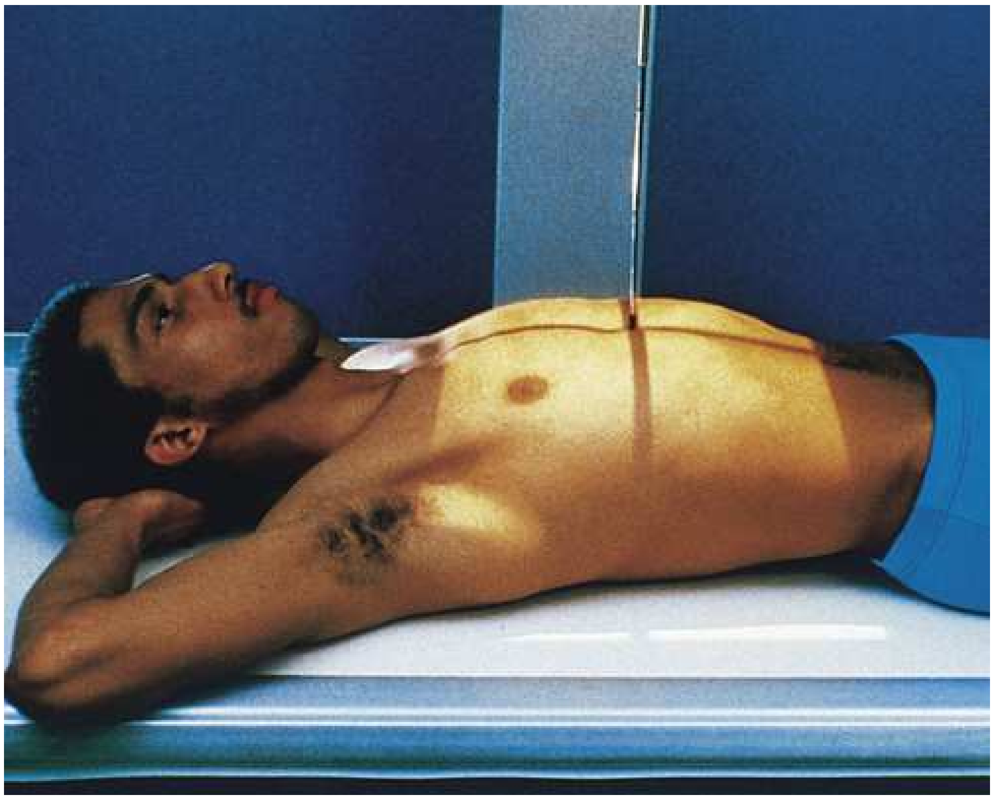


FIG. 10.34 AP ribs below diaphragm.

The patient is lying in a supine position. The patient's arms are extended to the sides, supporting his head. The central ray is directed to the point between the xiphoid process and the lower rib margin.

Central ray

- Perpendicular to the center of the IR

NOTE: Refer to the Exposure Technique Chart on p. 517 for the different exposure settings for the upper and lower rib projections.

Collimation

- Adjust radiation field to 14 × 17 inches (35 × 43 cm) on the collimator for bilateral ribs. For unilateral exams, collimate the width to 1 inch beyond MSP and the lateral border of the side of interest. Place side marker in the collimated exposure field.

Structures shown

The posterior ribs above or below the diaphragm, according to the region examined (Figs. 10.35 and 10.36). Although the anterior ribs are seen, the posterior ribs are shown in greater detail because they are closer to the IR.

Evaluation Criteria

The following should be clearly seen:

- Evidence of proper collimation and presence of side marker placed clear of anatomy of interest
- For ribs above the diaphragm, first through tenth posterior ribs from both sides in their entirety
- For ribs below the diaphragm, eighth through twelfth posterior ribs on both sides in their entirety
- Ribs visible through the lungs or abdomen, according to the region examined
- In a unilateral examination, ribs from the opposite side possibly not included in their entirety
- Bony trabecular detail and surrounding soft tissues

FIG. 10.35 AP ribs above diaphragm.

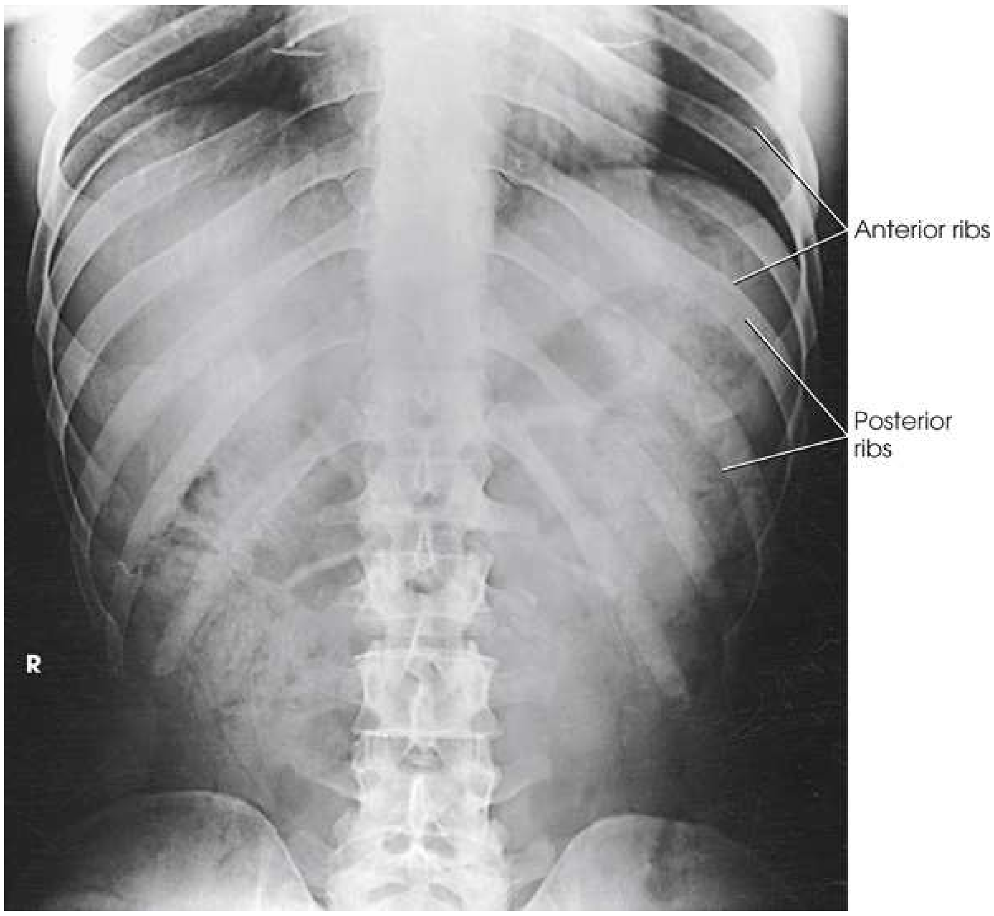


FIG. 10.36 AP lower ribs.

Axillary Ribs

AP Oblique Projection

RPO or LPO position

Image receptor + grid: Positioned by manufacturer or department protocol for proper anatomy display orientation; CR plate: 14 × 17 inches (35 × 43 cm) lengthwise.

Position of patient

- Examine the patient in the upright or recumbent position.
- Unless contraindicated by the patient's condition, use the upright position to image ribs above the diaphragm, and use the recumbent position to image ribs below the diaphragm. Gravity assists by moving the diaphragm.

Position of part

- Position the patient's body for a 45-degree AP oblique projection using the RPO or LPO position. Place the *affected* side closest to the IR.
- Center the affected side on a longitudinal plane drawn midway between the MSP and the lateral surface of the body.
- Position this plane to the midline of the grid.
- If the patient is in the recumbent position, support the elevated hip.
- Abduct the arm of the affected side, and elevate it to carry the scapula away from the rib cage.
- Rest the patient's hand on the head if the upright position is used (Fig. 10.37), or place the hand under or above the head if the recumbent position is used (Fig. 10.38).
- Abduct the opposite limb with the hand on the hip.
- Center the IR with the top 1½ inches (3.8 cm) above the upper border of the relaxed shoulder to image ribs above the diaphragm or to a point halfway between the xiphoid process and the lower rib margin to image ribs below the diaphragm.
- *Shield gonads.*
- *Respiration:* Suspend at the end of *full inspiration* for ribs *above* the diaphragm and at the end of *deep expiration* for ribs *below* the diaphragm.

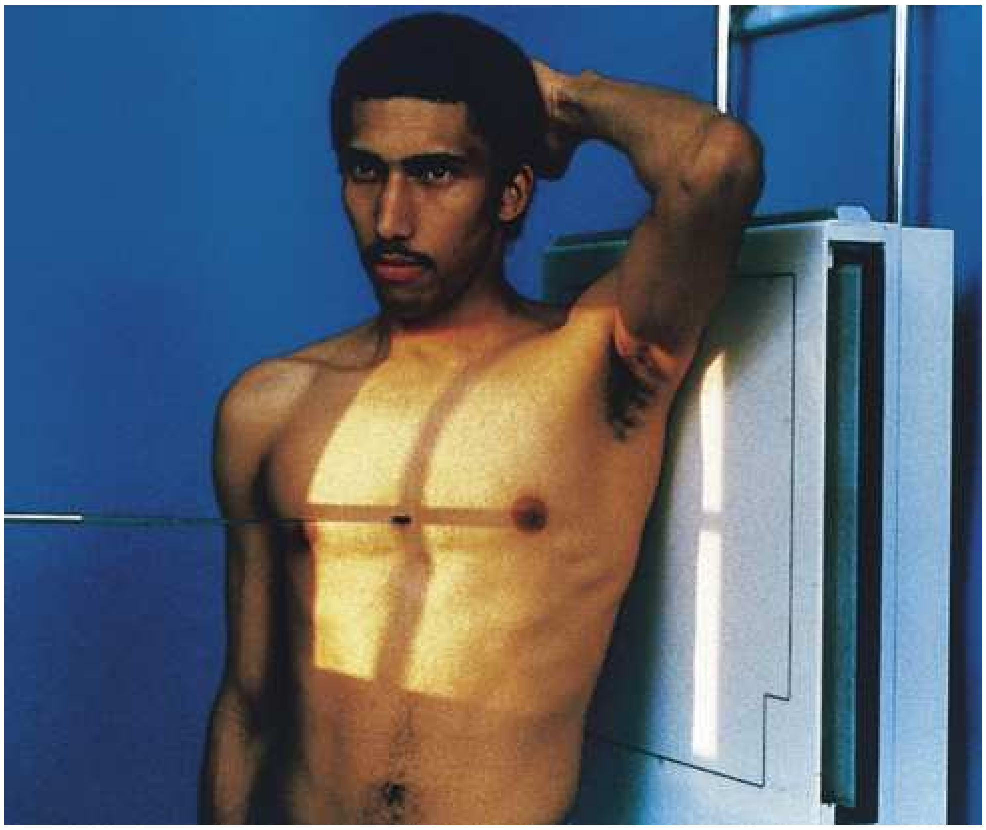


FIG. 10.37 Upright AP oblique ribs, LPO position.

The patient is standing in an upright position facing the I R at a 45-degree angle to the vertical grid. The arm of the affected side is abducted and extended above and resting on his head. The central ray is directed to 3.8 centimeters above the upper border of the shoulders.

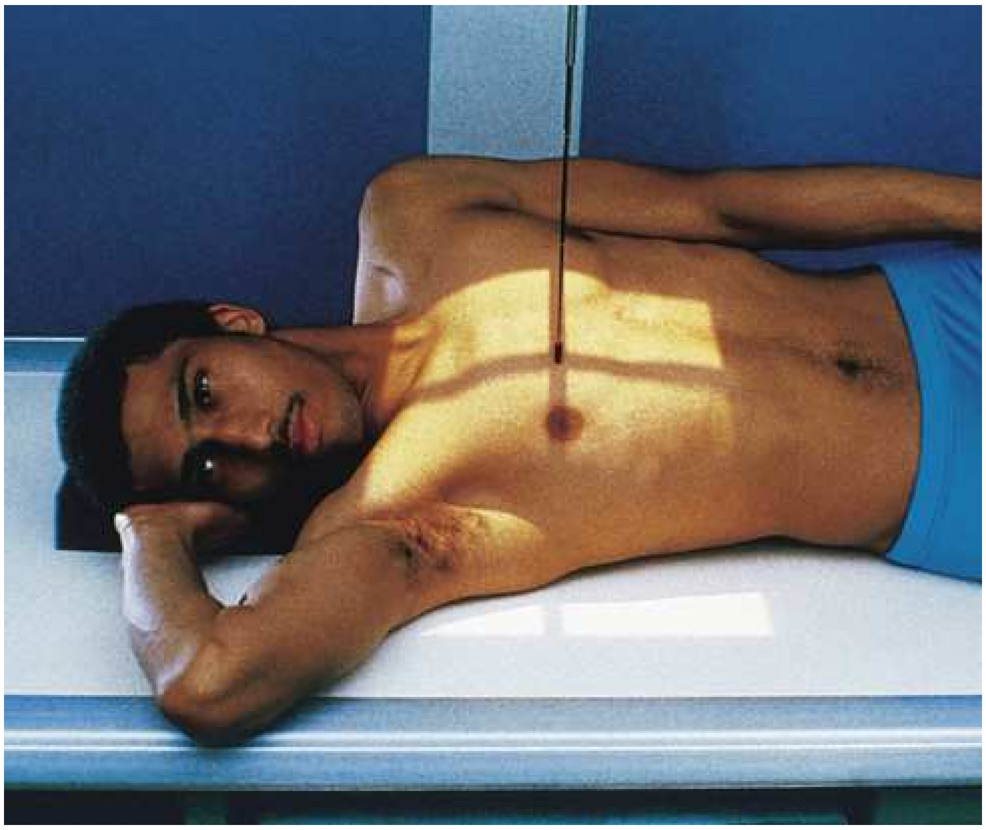


FIG. 10.38 Recumbent AP oblique ribs, RPO position.

The patient is lying in a supine position with his hips elevated to a 45-degree angle. The arm of the affected side is abducted and extended above, supporting his head. The central ray is directed to 3.8 centimeters above the upper border of the shoulders.

Central ray

- Perpendicular to the center of IR
- Closest to IR

Collimation

- Adjust radiation field to 14 × 17 inches (35 × 43 cm) on the collimator. Place side marker in the collimated exposure field.

Structures shown

The axillary portion of the ribs *closest* to the IR is projected free of superimposition with the thoracic spine (Fig. 10.39). The posterior ribs closest to the IR are also well shown.

Evaluation Criteria

The following should be clearly seen:

- Evidence of proper collimation and presence of side marker placed clear of anatomy of interest
- Approximately twice as much distance between the vertebral column and the lateral border of the ribs on the affected side as is present on the unaffected side
- Axillary portion of the ribs free of superimposition with the thoracic spine
- First through tenth ribs visible above the diaphragm for upper ribs
- Eighth through twelfth ribs visible below the diaphragm for lower ribs
- Ribs visible through the lungs or abdomen according to the region examined
- Bony trabecular detail and surrounding soft tissues

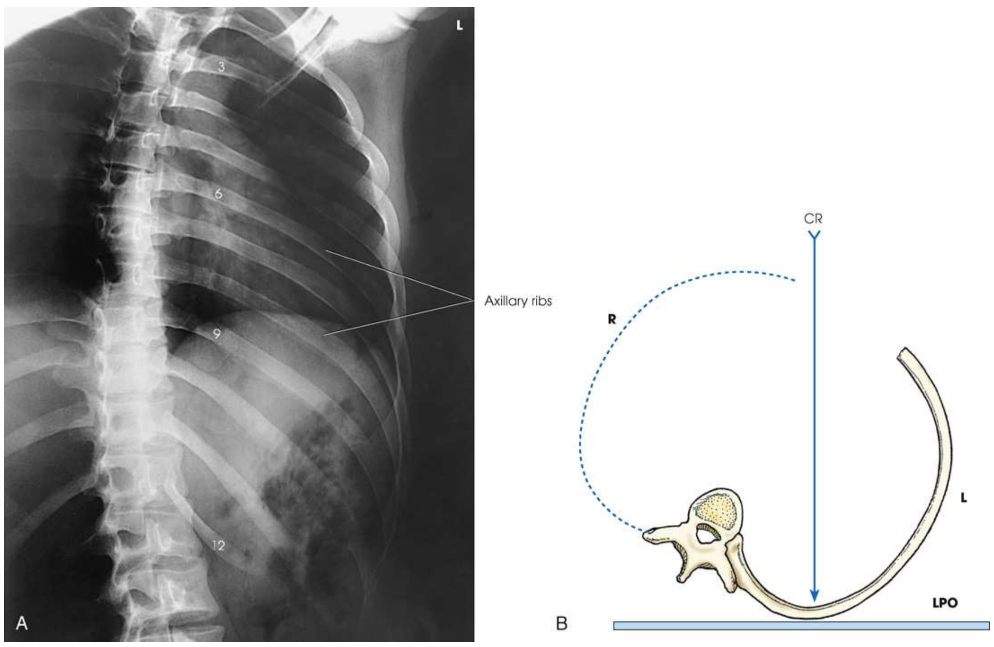


FIG. 10.39 (A) AP oblique ribs. LPO position shows left-side ribs. (B) Axial view (from feet upward) of ribs and CR, LPO position.

(A) An x-ray shows the axillary portion of the ribs free of superimposition with the thoracic spine. The ribs labeled are 3, 6, 9, 12. The axillary ribs are labeled. (B) A diagram shows the L P O position with hips elevated. The central ray is directed perpendicular to the center of the I R.

PA Oblique Projection

RAO or LAO position

Image receptor + grid: Positioned by manufacturer or department protocol for proper anatomy display orientation; CR plate: 14 × 17 inches (35 × 43 cm) lengthwise.

Position of patient

- Examine the patient in the upright or recumbent position.

- Unless contraindicated by the patient's condition, use the upright position to image ribs above the diaphragm and use the recumbent position to image ribs below the diaphragm. Gravity assists by moving the diaphragm.

Position of part

- Position the body for a 45-degree PA oblique projection using the RAO or LAO position. Place the affected side away from the IR (Fig. 10.40).
- If the recumbent position is used, have the patient rest on the forearm and flexed knee of the elevated side (Fig. 10.41).
- Align the body so that a longitudinal plane drawn midway between the midline and the lateral surface of the body side up is centered to the midline of the grid.
- Center IR with the top 1½ inches (3.8 cm) above the upper border of the shoulder to image ribs above the diaphragm or to a point halfway between the xiphoid process and the lower rib margin to image ribs below the diaphragm.
- *Shield gonads.*
- *Respiration:* Suspend at the end of *full expiration* for ribs *below* the diaphragm and at the end of *full inspiration* for ribs *above* the diaphragm.

FIG. 10.40 Upright PA oblique ribs, RAO position.

The patient is standing in an upright position facing the vertical grid at a 45-degree angle to the vertical grid. The affected side is positioned away from the I R. The central ray is directed to 3.8 centimeters above the upper border of the shoulders.

FIG. 10.41 Recumbent PA oblique ribs, LAO position.

The patient is lying in a supine position with his hips elevated to a 45-degree angle positioning the affected side away from the I R. The central ray is directed to 3.8 centimeters above the upper border of the shoulders.

Central ray

- Perpendicular to center of IR

Collimation

- Adjust radiation field to 14 × 17 inches (35 × 43 cm) on the collimator. Place side marker in the collimated exposure field.

Structures shown

The axillary portion of the ribs *farthest* from the IR is projected free of bony superimposition with the thoracic spine (Fig. 10.42). The anterior ribs farthest from the IR are also shown.

Evaluation Criteria

The following should be clearly seen:

- Evidence of proper collimation and presence of side marker placed clear of anatomy of interest
- Approximately twice as much distance between the vertebral column and the lateral border of the ribs on the affected side as is present on the unaffected side
- Axillary portion of the ribs free of superimposition with the thoracic spine
- First through tenth ribs visible above the diaphragm for upper ribs
- Eighth through twelfth ribs visible below the diaphragm for lower ribs
- Ribs visible through the lungs or abdomen according to the region examined

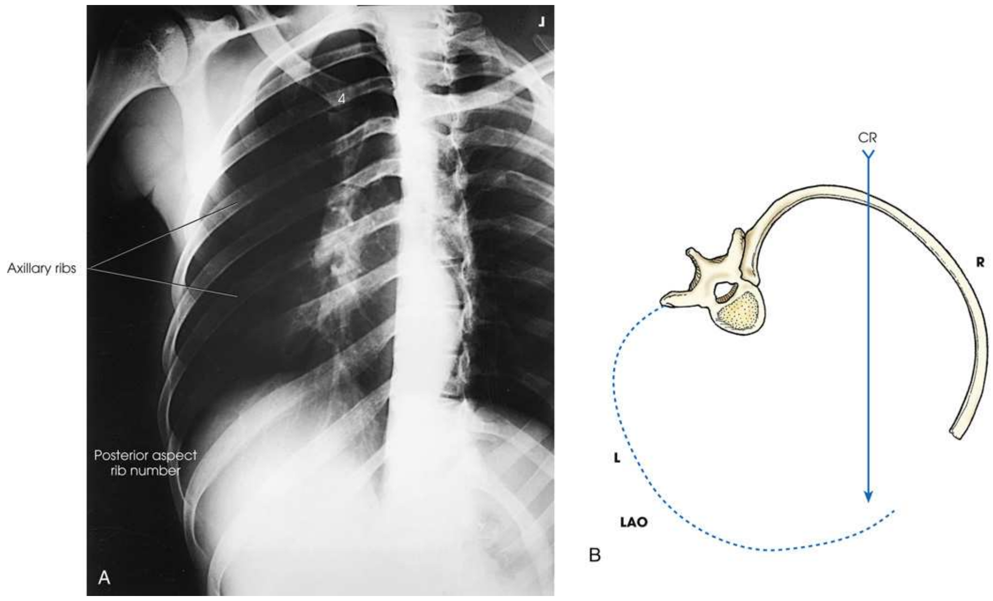


FIG. 10.42 (A) PA oblique ribs. LAO position shows right-side ribs. PA projection radiograph is placed in the anatomic position for display. (B) Axial view (from feet upward) of ribs and CR with the patient in LAO position.

An x-ray shows the axillary portion of the ribs free of superimposition with the thoracic spine. The axillary ribs labeled appear light over the radiolucent area. The eighth through twelfth ribs are visible below the diaphragm for lower ribs. The sternum appears radiopaque.

Reference

1. Moore T.F. An alternative to the standard radiographic position for the sternum. *Radiol Technol* . 1988;60:133.

Volume Two

OUTLINE

11: Cranium

Summary of Projections

Projections, Positions, And Methods					
Page	**Essential**	**Anatomy**	**Projection**	**Position**	**Method**
34		Skull	Lateral	R or L	
38		Skull	PA		
38		Skull	PA axial		CALDWELL
42		Skull	AP		
42		Skull	AP axial		REVERSE CALDWELL
44		Skull	AP axial		TOWNE
50		Skull	PA axial		HAAS
52		Cranial base	Submentovertical (SMV)		SCHÜLLER
59		Orbit	Lateral	R or L	
60		Orbits	PA axial		
61		Orbits	Parietoacanthial		MODIFIED WATERS
62		Facial bones	Lateral	R or L	
65		Facial bones	Parietoacanthial		WATERS
67		Facial bones	Modified parietoacanthial		MODIFIED WATERS
69		Facial bones	Acanthioparietal		REVERSE WATERS
71		Facial bones	PA axial		CALDWELL
73		Nasal bones	Lateral	R and L	
75		Zygomatic arches	Submentovertical		
77		Zygomatic arch	Tangential		
79		Zygomatic arches	AP axial		MODIFIED TOWNE
81		Mandibular rami	PA		
82		Mandibular rami	PA axial		
83		Mandibular body	PA		
84		Mandibular body	PA axial		
85		Mandible	Axiolateral, axiolateral oblique		
88		Mandible	Submentovertical		
89		TMJs	AP axial		
91		TMJs	Axiolateral	R and L	
93		TMJs	Axiolateral oblique	R and L	
95		Mandible	Panoramic		TOMOGRAPHY
98		Paranasal sinuses	Lateral	R or L upright	
100		Frontal and anterior ethmoidal sinuses	PA axial	Upright	CALDWELL
102		Maxillary sinuses	Parietoacanthial	Upright	WATERS
104		Maxillary and sphenoidal sinuses	Parietoacanthial	Upright with open mouth	WATERS
106		Ethmoidal and sphenoidal sinuses	Submentovertical	Upright	

Icons in the Essential column indicate projections frequently performed in the United States and Canada. Students should be competent in these projections.

AP, Anteroposterior; *L,* left; *LAO,* left anterior oblique; *PA,* posteroanterior; *R,* right; *RAO,* right anterior oblique.

Anatomy

Skull

The *skull* rests on the superior aspect of the vertebral column. It is composed of 22 separate bones divided into two distinct groups: 8 *cranial* bones and 14 *facial* bones. The cranial bones are divided further into the *calvaria* and the *floor* (Box 11.1). The cranial bones form a protective housing for the brain. The facial bones provide structure, shape, and support for the face. They also form a protective housing for the upper ends of the respiratory and digestive tracts and, with several of the cranial bones, form the orbital sockets for protection of the organs of sight. The *hyoid bone* is commonly discussed with this group of bones.

The bones of the skull are identified in Figs. 11.1–11.3. The 22 primary bones of the skull should be located and recognized in the different views before they are studied in greater detail.

BOX 11.1 Skull Bones

Cranial bones (8)		Facial bones (14)	2
Calvaria		Nasal (right and left)	2
Frontal	1	Lacrimal (right and left)	2
Occipital	1	Maxillary (right and left)	2
Right parietal	1	Zygomatic (right and left)	2
Left parietal	1	Palatine (right and left)	2
Floor		Inferior nasal conchae (right and left)	1
Ethmoid	1	Vomer	1
Sphenoid	1	Mandible	
Right temporal	1		
Left temporal	1		

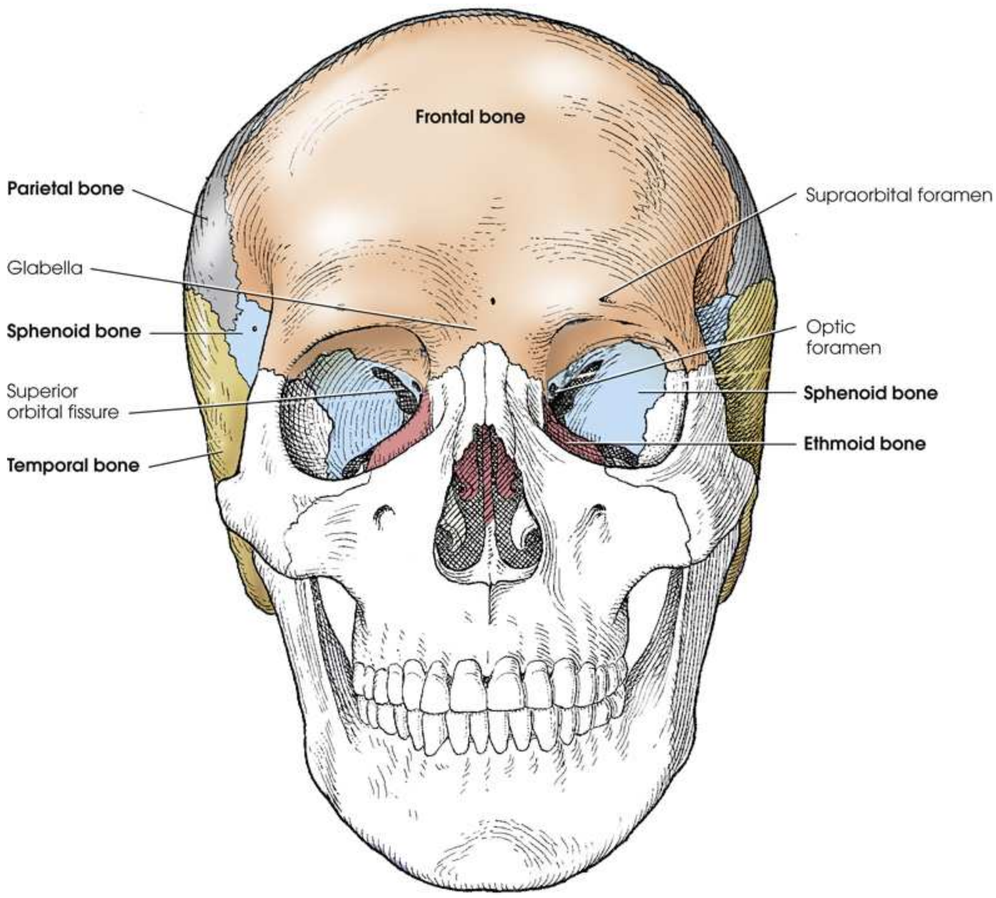


FIG. 11.1 Anterior aspect of cranium.

The anterior view of the human skull with the following parts labeled: Frontal bone, supraorbital foramen above the eye socket, optic foramen inside the eye socket, temporal bone on the temple, parietal bone above the temple, superior orbital fissure, sphenoid bone behind the socket, and glabella between the eye sockets.

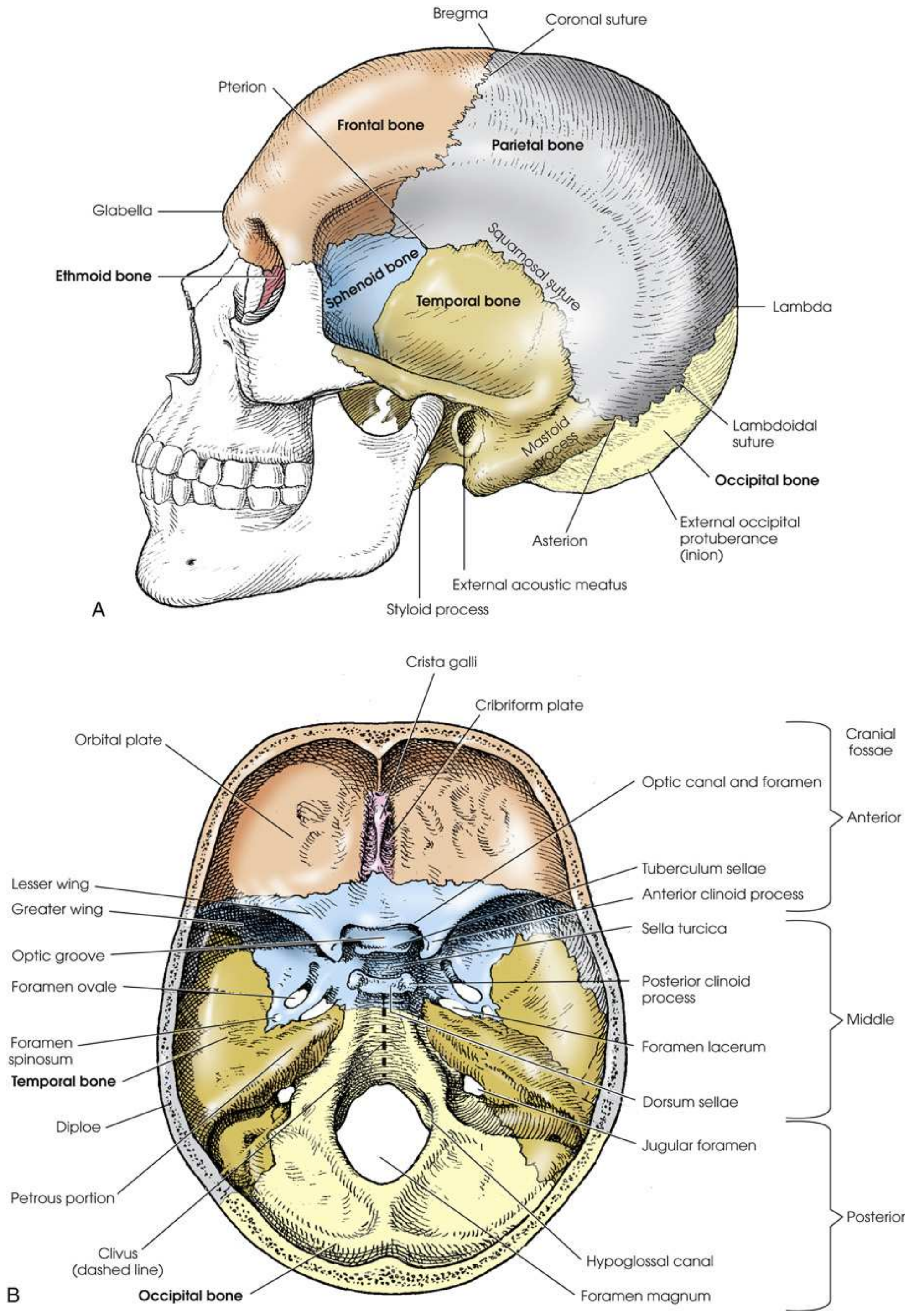


FIG. 11.2 (A) Lateral aspect of cranium. (B) Superior aspect of cranial base.

A) Lateral view showing the lateral, temporal, sphenoid, nasal, lacrimal, parietal and occipital bones. B) Superior view showing the foramen magnum, jugular foramen, temporal, sphenoid, parietal, occipital, and frontal bones.

The bones of the cranial vault are composed of two plates of compact tissue separated by an inner layer of spongy tissue called *diploë*. The outer plate, or table, is thicker than the inner table over most of the vault, and the thickness of the layer of spongy tissue varies considerably.

Except for the mandible, the bones of the cranium and face are joined by fibrous joints called *sutures*. The sutures are named *coronal*, *sagittal*, *squamosal*, and *lambdoidal* (see Figs. 11.1 and 11.2). The *coronal suture* is found between the frontal and parietal bones. The *sagittal suture* is located on the top of the head between the two parietal bones and just behind the coronal suture line (not visible in Figs. 11.1 and 11.2). The junction of the coronal and sagittal sutures is the *bregma*. Between the temporal bones and the parietal bones are the *squamosal sutures*. Between the occipital bone and the parietal bones is the *lambdoidal suture*. The *lambda* is the junction of the lambdoidal and sagittal sutures. On the lateral aspect of the skull, the junction of the parietal bone, squamosal suture, and greater wing of the sphenoid is the *pterion*, which overlies the middle meningeal artery. At the junction of the occipital bone, parietal bone, and mastoid portion of the temporal bone is the *asterion*.

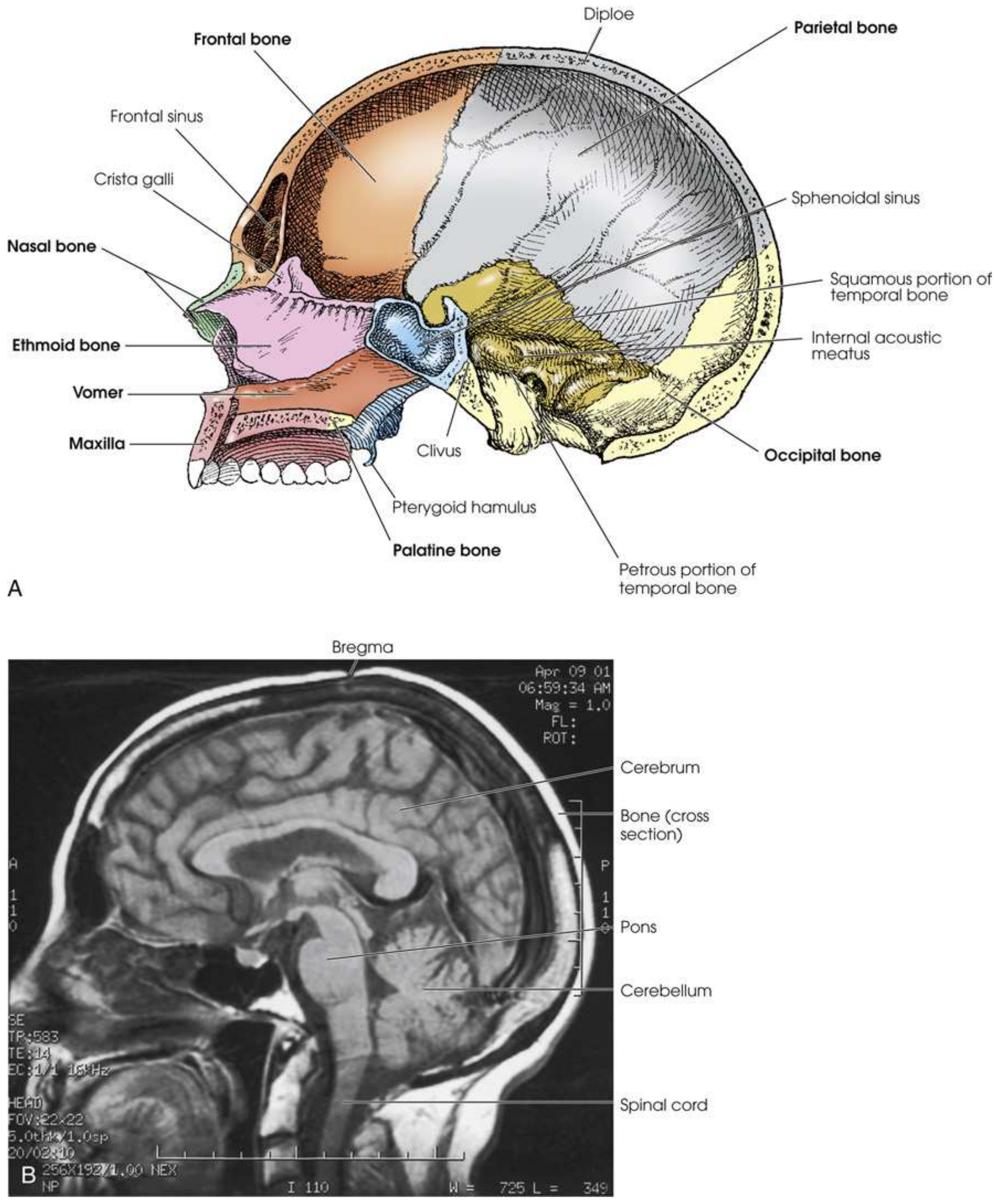


FIG. 11.3 (A) Lateral aspect of interior of cranium. (B) Sagittal magnetic resonance imaging of cranium showing contents and position of brain. Note bony protective housing.

An illustration of the lateral view of the skull (A) and a scan of lateral projection of skull (B). The lateral, temporal, sphenoid, nasal, lacrimal, parietal and occipital bones are visible in the illustration. The pons, cerebellum, cerebrum, and spinal cord are visible in the scan image.

In a newborn infant, the bones of the cranium are thin and not fully developed. They contain a small amount of calcium, are indistinctly marked, and present six areas of incomplete ossification called *fontanels*, often spelled *fontanelles* (Fig. 11.4). Two of the fontanels are situated in the midsagittal plane (MSP) at the superior and posterior angles of the parietal bones. The *anterior fontanel* is located at the junction of the two parietal bones and the one frontal bone at the bregma. Posteriorly and in MSP is the *posterior fontanel*, located at the point labeled *lambda* in Fig. 11.2. Two fontanels are also on each side at the inferior angles of the parietal bones. Each *sphenoidal fontanel* is found at the site of the pterion; the *mastoid fontanels* are found at the asteria. The posterior and sphenoidal fontanels normally close in the first and third months after birth, and the anterior and mastoid fontanels close during the second year of life.

The cranium develops rapidly in size and density during the first 5 or 6 years, after which a gradual increase occurs until adult size and density are achieved, usually by the age of 12 years. The thickness and degree of mineralization in normal adult crania show comparatively little difference in radiopacity from person to person, and the atrophy of old age is less marked than in other regions of the body.

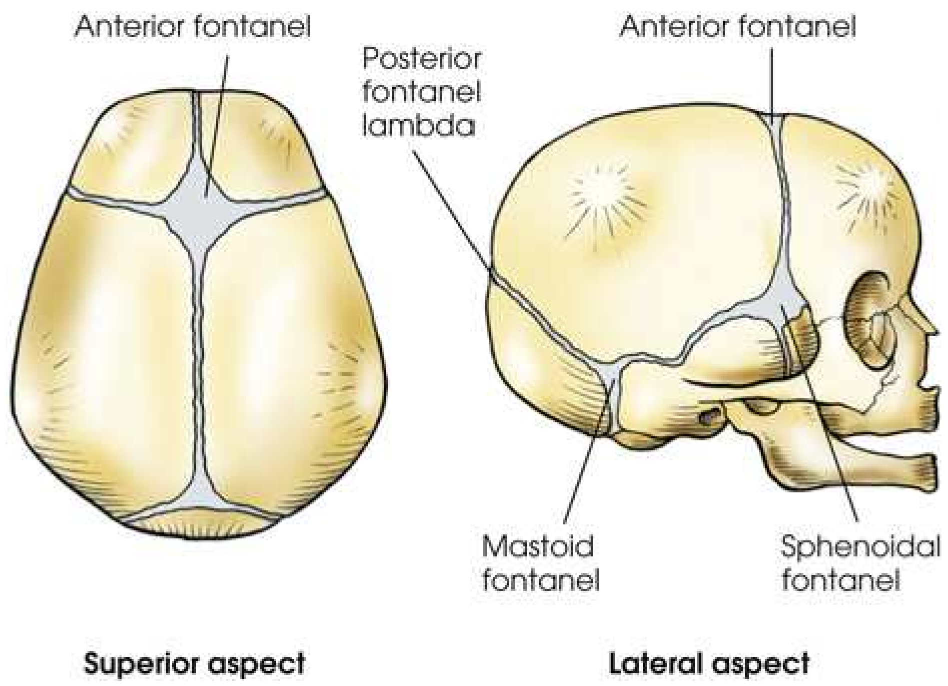


FIG. 11.4 Fontanels of a newborn.

The superior and lateral views of the skull with the fontanels labeled. The anterior fontanel is visible in the superior view, posterior fontanel, sphenoid fontanel, and mastoid fontanel are visible in the lateral view.

Internally, the cranial floor is divided into three regions: anterior, middle, and posterior cranial fossae (see Fig. 11.2B). The *anterior cranial fossa* extends from the anterior frontal bone to the lesser wings of the sphenoid. It is associated mainly with the frontal lobes of the cerebrum. The *middle cranial fossa* accommodates the temporal lobes and associated neurovascular structures and extends from the lesser wings of the sphenoid bone to the apices of petrous portions of the temporal bones. The deep depression posterior to the petrous ridges is the *posterior cranial fossa*, which protects the cerebellum, pons, and medulla oblongata (see Fig. 11.3B).

The average or so-called normal cranium is more or less oval in shape, wider in back than in front. The average cranium measures approximately 6 inches (15 cm) at its widest point from side to side, 7 inches (17.8 cm) at its longest point from front to back, and 9 inches (22 cm) at its deepest point from the vertex to the submental region. Crania vary in size and shape, with resultant variation in the position and relationship of internal parts.

Internal deviations from the norm are usually indicated by external deviations and can be estimated with a reasonable degree of accuracy. The length and width of the normally shaped head vary by 1 inch (2.5 cm). Any deviation from this relationship indicates a comparable change in the position and relationship of the internal structures. If the deviation involves more than a 5-degree change, it must be compensated for by a change in part rotation or central ray angulation. This "rule" applies to all images except direct lateral projections. A

½

-inch (1.3 cm) change in the 1-inch (2.5-cm) width-to-length measurement indicates an approximately 5-degree change in the direction of the internal parts with reference to MSP.

It is important for the radiographer to understand cranial anatomy from the standpoint of the size, shape, position, and relationship of component parts of the cranium, so that estimations and compensations can be made for deviations from the norm.

Cranial Bones

Frontal Bone

The *frontal bone* has a vertical portion and horizontal portions. The vertical portion, called the *frontal squama*, forms the forehead and the anterior part of the vault. The horizontal portions form the orbital plates (roofs of the orbits), part of the roof of the nasal cavity, and the greater part of the anterior cranial fossa (Figs. 11.5–11.7).

On each side of the MSP of the superior portion of the squama is a rounded elevation called the *frontal eminence*. Below the frontal eminences, just above the *supraorbital margins*, are two arched ridges that correspond in position to the eyebrows. These ridges are called the *superciliary arches*. In the center of the supraorbital margin is an opening for nerves and blood vessels called the *supraorbital foramen*. The smooth elevation between the superciliary arches is termed the *glabella*.

The *frontal sinuses* (Fig. 11.8) are situated between the two tables of the squama on each side of MSP. These irregularly shaped sinuses are separated by a bony wall, which may be incomplete and usually deviates from the midline.

The squama articulates with the parietal bones at the coronal suture, the greater wing of the sphenoid bone at the frontosphenoidal suture, and the nasal bones at the frontonasal suture. The midpoint of the frontonasal suture is termed the *nasion*.

The frontal bone articulates with the right and left parietals, the sphenoid, and the ethmoid bones of the cranium.

The *orbital plates* of the horizontal portion of the frontal bone are separated by a notch called the *ethmoidal notch*. This notch receives the cribriform plate of the ethmoid bone. At the anterior edge of the ethmoidal notch is a small inferior projection of bone, the *nasal spine,* which is the superior-most component of the bony nasal septum. The posterior margins of the orbital plates articulate with the lesser wings of the sphenoid bone.

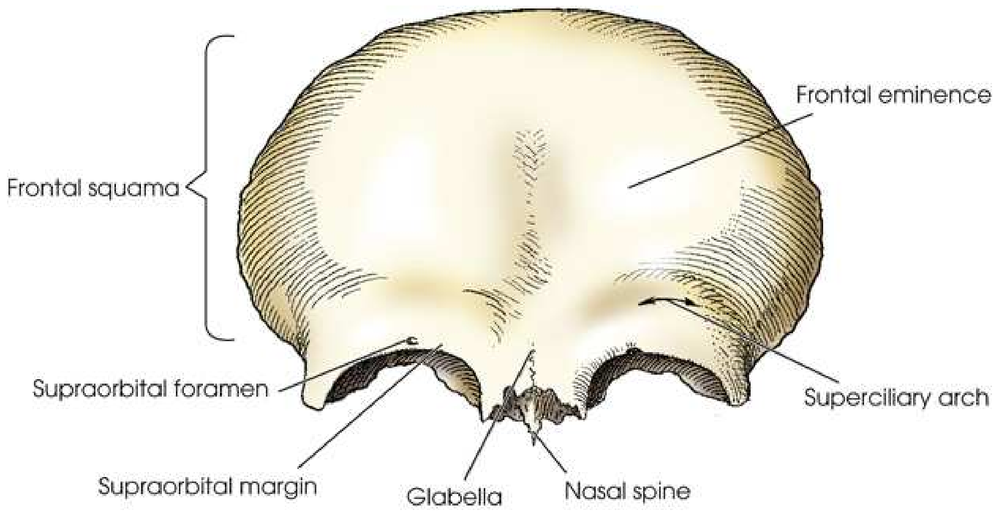


FIG. 11.5 Anterior aspect of frontal bone.

The anterior view of the frontal bone in the upper half of the skull with the parts labeled. The entire frontal squama, supraorbital margin, glabella, nasal apine, supraorbital foramen, and frontal eminence are labeled.

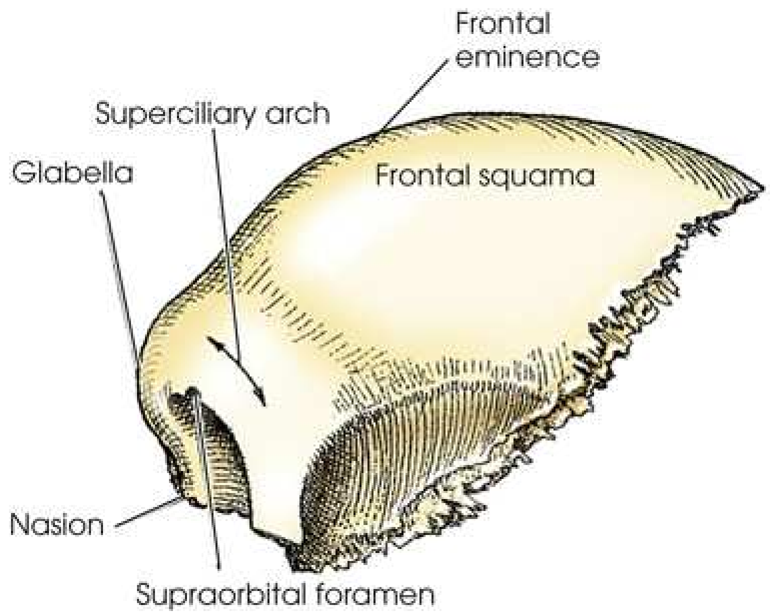


FIG. 11.6
LATERAL ASPECT OF FRONTAL BONE.

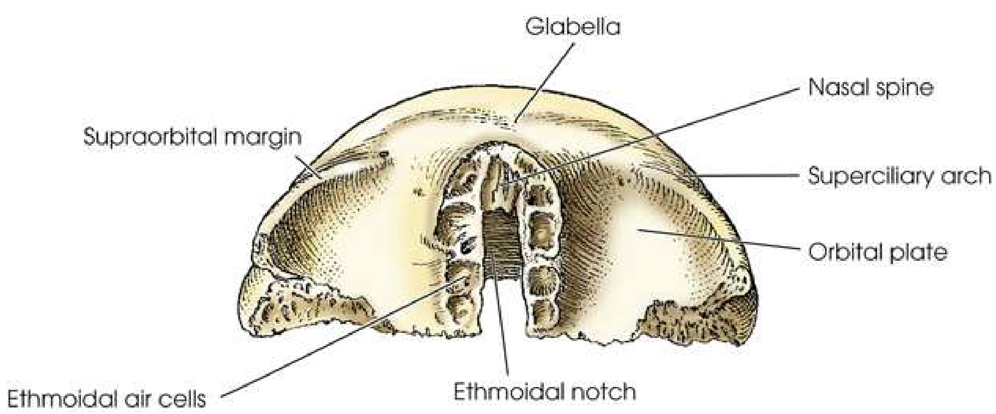


FIG. 11.7 Inferior aspect of frontal bone.

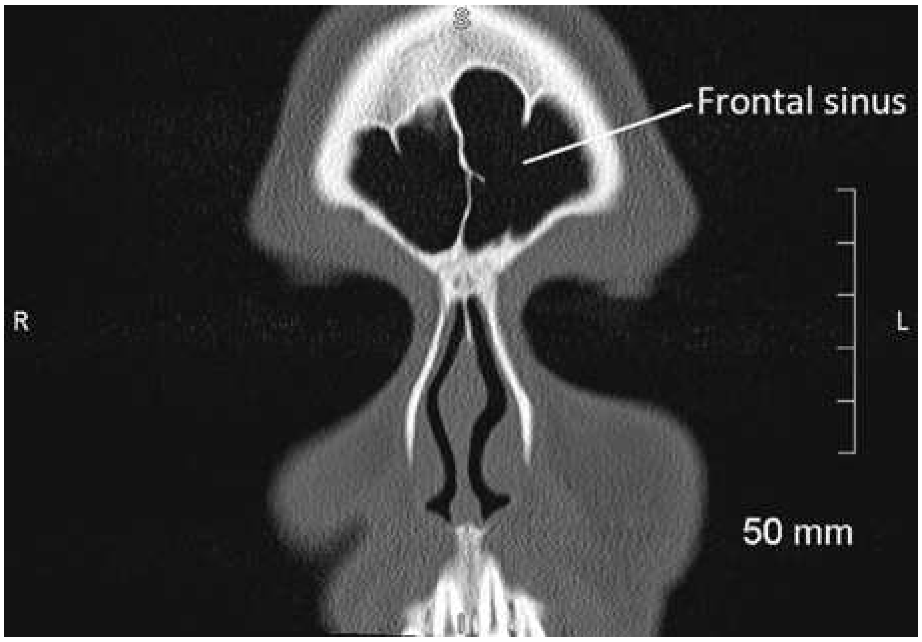


FIG. 11.8 Coronal CT image of frontal sinuses. Courtesy Heath Yarbrough, RT[R][MR][CT], NEA Baptist Memorial Hospital, Jonesboro, AR.

Ethmoid Bone

The *ethmoid bone* is a small, cube-shaped bone that consists of a horizontal plate; a vertical plate; and two light, spongy lateral masses called *labyrinths* (Figs. 11.9–11.12). Situated between the orbits, the ethmoid bone forms part of the anterior cranial fossa, the nasal cavity and orbital walls, and the bony nasal septum.

The horizontal portion of the ethmoid bone, called the *cribriform plate*, is received into the ethmoidal notch of the frontal bone. The cribriform plate is perforated by many foramina for the transmission of olfactory nerves. The plate also has a thick, conical process, the *crista galli*, which projects superiorly from its anterior midline and serves as the anterior attachment for the falx cerebri.

The vertical portion of the ethmoid bone is called the *perpendicular plate*. This plate is a thin, flat bone that projects inferiorly from the inferior surface of the cribriform plate and, with the nasal spine, forms the superior portion of the bony septum of the nose.

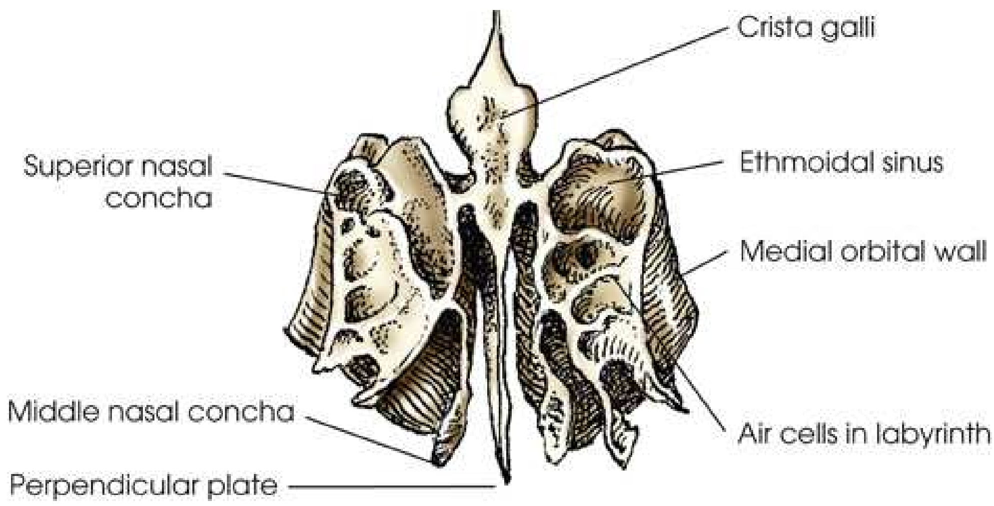


FIG. 11.9 Anterior aspect of ethmoid bone.

The anterior view of the ethmoid bone. The bone has a hollow structure. The location of ethmoid sinus, perpendicular plate, crista galli, medial orbital wall, superior and middle nasal concha are labeled.

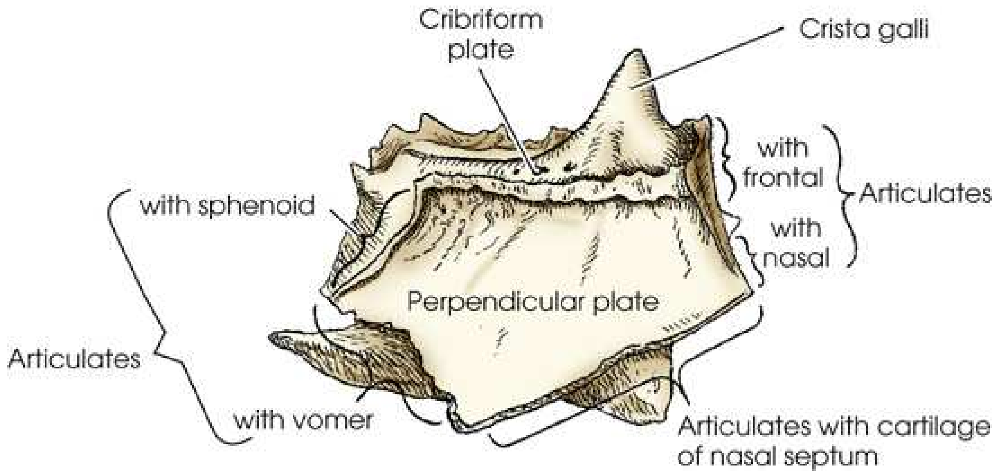


FIG. 11.10
LATERAL ASPECT OF ETHMOID BONE WITH LABYRINTH REMOVED.

The lateral view of ethmoid bone with the labyrinth removed. The location of cribriform plate, crita galli, articulates with cartilage of nasal septum, articulates with sphenoid and with vomer, articulates with frontal and with nasal.

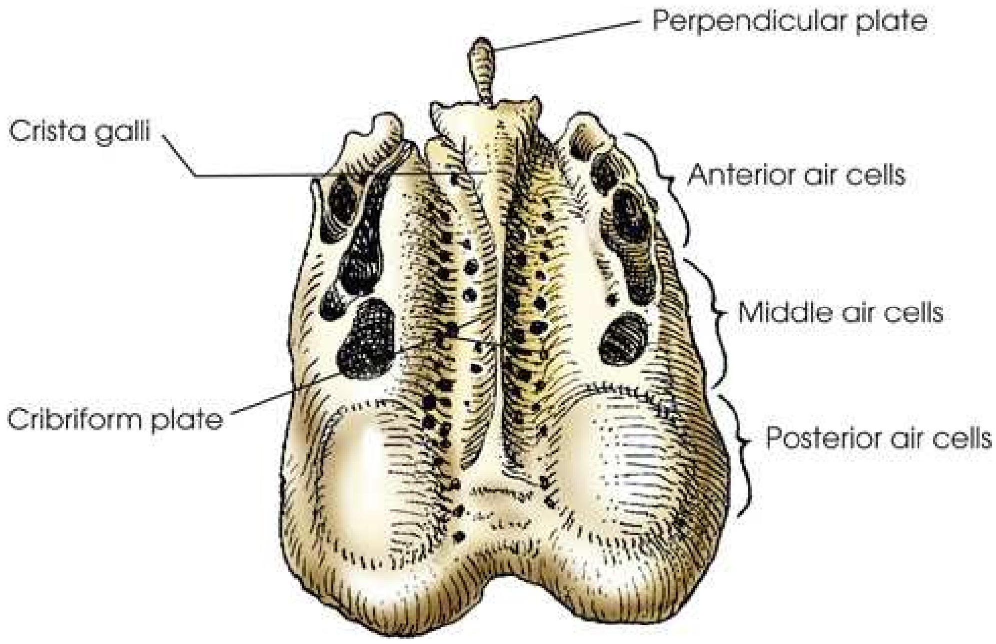


FIG. 11.11
SUPERIOR ASPECT OF ETHMOID BONE.

The superior view of the ethmoid bone. The bone has a hollow structure. The location of cribriform plate, crita galli, cribriform foramina, ethmoid sinus, perpendicular plate, superior nasal concha and middle nasal concha are labeled.

The *labyrinths* contain the *ethmoidal sinuses*, or air cells. The cells of each side are arbitrarily divided into three groups: the *anterior*, *middle*, and *posterior ethmoidal air cells* (see Fig. 11.12A and B). The walls of the labyrinths form part of the medial walls of the orbits and part of the lateral walls of the nasal cavity. Projecting inferiorly from each medial wall of the labyrinths are two thin, scroll-shaped processes called the *superior* and *middle nasal conchae*.

The ethmoid bone articulates with the frontal and sphenoid bones of the cranium.

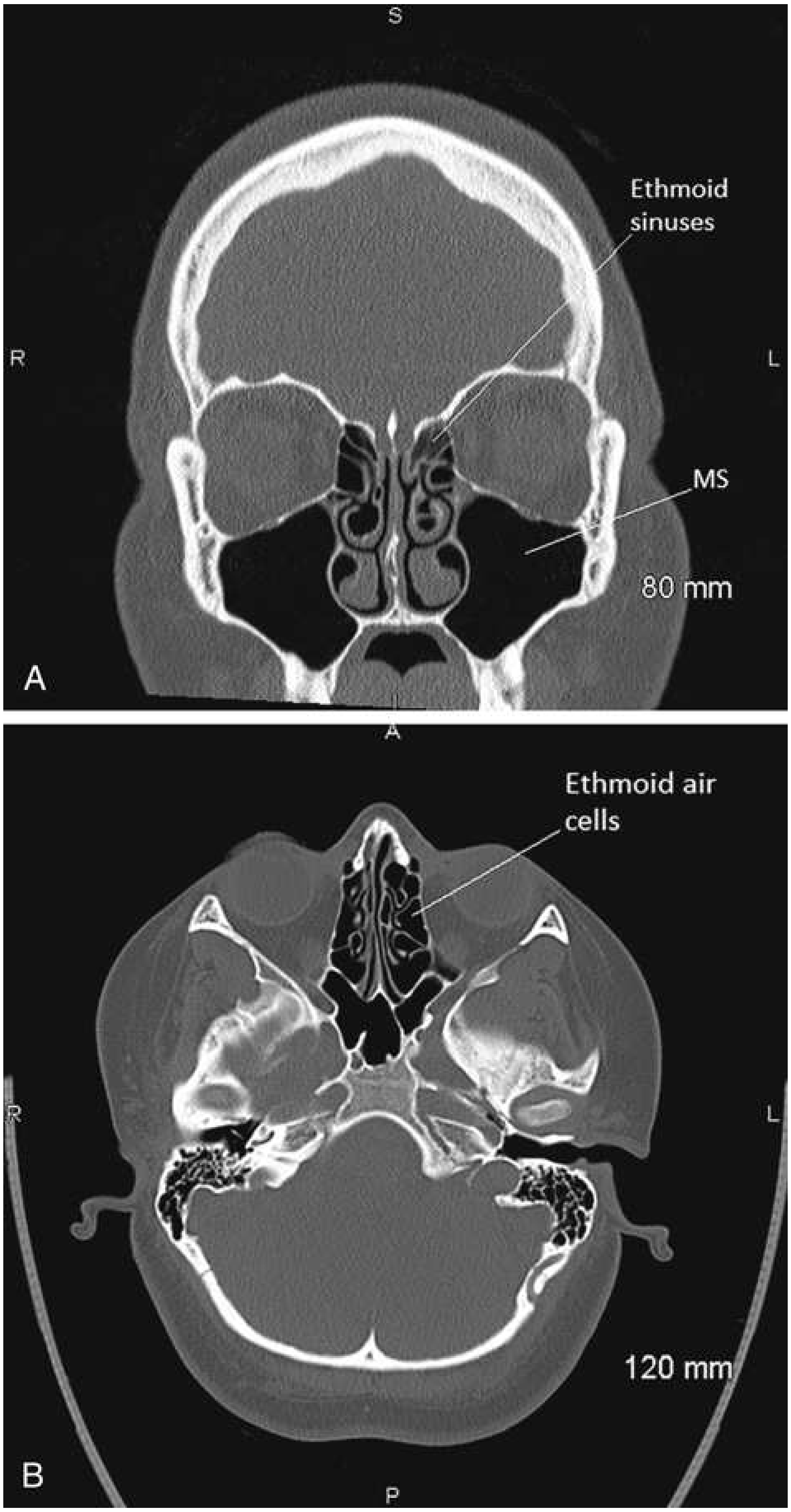


FIG. 11.12 (A) Coronal CT image of ethmoidal sinuses. (B) Axial CT scan of ethmoidal sinus. *MS,* Maxillary sinuses. Courtesy Bryan Harrison, RT(R) (CT), NEA Baptist Memorial Hospital, Jonesboro, AR.

Two C T scan images of the ethmoidal sinuses. A) Coronal view and second one is an axial view. In the first image the ethmoid sinuses and maxillary sinuses are labeled. B) Ethmoid air cells underneath the sinuses are labeled.

Parietal Bones

The two *parietal bones* are square and have a convex external surface and a concave internal surface (Figs. 11.13 and 11.14). The parietal bones form a large portion of the sides of the cranium. They also form the posterior portion of the cranial roof by their articulation with each other at the sagittal suture in the MSP.

Each parietal bone presents a prominent bulge, called the *parietal eminence*, near the central portion of its external surface. In radiography, the width of the head should be measured at this point because it is the widest point of the head.

Each parietal bone articulates with the frontal, temporal, occipital, sphenoid, and opposite parietal bones of the cranium.

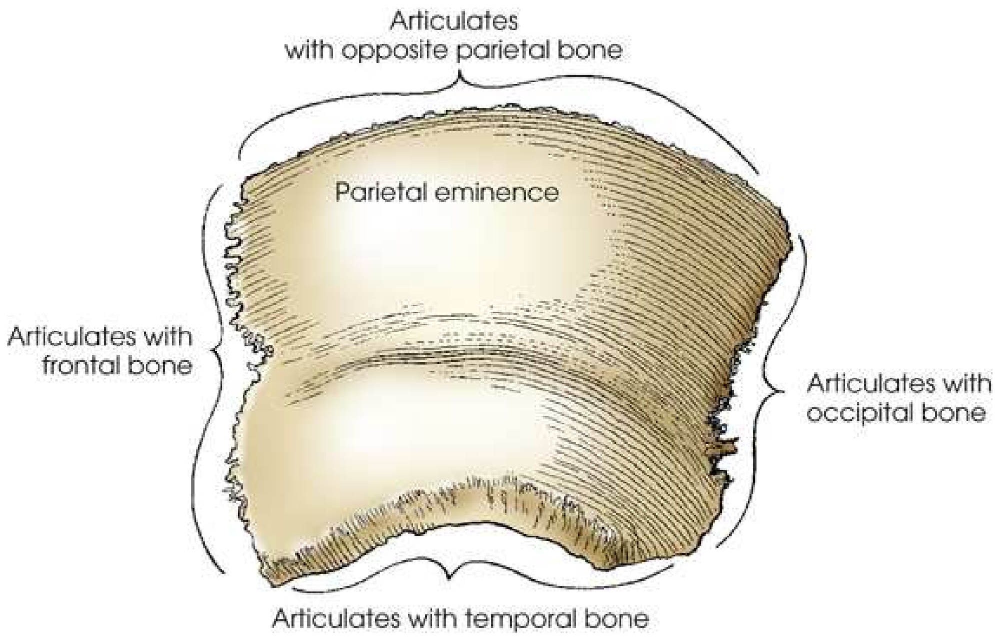


FIG. 11.13 External surface of parietal bone.

The lateral view of the parietal bone and the external surfaces. The articulate with opposite parietal bone is at the top, articulate with occipital bone is at the right, articulate with temporal bone is at the bottom, and articulate with frontal bone is at the left.

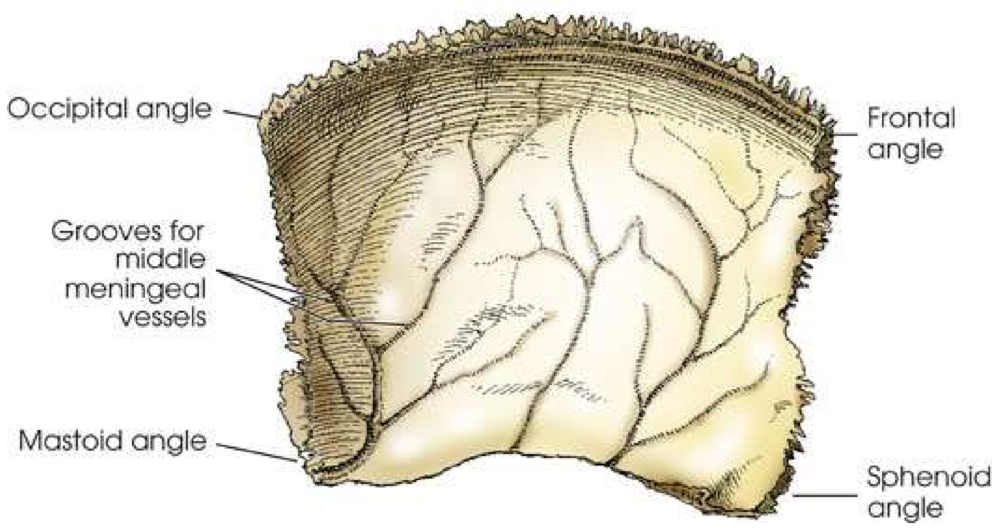
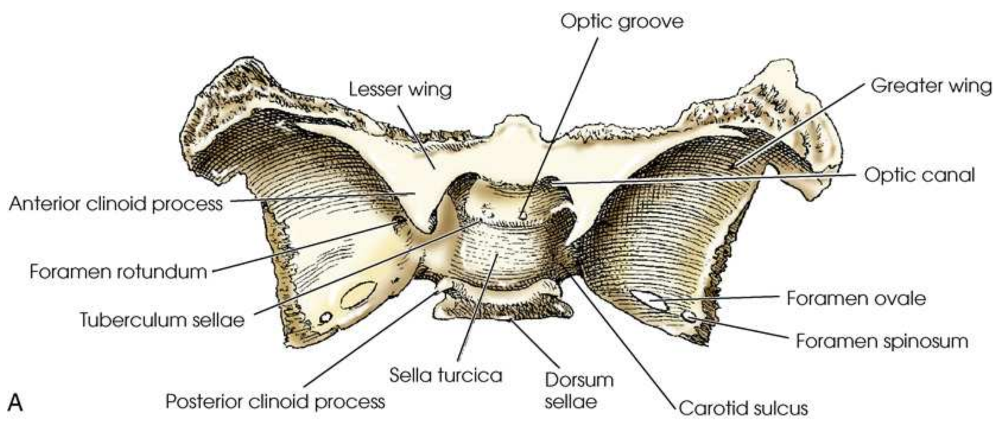


FIG. 11.14 Internal surface of parietal bone.

The internal surface of the parietal bone with the parts labeled. The occipital angle, grooves for middle meningeal vessels, and mastoid angle are labeled on the left. The frontal angle and sphenoid angle are labeled on the right.

Sphenoid Bone

The *sphenoid bone* is an irregularly wedge-shaped bone that resembles a bat with its wings extended. It is situated in the base of the cranium anterior to the temporal bones and basilar part of the occipital bone (Figs. 11.15–11.17). The sphenoid bone consists of a body; two lesser wings and two greater wings, which project laterally from the sides of the body; and two pterygoid processes, which project inferiorly from each side of the inferior surface of the body.



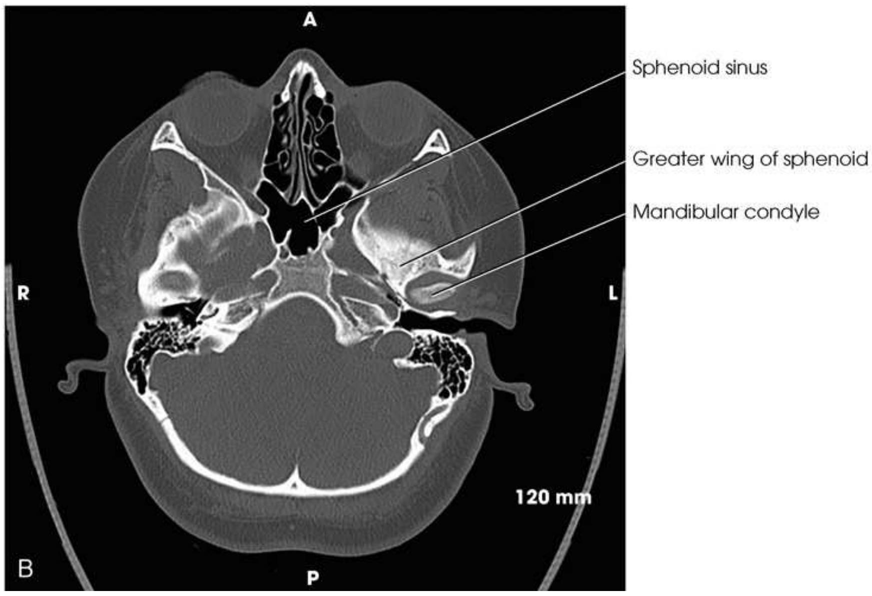


FIG. 11.15 (A) Superior aspect of sphenoid bone. (B) Axial CT scan of sphenoid bone. B, Courtesy Bryan Harrison, RT[R][CT], NEA Baptist Memorial Hospital, Jonesboro, AR.

A) Superior view of the sphenoid bone and the C T scan of the axial view of the bone. The greater wing, optic canal, foramen avale, and foramen spinosum are labeled on the right. The optic groove, sella turcica, and dorsum sellae are at the center. The lesser wing, anterior clinoid process, foramen rotundum, tuberculum sellae, and posterior clinoid process are labeled on the left. B) Scan shows labels for sphenoid sinus, greater wing of sphenoid, and mandibular condyle.

The *body* of the sphenoid bone contains the two *sphenoidal sinuses*, which are incompletely separated by a median septum (see Figs. 11.15B and 11.17). The anterior surface of the body forms the posterior bony wall of the nasal cavity. The superior surface presents a deep depression called the *sella turcica* and contains a gland called the *pituitary gland*. The sella turcica lies in the MSP of the cranium at a point

¾

inch (1.9 cm) anterior and

¾

inch (1.9 cm) superior to the level of the *external acoustic meatus* (EAM). The sella turcica is bounded anteriorly by the *tuberculum sellae* and posteriorly by the *dorsum sellae*, which bears the *posterior clinoid processes* (see Fig. 11.16B). The slanted area of bone posterior and inferior to the dorsum sellae is continuous with the basilar portion of the occipital bone and is called the *clivus*. The clivus supports the pons. On either side of the sella turcica is a groove, the *carotid sulcus*, in which the internal carotid artery and the cavernous sinus lie.

The *optic groove* extends across the anterior portion of the tuberculum sellae. The groove ends on each side at the *optic canal*. The optic canal is the opening into the apex of the orbit for the transmission of the optic nerve and ophthalmic artery. The actual opening is called the *optic foramen*.

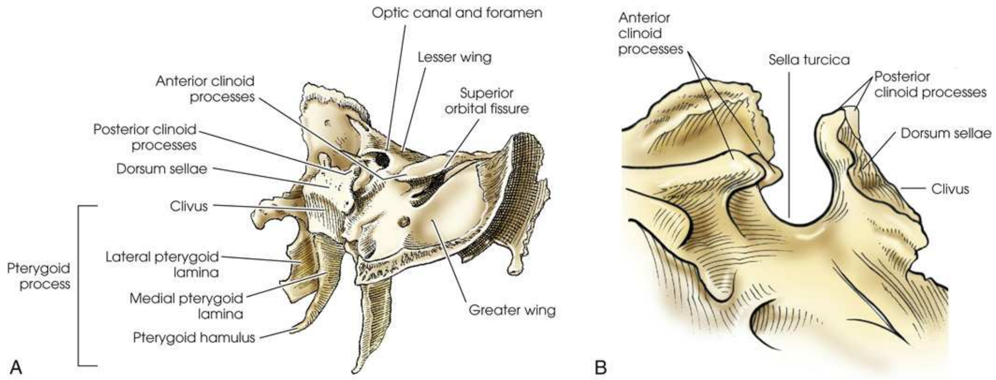


FIG. 11.16 (A) Oblique aspect of upper and lateroposterior aspects of sphenoid bone (right lateral pterygoid lamina removed). (B) Sella turcica of sphenoid bone, lateral view.

Two illustrations of the oblique aspect of upper (A) and lateroposterior aspects of sphenoid bone and the Sella turcica of the sphenoid bone (B). In the sphenoid bone the Optic canal and foramen, Lesser wing, Superior orbital fissure, and Greater wing are labeled on the right. The Anterior clinoid processes, Posterior clinoid processes, Dorsum sellae, and Clivus are labeled on the left. The Lateral pterygoid lamina, Medial pterygoid lamina, and Pterygoid hamulus together make up the pterygoid process. In the second image the clinoid processes, Posterior clinoid processes, Dorsum sellae, Clivus, and Sella turcica are labeled.

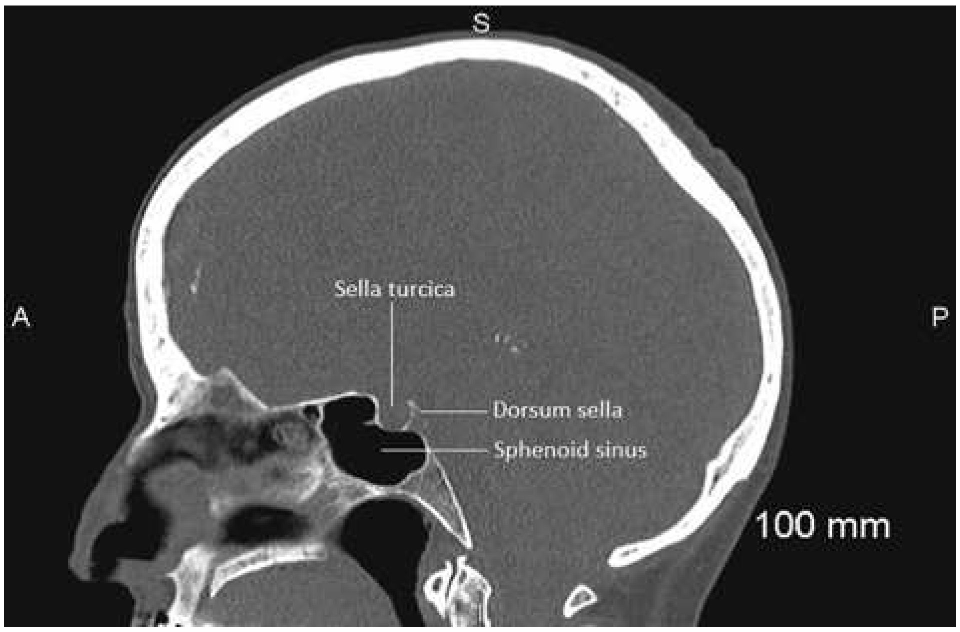


FIG. 11.17 Sagittal CT scan of sella turcica and sphenoid sinus. Courtesy Natalie Reece, RT(R) (CT)(MR), NEA Baptist Memorial Hospital, Jonesboro, AR.

The *lesser wings* are triangular in shape and nearly horizontal in position. They arise, one on each side, from the anterosuperior portion of the body of the sphenoid bone and project laterally, ending in sharp points. The lesser wings form the posteromedial portion of the roofs of the orbits, the posterior portion of the anterior cranial fossa, the upper margin of the *superior orbital fissures,* and the optic canals. The medial ends of their posterior borders form the *anterior clinoid processes*. Each process arises from two roots. The anterior (superior) root is thin and flat, and the posterior (inferior) root, referred to as the *sphenoid strut*, is thick and rounded. The circular opening between the two roots is the *optic canal*.

The *greater wings* arise from the sides of the body of the sphenoid bone and curve laterally, posteriorly, anteriorly, and superiorly. The greater wings form part of the middle cranial fossa, the posterolateral walls of the orbits, the lower margin of the superior orbital sulci, and the greater part of the posterior margin of the inferior orbital sulci. The *foramina rotundum*, *ovale*, and *spinosum* are paired and are situated in the greater wings. Because these foramina transmit nerves and blood vessels, they are subject to radiologic investigation for the detection of erosive lesions of neurogenic or vascular origin.

The *pterygoid processes* arise from the lateral portions of the inferior surface of the body of the sphenoid bone and the medial portions of the inferior surfaces of the greater wings. These processes project inferiorly and curve laterally. Each pterygoid process consists of two plates of bone, the *medial* and *lateral pterygoid laminae*, which are fused at their superoanterior parts. The inferior extremity of the medial lamina possesses an elongated, hook-shaped process, the *pterygoid hamulus*, which makes it longer and narrower than the lateral lamina. The pterygoid processes articulate with the palatine bones anteriorly and with the wings of the vomer, where they enter into the formation of the nasal cavity.

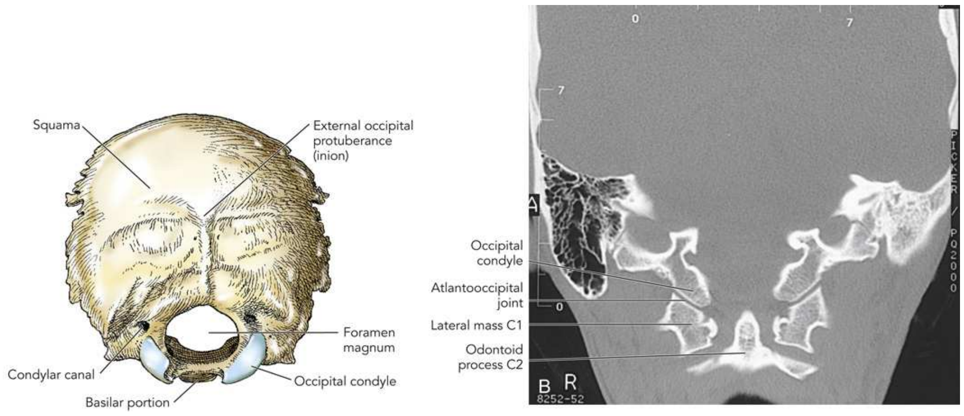


FIG. 11.18 (A) External surface of occipital bone. (B) Coronal CT showing atlantooccipital joint. B, Courtesy Siemens Medical Systems, Iselin, NJ.

An illustration of the external surface of occipital bone (A) and the C T scan image of the atlantooccipital joint (B). The condylar canal and squama are labeled on the left. The foramen magnum, external occipital protuberance and occipital condyle are labeled on the right. The basilar portion is labeled at the bottom. In the scan image the atlantooccipital joint is labeled below the occipital condyle. The lateral mass C 1, and Odontoi process C2 are labeled.

The sphenoid bone articulates with each of the other seven bones of the cranium.

Occipital Bone

The *occipital bone* is situated at the posteroinferior part of the cranium. It forms the posterior half of the base of the cranium and the greater part of the posterior cranial fossa (Figs. 11.18–11.20). The occipital bone has four parts: the *squama*, which is saucer-shaped, being convex externally; *two occipital condyles*, which extend anteriorly, one on each side of the foramen magnum; and the *basilar portion*. The occipital bone also has a large aperture, the *foramen magnum*, through which the inferior portion of the medulla oblongata passes as it exits the cranial cavity and joins the spinal cord.

The *squama* curves posteriorly and superiorly from the foramen magnum and is curved from side to side. It articulates with the parietal bones at the lambdoidal sutures and with the mastoid portions of the temporal bones at the occipitomastoid sutures. On the external surface of the squama, midway between its summit and the foramen magnum, is a prominent process termed the *external occipital protuberance*, or *inion*, which corresponds in position with the *internal occipital protuberance*.

The *occipital condyles* project anteriorly, one from each side of the squama, for articulation with the atlas of the cervical spine. Part of each lateral portion curves medially to fuse with the basilar portion and complete the foramen magnum, and part of it projects laterally to form the jugular process. On the inferior surface of the curved parts, extending from the level of the middle of the foramen magnum anteriorly to the level of its anterior margin, reciprocally shaped condyles articulate with superior facets of the atlas. These articulations, known as the *occipitoatlantal joints*, are the only bony articulations between the skull and the neck. The *hypoglossal canals* are found at the anterior ends of the condyles and transmit the hypoglossal nerves. At the posterior end of the condyles are the *condylar canals*, through which the emissary veins pass. The anterior portion of the occipital bone contains a deep notch that forms a part of the *jugular foramen* (see Fig. 11.2B). The jugular foramen is an important large opening in the skull for two reasons: It allows blood to drain from the brain via the internal jugular vein, and it lets three cranial nerves pass through it.

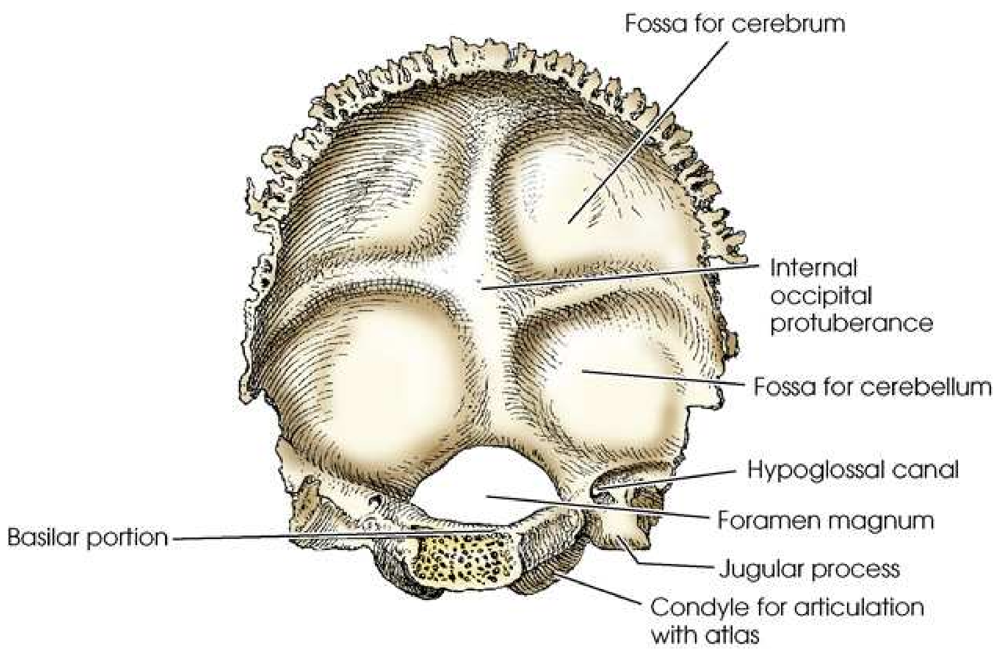


FIG. 11.19
INTERNAL SURFACE OF OCCIPITAL BONE.

The internal surface occipital bone with the parts labeled. It consists of the following parts: fossa for cerebrum on top, Internal occipital protuberance, Fossa for cerebellum, Foramen magnum, Jugular process, Condyle for articulation with atlas are labeled on the right. The basilar portion is at the bottom.

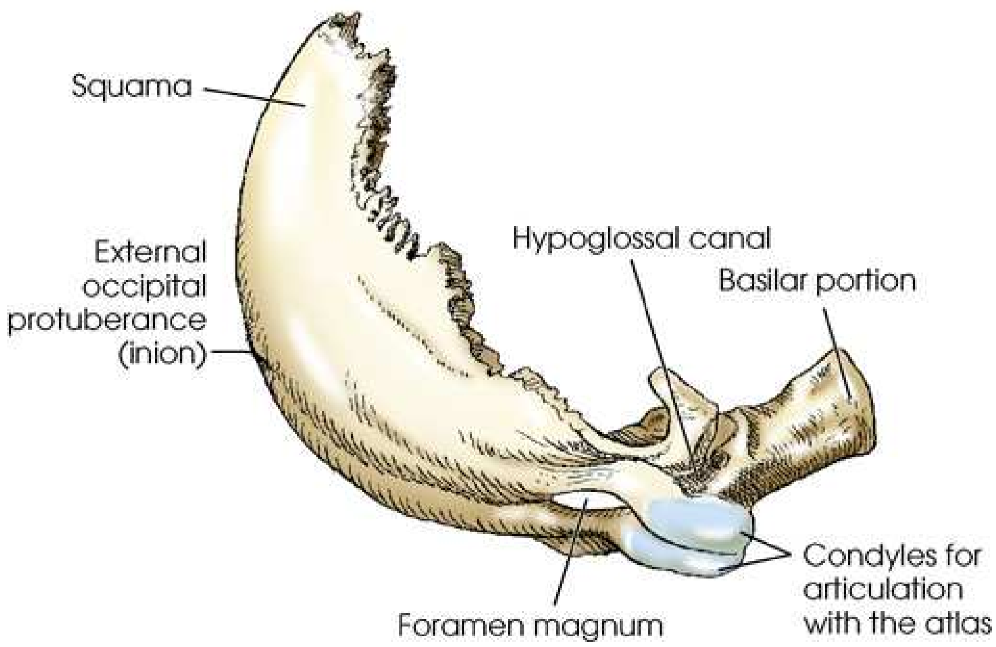


FIG. 11.20 Lateroinferior aspect of occipital bone.

The Lateroinferior view of the occipital bone. The squama and external occipital protuberance are on the left, the foramen magnum is at the bottom, the basilar portion, hypoglossal canal, and condyles for articulation with atlas are on the right.

The *basilar portion* of the occipital bone curves anteriorly and superiorly to its junction with the body of the sphenoid. In an adult, the basilar part of the occipital bone fuses with the body of the sphenoid bone, resulting in the formation of a continuous bone. The sloping surface of this junction between the dorsum sellae of the sphenoid bone and the basilar portion of the occipital bone is called the *clivus*.

The occipital bone articulates with the two parietals, the two temporal bones and the sphenoid of the cranium, and the first cervical vertebra.

Temporal Bones

The temporal bones are irregular in shape and are situated on each side of the base of the cranium between the greater wings of the sphenoid bone and the occipital bone (Figs. 11.21–11.25). The temporal bones form a large part of the middle fossa of the cranium and a small part of the posterior fossa. Each temporal bone consists of a squamous portion, a tympanic portion, a styloid process, a zygomatic process, and a petromastoid portion (the mastoid and petrous portions) that contains the organs of hearing and balance.

The *squamous portion* is the thin upper portion of the temporal bone. It forms a part of the side wall of the cranium and has a prominent arched process, the *zygomatic process*, which projects anteriorly to articulate with the zygomatic bone of the face and complete the zygomatic arch. On the inferior border of the zygomatic process is a rounded eminence, the *articular tubercle*, which forms the anterior boundary of the *mandibular fossa*. The mandibular fossa receives the condyle of the mandible to form the *temporomandibular joint* (TMJ).

The *tympanic portion* is situated below the squama and in front of the mastoid and petrous portions of the temporal bone. This portion forms the anterior wall, the inferior wall, and part of the posterior walls of the EAM. The EAM is approximately

½

inch (1.3 cm) in length and projects medially, anteriorly, and slightly superiorly.

The *styloid process*, a slender, pointed bone of variable length, projects inferiorly, anteriorly, and slightly medially from the inferior portion of the tympanic part of the temporal bone.

Petromastoid portion

The petrous and mastoid portions together are called the *petromastoid portion*. The mastoid portion, which forms the inferior, posterior part of the temporal bone, is prolonged into the conical *mastoid process* (see Figs. 11.23 and 11.25).

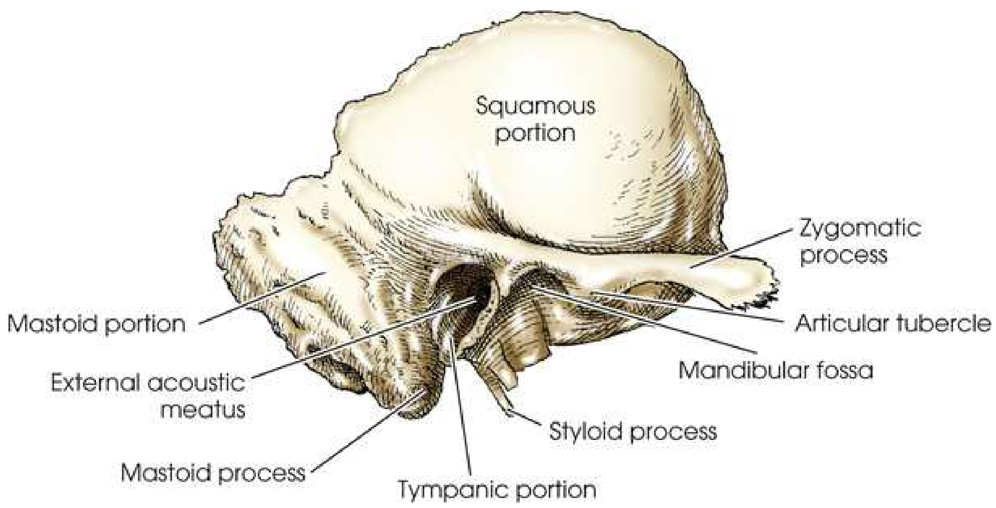


FIG. 11.21 Lateral aspect of temporal bone.

The lateral view of the temporal bone. The squamous portion takes up most of the upper part of the bone. The mastoid portion, External acoustic meatus, mastoid process are on the left. The tympanic portion, mandibular part, articular tubercle, styloid process, and auditory canal are on the right.

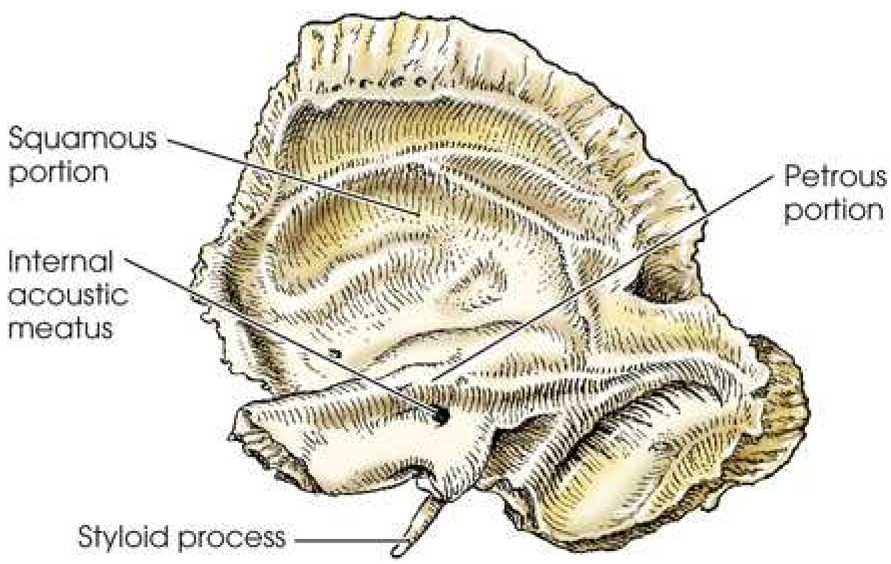


FIG. 11.22

INTERNAL SURFACE OF TEMPORAL BONE.

The *mastoid portion* articulates with the parietal bone at its superior border through the parietomastoid suture and with the occipital bone at its posterior border through the occipitomastoid suture, which is contiguous with the lambdoidal suture. The *mastoid process* varies considerably in size, depending on its pneumatization, and is larger in males than in females.

The first of the *mastoid air cells* to develop is situated at the upper anterior part of the process and is termed the *mastoid antrum*. This air cell is quite large and communicates with the tympanic cavity. Shortly before or after birth, smaller air cells begin to develop around the mastoid antrum and continue to increase in number and size until around puberty. The air cells vary considerably in size and number. Occasionally they are absent altogether, in which case the mastoid process is solid bone and is usually small.

The *petrous portion*, often called the *petrous pyramid*, is conical or pyramidal and is the thickest, densest bone in the cranium. This part of the temporal bone contains the organs of hearing and balance. From its base at the squamous and mastoid portions, the petrous portion projects medially and anteriorly between the greater wing of the sphenoid bone and the occipital bone to the body of the sphenoid bone, with which its apex articulates. The internal carotid artery in the *carotid canal* enters the inferior aspect of the petrous portion, passes superior to the cochlea, and then passes medially to exit the *petrous apex*. Near the petrous apex is a ragged foramen called the *foramen lacerum*. The carotid canal opens into this foramen, which contains the internal carotid artery (see Fig. 11.2B). At the center of the posterior aspect of the petrous portion is the *internal acoustic meatus* (IAM), which transmits the vestibulocochlear and facial nerves. The upper border of the petrous portion is commonly referred to as the *petrous ridge*. The top of the ridge lies approximately at the level of an external radiography landmark called the *top of ear attachment* (TEA).

The temporal bone articulates with the parietal, occipital, and sphenoid bones of the cranium.

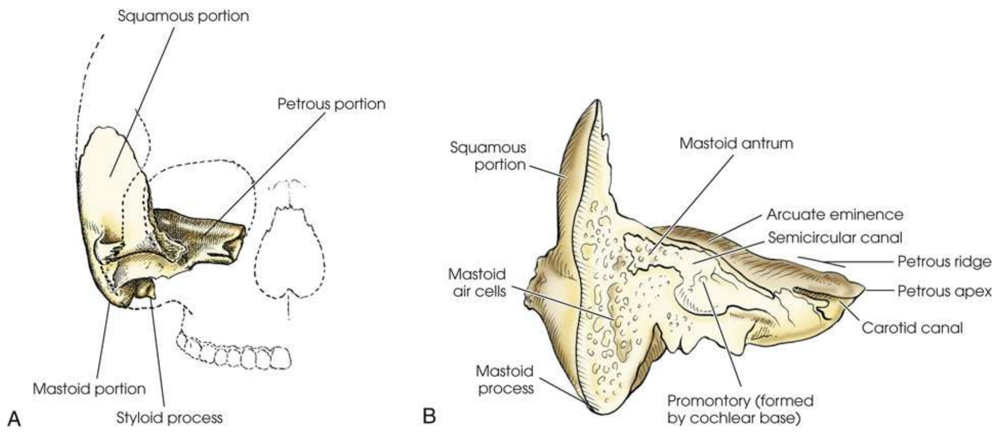


FIG. 11.23 (A) Anterior aspect of temporal bone in relation to surrounding structures. (B) Coronal section through mastoid and petrous portions of temporal bone.

The anterior (A) and coronal views of temporal bone (B). The anterior section consists of squamous portion, styloid process, and petrous portion. The coronal section consists of squamous portion, mastoid part, tympanic part, mandibular part, styloid process, and auditory canal.

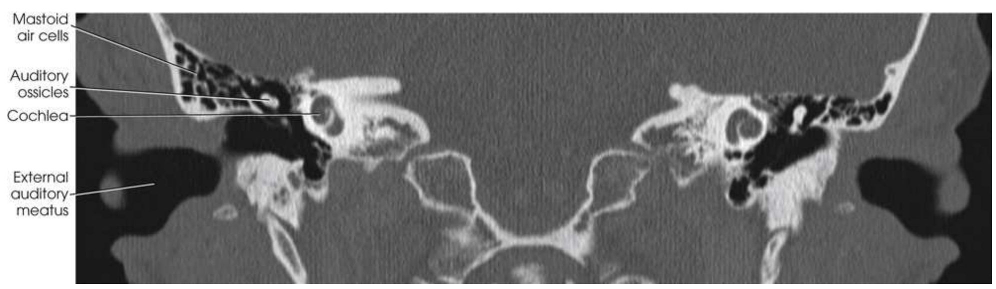


FIG. 11.24

CT SCAN THROUGH TEMPORAL BONES. **COURTESY KARL MOCKLER, RT[R].**

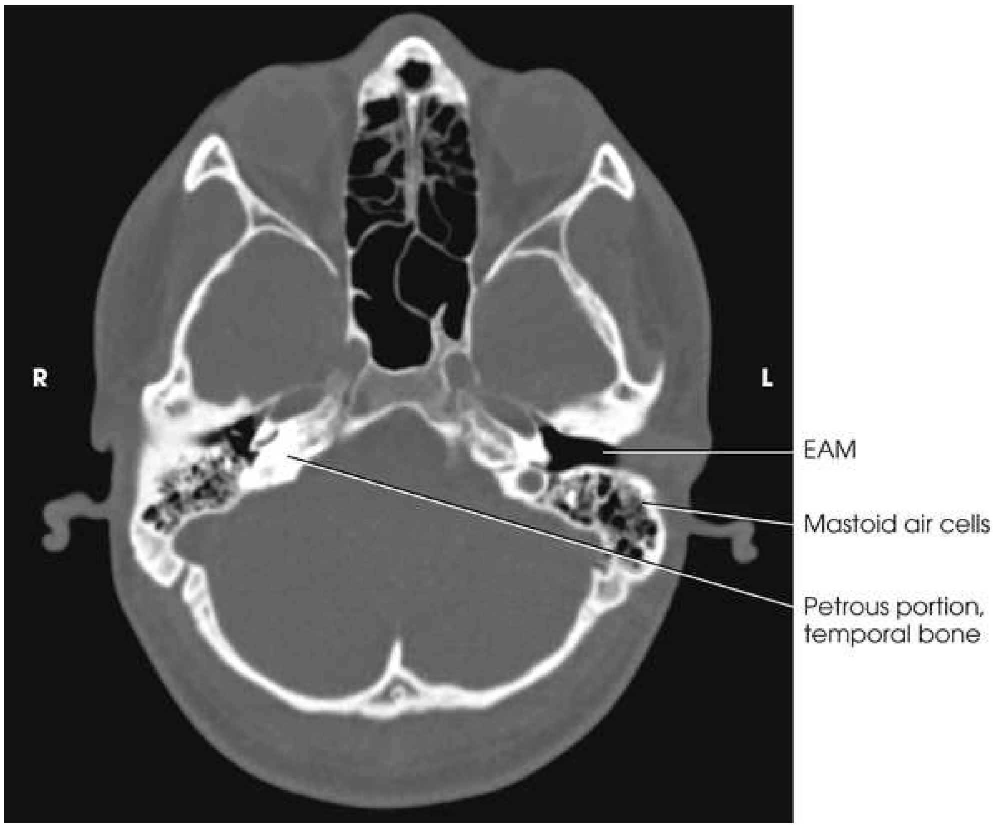


FIG. 11.25 Axial CT scan of petrous portion at level of external auditory meatus *(EAM)*. Courtesy Kylee Leath, RT[R][CT], NEA Baptist Memorial Hospital, Jonesboro, AR.

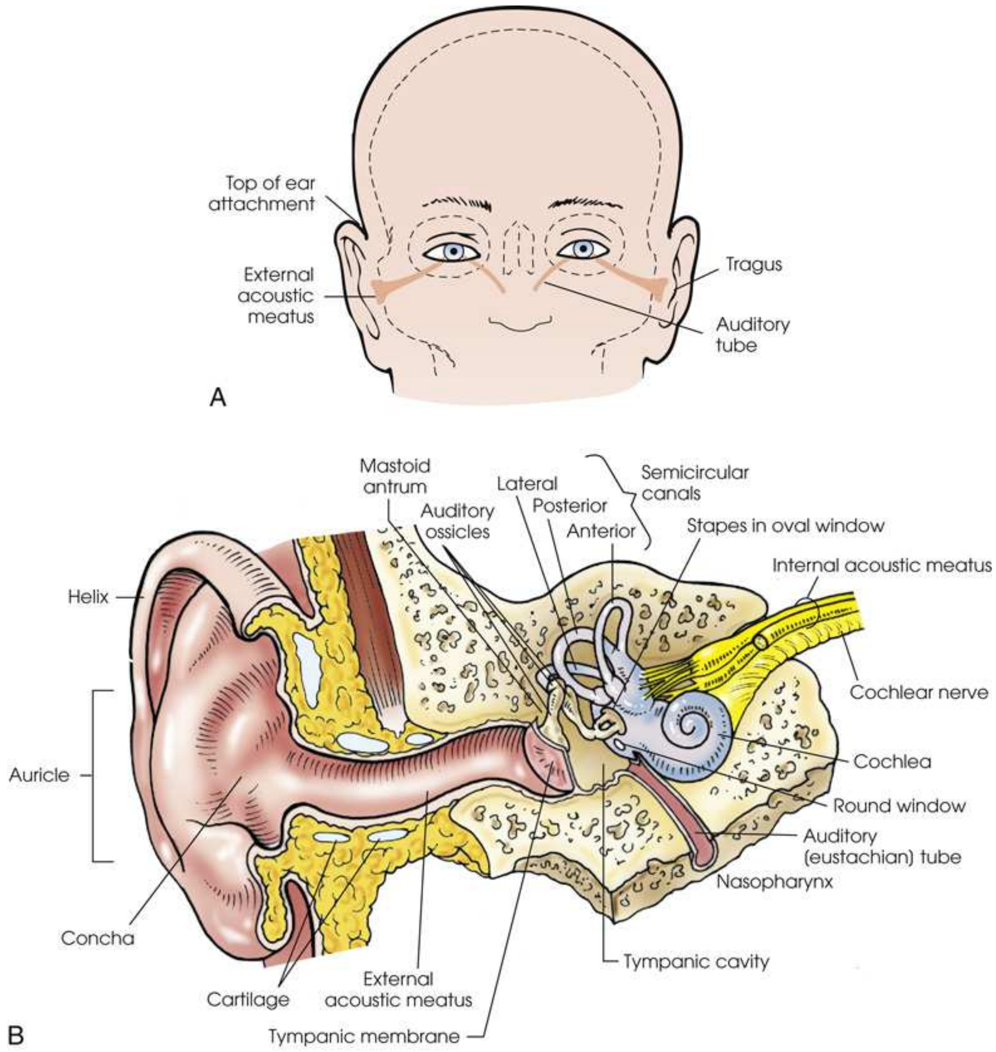


FIG. 11.26 (A) Frontal view of face showing internal structures of the ear *(shaded area)*. (B) External, middle, and internal ear.

A) In the anterior view the auditory tube and external acoustic meatus are connected. The top of ear attachment on the left and the tragus on the right are labeled. B) The external ear consists of the auricle and helix. It leads to the concha and cartilage. The internal ear consists of the ear canal, tympanic membrane, incus, stapes, malleus, cochlea, semicircular canals, vestibular and cochlear nerves.

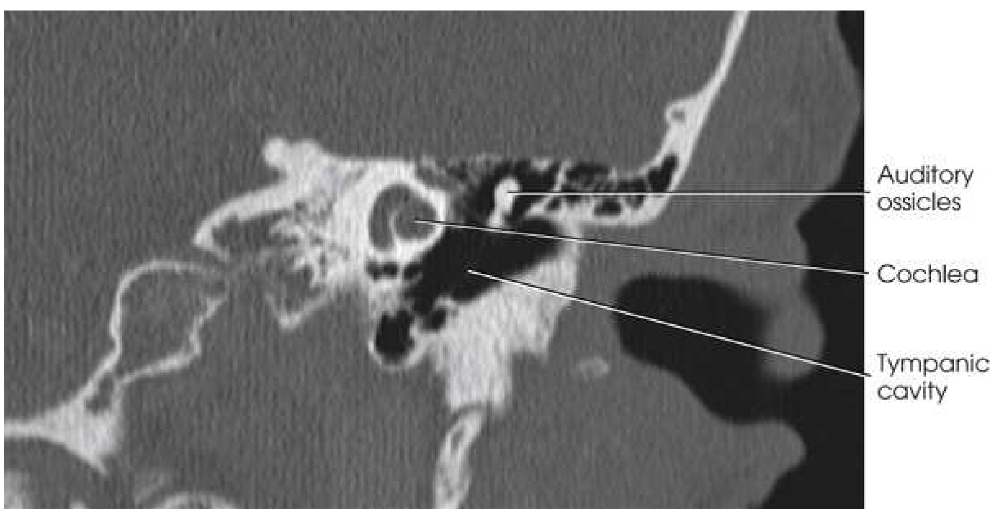


FIG. 11.27 Coronal CT scan through petrous portion of temporal bone showing middle and inner ear.
Courtesy Karl Mockler, RT[R].

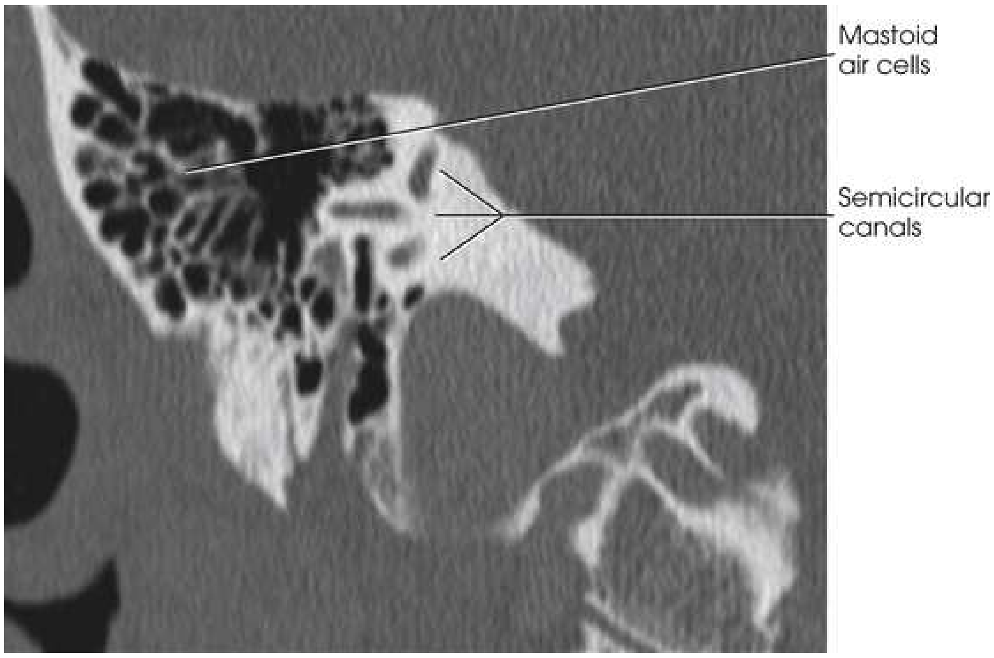


FIG. 11.28 Coronal CT scan of petromastoid portion of temporal bone showing semicircular canals and mastoid air cells. Courtesy Karl Mockler, RT[R].

Ear

The ear is the organ of hearing and balance (Fig. 11.26). The essential parts of the ear are housed in the petrous portion of the temporal bone. The organs of hearing and equilibrium consist of three main divisions: external ear, middle ear, and internal ear.

External Ear

The *external ear* consists of two parts: (1) the *auricle*, the oval-shaped, fibrocartilaginous, sound-collecting organ situated on the side of the head, and (2) the *EAM*, a sound-conducting canal. The superior attachment of the auricle is the TEA. The TEA is a reference point for positioning the lateral cervical spine. The auricle has a deep central depression, the *concha,* the lower part of which leads into the EAM. At its anterior margin, the auricle has a prominent cartilaginous lip, the *tragus*, which projects posteriorly over the entrance of the meatus. The outer rim of the ear is the *helix*. The EAM is about 1 inch (2.5 cm) long. The outer third of the canal wall is cartilaginous, and the inner two-thirds is osseous. From the meatal orifice, the canal forms a slight curve as it passes medially and anteriorly in line with the axis of the IAM. The EAM ends at the tympanic membrane of the middle ear.

Middle Ear

The *middle ear* is situated between the external ear and the internal ear. The middle ear proper consists of (1) the *tympanic membrane* (or eardrum); (2) an irregularly shaped, air-containing compartment called the *tympanic cavity*; and (3) three small bones called the *auditory ossicles* (see Figs. 11.25 and 11.26). The middle ear communicates with the mastoid antrum and auditory eustachian tube.

The *tympanic membrane* is a thin, concavoconvex, membranous disk with an elliptic shape. The disk, the convex surface of which is directed medially, is situated obliquely over the medial end of the EAM and serves as a partition between the external ear and the middle ear. The function of the tympanic membrane is the transmission of sound vibrations.

The *tympanic cavity* is a narrow, irregularly shaped chamber that lies just posterior and medial to the mandibular fossa. The cavity is separated from the external ear by the tympanic membrane and from the internal ear by the bony labyrinth. The tympanic cavity communicates with the nasopharynx through the *auditory (eustachian) tube*, a passage by which air pressure in the middle ear is equalized with the pressure in the outside air passages. The auditory tube is about 1

½

inches (3 cm) long. From its entrance into the tympanic cavity, the auditory tube passes medially and inferiorly to its orifice on the lateral wall of the nasopharynx.

The mastoid antrum is the large air cavity situated in the temporal bone above the mastoid air cells and immediately behind the posterior wall of the middle ear.

The *auditory ossicles,* named for their shape, are the *malleus* (hammer), *incus* (anvil), and *stapes* (stirrup). These three delicate bones are articulated to permit vibratory motion. They bridge the middle ear cavity for the transmission of sound vibrations from the tympanic membrane to the internal ear. The handle of the malleus (the outermost ossicle) is attached to the tympanic membrane, and its head articulates with the incus (the central ossicle). The head of the stapes (the innermost ossicle) articulates with the incus, and its base is fitted into the oval window of the inner ear.

Internal Ear

The *internal ear* contains the essential sensory apparatus of hearing and equilibrium, and lies on the densest portion of the petrous portion immediately below the arcuate eminence. Composed of an irregularly shaped bony chamber called the *bony labyrinth*, the internal ear is housed within the bony chamber and is an intercommunicating system of ducts and sacs known as the *membranous labyrinth*. The bony labyrinth consists of three distinctly shaped parts: (1) a spiral-coiled, tubular part called the *cochlea*, which communicates with the middle ear through the membranous covering of the *round window* (Fig. 11.27); (2) a small, ovoid central compartment behind the cochlea, known as the *vestibule*, which communicates with the middle ear via the *oval window*; and (3) three unequally sized *semicircular canals* that form right angles to one another and are called, according to their positions, the *anterior*, *posterior*, and *lateral semicircular canals* (Fig. 11.28). From its cranial orifice, the IAM passes inferiorly and laterally for a distance of about

½

inch (1.3 cm). Through this canal, the cochlear and vestibular nerves pass from their fibers in the respective parts of the membranous labyrinth to the brain. The cochlea is used for hearing, and the vestibule and semicircular canals are involved with equilibrium.

Facial Bones

Nasal Bones

The two small, thin *nasal bones* vary in size and shape in different individuals (Figs. 11.29 and 11.30). They form the superior bony wall (called the *bridge* of the nose) of the nasal cavity. The nasal bones articulate in the MSP, where at their posterosuperior surface they also articulate with the perpendicular plate of the ethmoid bone. They articulate with the frontal bone above and with the maxillae at the sides.

Lacrimal Bones

The two *lacrimal bones*, which are the smallest bones in the skull, are very thin and are situated at the anterior part of the medial wall of the orbits between the labyrinth of the ethmoid bone and the maxilla (see Figs. 11.29 and 11.30). Together with the maxillae, the lacrimal bones form the lacrimal fossae, which accommodate the lacrimal sacs. Each lacrimal bone contains a *lacrimal foramen* through which a tear duct passes. Each lacrimal bone articulates with the frontal and ethmoid cranial bones, and the maxilla and inferior nasal concha facial bones. The lacrimal bones can be seen on PA and lateral projections of the skull.

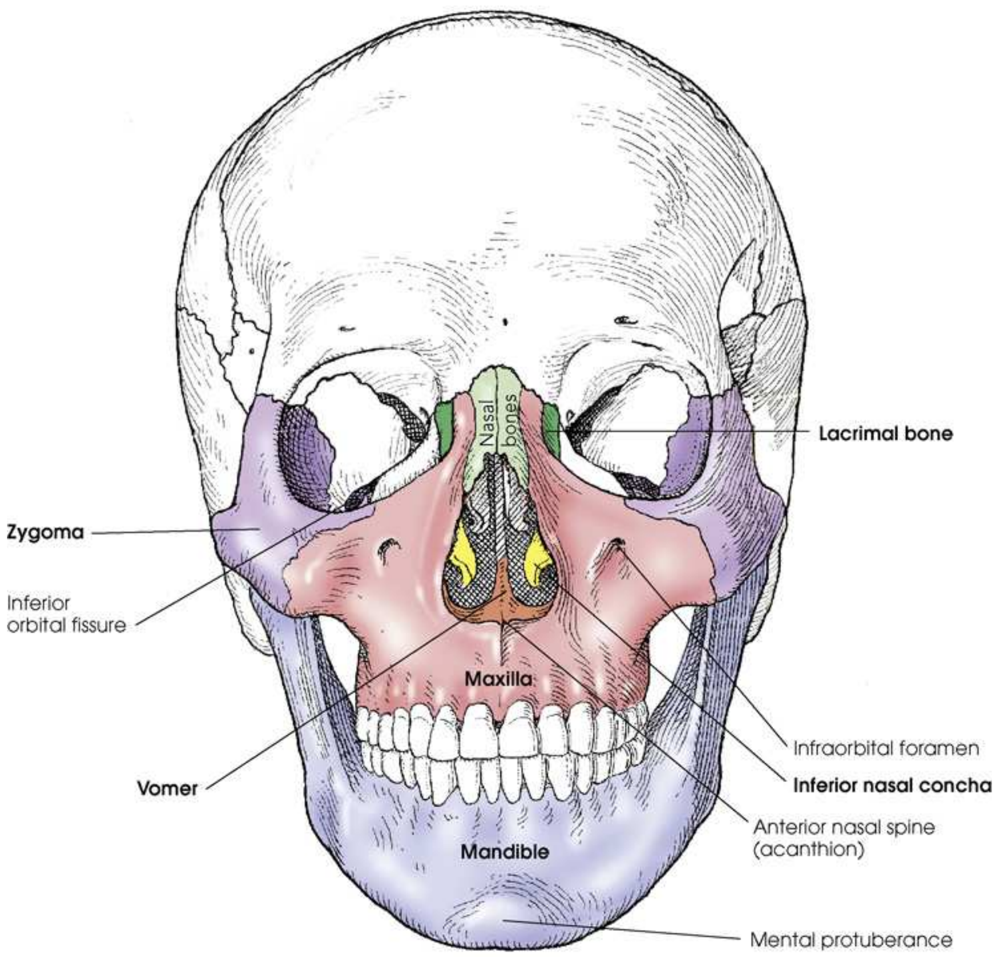


FIG. 11.29 Anterior aspect of skull showing facial bones.

The anterior view of the skull. The lacrimal bone, Anterior nasal spine [acanthion], Inferior nasal concha, and Infraorbital foramen are labeled on the right. The zygoma, inferior orbital fissure, and vomer are labeled on the left. The maxilla is below the nose and mandible is on the lower jaw..

Maxillary Bones

The two *maxillary bones* are the largest of the immovable bones of the face (see Figs. 11.29 and 11.30). Each articulates with all other facial bones except the mandible. Each also articulates with the frontal and ethmoid bones of the cranium. The maxillary bones form part of the lateral walls and most of the floor of the nasal cavity, part of the floor of the orbital cavities, and three-fourths of the roof of the mouth. Their zygomatic processes articulate with the zygomatic bones and assist in the formation of the prominence of the cheeks. The body of each maxilla contains a large, pyramidal cavity called the *maxillary sinus*, which empties into the nasal cavity. An *infraorbital foramen* is located under each orbit and serves as a passage through which the infraorbital nerve and artery reach the nose.

At their inferior borders, the maxillae possess a thick, spongy ridge called the *alveolar process*, which supports the roots of the teeth. In the anterior MSP at their junction with each other, the maxillary bones form a pointed, forward-projecting process called the *anterior nasal spine*. The midpoint of this prominence is called the *acanthion*.

Zygomatic Bones

The zygomatic bones form the prominence of the cheeks and a part of the side wall and floor of the orbital cavities (see Figs. 11.29 and 11.30). A posteriorly extending *temporal process* unites with the zygomatic process of the temporal bone to form the *zygomatic arch*. The zygomatic bones articulate with the frontal bone superiorly, with the zygomatic process of the temporal bone at the side, with the maxilla anteriorly, and with the sphenoid bone posteriorly.

Palatine Bones

The two palatine bones are L-shaped bones composed of *vertical* and *horizontal plates*. The horizontal plates articulate with the maxillae to complete the posterior fourth of the bony palate, or roof of the mouth (see Fig. 11.3). The vertical portions of the palatine bones extend upward between the maxillae and the pterygoid processes of the sphenoid bone in the posterior nasal cavity. The superior tips of the vertical portions of the palatine bones assist in forming the posteromedial bony orbit.

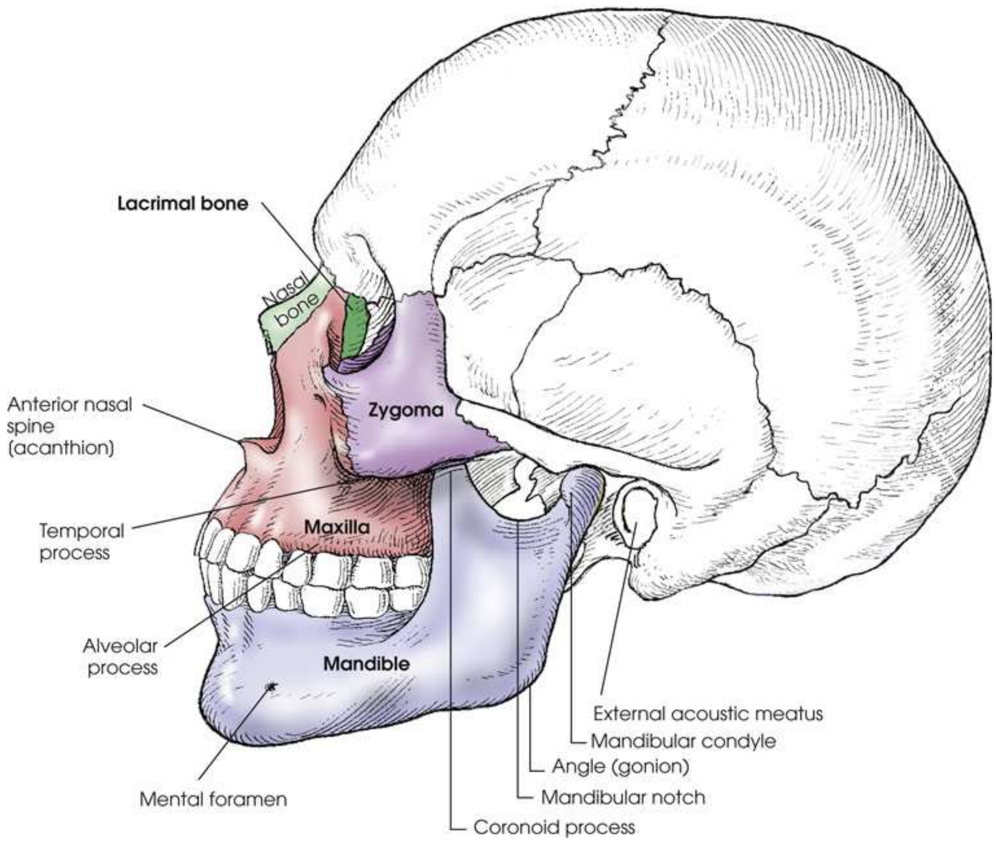


FIG. 11.30 Lateral aspect of skull showing facial bones.

A lateral view of the skull showing the following structures: lacrimal bone, maxilla, mandibular bone, anterior and posterior nasal spine, external acoustic meatus, angle (gonion), mandibular notch, mental foramen, and coronoid process.

Inferior Nasal Conchae

The inferior nasal conchae extend diagonally and inferiorly from the lateral walls of the nasal cavity at approximately its lower third (see Fig. 11.29). They are long, narrow, and extremely thin; they curl laterally, which gives them a scroll-like appearance.

The upper two nasal conchae are processes of the ethmoid bone. The three nasal conchae project into and divide the lateral portion of the respective sides of the nasal cavity into superior, middle, and inferior meatus. They are covered with a mucous membrane to warm, moisten, and cleanse inhaled air.

Vomer

The *vomer* is a thin plate of bone situated in the MSP of the floor of the nasal cavity, where it forms the inferior part of the *nasal septum* (see Fig. 11.29). The anterior border of the vomer slants superiorly and posteriorly from the anterior nasal spine to the body of the sphenoid bone, with which its superior border articulates. The superior part of its anterior border articulates with the perpendicular plate of the ethmoid bone; its posterior border is free.

Mandible

The *mandible*, the largest and densest bone of the face, consists of a curved horizontal portion, called the *body*, and two vertical portions, called the *rami*, which unite with the body at the *angle* of the mandible, or *gonion* (Fig. 11.31). At birth, the mandible consists of bilateral pieces held together by a fibrous symphysis that ossifies during the first year of life. At the site of ossification is a slight ridge that ends below in a triangular prominence, the *mental protuberance*. The *symphysis* is the most anterior and central part of the mandible. This is where the left and right halves of the mandible have fused.

The superior border of the body of the mandible consists of spongy bone, called the *alveolar portion*, which supports the roots of the teeth. Below the second premolar tooth, approximately halfway between the superior and inferior borders of the bone, is a small opening on each side for the transmission of nerves and blood vessels. These two openings are called the *mental foramina*.

The rami project superiorly at an obtuse angle to the body of the mandible, and their broad surface forms an angle of approximately 110 to 120 degrees. Each ramus presents two processes at its upper extremity—one coronoid and one condylar—which are separated by a concave area called the *mandibular notch*. The anterior process, the *coronoid process*, is thin, tapered, and projects to a higher level than the posterior process. The *condylar process* consists of a constricted area, the *neck*, above which is a broad, thick, almost transversely placed *condyle* that articulates with the mandibular fossa of the temporal bone (Fig. 11.32). This articulation, the TMJ, slants posteriorly approximately 15 degrees and inferiorly and medially approximately 15 degrees. Radiographic projections, produced from the opposite side, must reverse these directions. In other words, the central ray angulation must be superior and anterior to coincide with the long axis of the joint. The TMJ is situated immediately in front of the EAM.

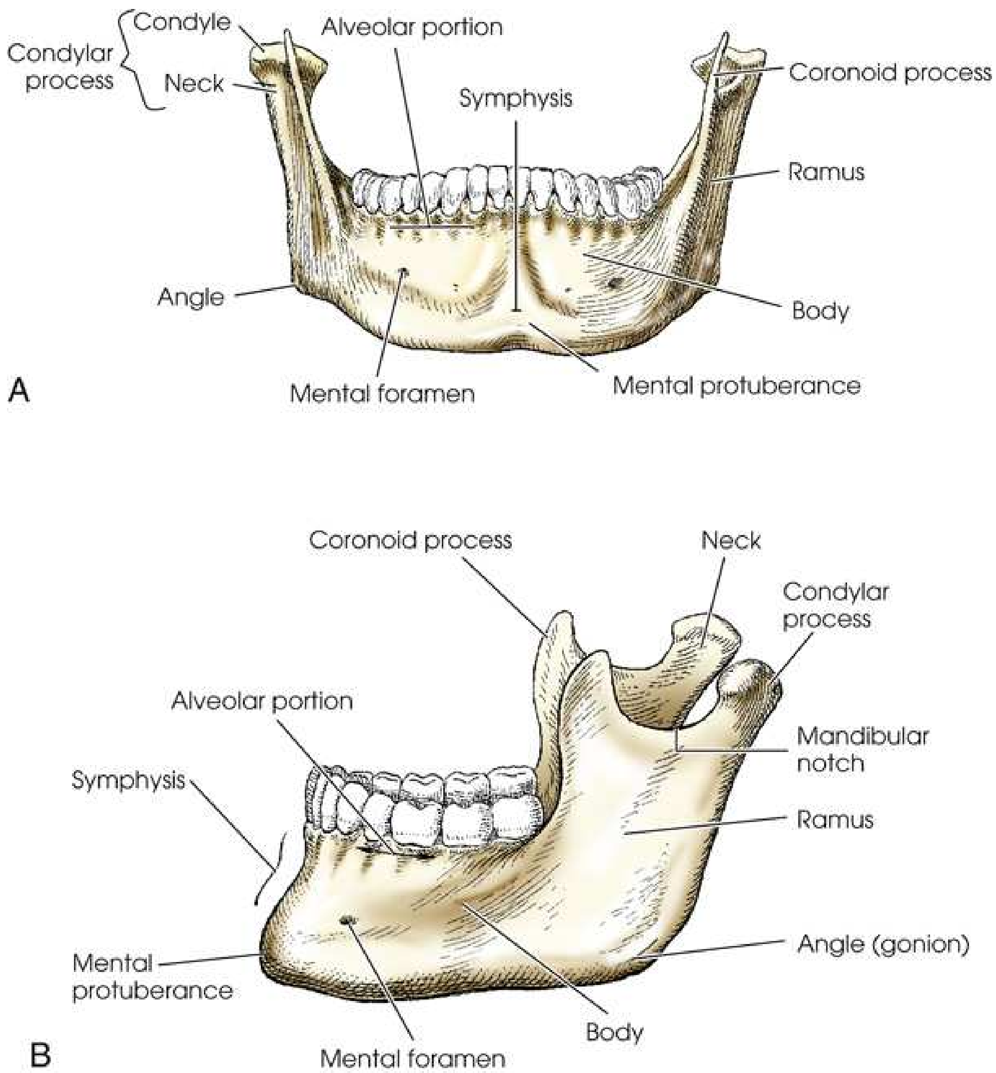


FIG. 11.31 (A) Anterior aspect of mandible. (B) Lateral aspect of mandible.

The anterior (A) and lateral aspects of the mandible (B). The Coronoid process, Ramus Body, Mental foramen, and Mental protuberance are labeled on the right. The angle and condylar process consisting of condyle and neck are labeled on the left. The Alveolar portion and Symphysis are at the center.

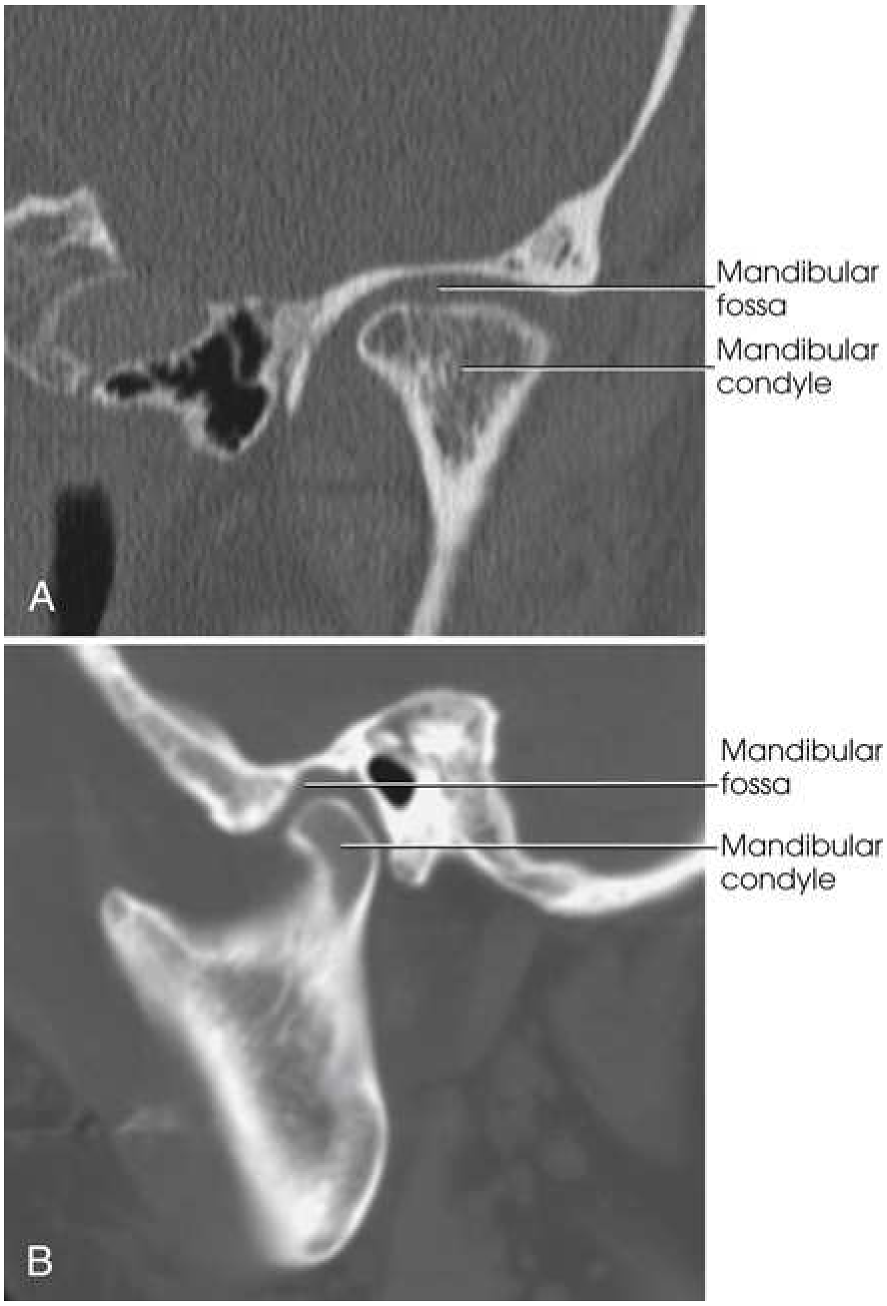


FIG. 11.32 CT scan of mandibular condyle situated in mandibular fossa. (A) Coronal. (B) Sagittal.
Courtesy Karl Mockler, RT[R].

Hyoid Bone

The *hyoid bone* is a small, U-shaped structure situated at the base of the tongue, where it is held in position in part by the stylohyoid ligaments extending from the styloid processes of the temporal bones (Fig. 11.33). Although the hyoid bone is an accessory bone of the axial skeleton, it is described in this chapter because of its connection with the temporal bones. The hyoid is the only bone in the body that does not articulate with any other bone.

The hyoid bone is divided into a *body*, two *greater cornua*, and two *lesser cornua*. The bone serves as an attachment for certain muscles of the larynx and tongue and is easily palpated just above the larynx.

TABLE 11.1

Joint	Structural Classification		Movement
	Tissue	Type	
Coronal suture	Fibrous	Suture	Immovable
Sagittal suture	Fibrous	Suture	Immovable
Lambdoidal suture	Fibrous	Suture	Immovable
Squamosal suture	Fibrous	Suture	Immovable
Temporomandibular	Synovial	Hinge and gliding	Freely movable
Alveolar sockets	Fibrous	Gomphosis	Immovable
Atlantooccipital	Synovial	Ellipsoidal	Freely movable

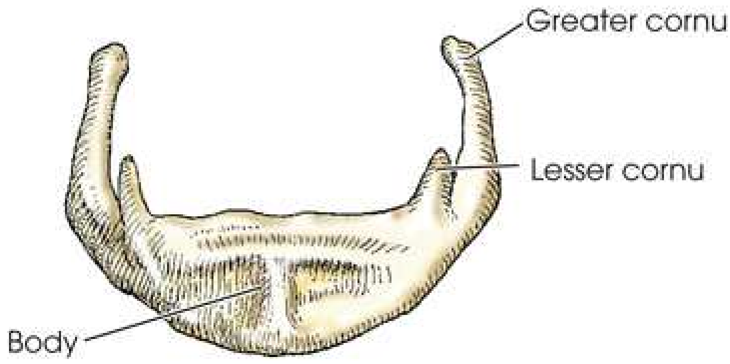


FIG. 11.33 Anterior aspect of hyoid.

Orbits

Each orbit is composed of *seven* different bones (Fig. 11.34). Three of these are cranial bones: *frontal*, *sphenoid*, and *ethmoid*. The other four bones are the facial bones: *maxilla*, *zygoma*, *lacrimal*, and *palatine*. The circumference of the orbit, or outer rim area, is composed of three of the seven bones—frontal, zygoma, and maxilla. The remaining four bones compose most of the posterior aspect of the orbit.

Articulations of the Skull

The sutures of the skull are connected by toothlike projections of bone interlocked with a thin layer of fibrous tissue. These articulations allow no movement and are classified as *fibrous* joints of the *suture* type. The articulations of the facial bones, including the joints between the roots of the teeth and the jawbones, are *fibrous gomphoses*. The exception is the point at which the rounded condyle of the mandible articulates with the mandibular fossa of the temporal bone to form the TMJ. The TMJ articulation is a *synovial* joint of the *hinge* and *gliding* type. The atlantooccipital joint is a *synovial ellipsoidal* joint that joins the base of the skull (occipital bone) with the atlas of the cervical spine. The seven joints of the skull are summarized in Table 11.1.

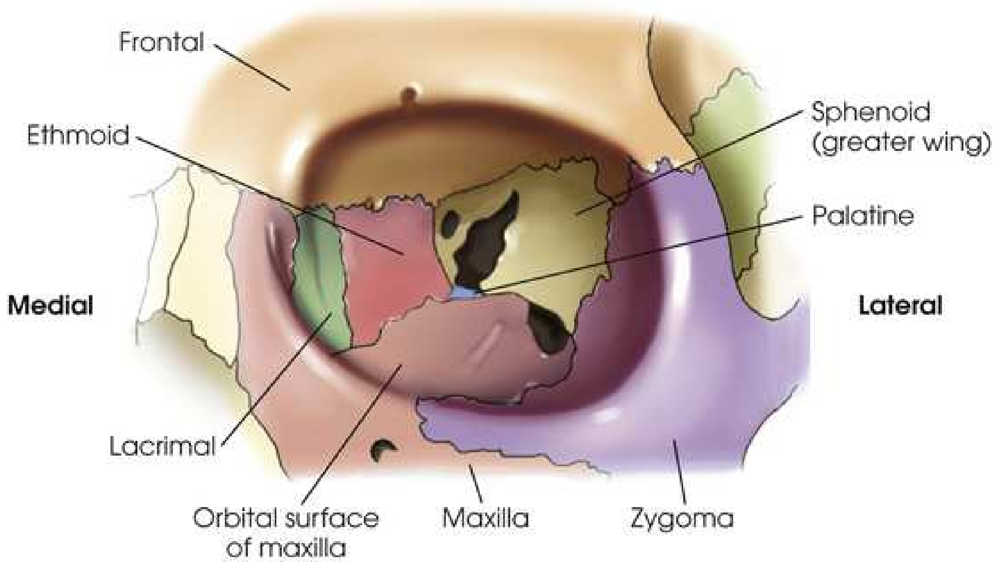


FIG. 11.34 Orbit. Seven bones of orbit are shown.

An illustration of the seven bones of the orbit. The bones are labeled from the top-left in clockwise direction as follows: frontal, ethmoid, lacrimal, maxilla, zygomatic, sphenoid of greater wing, orbital surface of maxilla.

Sinuses

The air-containing cavities situated in the frontal, ethmoidal, and sphenoidal bones of the cranium and the maxillary bones of the face are called the *paranasal sinuses* because of their formation from the nasal mucosa and their continued communication with the nasal fossae (Fig. 11.35). Although the functions of the sinuses are not agreed on by all anatomists, these cavities are believed to do the following:

- Serve as a resonating chamber for the voice
- Decrease the weight of the skull by containing air
- Help warm and moisten inhaled air
- Act as shock absorbers in trauma (as airbags do in automobiles)
- Possibly control the immune system

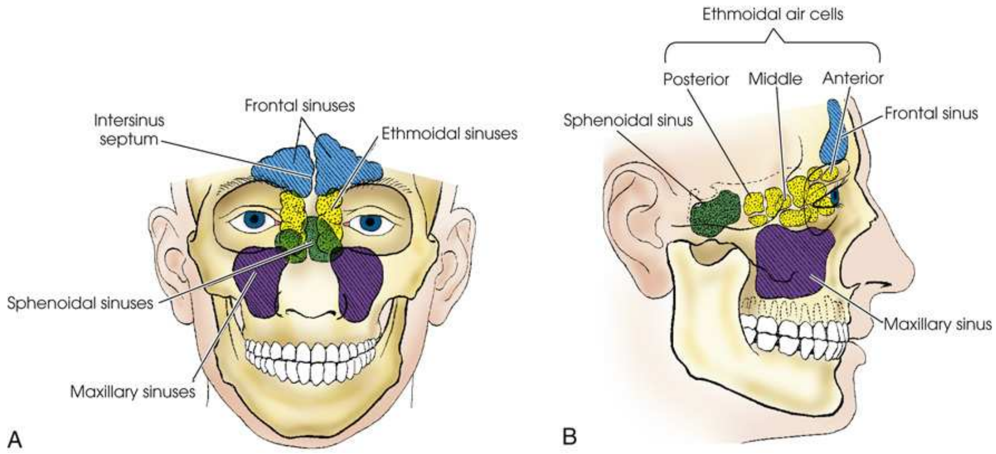


FIG. 11.35 (A) Anterior aspect of paranasal sinuses, showing lateral relationship to each other and to surrounding parts. (B) Schematic drawing of paranasal sinuses, showing AP relationship to each other and surrounding parts.

A) In the anterior view the intersinus septum, Frontal sinuses, and Ethmoidal sinuses are labeled on the forehead, the Sphenoidal sinuses are on the nose and Maxillary sinuses on the cheek bones. B) In the lateral view the Posterior, Middle, and Anterior ethmoid air cells are behind the eyes. The sphenoid sinuses lie behind them.

The sinuses begin to develop early in fetal life, at first appearing as small sacculations of the mucosa of the nasal meatus and recesses. As the pouches, or sacs, grow, they gradually invade the respective bones to form the air sinuses and cells. The maxillary sinuses are usually sufficiently well developed and aerated at birth, to be shown radiographically. The other groups of sinuses develop more slowly; by age 6 or 7 years, the frontal and sphenoidal sinuses are distinguishable from the ethmoidal air cells. The paranasal sinuses are not completely developed until the age of 17 or 18 years. When fully developed, each of the sinuses communicates with the others and with the nasal cavity.

An understanding of the actual size, shape, and position of the sinuses within the skull is made possible by studying the sinuses on computed tomography (CT) head images (Fig. 11.36).

Maxillary Sinuses

The largest sinuses, the maxillary sinuses, are paired and are located in the body of each maxilla (see Figs. 11.35 and 11.36). Although the maxillary sinuses appear rectangular in the lateral image, they are approximately pyramidal in shape and have only three walls. The apices are directed inferiorly and laterally. The two maxillary sinuses vary considerably in size and shape but are usually symmetric. In adults, each maxillary sinus is approximately 1½ inches (3.5 cm) high and 1 to 1⅓ inches (2.5 to 3.3 cm) wide. The sinus is often divided into subcompartments by partial septa, and occasionally it is divided into two sinuses by a complete septum. The sinus floor presents several elevations that correspond to the roots of the subjacent teeth. The maxillary sinuses communicate with the middle nasal meatus at the superior aspect of the sinus.

Frontal Sinuses

The frontal sinuses, the second largest sinuses, are paired and are normally located between the tables of the vertical plate of the frontal bone (see Figs. 11.35 and 11.36). The frontal sinuses vary greatly in size and form. Occasionally they are absent. One or both may be approximately ¾ to 1 inch (2 to 2.5 cm) in the vertical or lateral dimension. The sinuses often extend beyond the frontal region of the bone, most frequently into the orbital plates. The *intersinus septum* is usually deviated from the midline; for this reason, the frontal sinuses are rarely symmetric. Multiple septa are sometimes present. Similar to maxillary sinuses, the frontal sinuses drain into the middle nasal meatus.

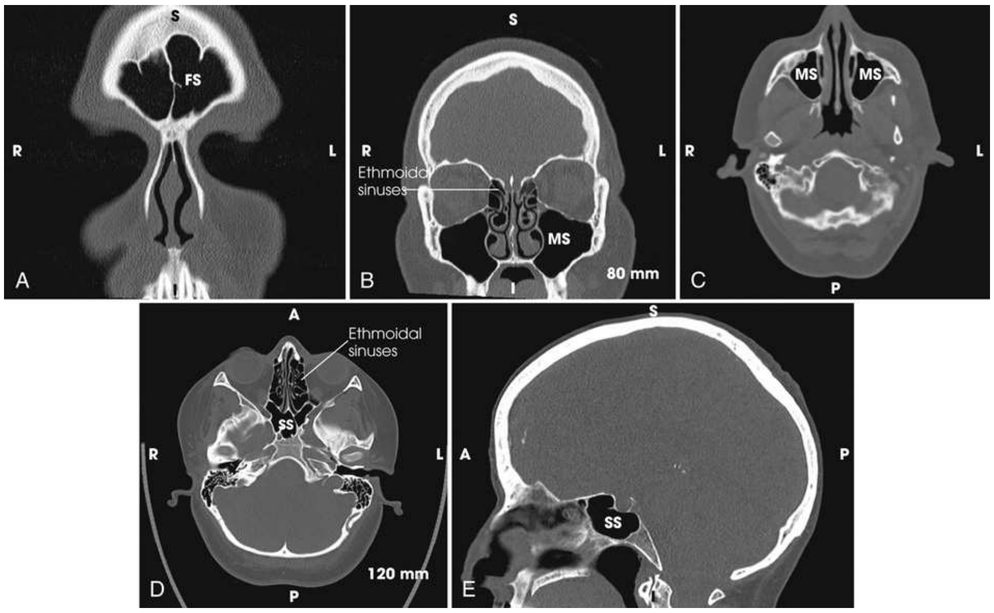


FIG. 11.36 (A) Coronal CT image of frontal sinuses (FS). (B) Coronal CT image of ethmoidal and maxillary sinuses *(MS)*. (C) Axial CT image of MS. (D) Axial CT image of ethmoidal and sphenoid sinuses *(SS)*. (E) Sagittal CT image of SS. Courtesy NEA Baptist Memorial Hospital, Jonesboro, AR.

Five C T scan images depict (from top-left in clockwise) the coronal view of frontal sinuses, Coronal view of ethmoidal and maxillary sinuses, Axial image of M S, Axial view of ethmoidal and sphenoid sinuses, and sagittal view of sphenoid sinuses.

Ethmoidal Sinuses

The two ethmoidal sinuses are located within the lateral masses of the labyrinths of the ethmoid bone. They are composed of a varying number of air cells that are divided into three main groups: anterior, middle, and posterior (see Figs. 11.35 and 11.36). The anterior and middle ethmoidal cells range in number from two to eight, and each group opens into the middle nasal meatus. The posterior cells range in number from two to six or more and drain into the superior nasal meatus.

Sphenoidal Sinuses

The sphenoidal sinuses are normally paired and occupy the body of the sphenoid bone (see Figs. 11.35 and 11.36). Anatomists state that often only one sphenoidal sinus is present; however, more than two sphenoidal sinuses are never present. The sphenoidal sinuses vary considerably in size and shape and are usually asymmetric. They lie immediately below the sella turcica and extend between the dorsum sellae and the posterior ethmoidal air cells. The sphenoidal sinuses open into the sphenoethmoidal recess of the nasal cavity.

Skull	Fossae	Sphenoid bone	Occipital bone
• **Cranial bones (8)**	• Anterior cranial fossa	• Body	• Foramen magnum
• **Facial bones (14)**	• Middle cranial fossa	• Sphenoidal sinuses	• Squama
Cranial bones	• Posterior cranial fossa	• Sella turcica	• External occipital protuberance (inion)
• **Calvaria**	Frontal bone	• Tuberculum sellae	• Internal occipital protuberance
• **Frontal**	• Frontal squama	• Dorsum sellae	• Occipital condyles
• **Right parietal**	• Frontal eminence	• Posterior clinoid processes	• Hypoglossal canals
• **Left parietal**	• Supraorbital margins	• Clivus	• Condylar canals
• **Occipital**	• Superciliary arches	• Carotid sulcus	• Jugular foramen
• **Floor**	• Supraorbital foramen	• Optic groove	• Basilar portion
• **Right temporal**	• Glabella	• Optic canals	Temporal bones (R & L)
• **Left temporal**	• Frontal sinuses	• Optic foramen	• Squamous portions
• **Sphenoid**	• Nasion	• Lesser wings	• Zygomatic process
• **Ethmoid**	• Orbital plates	• Superior orbital fissures	• Articular tubercle
• **Diploë**	• Ethmoidal notch	• Anterior clinoid processes	• Mandibular fossa
Sutures	• Nasal spine	• Sphenoid strut	• Tympanic portions
• **Coronal suture**	Ethmoid bone	• Greater wings	• External acoustic meatus (EAM)
• **Sagittal suture**	• Cribriform plate	• Foramen rotundum	• Styloid process
• **Squamosal sutures**	• Crista galli	• Foramen ovale	• Petromastoid portions
• **Lambdoidal suture**	• Perpendicular plate	• Foramen spinosum	• Mastoid portions
• **Bregma**	• Labyrinths	• Pterygoid processes	• Mastoid process
• **Lambda**	• Anterior air cells	• Medial pterygoid lamina	• Mastoid antrum
• **Pterion**	• Middle air cells	• Lateral pterygoid lamina	• Mastoid air cells
• **Asterion**	• Posterior air cells	• Pterygoid hamulus	• Petrous portions (petrous pyramids)
Fontanels	• Ethmoidal sinuses		• Carotid canals
• **Anterior fontanel**	• Superior nasal conchae		• Petrous apex
• **Posterior fontanel**	• Middle nasal conchae		• Foramen lacerum
• **Sphenoidal fontanels (2)**	Parietal bones (R & L)		• Internal acoustic meatus (IAM)
• **Mastoid fontanels (2)**	• Parietal eminence		• Petrous ridge
			• Top of ear attachment (TEA)

Table Continued

Skull	Fossae	Sphenoid bone	Occipital bone
Ear	Facial bones (14)	Inferior nasal conchae (R & L)	**Articulations**
• **External ear**	• Nasal (R & L)	• ***Vomer (1)***	• Coronal suture
• **Auricle**	• Lacrimal (R & L)	• Nasal septum	• Sagittal suture
• **Concha**	• Maxillary (R & L)	***Mandible (1)***	• Lambdoidal sutures
• **Tragus**	• Zygomatic (R & L)	• Body	• Squamosal sutures
• **Helix**	• Palatine (R & L)	• Alveolar portion	• Temporomandibular (TMJ)
• **EAM**	• Inferior nasal conchae (R & L)	• Mental foramina	• Alveolar sockets
• **Middle ear**	• Vomer (1)	• Angle (gonion)	• Atlantooccipital
• **Tympanic membrane**	• Mandible (1)	• Rami	Morphology
• **Tympanic cavity**	• Hyoid bone	• Coronoid process	• Mesocephalic
• **Auditory (eustachian) tube**	• Diploë	• Condylar process	• Brachycephalic
• **Auditory ossicles**	Lacrimal bones (R & L)	• Condyle	• Dolichocephalic
• **Malleus**	• Lacrimal foramen	• Neck	Orbit
• **Incus**	Maxillary bones (R & L)	• Temporomandibular joint (TMJ)	• Base
• **Stapes**	• Maxillary sinuses	• Mandibular notch	• Apex
• **Internal ear**	• Infraorbital foramen	• Mental protuberance (mentum)	• Optic foramen
• **Arcuate eminence**	• Alveolar process	• Symphysis	• Superior orbital fissures
• **Bony labyrinth**	• Anterior nasal spine	Hyoid bone	• Inferior orbital fissures
• **Cochlea**	• Acanthion	• Body	Eye
• **Round window**	Zygomatic bones (R & L)	• Greater cornua	• Eyeball
• **Vestibule**	• Temporal process	• Lesser cornua	• Conjunctiva
• **Oval window**	• Zygomatic arch	Paranasal sinuses	• Sclera
• **Semicircular canals**	Palatine bones (R & L)	• Maxillary sinuses	• Cornea
• **Anterior**	• Vertical plates	• Frontal sinuses	• Retina
• **Posterior**	• Horizontal plates	• Intersinus septum	• Rods
• **Lateral**		• Ethmoidal sinuses	• Cones
• **Membranous labyrinth**		• Anterior ethmoidal cells	
		• Middle ethmoidal cells	
		• Posterior ethmoidal cells	
		• Sphenoidal sinuses	

Condition	Definition
Fracture	Disruption in continuity of bone
Basal	Fracture located at the base of the skull
Blowout	Fracture of the floor of the orbit
Contrecoup	Fracture to one side of a structure caused by trauma to the other side
Depressed	Fracture causing a portion of the skull to be pushed into the cranial cavity
Le Fort	Bilateral horizontal fractures of the maxillae
Linear	Irregular or jagged fracture of the skull
Tripod	Fracture of the zygomatic arch and orbital floor or rim and dislocation of the frontozygomatic suture
Mastoiditis	Inflammation of the mastoid antrum and air cells
Metastasis	Transfer of cancerous lesion from one area to another
Osteomyelitis	Inflammation of bone due to a pyogenic infection
Osteopetrosis	Increased density of atypically soft bone
Osteoporosis	Loss of bone density
Paget disease	Thick, soft bone marked by bowing and fractures
Polyp	Growth or mass protruding from a mucous membrane
Sinusitis	Inflammation of one or more of the paranasal sinuses
TMJ syndrome	Dysfunction of temporomandibular joint (TMJ)
Tumor	New tissue growth where cell proliferation is uncontrolled
Acoustic neuroma	Benign tumor arising from Schwann cells of eighth cranial nerve (also termed "schwannoma")
Multiple myeloma	Malignant neoplasm of plasma cells involving the bone marrow and causing destruction of the bone
Osteoma	Tumor composed of bony tissue
Pituitary adenoma •	Tumor arising from the pituitary gland, usually in the anterior lobe

Eponymous (named) pathologies are listed in nonpossessive form to conform to the *AMA manual of style: a guide for authors and editors*. 10th ed. Oxford: Oxford University Press; 2009.

These techniques were accurate for the equipment used to produce each exposure. However, use caution when applying them in your department because "there is considerable variability in image receptor response owing to varying scatter sensitivity, the use of grids with different grid ratios, collimation, beam filtration, the choice of kilovoltage, source-to-image distance, and image receptor size."[a]

CRANIUM

Part	cm	kVp[b]	SID[c]	Collimation	CR[d] mAs	CR[d] Dose (mGy)[f]	DR[e] mAs	DR[e] Dose (mGy)[f]
Skull								
Lateral[g]	15	85	40″	11″ × 9″ (28 × 23 cm)	6.3[h]	0.794	3.2[h]	0.399
PA[g]	20	85	40″	8″ × 10″ (20 × 25 cm)	12.5[h]	1.781	6.3[h]	0.891
PA axial (Caldwell)[g]	20	85	40″	8″ × 11″ (20 × 28 cm)	14[h]	2.008	7.1[h]	1.014
AP[g]	20	85	40″	8″ × 10″ (20 × 25 cm)	12[h]	1.781	6.3[h]	0.893
AP axial[g]	20	85	40″	8″ × 11″ (20 × 28 cm)	14[h]	2.005	7.1[h]	1.014
AP axial (Towne)[g]	22	85	40″	8.5″ × 12″ (21.3 × 30 cm)	20[i]	3.030	10[i,j]	1.507
PA axial (Haas)[g]	21	85	40″	8.5″ × 12″ (21.3 × 30 cm)	20[i]	2.950	10[i]	1.467
Cranial base								
SMV[g]	23	85	40″	8″ × 11″ (20 × 28 cm)	28[i]	4.330	14[i]	2.169
Facial bones								
Lateral[g]	15	80	40″	7″ × 7″ (18 × 18 cm)	6.3[h]	0.701	3.2[h]	0.354
Parietoacanthial (Waters)[g]	24	85	40″	7.5″ × 8″ (18.8 × 20 cm)	16[h]	2.470	8[h]	1.231
Acanthioparietal (reverse Waters)[g]	24	85	40″	7.5″ × 8″ (18.8 × 20 cm)	16[h]	2.470	8[h]	1.231
PA axial (Caldwell)[g]	20	85	40″	7.5″ × 8″ (18.8 × 20 cm)	14[h]	1.958	7.1[h]	0.988
Nasal bones								
Lateral[j]	6	70	40″	3″ × 5″ (8 × 13 cm)	5.0[h]	0.282	2.5[h]	1.408
Zygomatic arches								
SMV[g]	23	80	40″	8″ × 5″ (20 × 13 cm)	16[i]	2.094	8[i]	1.041
Tangential[g]	20	80	40″	3″ × 5″ (8 × 13 cm)	14[i]	1.294	7.1[i]	0.653
AP axial[g]	17	80	40″	8.5″ × 7″ (21.3 × 18 cm)	20[i]	2.270	6.3[i]	1.126
Mandibular rami								
PA[g]	17	80	40″	8″ × 5″ (20 × 13 cm)	12.5[h]	1.367	6.3[h]	0.686
PA axial[g]	17	80	40″	8″ × 5″ (20 ×13 cm)	14[h]	1.532	7[h]	0.773
Mandible								
Axiolateral oblique[g]	13	80	40″	8″ × 6″ (20 × 15 cm)	12.5[h]	1.266	6.3[h]	0.635
TMJ								
AP axial[g]	21	80	40″	8.5″ × 7″ (21.3 × 18 cm)	20[h]	2.480	10[h]	1.233
Axiolateral oblique[g]	15	80	40″	4″ × 4″ (10 × 10 cm)	16[i]	1.501	8[i]	0.748
Paranasal sinuses								
Lateral[g]	15	85	40″	6″ × 6″ (15 × 15 cm)	6.3[h]	0.721	3.2[h]	0.363
Frontal and anterior ethmoidal sinuses								
PA axial (Caldwell)[g]	20	85	40″	6″ × 6″ (15 × 15 cm)	14[h]	1.807	7.1[h]	0.912
Maxillary sinuses								
Parietoacanthial (Waters)[g]	24	85	40″	6″ × 6″ (15 × 15 cm)	16[h]	2.280	8[h]	1.133
Maxillary and sphenoidal sinuses								
Parietoacanthial (open-mouth Waters)[g]	24	85	40″	6″ × 6.5″ (15 × 16.3 cm)	14[h]	2.003	7.1[h]	1.011
Ethmoidal and sphenoidal sinuses								
SMV[g]	23	85	40″	6.5″ × 6.5″ (16.3 × 16. 3 cm)	28[i]	3.900	14[i]	1.948

This chart was created in collaboration with Dennis Bowman, AS, RT(R), Clinical Instructor, Community Hospital of the Monterey Peninsula, Monterey, CA. http://digitalradiographysolutions.com/.

[a] ACR-AAPM-SIMM Practice Parameter for Digital Radiography, revised 2017.

[b] kVp values are for a high-frequency generator.

[c] 40 inches minimum; 44 to 48 inches recommended to improve spatial resolution (mAs increase needed, but no increase in patient dose will result).

[d] AGFA CR MD 4.0 General IP, CR 75.0 reader, 400 speed class, with 6:1 (178LPI) grid when needed.

[e] GE Definium 8000, with 13:1 grid when needed.

[f] All doses are skin entrance for an average adult (160- to 200-pound male, 150- to 190-pound female) at part thickness indicated.

[g] Bucky/Grid.

[h] Small focal spot.

[i] Large focal spot.

[j] Nongrid.

Abbreviations Used in Chapter 11

AML	Acanthiomeatal line
EAM	External acoustic meatus
GML	Glabellomeatal line
IAM	Internal acoustic meatus
IOML	Infraorbitomeatal line
IPL	Interpupillary line
MML	Mentomeatal line
OID	Object-to-IR distance
OML	Orbitomeatal line
TEA	Top of ear attachment
TMJ	Temporomandibular joint

See Addendum B for a summary of all abbreviations used in Volume 2.

Skull Radiography

Skull Topography

The basic localization points and planes of the skull (all of which can be seen or palpated) used in radiographic positioning are illustrated in Figs. 11.37 and 11.38.

Accurate positioning of the skull requires a full understanding of these landmarks, *which should be studied thoroughly before positioning of the skull is learned.* The planes, points, lines, and abbreviations most frequently used in skull positioning are as follows:

- Midsagittal plane (MSP)
- Interpupillary line (IPL)
- Acanthion
- Outer canthus
- Infraorbital margin
- EAM
- Orbitomeatal line (OML)
- Infraorbitomeatal line (IOML)
- Acanthiomeatal line (AML)
- Mentomeatal line (MML)

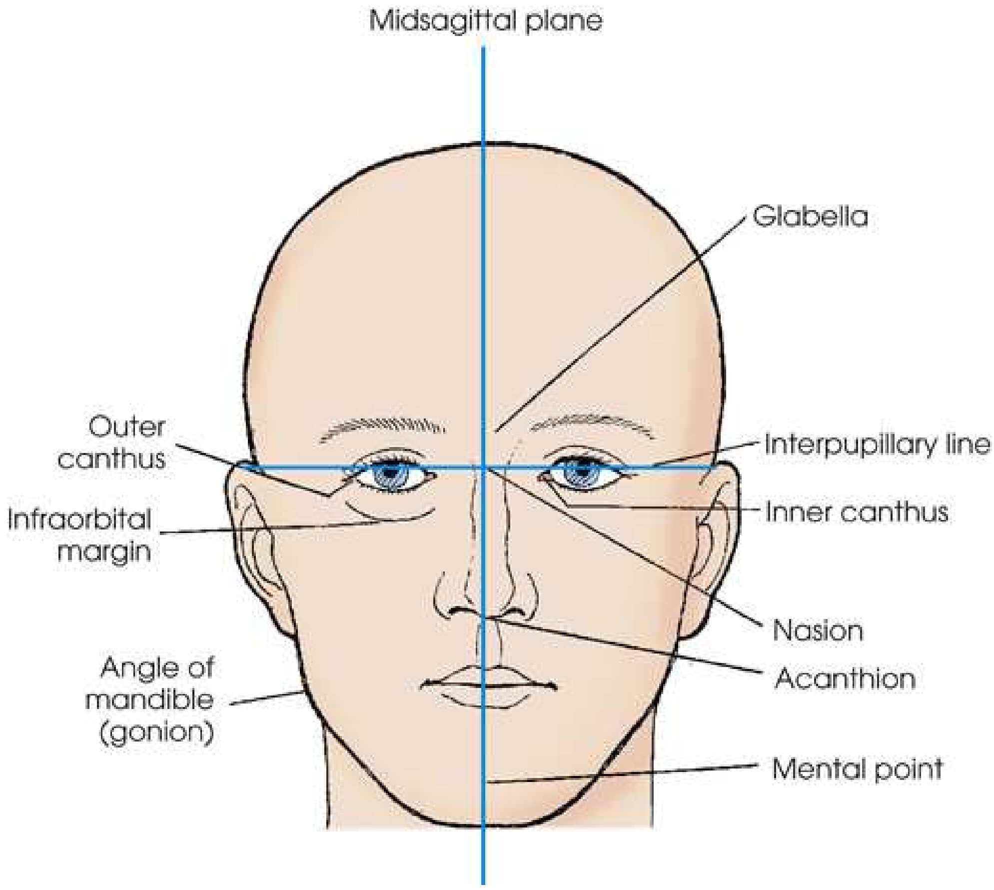


FIG. 11.37 Anterior landmarks.

The anterior view of the face consists of the inner and outer canthus around the eyes, angle of mandible on the lower jaw, glabella, and acanthion. The median sagital plane is a vertical line that divides the face into equal halves. The interpupilary line is a horizontal line drawn through the pupils. They intersect at the nasion.

In an adult, an average 7-degree angle difference exists between the OML and the IOML, and an average 8-degree angle difference exists between the OML and the glabellomeatal line. The degree difference between the cranial positioning lines must be recognized. Often the relationship of the patient, image receptor (IR), and central ray is the same, but the angle that is described may vary depending on the cranial line of reference.

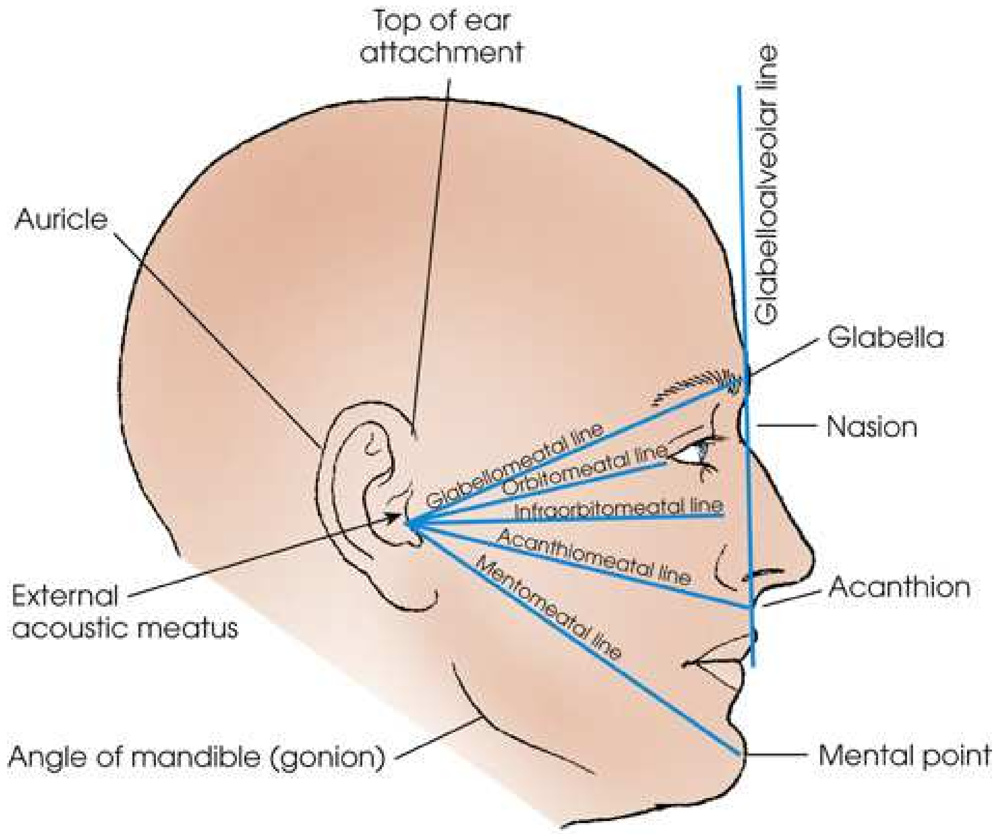


FIG. 11.38 Lateral landmarks.

The lateral view of the face showing the external acoustic meatus, auricle, glabella, acanthion, nasion, the glabellomeatal, orbitomeatal, acanthiomeatal, and mentomeatal lines are drawn from the meatus in the ear.

Skull Morphology

All radiographic images of the skull are based on the normal size and shape of the cranium. Rules have been established for centering and adjustment of localization points and planes and for the exact degree of central ray angulation for each projection. Although the heads of many patients fall within the limits of normality and can be radiographed satisfactorily using established positions, numerous skulls vary enough in shape that the standard procedure must be adjusted to obtain an undistorted image.

In the typically shaped head (Fig. 11.39), the petrous pyramids project anteriorly and medially at an angle of 47 degrees from the MSP of the skull. The superior borders of these structures are situated in the base of the cranium.

Depending on its shape, the atypical cranium requires more or less rotation of the head or an increase or decrease in angulation of the central ray compared with the typical, or *mesocephalic*, skull (see Fig. 11.39). In the *brachycephalic* skull (Fig. 11.40), which is short from front to back, broad from side to side, and shallow from vertex to base, the internal structures are higher with reference to the IOML, and their long axes are more frontal in position (i.e., the petrous pyramids form a wider angle with the MSP). The petrous pyramids lie at an average angle of 54 degrees. In the *dolichocephalic* skull (Fig. 11.41), which is long from front to back, narrow from side to side, and deep from vertex to base, the internal structures are lower with reference to the IOML, and their long axes are less frontal in position (i.e., the petrous pyramids form a narrower angle with the MSP). The petrous pyramids form an average angle of 40 degrees in the dolichocephalic skull.

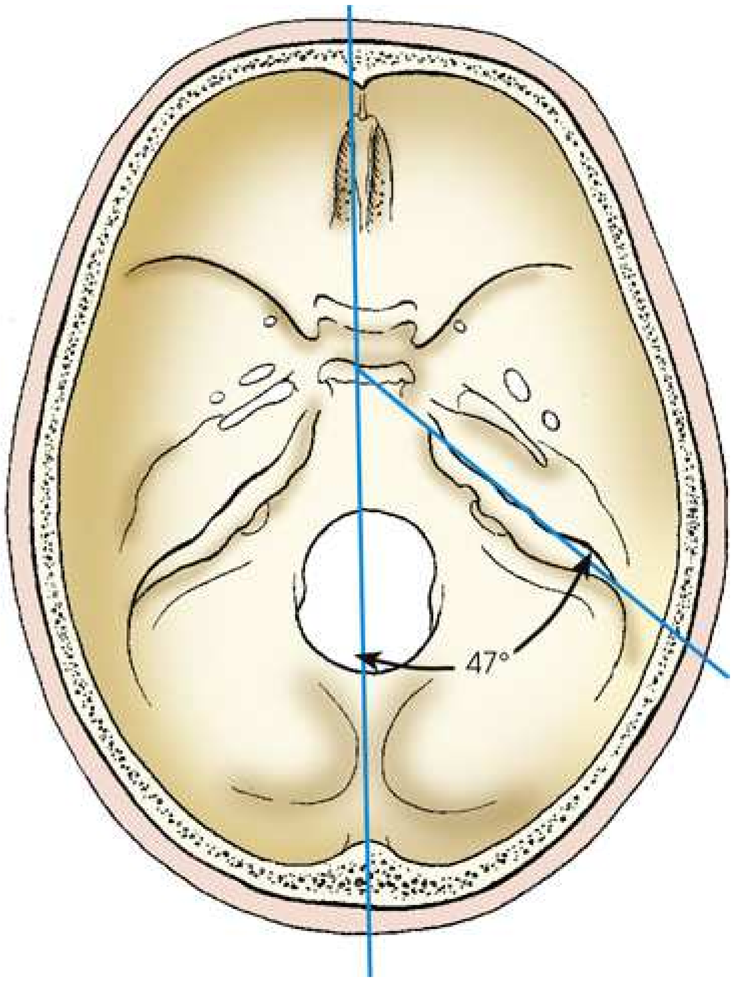


FIG. 11.39 Mesocephalic skull.

Asymmetry must also be considered. The orbits are not always symmetric in size and shape, the lower jaw is often asymmetric, and the nasal bones and cartilage are frequently deviated from the MSP. Many deviations are not as obvious as these, but if the radiographer adheres to the fundamental rules of positioning, relatively little difficulty is encountered. Varying the position of the part or the degree of central ray angulation to compensate for structural variations becomes a simple procedure if care and precision are used initially.

The radiographic positions depicted in this chapter show the patient seated at the vertical grid device or lying on a radiographic table. Whether the radiographer elects to perform the examination with the patient in the recumbent or upright position depends on four variables: (1) the equipment available, (2) the age and condition of the patient, (3) the preference of the radiographer and/or radiologist, and (4) whether upright images would increase diagnostic value, such as showing air-fluid levels in paranasal sinuses.

Comparable images of the skull and facial bones can usually be obtained with the patient either upright or recumbent, as long as the patient/part positioning and central ray are correctly aligned with the IR. For radiography of the paranasal sinuses, *the upright position is essential* for demonstration of air/fluid levels. Therefore, unless specifically noted in the text, the photographic illustration does *not* constitute a recommendation for performing the examination with the patient in the upright or recumbent position. Line drawings illustrating both table and upright radiography are included for most radiographic positions in this chapter.

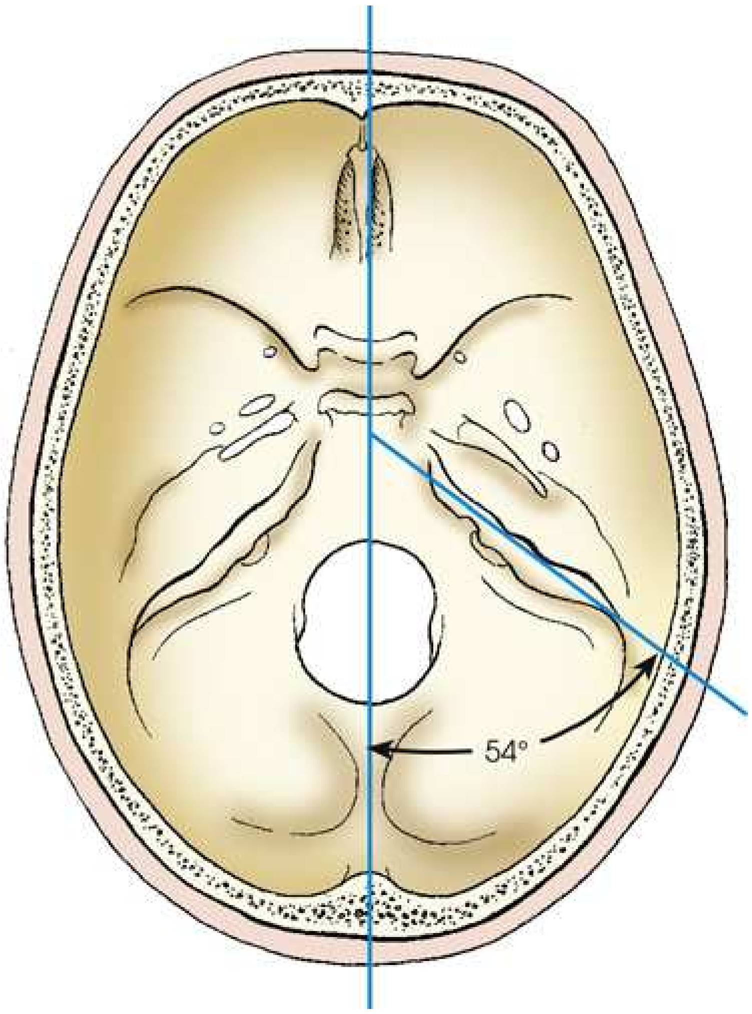


FIG. 11.40 Brachycephalic skull.

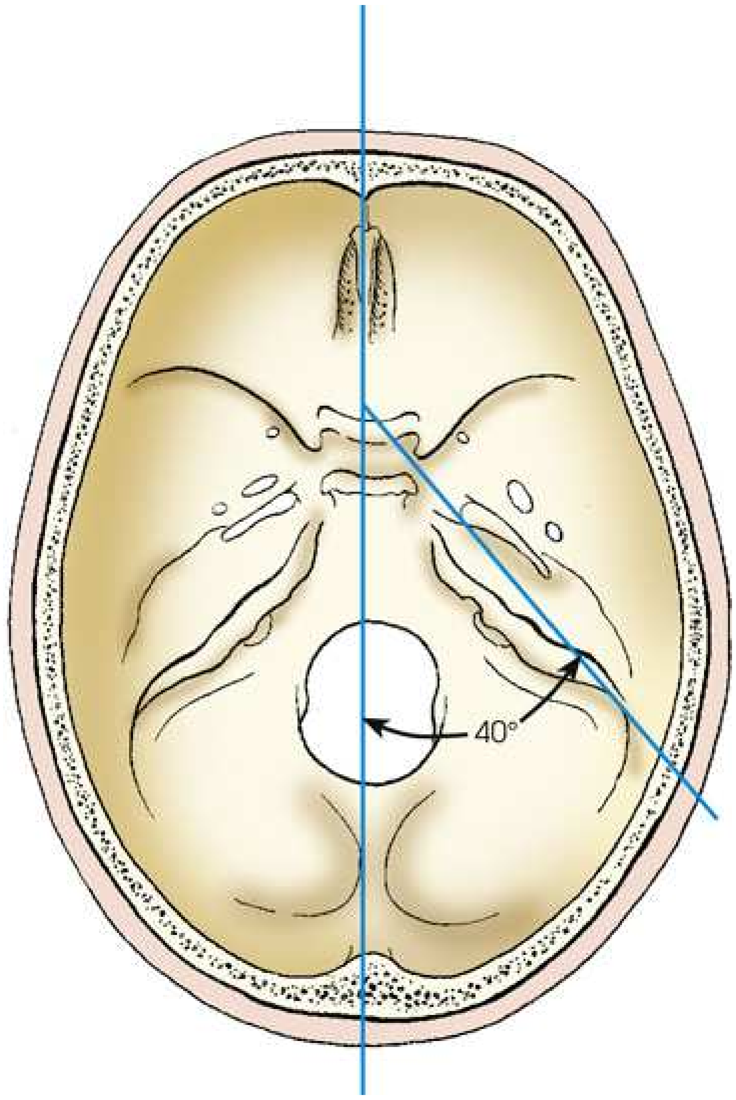


FIG. 11.41 Dolichocephalic skull.

Technical Considerations

General Body Position

The position of the body is important in radiography of the cranium to obtain quality images (Fig. 11.42). If the body is not correctly adjusted, great strain is placed on the muscles, making it difficult for the patient to maintain the correct head position. This is especially true when recumbent positions are used for skull radiography. An uncomfortable body position can contribute to positioning errors during skull, facial bone, and sinus radiography, such as rotation and tilt. Rotation results from lateral misplacement of MSP. Tilt results from longitudinal angulation of MSP of the head in relation to MSP of the entire body (Fig. 11.43). Some guidelines to alleviate strain and facilitate accurate positioning are as follows:

- To prevent rotation of the head, place the patient's body so that its long axis, depending on the image, either coincides with or is parallel to the midline of the radiographic table.
- To prevent tilt (superior or inferior pull on the head), align the long axis of the cervical vertebrae with the level of the midpoint of the foramen magnum.
- Support any elevated part, such as the patient's shoulder or hip, on a pillow or sandbags to relieve strain.
- For recumbent examinations of hyposthenic or asthenic patients, elevate the patient's chest on a small pillow to raise the cervical vertebrae to the correct level for the lateral, PA, and oblique projections (Figs. 11.44 and 11.45).
- For recumbent examination of obese or hypersthenic patients, elevate the patient's head on a radiolucent pad to obtain the correct part-IR relationship (Figs. 11.46 and 11.47).
- While adjusting the body, stand in a position that facilitates estimation of the approximate part position. For example, stand so that the longitudinal axis of the radiographic table is visible as the MSP of the body is being centered. This allows the anterior surface of the forehead to be viewed while the degree of body rotation for a lateral projection of the skull is adjusted. As a result, the body can be adjusted in such a way that it does not interfere with the final adjustment of the head, and the final position is comfortable for the patient.

FIG. 11.42 Correct parietoacanthial (Waters) without rotation or tilt.

- When the body is correctly placed and adjusted so that the long axis of the cervical vertebrae is supported at the level of the foramen magnum, the final position of the head requires only minor adjustments. The average patient can maintain this relatively comfortable position without the aid of elaborate immobilization devices, although the following techniques may be helpful:
    - If necessary, apply a head clamp with equal pressure on the two sides of the head.

FIG. 11.43 Incorrect parietoacanthial (Waters) with rotation and tilt. *Red lines* show rotation, evidenced by the unequal distances from the lateral orbital margins to lateral skull borders. Tilt is shown by the *yellow line*, demonstrating MSP of the head is not aligned with long axis of collimated field.

  - If such a clamp is not available, use a strip of adhesive tape where it will not be projected onto the image. The portion of the tape touching the hair should have the adhesive side covered with a second piece of tape so that the hairs are not pulled out when the tape is removed. Do *not* place adhesive tape directly on the patient's skin.
  - When the area to be exposed is small, immobilize the head with sandbags placed against the sides or vertex.
- Correct basic body positions and compensatory adjustments for recumbent radiography are illustrated in Figs. 11.44–11.51.

Cleanliness

The hair and face are naturally oily and leave a residue, even with the most hygienic patients. If the patient is sick, the residue is worse. During positioning of the skull, the patient's hair, mouth, nose, and eyes come in direct contact with the vertical grid device, tabletop, or IR. For medical asepsis, a paper towel or a cloth sheet may be placed between the imaging surface and the patient. As part of standard procedure, the contacted area should be cleaned with a disinfectant before and after positioning.

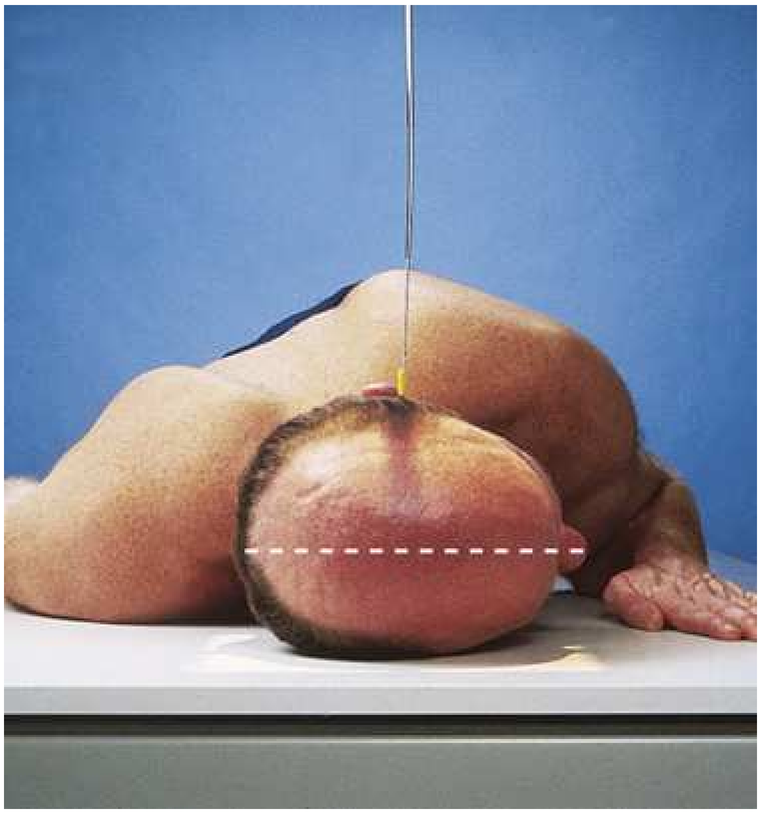


FIG. 11.44 Horizontal sagittal plane *(dashed lines)*.

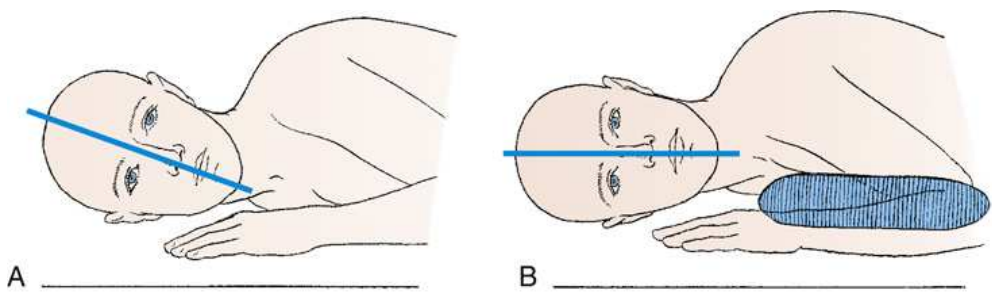


FIG. 11.45 Adjusting sagittal planes to horizontal position. (A) Asthenic or hyposthenic patient. (B) Angulation corrected.

Two positions of a patient lying on his side on an X-ray table. In A, his head is tilted up and the horizontal sagittal plane denoted by a horizontal line through the center of the face is tilted. In B, a cushion is placed below the chest and the horizontal sagittal plane is parallel to the table.

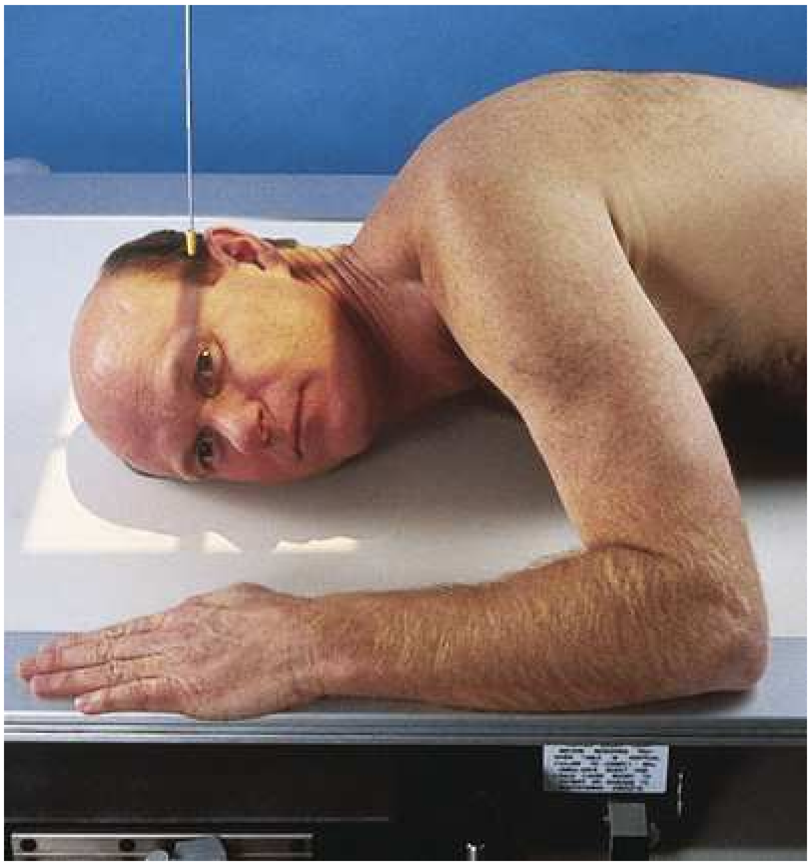


FIG. 11.46 Horizontal sagittal plane.

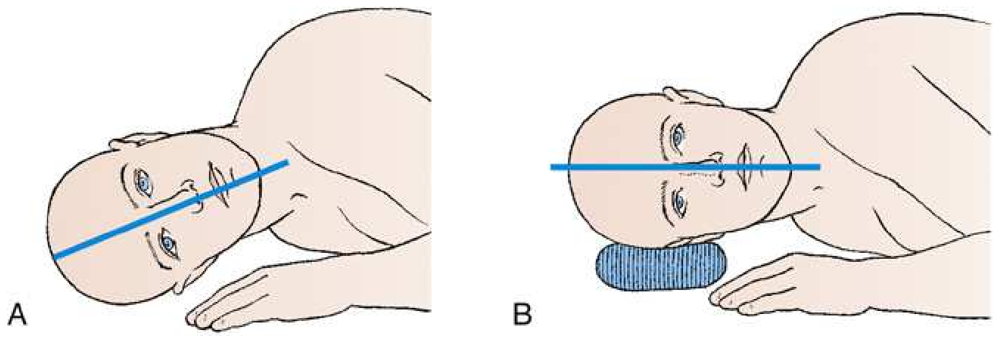


FIG. 11.47 Adjusting sagittal plane to horizontal position. (A) Hypersthenic patient. (B) Angulation corrected.

Two positions of a patient lying on his side on an X-ray table. In the first position his head is tilted up and the horizontal sagittal plane denoted by a horizontal line through the center of the face is tilted. In the second image a cushion is placed below the head and the horizontal sagittal plane is parallel to the table.

Radiation Protection

Protection of the patient from unnecessary radiation is a professional responsibility of the radiographer (see Chapter 1 for specific guidelines). In this chapter, radiation shielding of the patient is not specified or illustrated. The federal government has reported that placing a lead shield over a patient's pelvis does not significantly reduce gonadal exposure during imaging of the skull, facial bones, or sinuses. [1] However, lead shields may be used to reassure the patient, if requested, and shielding the abdomen of a pregnant woman is recommended by the authors of this atlas.

Infants and children may receive radiation shielding of the thyroid and thymus glands and the gonads, if the procedure is not compromised. The protective lead shielding used to cover the thyroid and thymus glands may assist in immobilizing pediatric patients.

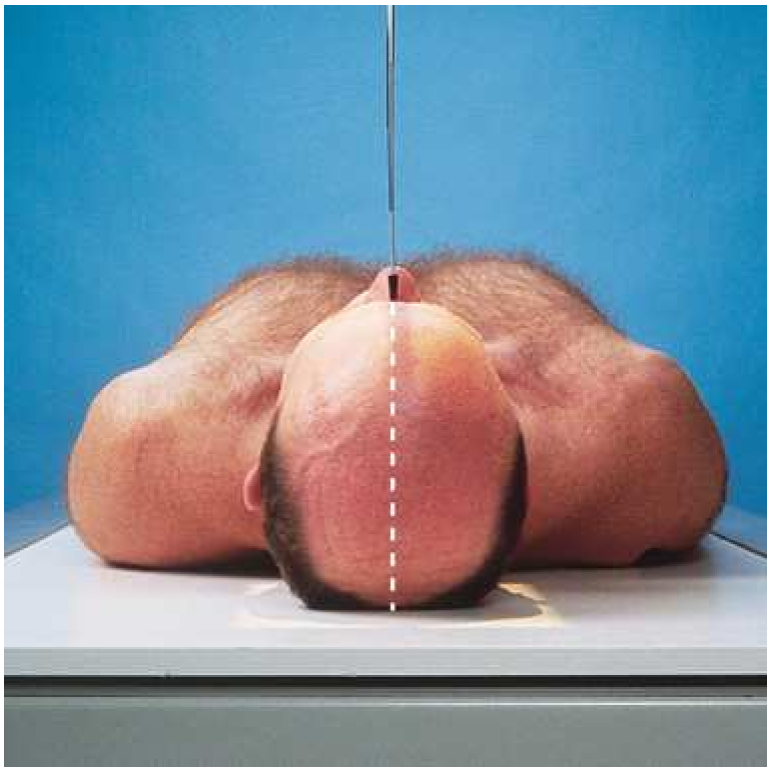


FIG. 11.48

PERPENDICULAR SAGITTAL PLANE *(DASHED LINES)*.

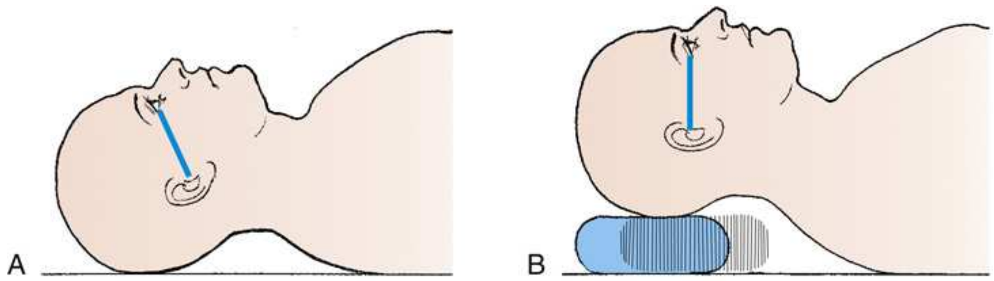


FIG. 11.49

ADJUSTING ORBITOMEATAL LINE TO VERTICAL POSITION. (A) HYPERSTHENIC OR ROUND-SHOULDERED PATIENT. (B) ANGULATION CORRECTED.

Two positions of a round-shouldered patient lying on his side on an X-ray table. In A, the patient is lying with his head is tilted up and the orbitomeatal plane is denoted by a line between the eyes and ears. In B, a cushion is placed below the head and the orbitomeatal plane is denoted by a line between the eyes and ears.

The most effective way to protect the patient from unnecessary radiation is to restrict the radiation beam by using *proper collimation*. Taking care to ensure that the patient is properly instructed and immobilized also reduces the likelihood of having to repeat the procedure, further limiting the radiation exposure received by the patient.

FIG. 11.50
PERPENDICULAR SAGITTAL PLANE *(DASHED LINES)*.

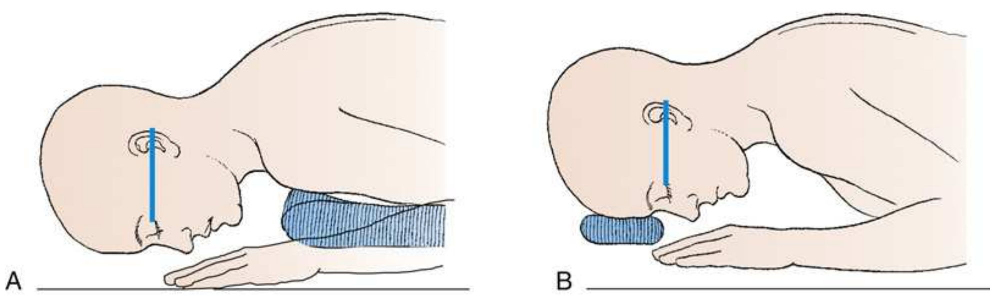


FIG. 11.51 Adjusting orbitomeatal line to vertical position. (A) Correction for hyposthenic patient. (B) Correction for hypersthenic patient.

Two positions of a patient lying face down on an X-ray table. In A, his chest is supported by a cushion and the orbitomeatal plane is denoted by a line between the eyes and ears. In B, a cushion is placed below the head and the orbitomeatal plane is denoted by a line between the eyes and ears.

Skull

Lateral Projection

Right or left position

Image receptor + grid: Positioned by manufacturer or department protocol for proper anatomy display orientation; CR plate: 10 × 12 inches (24 × 30 cm) crosswise.

Position of patient

- Place the patient in the anterior oblique position, seated upright or recumbent.
- If recumbent anterior oblique position is used, have the patient rest on the forearm and flex the knee of the elevated side.

Position of part

- Adjust the patient's head so that the MSP is parallel to the plane of the IR. If necessary, place a support under the side of the mandible to prevent it from sagging.

- Adjust the flexion of the patient's neck so that the IOML is perpendicular to the front edge of the IR. The IOML should also be parallel to the long axis of the IR.
- Position the head to place the IPL perpendicular to the IR (Figs. 11.52 and 11.53). Patient's head usually rests on the auricle of the ear.
- Immobilize the head.
- *Respiration:* Suspend.

Central ray

- Perpendicular, entering 2 inches (5 cm) superior to the EAM.
- Center the IR to the central ray.

Collimation

Adjust radiation field to extend 1 inch (2.5 cm) beyond the skin line of the skull. Check for light at vertex, anterior, posterior, and base of the skull borders. Place the side marker in the collimated exposure field.

Structures shown

Superimposed halves of the cranium with the details of the side adjacent to the IR. The sella turcica, anterior clinoid processes, dorsum sellae, and posterior clinoid processes are well shown in the lateral projection (Figs. 11.54 and 11.55).

Evaluation Criteria

The following should be clearly seen:

n Evidence of proper collimation and presence of the side marker placed clear of anatomy of interest
n Entire cranium without rotation or tilt, demonstrated by:
  ▫ Superimposed orbital roofs and greater wings of sphenoid
  ▫ Superimposed mastoid regions and EAM
  ▫ Superimposed TMJs
  ▫ Sella turcica in profile
n No overlap of cervical spine by mandible
n Bony detail of cranium and surrounding soft tissues

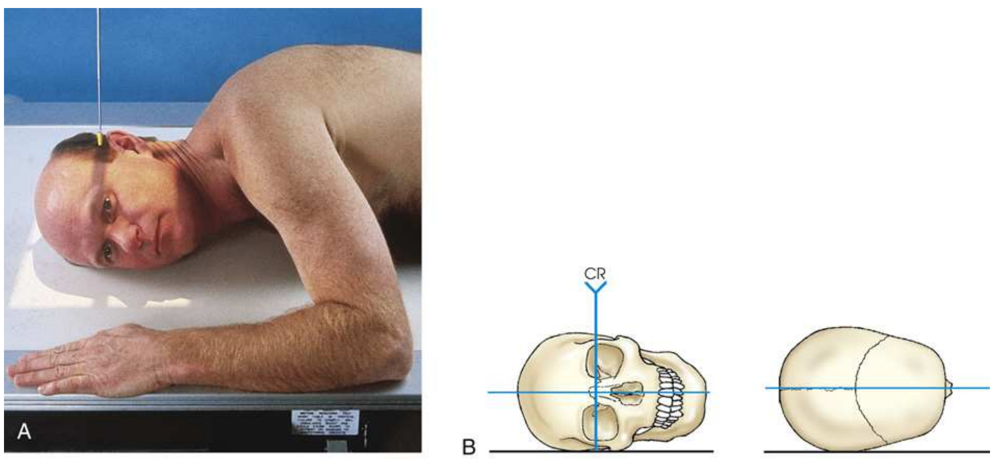


FIG. 11.52 (A) Lateral skull, recumbent position. (B) Table radiography diagram: lateral skull.

A patient lies on an X-ray table with the side of the face against the image receptor. Two illustrations beside depict the skull in anterior and posterior positions, lying on an image receptor with the central ray passing through the orbits.

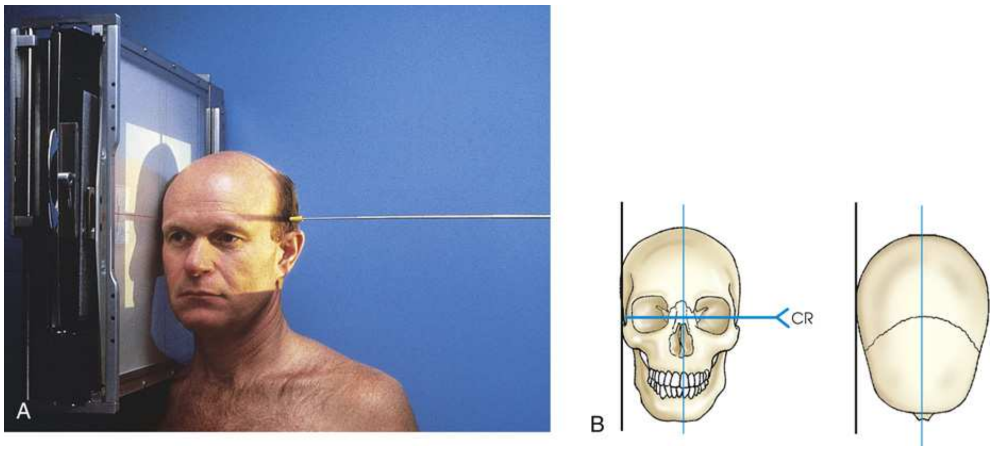


FIG. 11.53 (A) Lateral skull, upright position. (B) Upright radiography diagram: lateral skull.

A patient stands adjacent to an image receptor. Two illustrations beside depict a skull in anterior and posterior positions, adjacent to an image receptor with the central ray passing through the orbits.

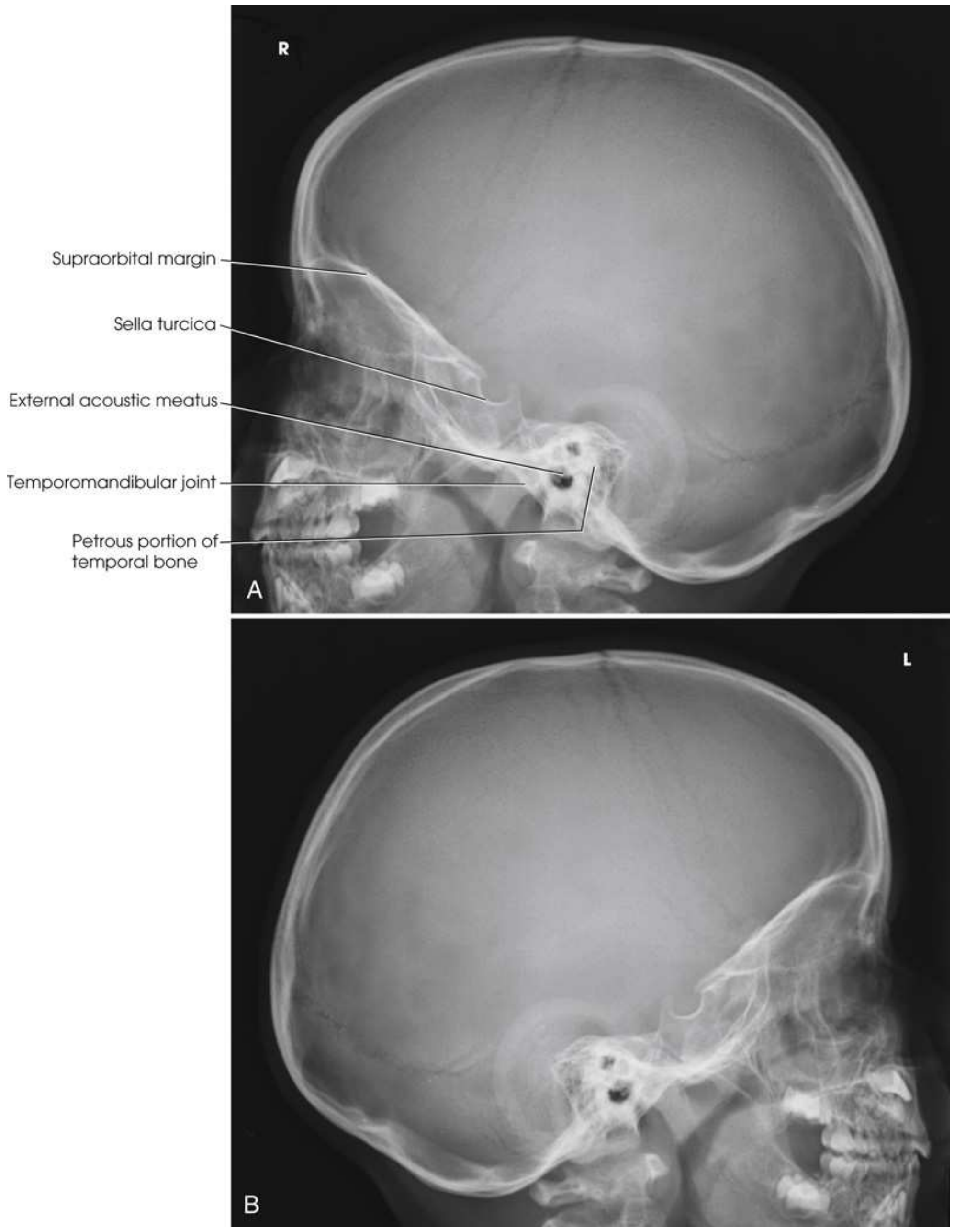


FIG. 11.54 Skull images on pediatric patient. (A) Right lateral. (B) Left lateral. Courtesy St. Bernard's Medical Center, Jonesboro, AR.

Two X-ray images of the lateral view of skull. The first one is the right lateral and the second one is the left lateral view. The temporal bone, external acoustic meatus, supraorbital margin and parietal bone are visible in the right lateral view.

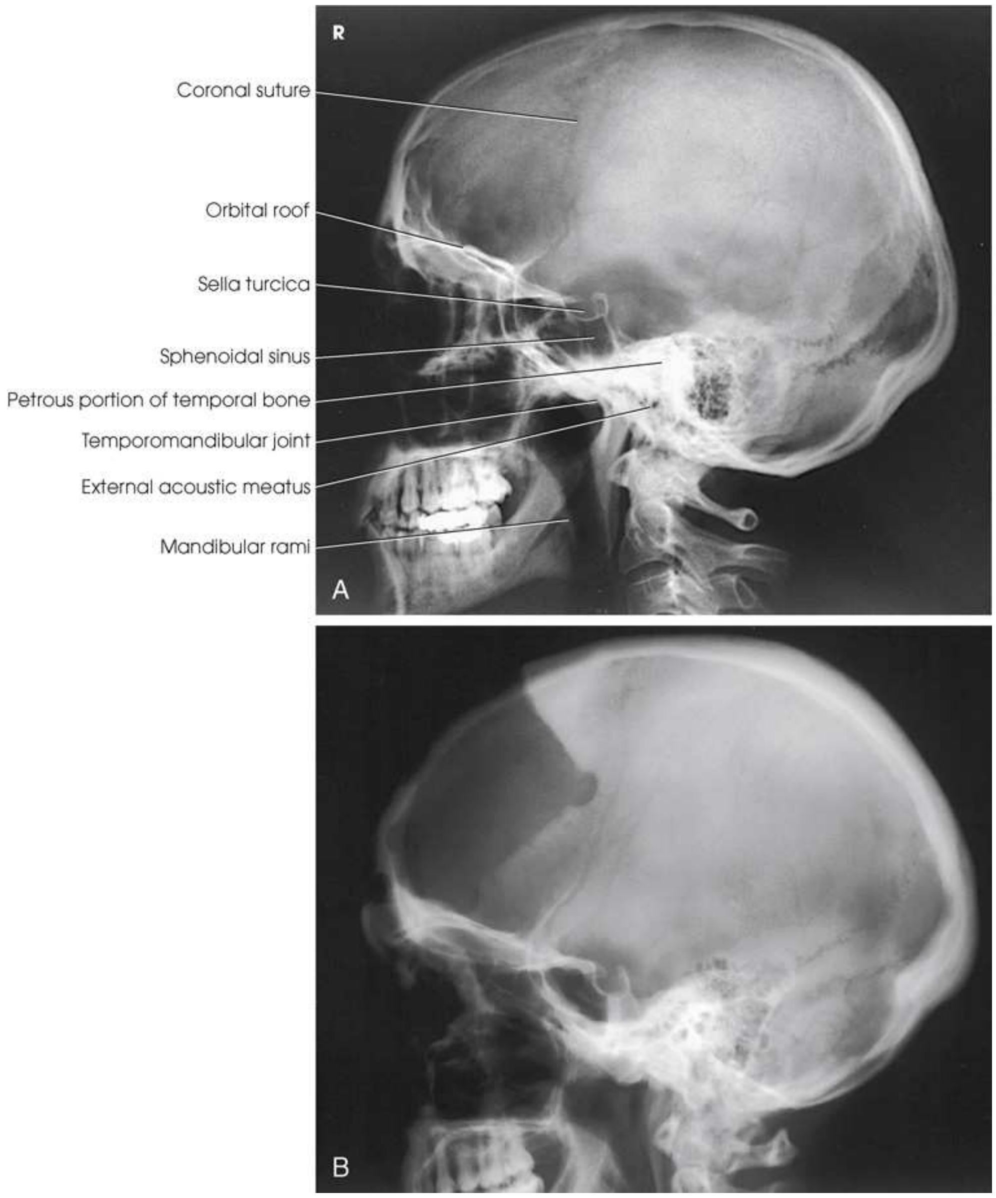


FIG. 11.55 Skull images on adult patients. (A) Right lateral. (B) Right lateral showing surgical removal of frontal bone.

Two X-ray images of the lateral view of skull. The Coronal suture, Orbital roof, Sella turcica, Sphenoidal sinus, Petrous portion of temporal bone, Temporal mandibular joint, External acoustic meatus, and Mandibular rami are labeled in the first image. In the second image the frontal bone is removed.

Pa Projection And Pa Axial Projection

Caldwell Method

Image receptor + grid: Positioned by manufacturer or department protocol for proper anatomy display orientation; CR plate: 10 × 12 inches (24 × 30 cm) lengthwise.

Position of patient

- Place the patient in a prone or seated position.
- Center MSP of the patient's body to the midline of the grid.
- Rest the patient's forehead and nose on the table or against the upright bucky.
- Flex the patient's elbows, and place the arms in a comfortable position.

Position of part

- Adjust the flexion of the patient's neck so that the OML is perpendicular to the plane of the IR.
- If the patient is recumbent, support the chin on a radiolucent sponge if needed.
- If the patient is obese or hypersthenic, a small radiolucent sponge may need to be placed under (or in front of) the forehead.
- Align MSP perpendicular to the IR. This is accomplished by adjusting the lateral margins of the orbits or the EAM equidistant from the tabletop.
- Immobilize the patient's head, and center the IR to the nasion.
- *Respiration:* Suspend.

Central ray

- For the PA projection, when the frontal bone is of primary interest, direct the central ray perpendicular to exit the nasion (Fig. 11.56).
- For the PA axial projection, Caldwell method, direct the central ray to exit the nasion at an angle of 15 degrees caudad (Figs. 11.57–11.59).
- Center the IR to the central ray.
- To show the superior orbital fissures, direct the central ray through the mid-orbits at an angle of 20 to 25 degrees caudad.
- To show the rotundum foramina, direct the central ray to the nasion at an angle of 25 to 30 degrees caudad. (The Waters method, presented in the Sinus Radiography section, is also used to show the rotundum foramina.)

Collimation

- Adjust radiation field to extend 1 inch (2.5 cm) beyond the skin line of the skull. Check for light at vertex and on both sides. Place the side marker in the collimated exposure field.

FIG. 11.56 PA skull: central ray angulation of 0 degree for frontal bone.

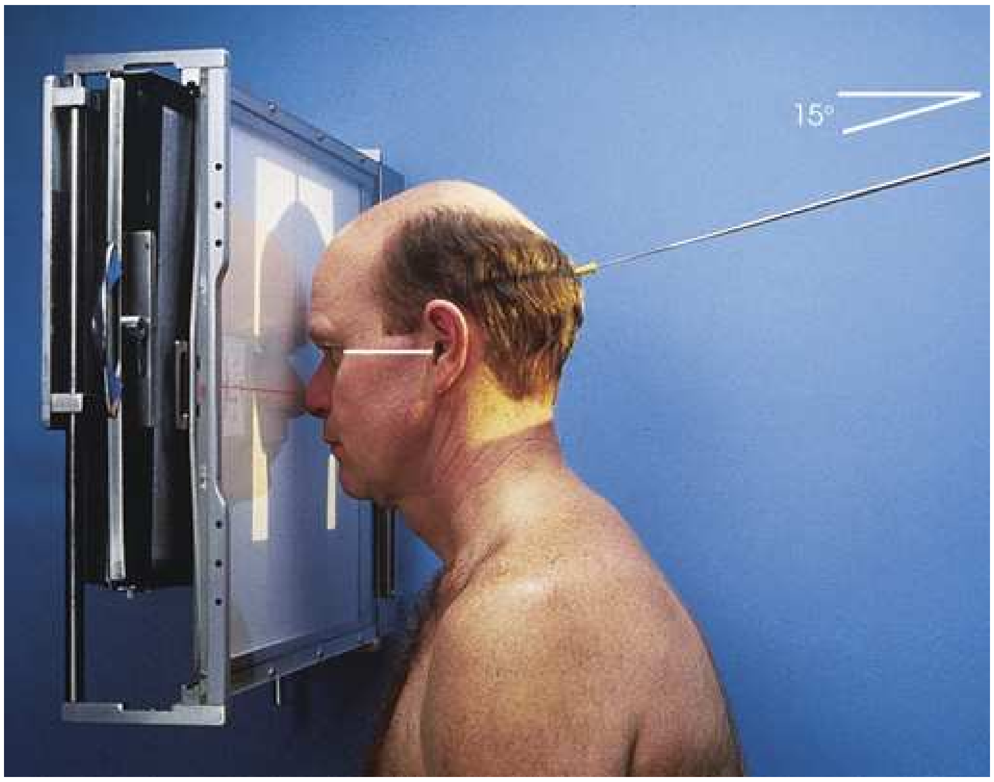


FIG. 11.57 PA axial skull: Caldwell method with central ray angulation of 15 degrees.

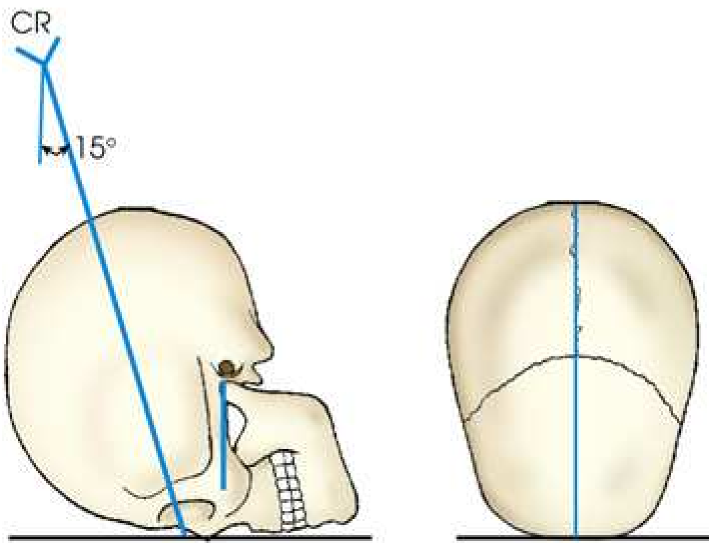


FIG. 11.58
TABLE RADIOGRAPHY DIAGRAM: CALDWELL METHOD.

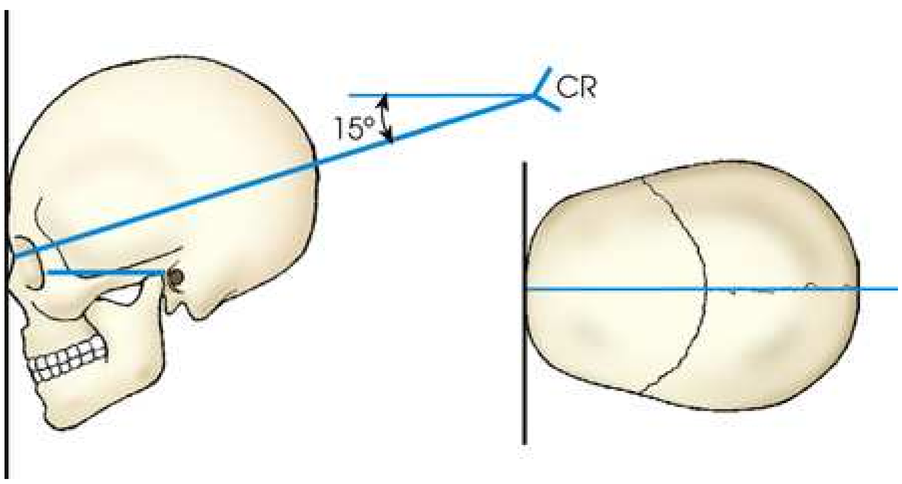


FIG. 11.59 Upright radiography diagram: Caldwell method.

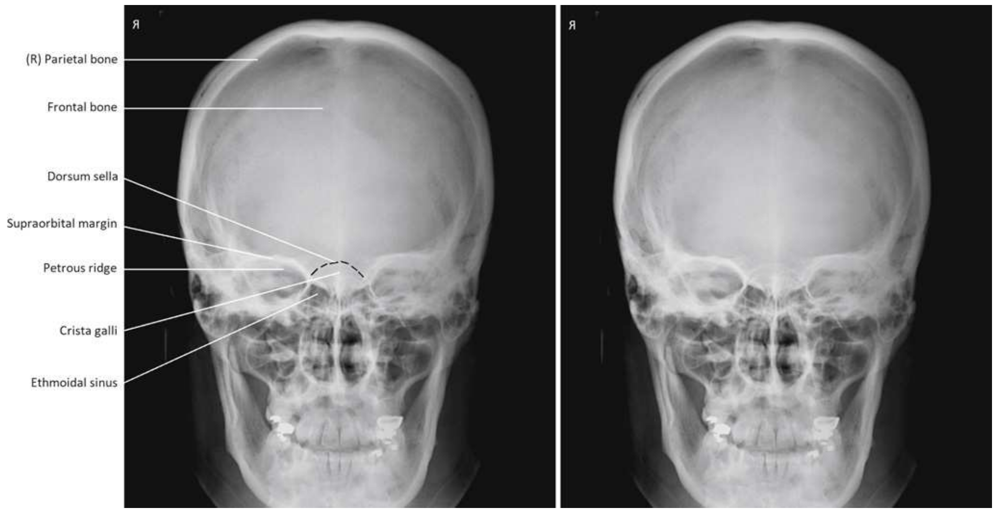


FIG. 11.60 PA skull with perpendicular central ray. Courtesy St. Bernard's Medical Center, Jonesboro, AR.

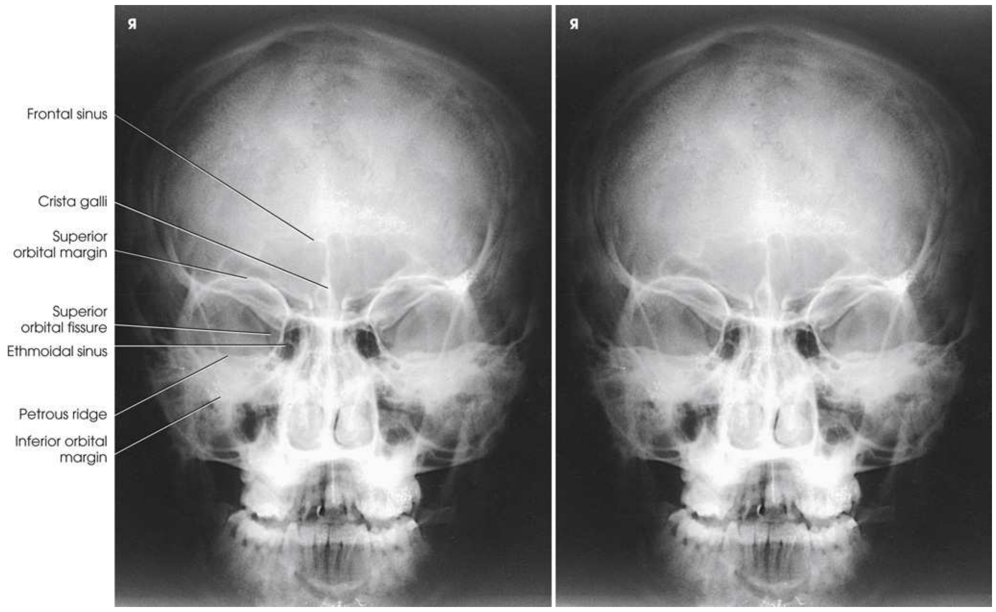


FIG. 11.61 PA axial skull: Caldwell method with 15-degree caudal central ray angulation.

Two X-ray images of the PA axial skull. In the first image the Frontal sinus, Crista galli, Superior orbital margin, Superior orbital fissure, Ethmoidal sinus, Petrous ridge, and Inferior orbital margin are labeled on the left.

Structures shown

For the PA projection with a perpendicular central ray (Fig. 11.60), the orbits are filled by the margins of the petrous pyramids. Other structures shown include the posterior ethmoidal air cells, crista galli, frontal bone, and frontal sinuses. The dorsum sellae is seen as a curved line extending between the orbits, just above the ethmoidal air cells.

When the central ray is angled 15 degrees caudad to the nasion for the PA axial projection, Caldwell method, many of the same structures that appear in the PA projection are seen (Fig. 11.61); however, the petrous ridges are projected into the lower third of the orbits. The Caldwell method also shows the anterior ethmoidal air cells. Schüller, [2] who first described this positioning for the skull, recommended a caudal angle of 25 degrees.

Stretcher and bedside examinations

Lateral decubitus position

- When the patient cannot be turned to the prone position for the PA or PA axial Caldwell projection, and cervical spinal injury has been ruled out, elevate one side enough to place the patient's head in a true lateral position, and support the shoulder and hip on pillows or sandbags if needed.
- Elevate the patient's head on a suitable support, and adjust its height to center MSP of the head to a vertically positioned grid.
- Adjust the patient's head so that the OML is perpendicular to the plane of the IR (Fig. 11.62).
- Direct the *horizontal* central ray perpendicular, or 15 degrees caudad, to exit the nasion.

Evaluation Criteria

The following should be clearly seen:

- Evidence of proper collimation and presence of the side marker placed clear of anatomy of interest
- Entire cranium without rotation or tilt, demonstrated by:
    - Equal distances from lateral borders of skull to lateral borders of orbits on both sides
    - Symmetric petrous ridges
    - MSP of cranium aligned with long axis of collimated field
- PA axial (Caldwell) demonstrates petrous pyramids lying in lower third of orbit
- PA projection shows orbits filled by petrous ridges
- Entire cranial perimeter showing three distinct tables of squamous bone
- Bony detail of frontal bone and surrounding soft tissues

FIG. 11.62 PA skull with patient semisupine.

Ap Projection And Ap Axial Projection

Reverse Caldwell Method

Image receptor + grid: Positioned by manufacturer or department protocol for proper anatomy display orientation; CR plate: 10 × 12 inches (24 × 30 cm) lengthwise.

When the patient cannot be positioned for a PA or PA axial projection, a similar but magnified image can be obtained with an AP projection. The AP axial is often referred to as a *reverse Caldwell.*

Position of patient and part

- Position the patient supine with the MSP of the body centered to the grid.
- Ensure that MSP and OML are perpendicular to the IR.

Central ray

- Perpendicular (Fig. 11.63) or directed to the nasion at an angle 15 degrees cephalad (Fig. 11.64).
- Center IR to the central ray.

Collimation

- Adjust radiation field to extend 1 inch (2.5 cm) beyond the skin line of the skull. Check for light above the vertex and on both sides of the face. Place the side marker in the collimated exposure field.

Structures shown

The structures shown on the AP projection are the same as the structures shown on the PA projection. On the AP projection (Fig. 11.65), the orbits are considerably magnified because of the increased object–to–image receptor distance (OID). Similarly, because of the magnification, the distance from the lateral margin of the orbit to the lateral margin of the temporal bone measures less on the AP projection than on the PA projection.

Evaluation Criteria

The following should be clearly seen:

- n Evidence of proper collimation and presence of the side marker placed clear of anatomy of interest
- n Entire cranium without rotation or tilt, demonstrated by:
  - ▫ Equal distances from lateral borders of skull to lateral borders of orbits on both sides
  - ▫ Symmetric petrous ridges
  - ▫ MSP of cranium aligned with long axis of collimated field
- n Petrous pyramids lying in lower third of orbit with a cephalad central ray angulation of 15 degrees and filling orbits with a 0-degree central ray angulation
- n Entire cranial perimeter showing three distinct areas of squamous bone
- n Bony detail of frontal bone and surrounding soft tissues

FIG. 11.63 AP skull.

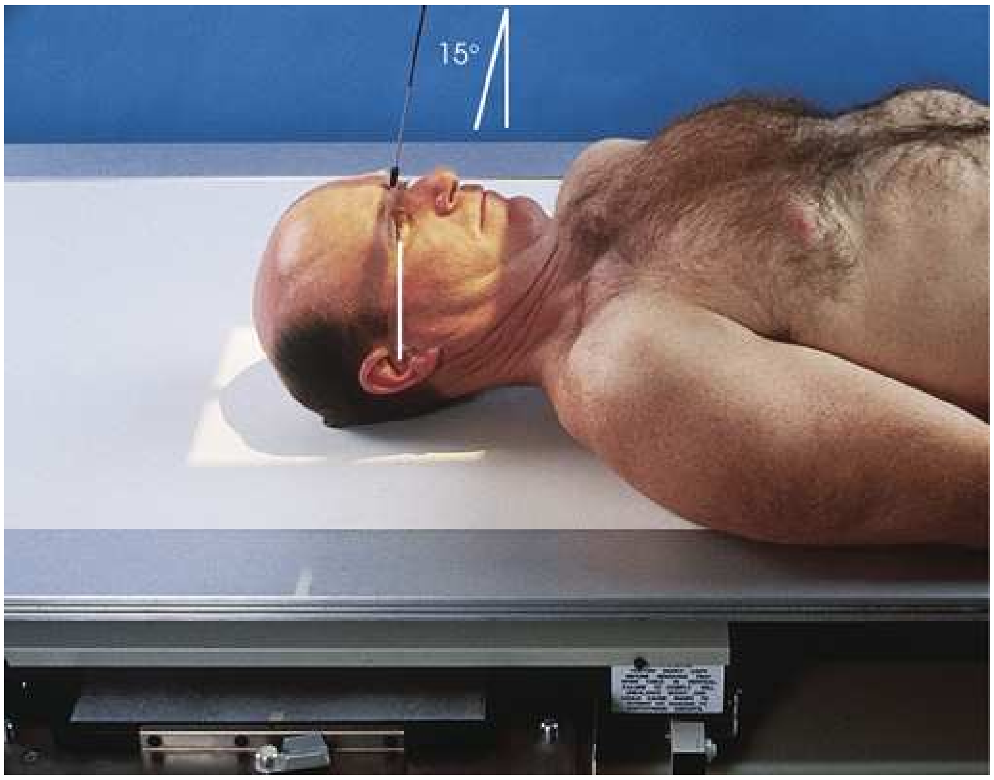


FIG. 11.64 AP axial, reverse Caldwell, skull with 15-degree cephalad central ray.

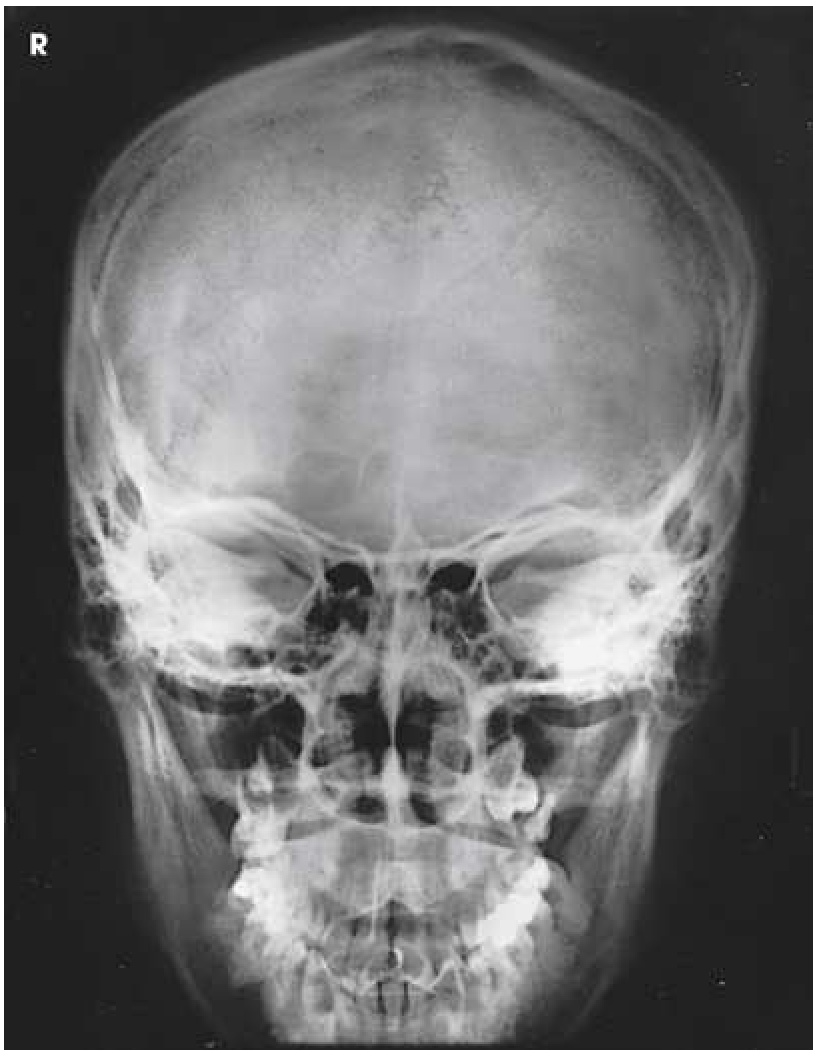


FIG. 11.65 AP skull with perpendicular central ray.

Ap Axial Projection

Towne Method

Image receptor + grid: Positioned by manufacturer or department protocol for proper anatomy display orientation; CR plate: 10 × 12 inches (24 × 30 cm) lengthwise.

NOTE: Although this technique is most commonly referred to as the Towne method, [3] numerous authors have described slightly different variations. In 1912 Grashey [4] published the first description of the AP axial projection of the cranium. In 1926 Altschul [5] and Towne [3] described the position. Altschul recommended strong depression of the chin and direction of the central ray through the foramen magnum at a caudal angle of 40 degrees. Towne (citing Chamberlain) recommended that with the patient's chin depressed, the central ray should be directed through the MSP from a point about 3 inches (7.6 cm) above the eyebrows to the foramen magnum. Towne gave no specific central ray angulation, but the angulation would depend on the flexion of the neck.

Position of patient

- With the patient supine or seated upright, center MSP of the patient's body to the midline of the grid.
- Place the patient's arms in a comfortable position, and adjust the shoulders to lie in the same horizontal plane.
- To ensure the patient's comfort without increasing the IR distance, examine the hypersthenic or obese patient in the seated-upright position, if possible.
- The skull can be brought closer to the IR by having the patient lean back lordotically and rest the shoulders against the vertical grid device. When this is impossible, the desired projection of the occipitobasal region may be obtained by using the PA axial projection described by Haas (pp. 50-51). The Haas method is the reverse of the AP axial projection and produces a comparable result.

Position of part

- Adjust the patient's head so that MSP is perpendicular to the midline of the IR.
- Flex the patient's neck enough to place the OML perpendicular to the plane of the IR.
- When the patient cannot flex the neck to this extent, adjust the neck so that the IOML is perpendicular and then increase the central ray angulation by 7 degrees (Figs. 11.66–11.69).
- Position the IR center at or near the level of the foramen magnum.
- For a localized image of the dorsum sellae and petrous pyramids, adjust the IR so that its midpoint coincides with the central ray. The IR is centered at or slightly below the level of the occlusal plane.
- Recheck the position and immobilize the head.
- *Respiration:* Suspend.

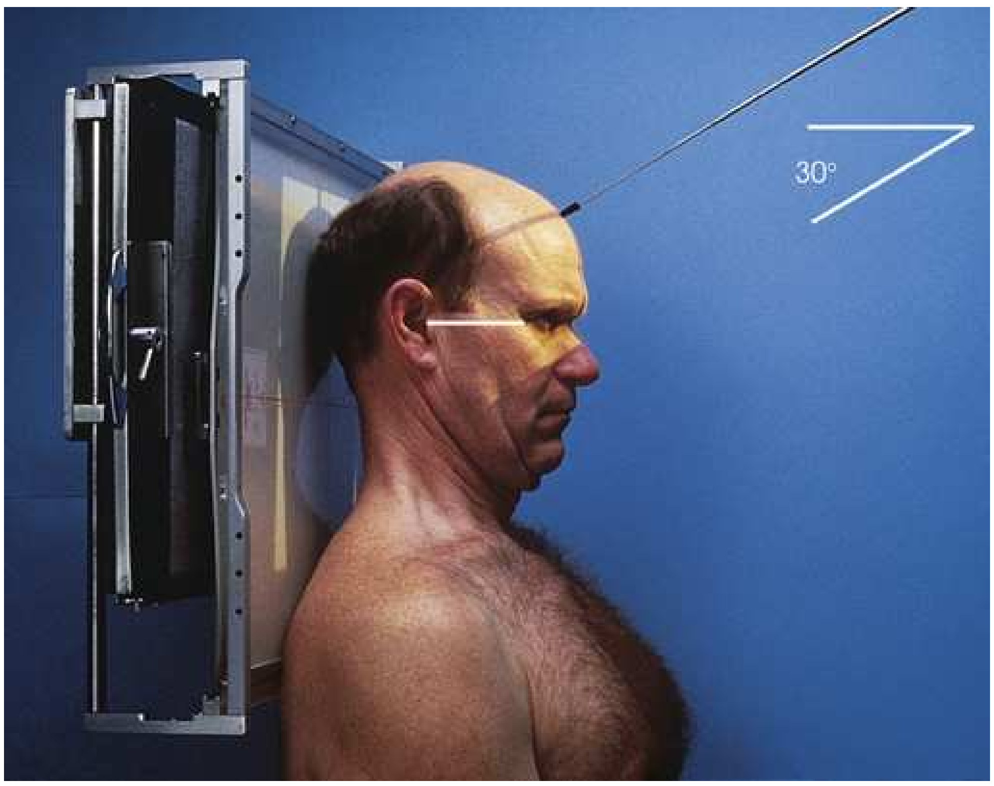


FIG. 11.66 AP axial skull: Towne method, upright position.

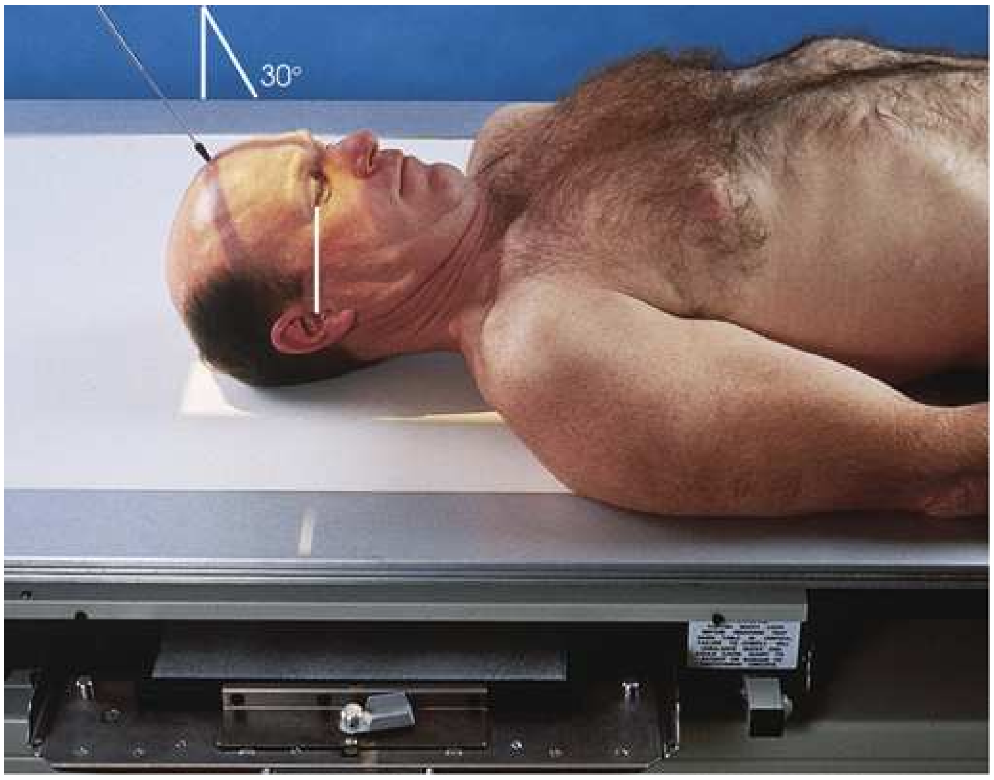


FIG. 11.67

AP AXIAL SKULL: TOWNE METHOD, SUPINE POSITION.

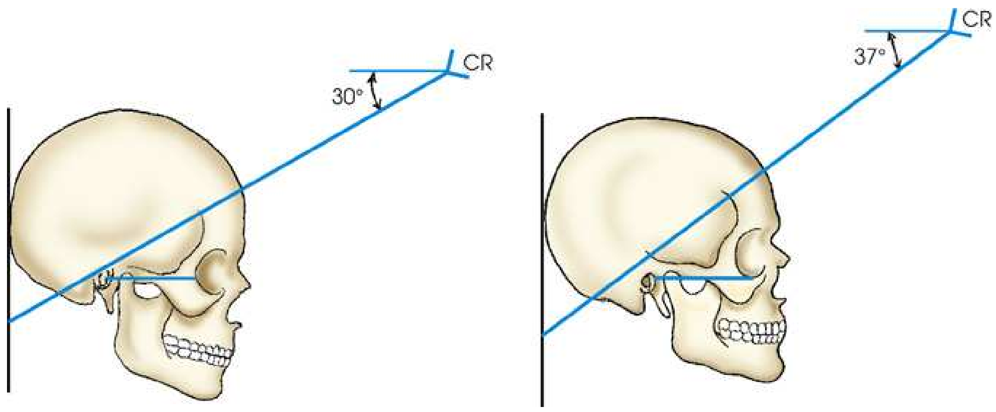


FIG. 11.68

UPRIGHT RADIOGRAPHY DIAGRAM: AP AXIAL SKULL: TOWNE METHOD. SAME RADIOGRAPHIC RESULT WITH CENTRAL RAY DIRECTED 30 DEGREES TO OML OR 37 DEGREES TO IOML.

Two illustrations of the skull in lateral view. The back of the skull is rested on an image receptor. A central ray is passing through the temporal bone at an angle of 30 degrees in the first illustration and at 37 degrees in the second one.

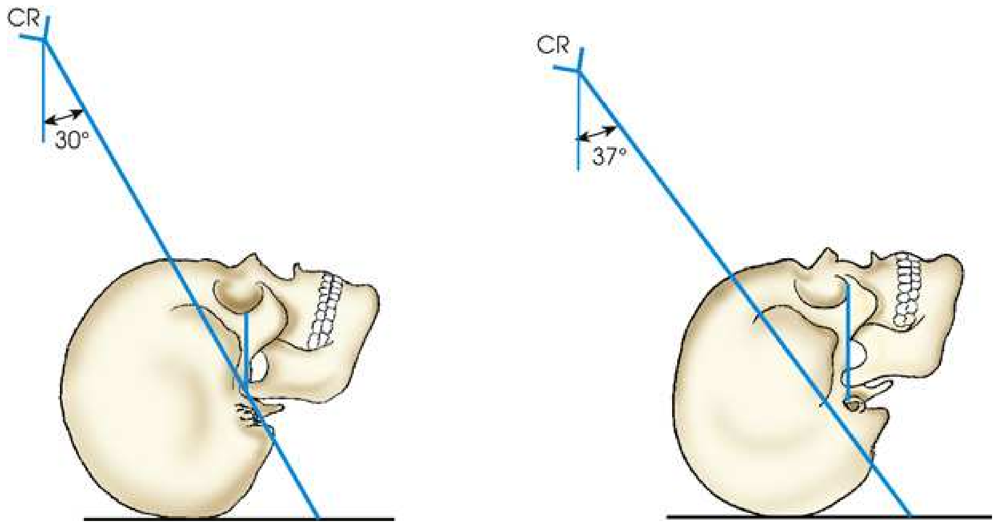


FIG. 11.69 Table radiography diagram: AP axial skull: Towne method.

Two illustrations of the skull facing upwards in lateral view. The back of the skull lies on an image receptor. A central ray is passing through the temporal bone at an angle of 30 degrees in the first illustration and at 37 degrees in the second one.

Central ray

- Directed through the foramen magnum at a caudal angle of 30 degrees to the OML or 37 degrees to the IOML. The central ray enters approximately 2 ½ inches (6.3 cm) above the glabella and passes through the level of the EAM.

Collimation

- Adjust the radiation field to extend 1 inch (2.5 cm) beyond the skin line of the skull. Check for light at the vertex and on both sides. Place the side marker in the collimated exposure field.

Structures shown

A symmetric image of the petrous pyramids, the posterior portion of the foramen magnum, the dorsum sellae, and the posterior clinoid processes projected within the foramen magnum, the occipital bone, and the posterior portion of the parietal bones (Fig. 11.70).

Evaluation Criteria

The following should be clearly seen:

- Evidence of proper collimation and presence of the side marker placed clear of anatomy of interest
- Entire cranium, without rotation or tilt, demonstrated by:
  - Equal distances from lateral borders of skull to lateral margins of foramen magnum on both sides
  - Symmetric petrous pyramids
  - MSP of cranium aligned with long axis of collimated field
- Dorsum sellae and posterior clinoid processes visible within foramen magnum
- Bony detail of occipital bone and surrounding soft tissues

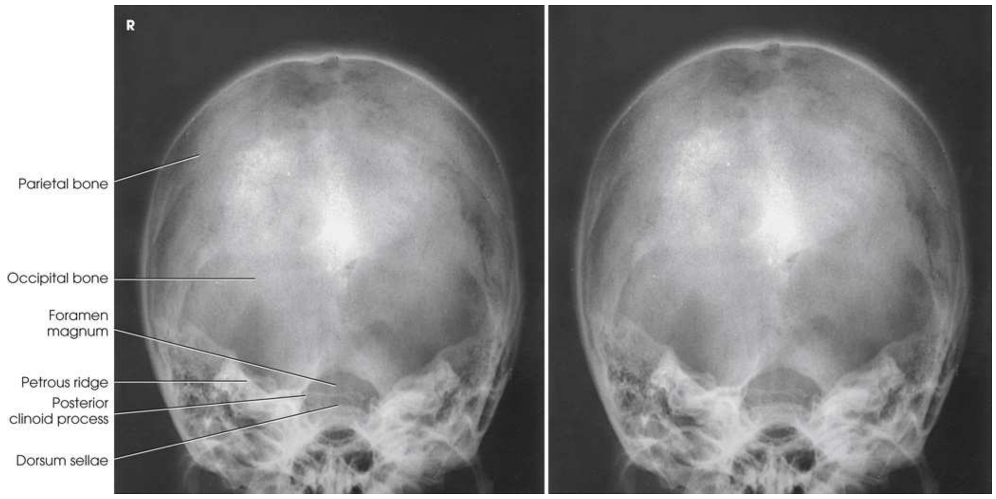


FIG. 11.70 AP axial skull: Towne method with 30-degree central ray angulation to OML.

Pathologic condition or trauma

To show the entire foramen magnum, the caudal angulation of the central ray is increased from 40 to 60 degrees to the OML (Figs. 11.71–11.75).

FIG. 11.71 AP axial skull, Towne method, on a trauma patient. OML and IOML lines are not perpendicular, which would require CR angulation greater than 37 degrees.

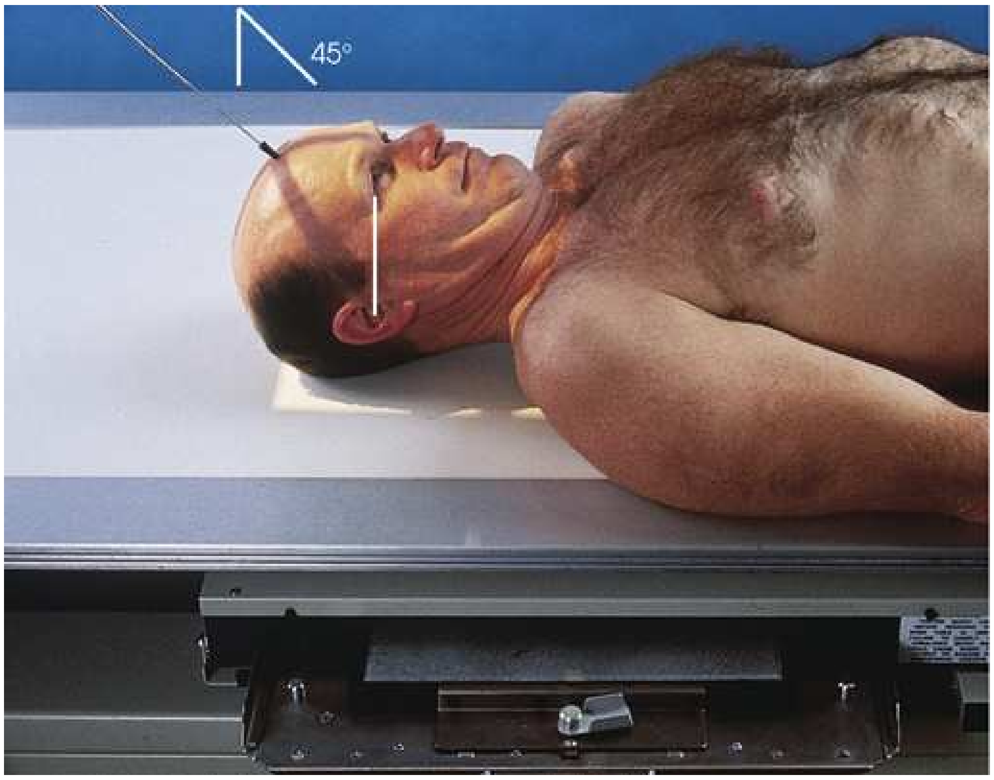


FIG. 11.72
AP AXIAL SKULL: CENTRAL RAY ANGULATION OF 40 TO 45 DEGREES.

Lateral decubitus position

For pathologic conditions, trauma, or a deformity such as a strongly accentuated dorsal kyphosis when the patient cannot be examined in a direct supine or prone position, the following steps should be taken:

- Adjust and support the body in a semirecumbent position; this allows the head to be placed in a true lateral position.

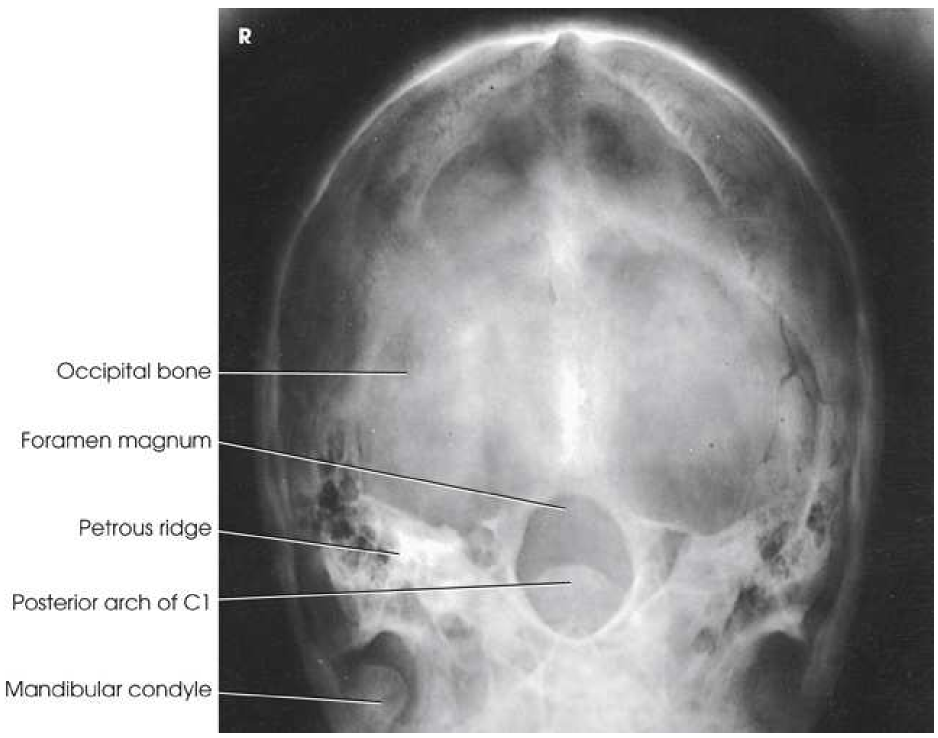


FIG. 11.73
AP AXIAL SKULL: CENTRAL RAY ANGULATION OF 45 DEGREES.

- Immobilize the IR and grid in a vertical position behind the patient's occiput.
- Direct the *horizontal* central ray 30 degrees caudally to the OML (Fig. 11.76).

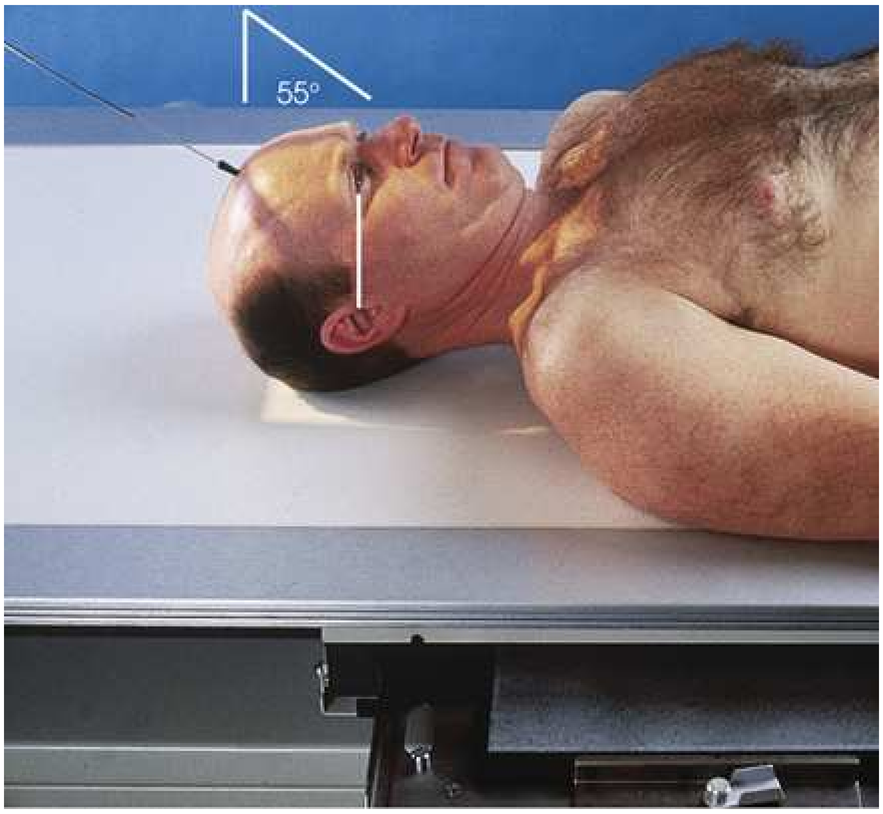


FIG. 11.74
AP AXIAL FORAMEN MAGNUM, SUPINE POSITION.

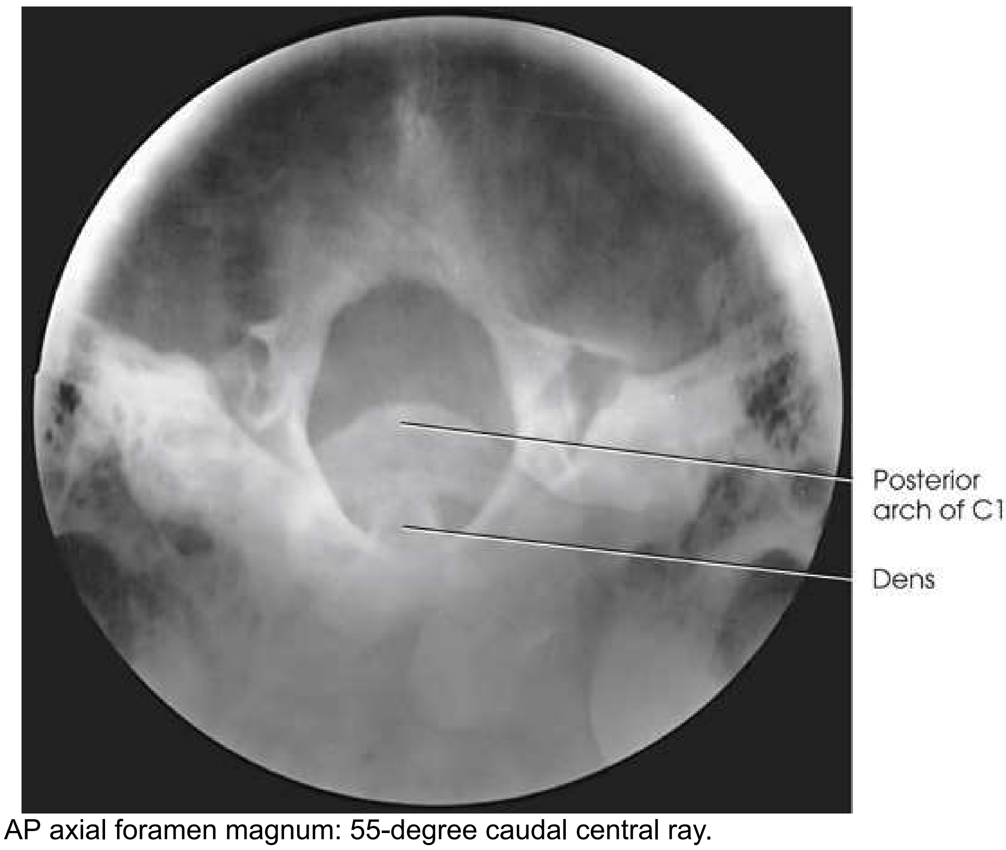


FIG. 11.75 AP axial foramen magnum: 55-degree caudal central ray.

FIG. 11.76 AP axial skull, with the patient's head in lateral decubitus position and with IR and grid vertical.

A patient lies on his side on an X-ray table, with his head supported by a solid block. The image receptor is adjacent to the back of his head. The patient's head is in lateral decubitus position with the image receptor.

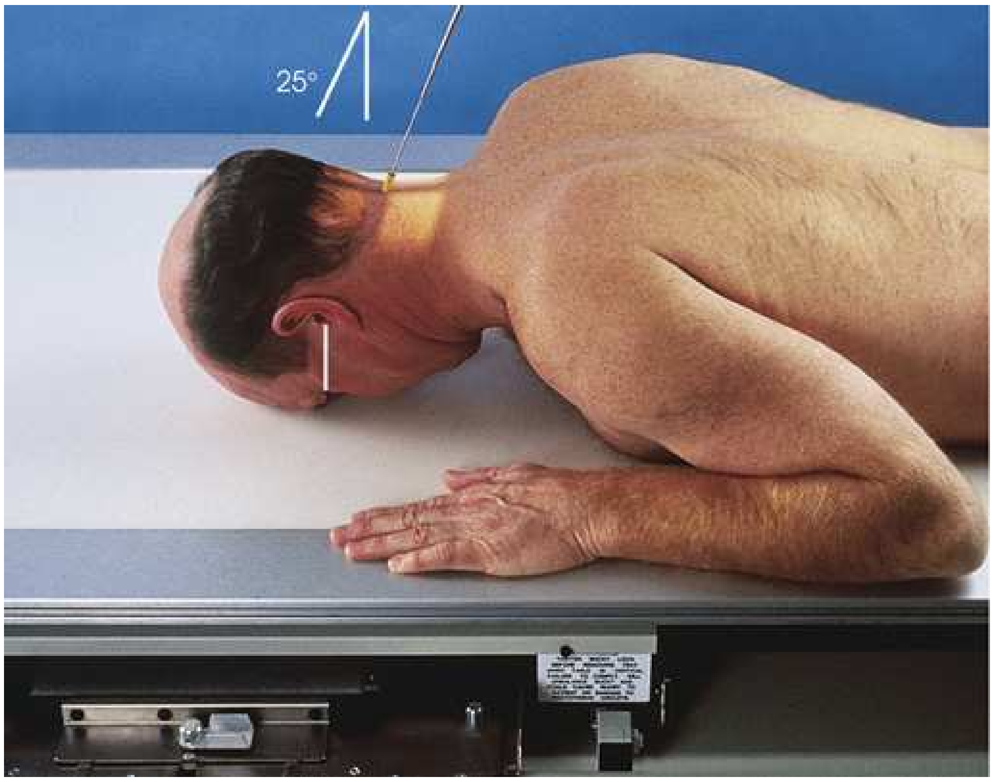


FIG. 11.77 PA axial skull: Haas method.

A patient lies face down on an X-ray table. His palms are placed on either sides of his head on the table. The central ray is directed towards the center of the back of his head at an angle 25 degrees.

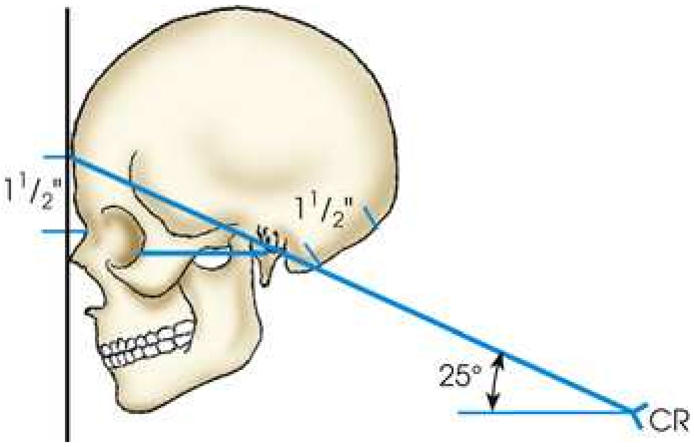


FIG. 11.78
UPRIGHT RADIOGRAPHY DIAGRAM: PA AXIAL SKULL: HAAS METHOD DIAGRAM.

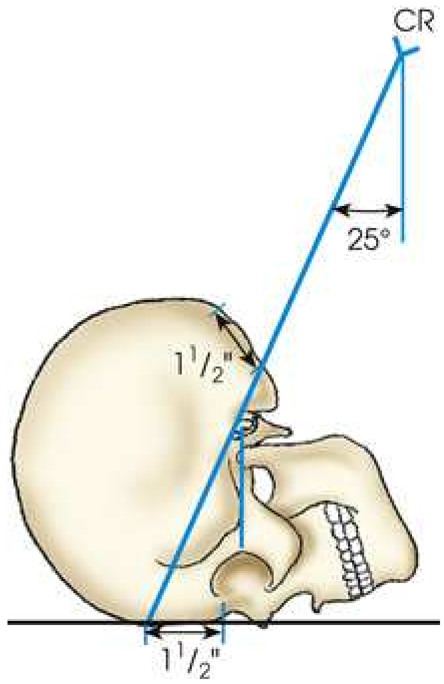


FIG. 11.79 Table radiography diagram: PA axial skull: Haas method diagram.

Pa Axial Projection

Haas Method

Haas [6] devised this projection for obtaining an image of the sellar structures projected within the foramen magnum on hypersthenic, obese, or other patients who cannot be adjusted correctly for the AP axial (Towne) projection.

Image receptor + grid: Positioned by manufacturer or department protocol for proper anatomy display orientation; CR plate: 10 × 12 inches (24 × 30 cm) lengthwise.

Position of patient

- Adjust the patient in the prone or seated-upright position, and center MSP of the body to the midline of the grid.
- Flex the patient's elbows, place the arms in a comfortable position, and adjust the shoulders to lie in the same horizontal plane.

Position of part

- Rest the patient's forehead and nose on the table, with MSP perpendicular to the midline of the grid.
- Adjust the flexion of the neck so that the OML is perpendicular to the IR (Figs. 11.77–11.79).
- Immobilize the head.
- For a localized image of the sellar region or the petrous pyramids, or both, adjust the position of the IR so that the midpoint coincides with the central ray; shift the IR cephalad approximately 3 inches (7.6 cm) to include the vertex of the skull.
- *Respiration:* Suspend.

Central ray

- Directed at a cephalad angle of 25 degrees to the OML to enter a point 1 ½ inches (3.8 cm) below the external occipital protuberance (inion) and to exit approximately 1 ½ inches (3.8 cm) superior to the nasion. The central ray can be varied to show other cranial anatomy.

Collimation

- Adjust the radiation field to extend 1 inch (2.5 cm) beyond the skin line of the skull. Check for light above the vertex and on both sides. Place the side marker in the collimated exposure field.

Structures shown

The occipital region of the cranium, a symmetric image of the petrous pyramids, and the dorsum sellae and posterior clinoid processes within the foramen magnum (Figs. 11.80 and 11.81).

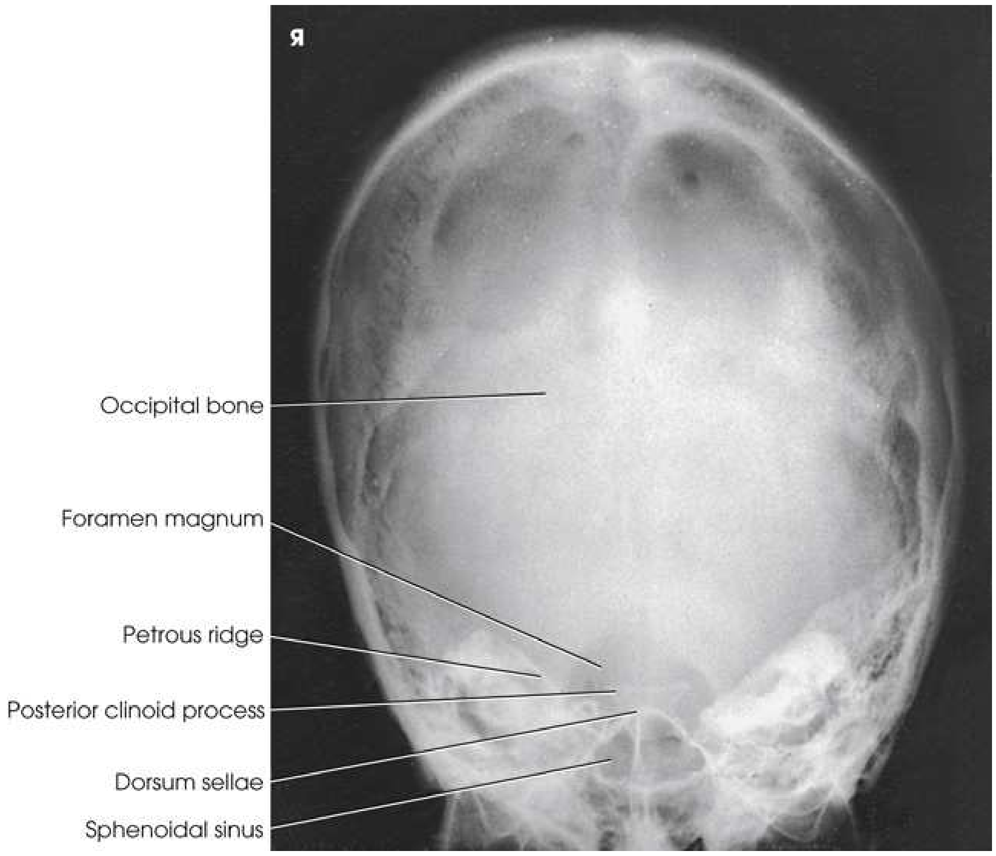


FIG. 11.80 PA axial skull: Haas method, with 25-degree cephalad CR.

Evaluation Criteria

The following should be clearly seen:

- Evidence of proper collimation and presence of the side marker placed clear of anatomy of interest
- Entire cranium, without rotation or tilt, demonstrated by:
  - Equal distances from lateral borders of skull to lateral margins of foramen magnum on both sides
  - Symmetric petrous pyramids
  - MSP of cranium aligned with long axis of collimated field
- Dorsum sellae and posterior clinoid processes within the foramen magnum
- Bony detail of occipital bone and surrounding soft tissues

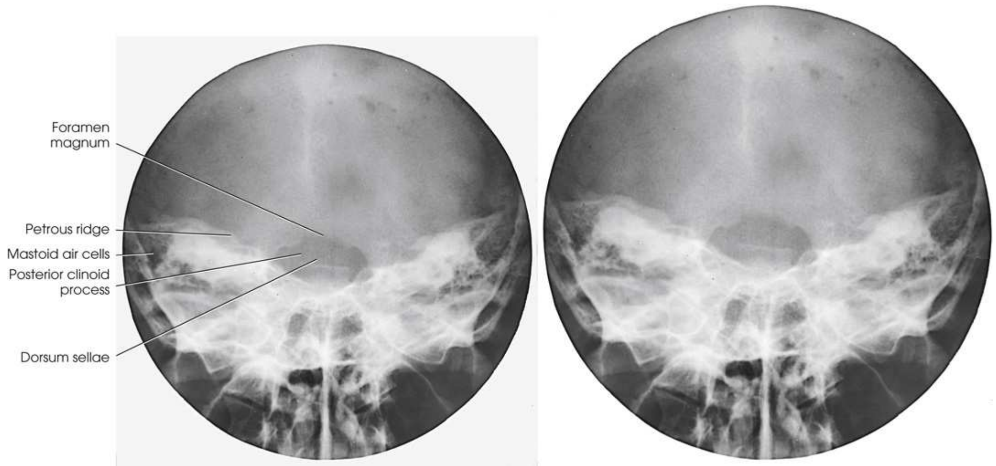


FIG. 11.81 PA axial sella turcica: Haas method, using cylindric extension cone that restricts the exposure field to small area. Beam restriction decreases scatter radiation and increases visibility of detail of sellar structures.

Two circular X-ray images of the P A axial view of sella turcica. The occipital bone, foramen magnum, petrous ridge, posterior clinoid process, dorsum sellae, and sphenoidal sinus are labeled in the first image.

Cranial Base

Submentovertical Projection

Schüller Method

Image receptor + grid: Positioned by manufacturer or department protocol for proper anatomy display orientation; CR plate: 10 × 12 inches (24 × 30 cm) lengthwise.

Position of patient

The success of the submentovertical (SMV) projection of the cranial base depends on placing the IOML as nearly parallel with the plane of the IR as possible and directing the central ray perpendicular to the IOML. The following steps are taken:

- Place the patient in the supine or the seated-upright position; the latter is more comfortable. If a chair that supports the back is used, the upright position allows greater freedom in positioning the patient's body to place the IOML parallel with the IR. If the patient is seated far enough away from the vertical grid device, the head can usually be adjusted without placing great pressure on the neck.
- When the patient is placed in the supine position, elevate the torso on firm pillows or a suitable pad to allow the head to rest on the vertex with the neck in hyperextension.
- Flex the patient's knees to relax the abdominal muscles.
- Place the patient's arms in a comfortable position, and adjust the shoulders to lie in the same horizontal plane.

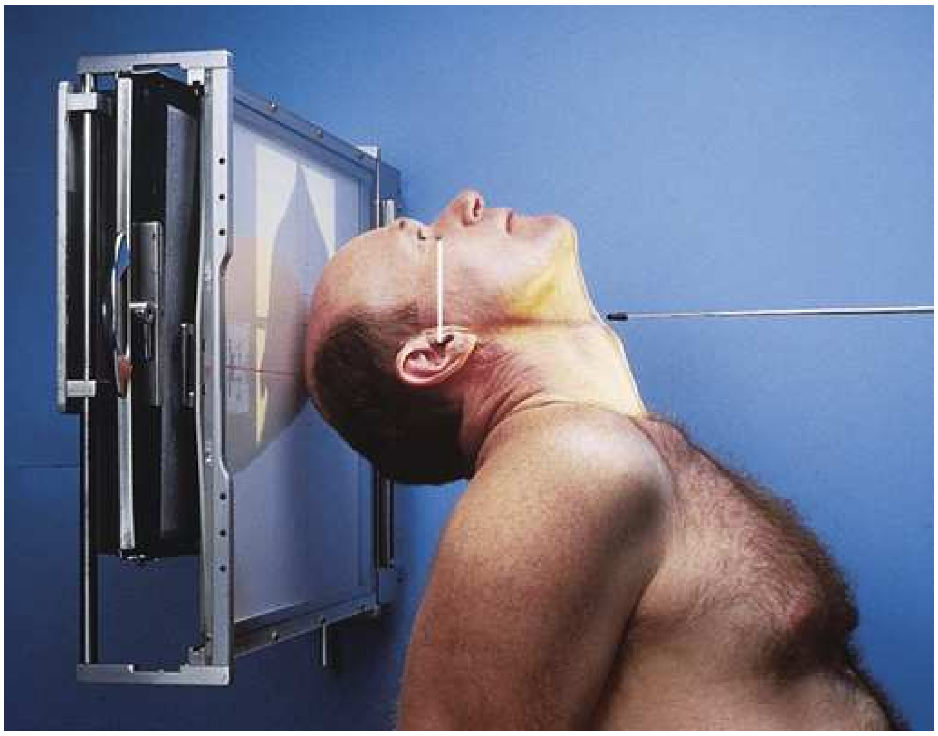


FIG. 11.82 SMV cranial base, patient upright.

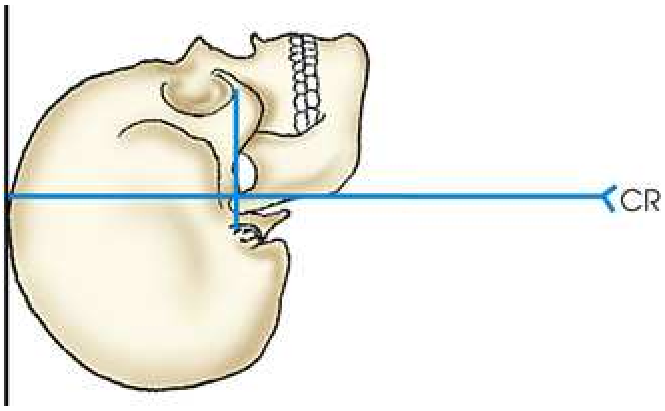


FIG. 11.83
UPRIGHT RADIOGRAPHY DIAGRAM: SMV SKULL.

- Do not keep the patient in the final adjustment longer than is absolutely necessary, because the supine position places considerable strain on the neck.

Position of part

- With MSP of the patient's body centered to the midline of the grid, extend the patient's neck to the greatest extent as can be achieved, placing the IOML as parallel as possible to the IR.
- Adjust the patient's head so that MSP is perpendicular to the IR (Figs. 11.82–11.85).

NOTE: Patients placed in the supine position for the cranial base may have increased intracranial pressure. As a result, they may be dizzy or unstable for a few minutes after having been in this position. Use of the upright position may alleviate some of this pressure.

FIG. 11.84
SMV CRANIAL BASE, PATIENT SUPINE.

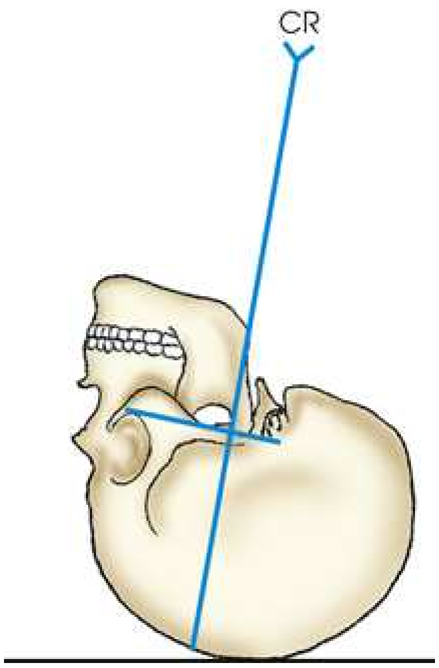


FIG. 11.85 Table radiography diagram: SMV skull.

- Immobilize the patient's head. In the absence of a head clamp, place a suitably backed strip of adhesive tape across the tip of the chin and anchor it to the sides of the radiographic unit if needed. (The part of the tape touching the skin should be covered.)
- *Respiration:* Suspend.

Central ray

- Directed through the sella turcica perpendicular to the IOML. The central ray enters MSP of the throat between the angles of the mandible and passes through a point ¾ inch (1.9 cm) anterior to the level of the EAM.
- Center the IR to the central ray. The IR should be parallel to the IOML.

Collimation

- Adjust the radiation field to extend 1 inch (2.5 cm) beyond the shadow of the tip of the nose and 1 inch (2.5 cm) beyond the lateral borders. Place the side marker in the collimated exposure field.

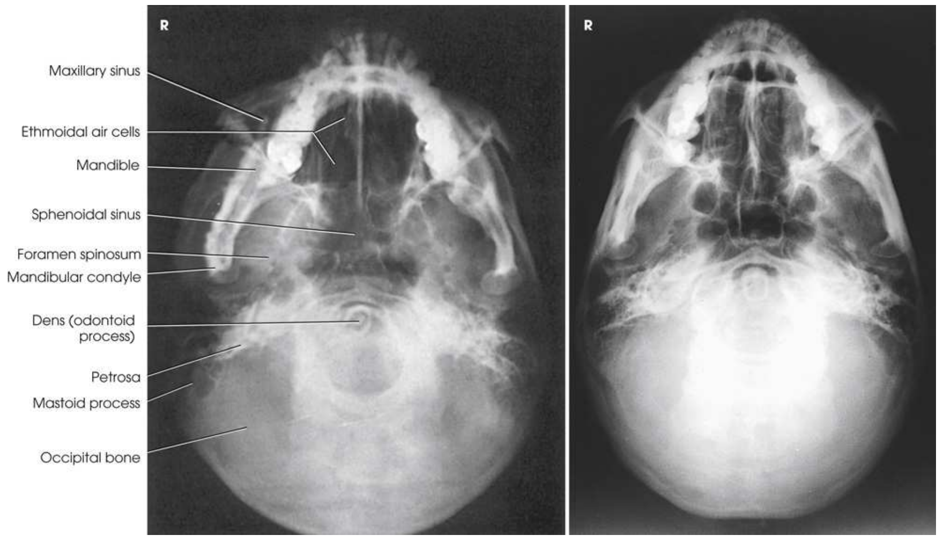


FIG. 11.86 SMV cranial base.

Two X-ray images of the cranial part of the skull. The Maxillary sinus, Ethmoidal air cells, Mandible, Sphenoidal sinus, Foramen spinosum, Mandibular condyle, Dens (odontoid process), Petrosa, Mastoid process, and Occipital bone.

Structures shown

Symmetric images of the petrosae, the mastoid processes, the foramina ovale and spinosum (which are best shown in this projection), the carotid canals, the sphenoidal and ethmoidal sinuses, the mandible, the bony nasal septum, the dens of the axis, and the occipital bone. The maxillary sinuses are superimposed over the mandible (Fig. 11.86).

SMV projection is also used to demonstrate the zygomatic arches, mandible, ethmoidal, and sphenoidal sinuses with an adjustment in exposure factors (see sections on Facial Bone Radiography and Sinus Radiography later in this chapter).

Evaluation Criteria

The following should be clearly seen:

- n Evidence of proper collimation and presence of the side marker placed clear of anatomy of interest
- n Entire cranium, without tilt or rotation, demonstrated by:
  - ▫ Equal distances from the lateral borders of the skull to the mandibular condyles on both sides
  - ▫ Symmetric petrosae
- n IOML is parallel to IR (full neck extension), demonstrated by:
  - ▫ Mental protuberance superimposed over anterior frontal bone
  - ▫ Mandibular condyles anterior to petrosae
- n Bony details of the cranial base and surrounding soft tissues.

NOTE: Schüller [7] described and illustrated the basal projections—SMV and verticosubmental (VSM)—but Pfeiffer [8] gave specific directions for the central ray angulation.

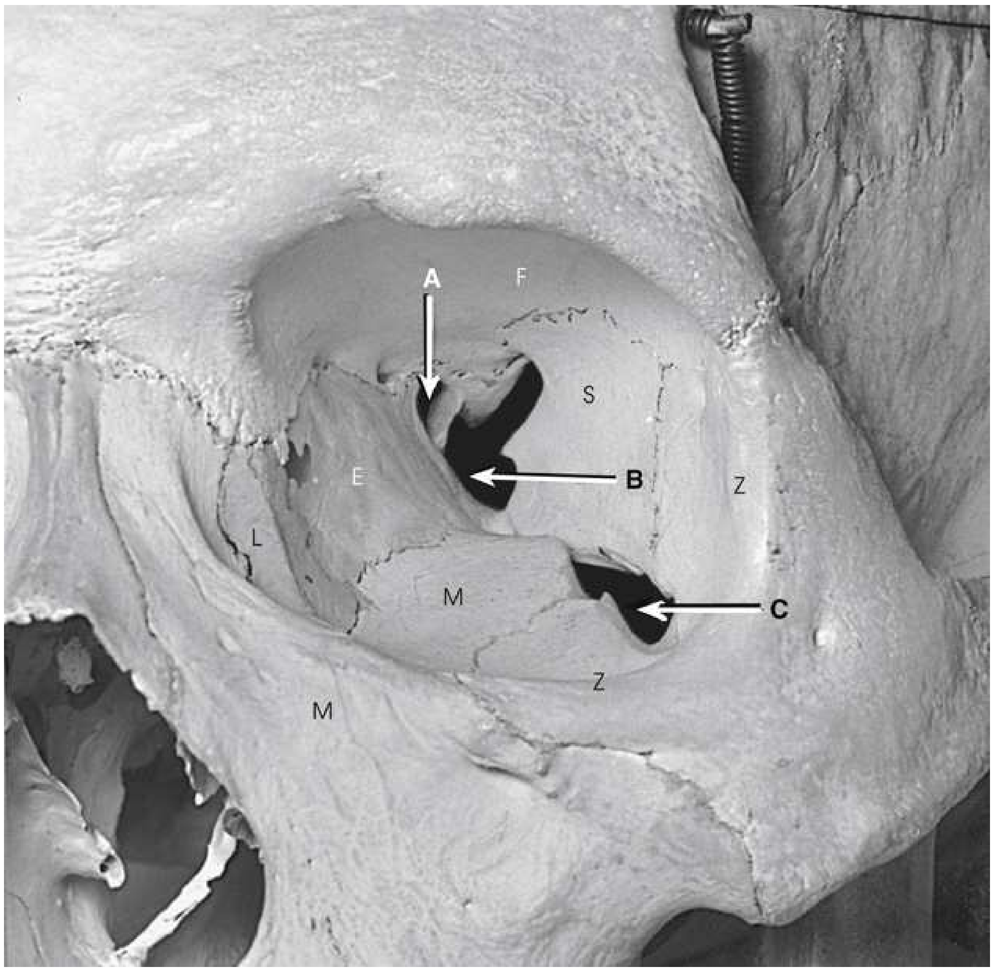


FIG. 11.87 Bones of left orbit of dry specimen. *A,* Optic canal and foramen. *B,* Superior orbital fissure. *C,* Inferior orbital fissure. *E,* Ethmoid; *F,* frontal; *L,* lacrimal; *M,* maxilla; *S,* sphenoid; *Z,* zygomatic (palatine not shown).

A specimen of the left orbit of a skull with the following parts labeled: Optic canal and foramen, Superior orbital fissure, Inferior orbital fissure, Ethmoid, frontal, lacrimal, maxilla, sphenoid and zygomatic.

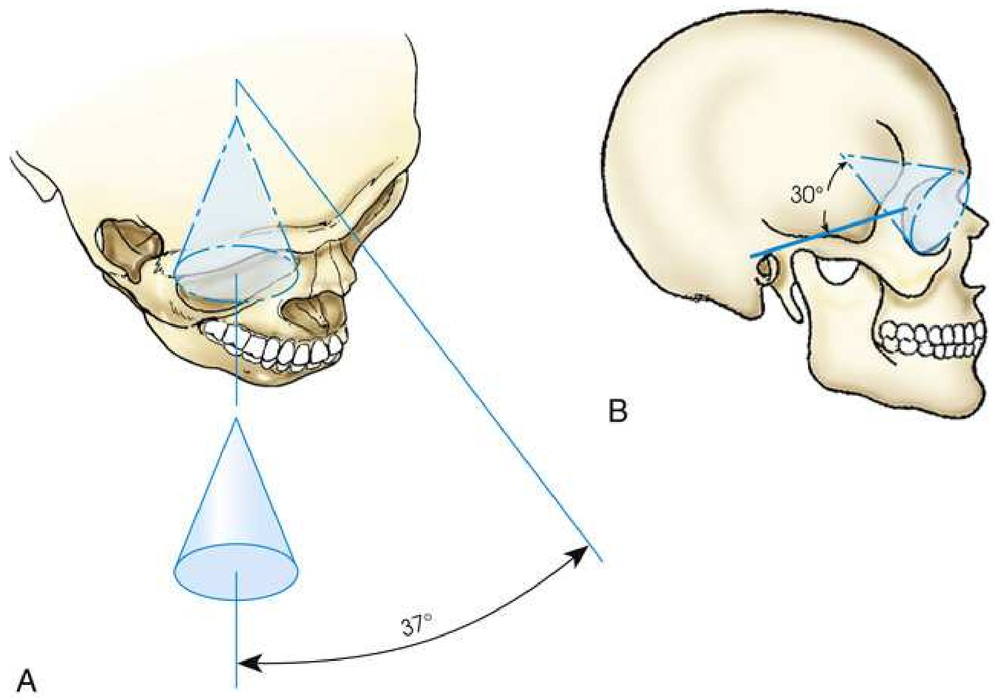


FIG. 11.88 Cone-shaped orbit. (A) Average angle of 37 degrees from midsagittal plane. (B) Average angle of 30 degrees superior to OML.

Orbit

The orbits are cone-shaped, bony-walled cavities situated on each side of the MSP of the head (Fig. 11.87). They are formed by the seven previously described and illustrated bones of the cranium (frontal, ethmoid, and sphenoid) and the face (lacrimal, palatine, maxillary, and zygomatic). Each orbit has a roof, a medial wall, a lateral wall, and a floor. The easily palpable, quadrilateral-shaped anterior circumference of the orbit is called its *base*. The *apex* of the orbit corresponds to the *optic foramen*. The long axis of each orbit is directed obliquely, posteriorly, and medially at an average angle of 37 degrees to the MSP of the head and superiorly at an angle of about 30 degrees from the OML (Fig. 11.88).

The orbits serve primarily as bony sockets for the eyeballs and the structures associated with them, but they also contain blood vessels and nerves that pass through openings in their walls to other regions. The major and frequently radiographed openings are the previously described optic foramina and the superior and inferior orbital sulci.

The *superior orbital fissure* is the cleft between the greater and lesser wings of the sphenoid bone. From the body of the sphenoid at a point near the orbital apex, this sulcus extends superiorly and laterally between the roof and the lateral wall of the orbit. The *inferior orbital fissure* is the narrow cleft extending from the lower anterolateral aspect of the sphenoid body anteriorly and laterally between the floor and lateral wall of the orbit. The anterior margin of the cleft is formed by the orbital plate of the maxilla, and its posterior margin is formed by the greater wing of the sphenoid bone and the zygomatic bone.

Because the walls of the orbits are thin, they are subject to fracture. When a person is forcibly struck squarely on the eyeball (e.g., by a fist, by a piece of sporting equipment), the resulting pressure directed to the eyeball forces the eyeball into the cone-shaped orbit and "blows out" the thin, delicate bony floor of the orbit (Figs. 11.89 and 11.90). The injury must be diagnosed and treated accurately so that the person's vision is not jeopardized. Blowout fractures may be shown radiographically using the parietoacanthial projection (Waters method) or CT.

FIG. 11.89 Parietoacanthial orbits using Waters method and showing blowout fracture of right orbit *(arrows)*.

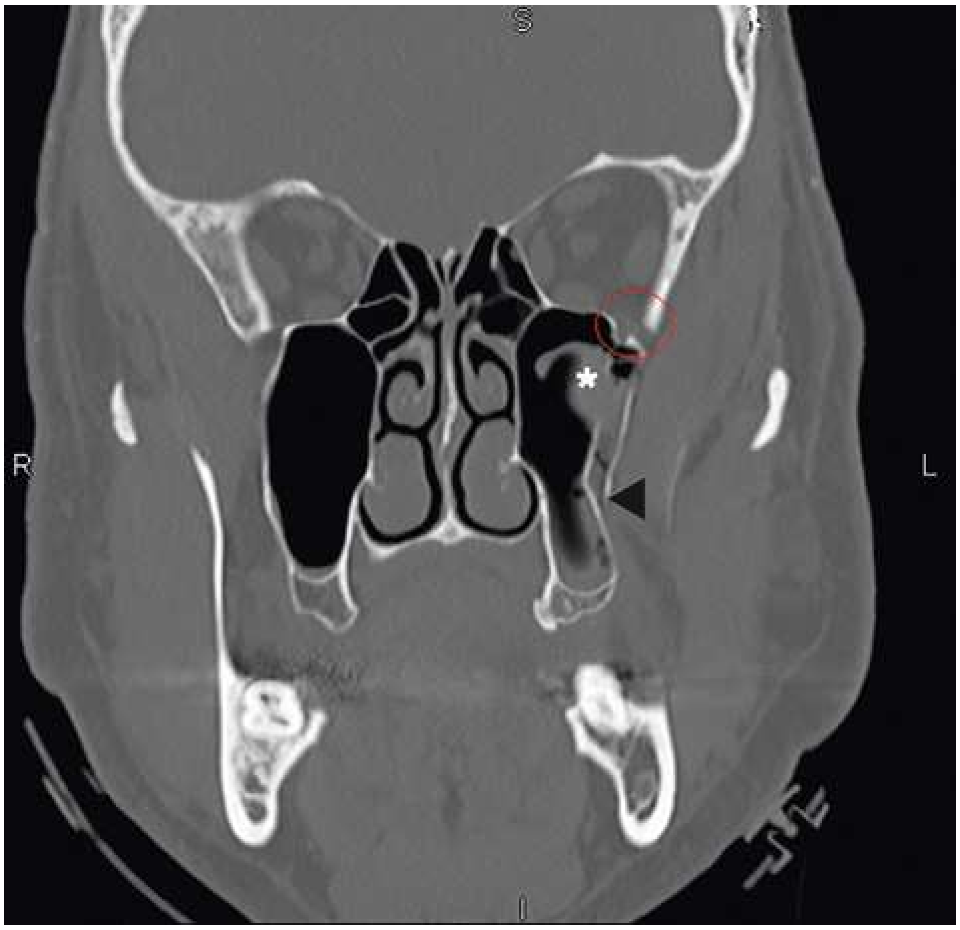


FIG. 11.90 Coronal CT of complex blowout fracture, zygoma fracture *(red circle),* and additional maxilla fracture *(arrowhead)*. Associated blood/soft tissue in maxillary sinus *(*)*. Courtesy Priscilla Rounds, RT[R], NEA Baptist Memorial Hospital, Jonesboro, AR.

Eye

The organ of vision, or eye (Latin, *oculus*; Greek, *ophthalmos*), consists of the following: eyeball; optic nerve, which connects the eyeball to the brain; blood vessels; and accessory organs such as extrinsic muscles, lacrimal apparatus, and eyelids (Figs. 11.91 and 11.92).

The *eyeball* is situated in the anterior part of the orbital cavity. Its posterior segment (about two thirds of the bulb) is adjacent to the soft parts that occupy the remainder of the orbital cavity (chiefly muscles, fat, and connective tissue). The anterior portion of the eyeball is exposed and projects beyond the base of the orbit. Bone-free radiographic images of the anterior segment of the eye can be obtained. The exposed part of the eyeball is covered by a thin mucous membrane known as the *conjunctiva*, portions of which line the eyelids. The conjunctival membrane is kept moist by tear secretions from the lacrimal gland. These secretions prevent drying and friction irritation during movements of the eyeball and eyelids.

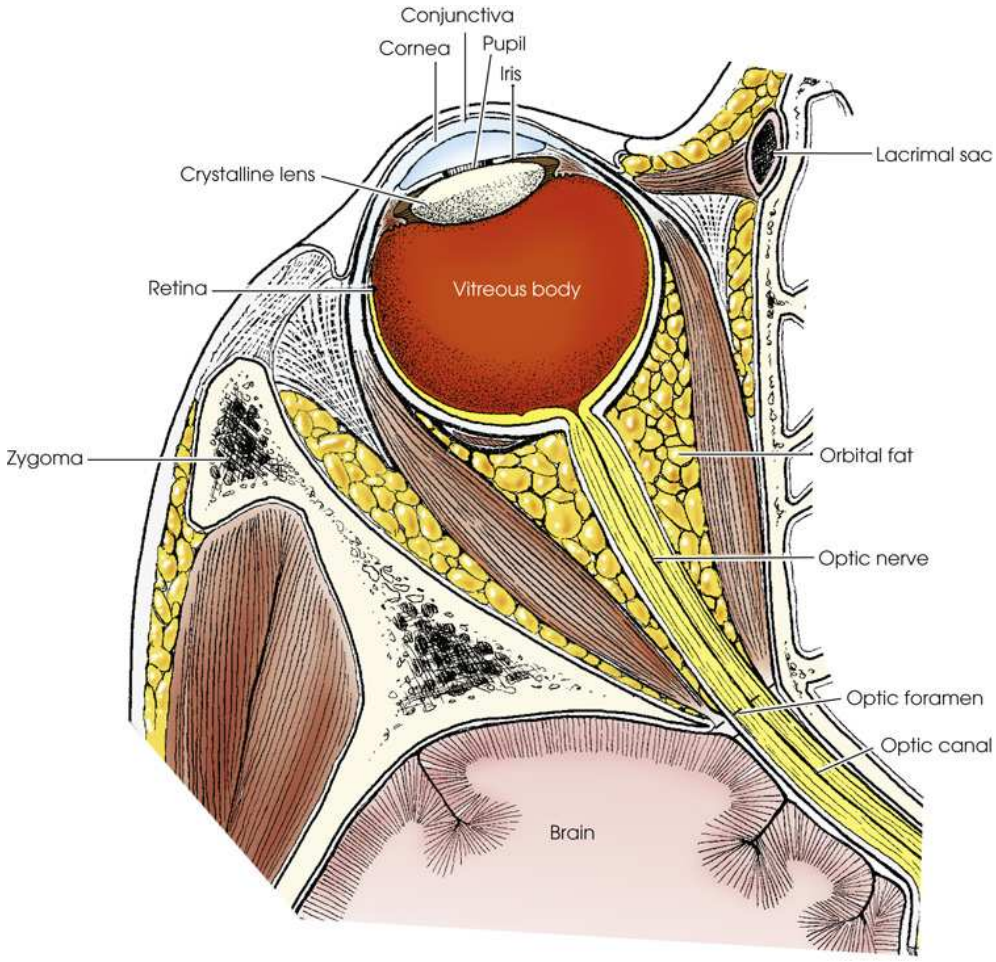


FIG. 11.91 Diagrammatic horizontal section of right orbital region: top-down view.

A horizontal section of the right orbital region. The conjunctiva, pupil, iris, cylindrical lens, vitreous body, retina, zygoma, optic nerve, optic canal, optic foramen, orbital fat, and lacrimal sac are labeled.

The outer, supporting coat of the eyeball is a firm, fibrous membrane consisting of a posterior segment called the *sclera* and an anterior segment called the *cornea*. The opaque, white sclera is commonly referred to as the "white of the eye." The cornea is situated in front of the *iris*, with its center point corresponding to the pupil. The corneal part of the membrane is transparent, allowing the passage of light into the eyeball, and it serves as one of the four refractive media of the eye.

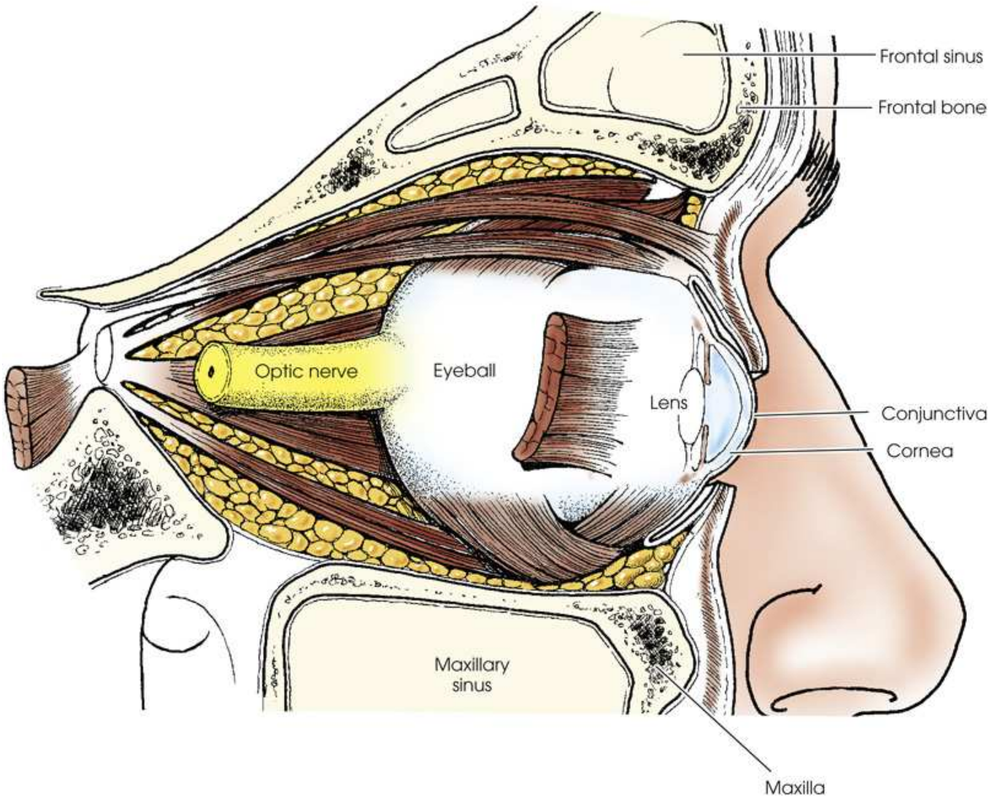


FIG. 11.92 Diagrammatic sagittal section of right orbital region.

A sagittal section of right orbital region with the forehead, nose, maxillary sinus and maxilla. The eyeball, lens, optic nerve, conjunctiva, cornea, maxilla, frontal bones with frontal sinus are labeled.

The inner coat of the eyeball is called the *retina*. This delicate membrane is contiguous with the optic nerve. The retina is composed chiefly of nervous tissue and several million minute receptor organs, called *rods* and *cones*, which transmit light impulses to the brain. The rods and cones are important radiographically because they play a role in the ability of the radiologist or radiographer to see the fluoroscopic image. Their function is described in discussions of fluoroscopy in radiography physics and imaging textbooks.

Orbits

Localization Of Foreign Bodies Within Orbit Or Eye

Ultrasonography and CT (Fig. 11.93) have been increasingly used to locate foreign bodies in the eye. (Magnetic resonance imaging [MRI] is not used for foreign body localization because movement of a metallic foreign object by the magnetic field could lead to hemorrhage or other serious complications.) Whether an ultrasound or a radiographic approach is used, accurate localization of foreign particles lodged within the orbit or eye requires the use of a precision localization technique.

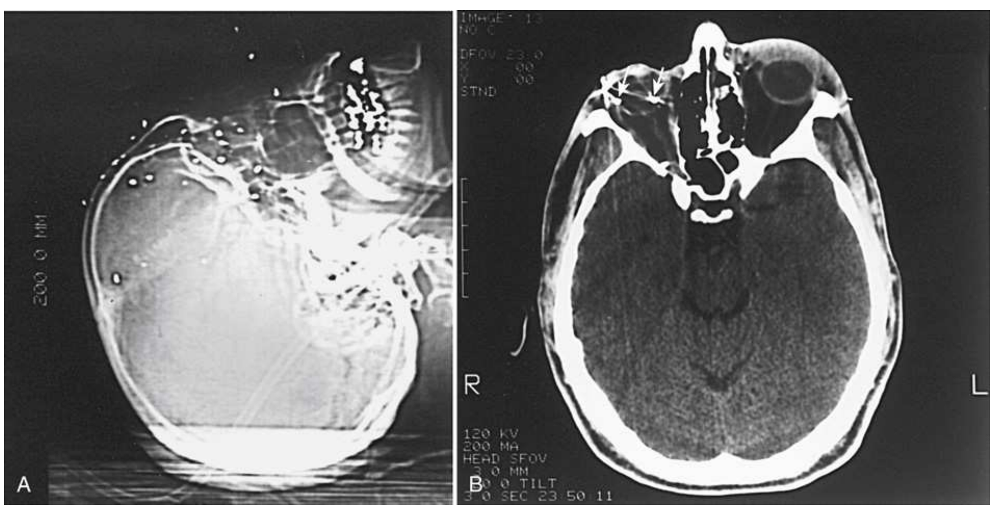


FIG. 11.93 (A) Lateral localizer CT image showing multiple buckshot in the face. (B) Axial CT image of same patient, showing shotgun pellets within the eye *(arrows)*.

Image Quality

The highest possible spatial resolution is essential for detecting and localizing minute foreign particles within the orbit or eyeball. Optimal image quality requires the following:

1. Reduce geometric unsharpness as much as possible by using minimal OID and a small focal spot at a SID that is as long as is consistent with the exposure factors required.
2. Minimize secondary radiation by close collimation.
3. Eliminate motion by firmly immobilizing the patient's head and by having the patient gaze steadily at a fixed object, immobilizing the eyeballs.
4. Minimize possibility of artifacts by thoroughly cleaning IRs just prior to imaging. An artifact can cast an image that simulates the appearance of a foreign body located within the orbit or eye.

Preliminary Examination

Lateral projections, PA projections, and bone-free studies are performed to determine whether a radiographically demonstrable foreign body is present. For these images, the patient may be placed in the recumbent position or may be seated upright before a vertical grid device. These projections may be used for metallic foreign body screening before MRI procedures are performed or to evaluate trauma to the bony orbits.

Lateral Projection

Right or left position

A nongrid technique is recommended to reduce magnification and eliminate possible artifacts in or on the radiographic table and grid. The following steps are taken:

- Position patient in an upright or recumbent anterior oblique position and place the outer canthus of the affected eye adjacent to and centered over the midpoint of the IR.
- Adjust the patient's head to place the MSP parallel with the plane of the IR and the IPL perpendicular to the IR plane. Adjust neck flexion to place IOML perpendicular to the front IR edge.
- *Respiration* Suspend.

Central ray

- Perpendicular through the outer canthus.
- Instruct the patient to look straight ahead for the exposure (Figs. 11.94 and 11.95).

Evaluation Criteria

The following should be clearly shown:

n Entire orbit(s)
n No rotation, demonstrated by:
  - Superimposed orbital roofs
n Close beam restriction centered to orbital region
n Bony orbit and soft tissues of the eye for localization of foreign bodies

FIG. 11.94 Lateral projection for orbital foreign body localization.

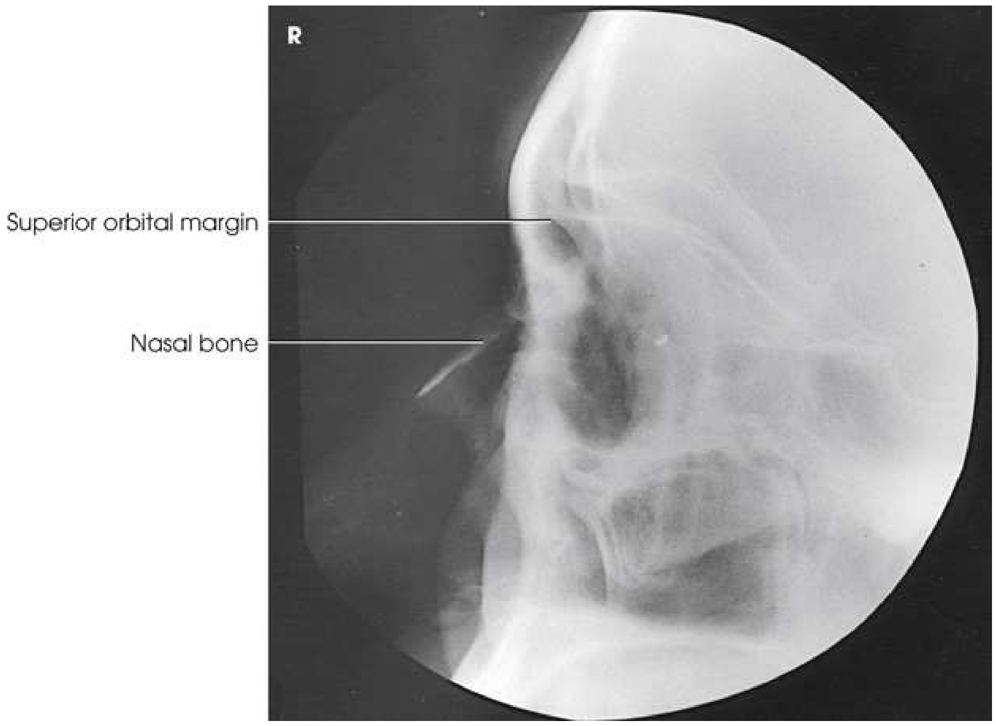


FIG. 11.95 Lateral projection showing foreign body *(white speck)*.

FIG. 11.96 PA axial projection for orbital foreign body localization.

FIG. 11.97 PA axial projection showing foreign body *(arrow)* in the right eye.

An X-ray of the axial projection of skull. The maxilla, nasal bones, frontal bones, glabella, teeth, mandible, and orbit are visible. An arrow indicates a small foreign object lodged in the right eye.

Pa Axial Projection

A nongrid (very high resolution) technique is recommended to reduce magnification and eliminate possible artifacts in or on the radiographic table and grid. The following steps are taken:

- Rest the patient's forehead and nose on the IR and center the IR ¾ inch (1.9 cm) distal to the nasion.
- Adjust the patient's head so that the MSP and OML are perpendicular to the plane of the IR.
- *Respiration:* Suspend.

Central ray

- Directed through the center of the orbits at a caudal angulation of 30 degrees. This angulation is used to project the petrous portions of the temporal bones below the inferior margin of the orbits (Figs. 11.96 and 11.97).
- Instruct the patient to close the eyes and to concentrate on holding them still for the exposure.

Evaluation Criteria

The following should be clearly shown:

n Entire orbit(s)
n Petrous pyramids lying below orbital shadows
n No rotation of cranium, demonstrated by:
  ▫ Symmetric visualization of the orbits
n Close beam restriction centered to orbital region
n Bony details of orbit and soft tissues of the eye for localization of foreign bodies

Parietoacanthial Projection

Modified Waters Method

Some physicians prefer to have the PA projection performed with the patient's head adjusted in a modified Waters position so that the petrous margins are displaced by part adjustment rather than by central ray angulation. The following steps are taken:

- With the IR centered at the level of the center of the orbits, rest the patient's chin on the IR holder.
- Adjust the patient's head so that the MSP is perpendicular to the plane of the IR.
- Adjust the flexion of the patient's neck so that the OML forms an angle of 50 degrees with the plane of the IR.
- *Respiration:* Suspend.

Central ray

- Perpendicular through the mid-orbits (Figs. 11.98 and 11.99).
- Instruct the patient to close the eyes and to concentrate on holding them still for the exposure.

Evaluation Criteria

The following should be clearly shown:

n Entire orbit(s)
n Petrous pyramids lying well below orbital shadows
n No rotation, demonstrated by:
  ▫ Symmetric visualization of orbits
n Close beam restriction centered to the orbital region
n Bony orbit and soft tissues of the eye for localization of foreign bodies

FIG. 11.98 Parietoacanthial projection, modified Waters method, for orbital foreign body localization.

A patient lies face down on an X-ray table, with the forehead rested on the image receptor. The head is tilted slightly upwards. The central ray is directed at a 30 degrees angle at the back of the head.

FIG. 11.99 Parietoacanthial projection, modified Waters method, showing foreign body *(arrow)*.

An X-ray of the axial projection of skull. The maxilla, nasal bones, frontal bones, glabella, teeth, mandible, and orbit are visible. An arrow indicates a small foreign object lodged in the right eye.

Facial Bone Radiography

Facial Bones

Lateral Projection

Right or left position

Image receptor + grid: Positioned by manufacturer or department protocol for proper anatomy display orientation; CR plate: 10 × 12 inches (24 × 30 cm) lengthwise.

Position of patient

- Place the patient in a recumbent anterior oblique or seated anterior oblique position before a vertical grid device. This is the same basic position that is used for the lateral skull position.

Position of part

- Adjust the patient's head so that MSP is parallel with the IR and the IPL is perpendicular to the IR.
- Adjust the flexion of the patient's neck so that the IOML is perpendicular to the front edge of the IR (Figs. 11.100–11.102).
- Immobilize the head.
- *Respiration:* Suspend.

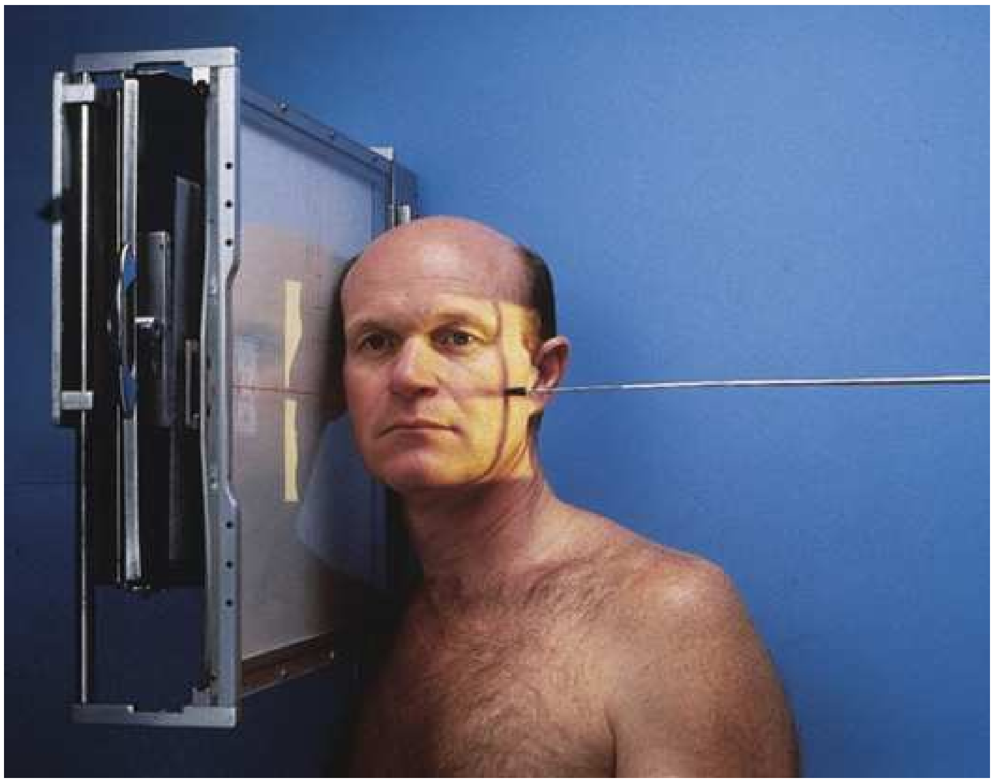


FIG. 11.100 Lateral facial bones.

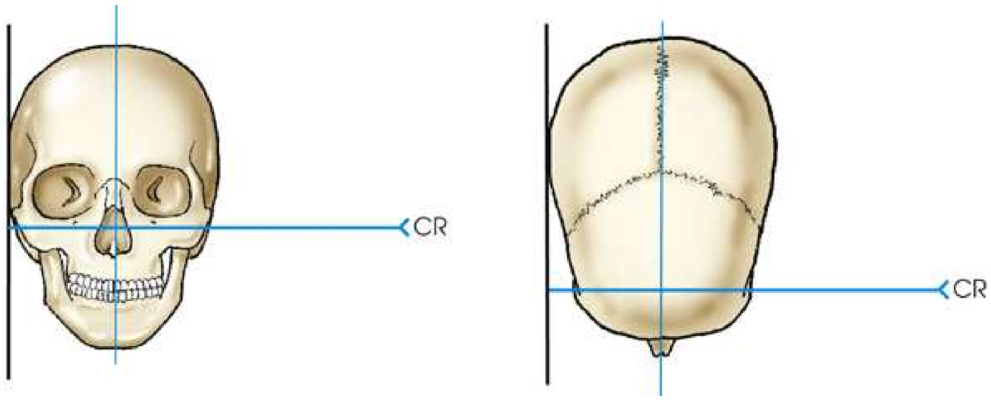


FIG. 11.101 Upright radiography diagram: lateral facial bones.

The anterior and posterior positions of the skull adjacent to an imaging receptor. The central ray passes through the nasal bone ins anterior position and passes through the jaws in the posterior position.

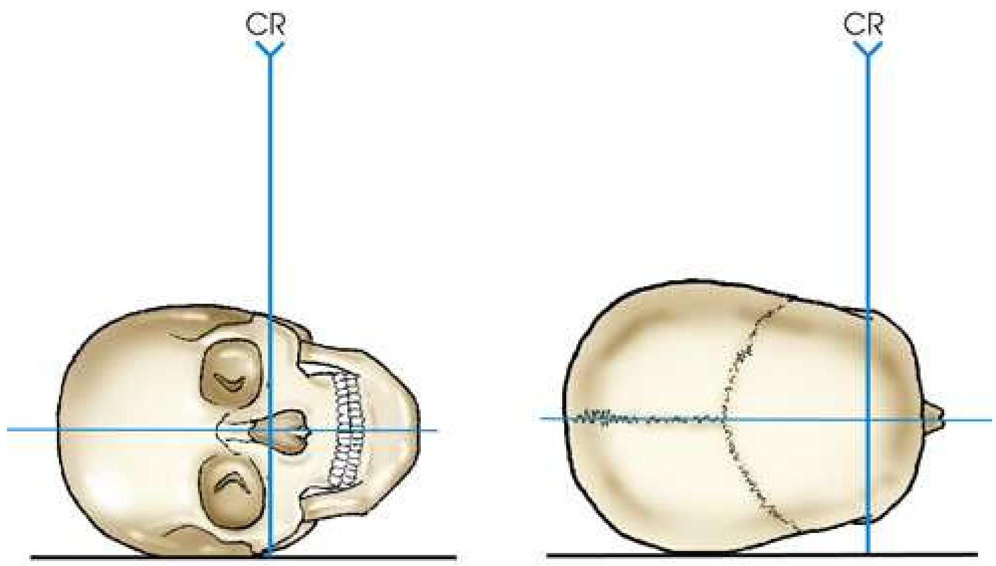


FIG. 11.102 Table radiography diagram: lateral facial bones.

The anterior and posterior positions of the skull lying on an imaging receptor. The central ray passes through the nasal bone ins anterior position and passes through the jaws in the posterior position.

Central ray

- Perpendicular and entering the lateral surface of the zygomatic bone halfway between the outer canthus and the EAM.
- Center IR to the central ray.

Collimation

- Adjust radiation field to extend 1 inch (2.5 cm) beyond the shadow of the tip of the nose, superiorly to 1 inch (2.5 cm) above the supraorbital margins, inferiorly to the gonion, and posteriorly to the EAM. The exposure field should be set no larger than 6 × 10 inches (15 × 24 cm). Place the side marker in the collimated exposure field.

Structures shown

A lateral image of the bones of the face, with the right and left sides superimposed (Fig. 11.103).

Evaluation Criteria

The following should be clearly seen:

- n Evidence of proper collimation and presence of the side marker placed clear of anatomy of interest
- n All facial bones in their entirety, with the zygomatic bone in the center
- n No rotation or tilt of the facial bones, demonstrated by:
  - Almost perfectly superimposed mandibular rami
  - Superimposed orbital roofs
  - Sella turcica in profile

n Soft tissue and bony trabecular detail

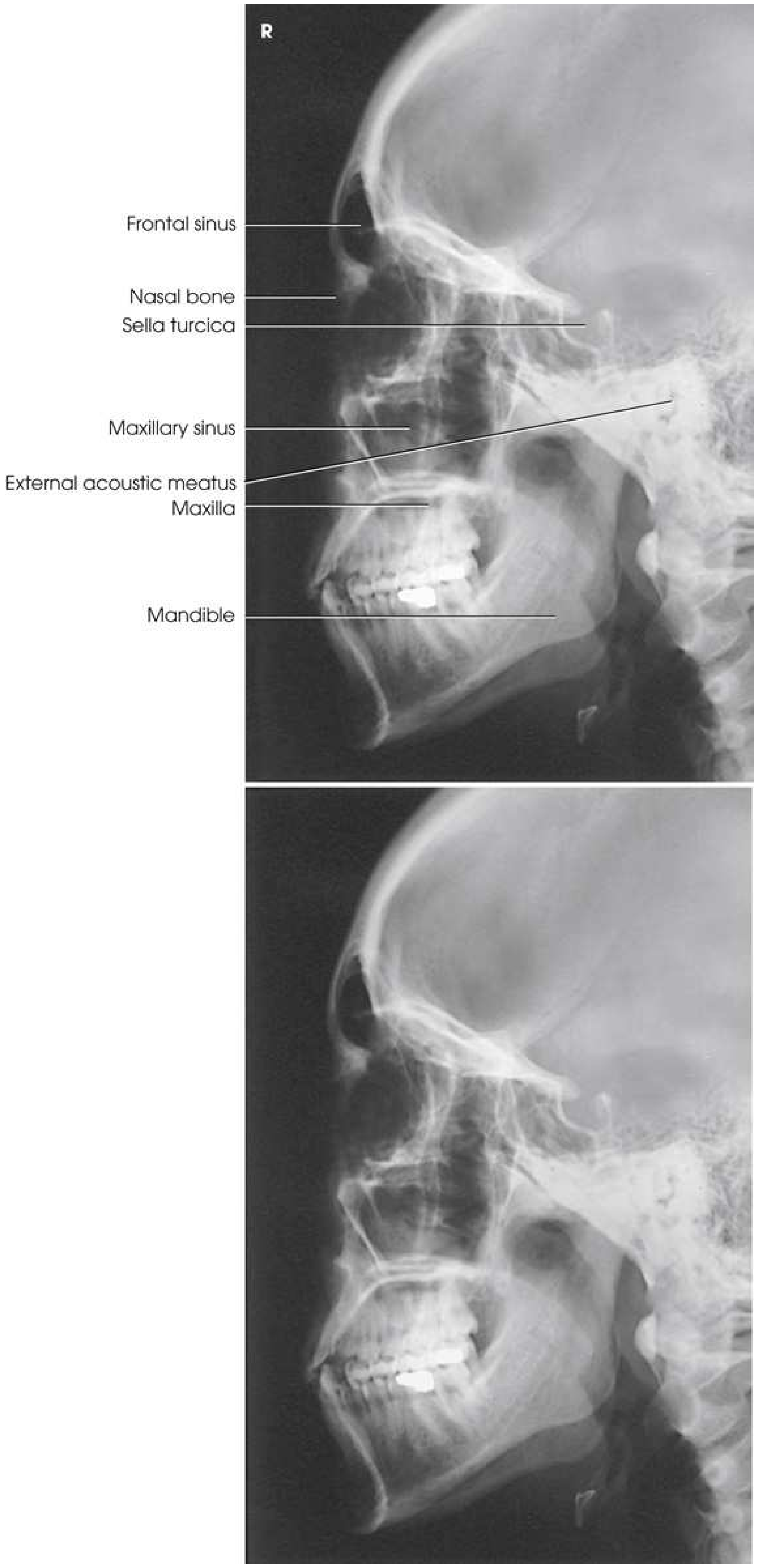


FIG. 11.103 Lateral facial bones.

Two X-ray images of lateral facial bones. The frontal bones, maxilla, teeth, nasal bones are visible. The Frontal sinus, Nasal bone, Sella turcica, Maxillary sinus, External acoustic meatus, Maxilla, and Mandible are labeled in the first one.

Parietoacanthial Projection

Waters Method [9]

Image receptor + grid: Positioned by manufacturer or department protocol for proper anatomy display orientation; CR plate: 10 × 12 inches (24 × 30 cm) lengthwise.

Position of patient

- Place the patient in the prone or seated-upright position.
- Center MSP of the patient's body to the midline of the grid device.

Position of part

- Rest the patient's head on the tip of the extended chin. Hyperextend the neck so that the OML forms a 37-degree angle with the plane of the IR.
- The MML is approximately perpendicular to the plane of the IR; the average patient's nose is about ¾ inch (1.9 cm) away from the grid device.
- Adjust the head so that MSP is perpendicular to the plane of the IR (Figs. 11.104–11.106).
- Center the IR at the level of the acanthion.
- Immobilize the head.
- *Respiration:* Suspend.

Central ray

- Perpendicular to exit the acanthion

Collimation

- Adjust the radiation field to 1 inch (2.5 cm) beyond the shadows of the lateral sides of the face, superiorly to include the supraorbital margins and inferiorly to the level of the chin. The exposure field should be no larger than 8 × 10 inches (18 × 24 cm). Place the side marker in the collimated exposure field.

Structures shown

The orbits, maxillae, and zygomatic arches (Fig. 11.107).

Evaluation Criteria

The following should be clearly seen:

n Evidence of proper collimation and presence of the side marker placed clear of anatomy of interest
n Entire orbits and facial bones
n No rotation or tilt, demonstrated by:
- Distances between the lateral borders of the skull and the orbits equal on each side
- MSP of head aligned with long axis of collimated field

n Petrous ridges projected immediately below maxillary sinuses
n Soft tissue and bony trabecular detail

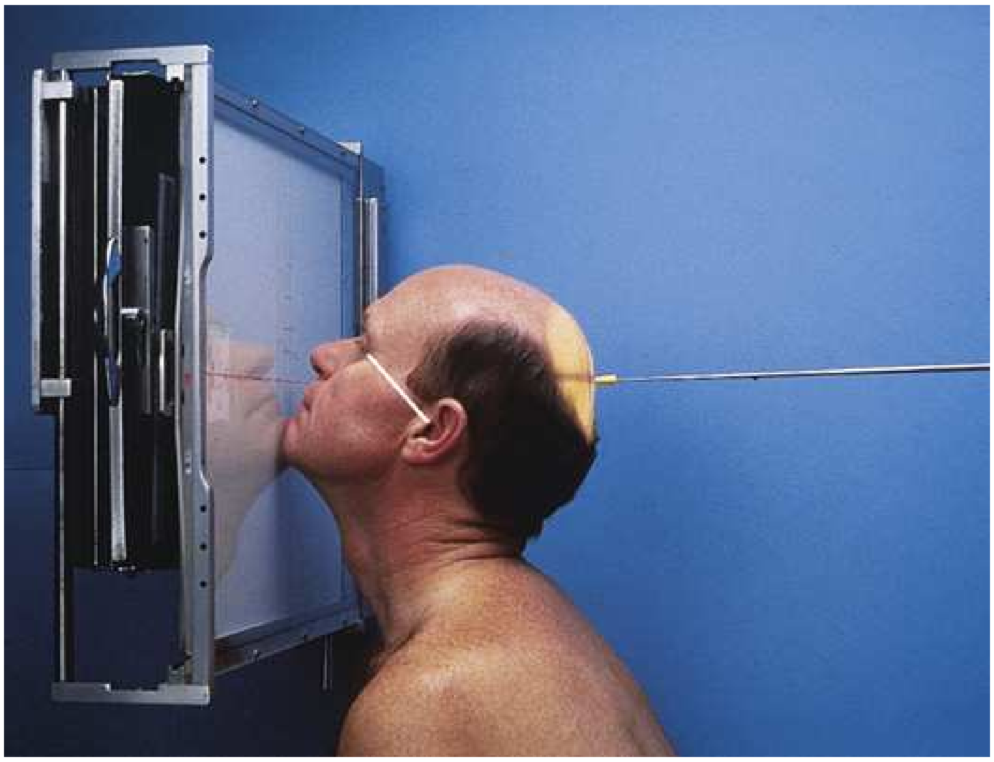


FIG. 11.104 Parietoacanthial facial bones: Waters method.

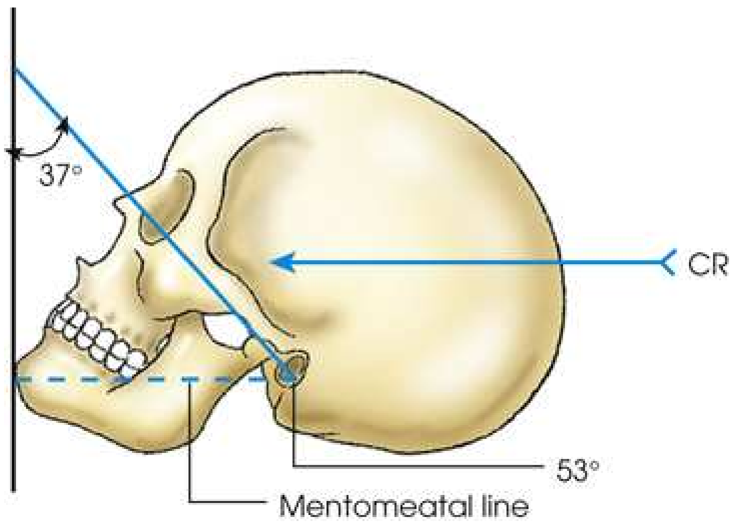


FIG. 11.105 Upright radiography diagram: parietoacanthial facial bones: Waters method.

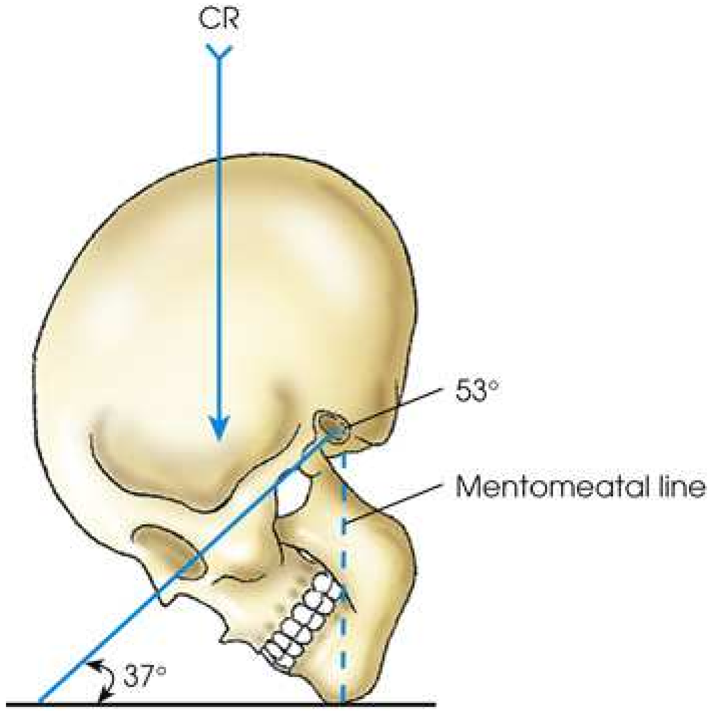


FIG. 11.106 Table radiography diagram: parietoacanthial facial bones: Waters method.

FIG. 11.107 Parietoacanthial facial bones: Waters method. Courtesy St. Bernard's Medical Center, Jonesboro, AR.

FIG. 11.108 Modified parietoacanthial facial bones: modified Waters method.

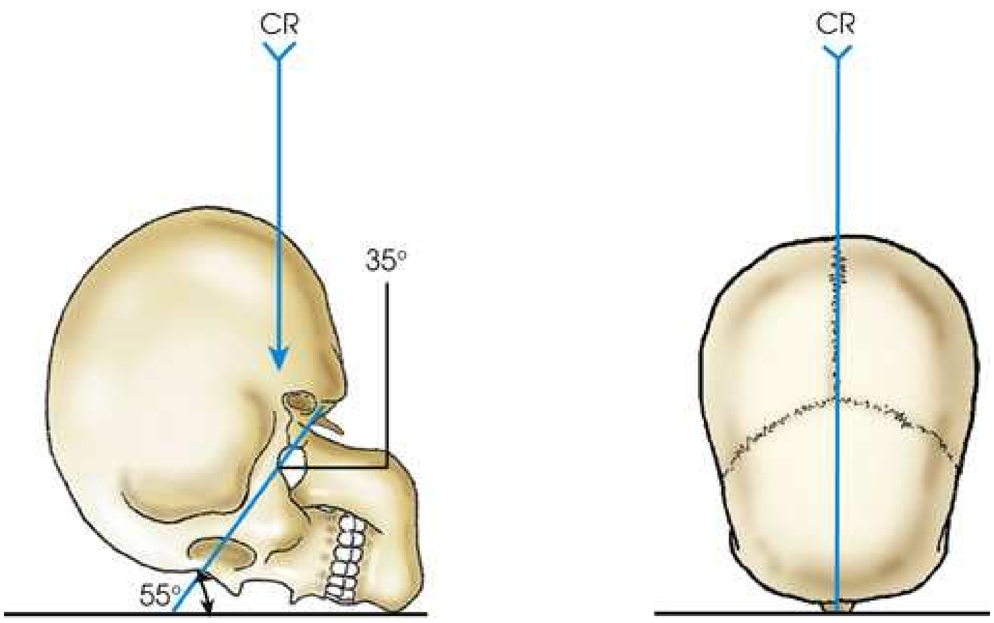


FIG. 11.109 Table radiography diagram, modified parietoacanthial facial bones: modified Waters method with OML adjusted to 55 degrees.

The anterior and posterior positions of the skull lying on an imaging receptor. The skull is facing the receptor. The central ray is directed towards the nasal bone in anterior position and it is directed towards the axis of the skull in posterior position.

Modified Parietoacanthial Projection

Modified Waters Method

Although the parietoacanthial projection (Waters method) is widely used, many institutions modify the projection by radiographing the patient using less extension of the patient's neck. This modification, although sometimes called a "shallow" Waters, actually increases the angulation of the OML by placing it more perpendicular to the plane of the IR. The patient's head is positioned as described using the Waters method, but the neck is extended to a lesser degree. In the modification, the OML is adjusted to form an approximately 55-degree angle with the plane of the IR (Figs. 11.108–11.110). The resulting radiographic image shows the facial bones with less axial angulation than with the Waters method (see Fig. 11.107). With the modified Waters method, the petrous ridges are projected immediately below the inferior border of the orbits at a level midway through the maxillary sinuses (Fig. 11.111).

The modified Waters method is a good projection to show blowout fractures. This method places the orbital floor perpendicular to the IR and parallel to the central ray, showing inferior displacement of the orbital floor and the commonly associated opacified maxillary sinus.

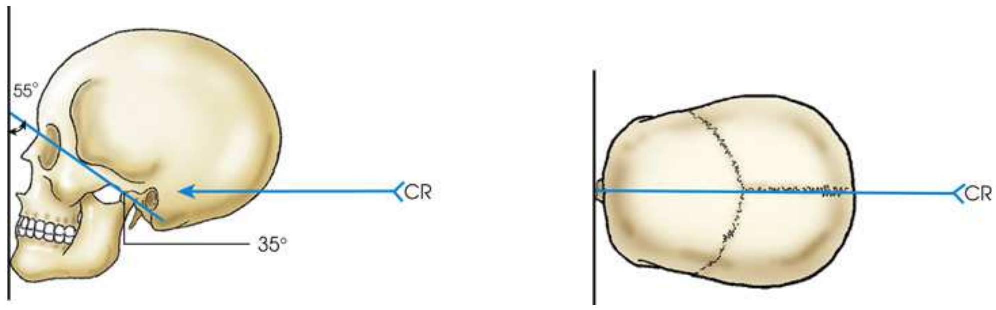


FIG. 11.110 Upright radiography diagram, modified parietoacanthial facial bones: modified Waters method with OML adjusted to 55 degrees.

The anterior and posterior positions of the skull lying facing an imaging receptor adjacent to it. The central ray is directed towards the nasal bone in anterior position and it is directed towards the axis of the skull in posterior position.

FIG. 11.111 Modified parietoacanthial facial bones: modified Waters method.

Two radiographs of the axial projection of the skull showing parietoacanthial facial bones. The Inferior orbital margin, Maxillary sinus, Zygomatic bone, Petrous ridge, Nasal septum, and Mandible are labeled on the first image.

Acanthioparietal Projection

Reverse Waters Method

Image receptor + grid: Positioned by manufacturer or department protocol for proper anatomy display orientation; CR plate: 10 × 12 inches (24 × 30 cm) lengthwise.

The *reverse* Waters method is used to show the facial bones when the patient cannot be placed in the prone position. (See the sections on the trauma method in Chapter 12, p. 142.)

Position of patient

- With the patient in the supine position, center MSP of the body to the midline of the grid.

Position of part

- Bringing the patient's chin up, adjust the extension of the neck so that the OML forms a 37-degree angle with the plane of the IR (Fig. 11.112). If necessary, place a support under the patient's shoulders to help extend the neck.

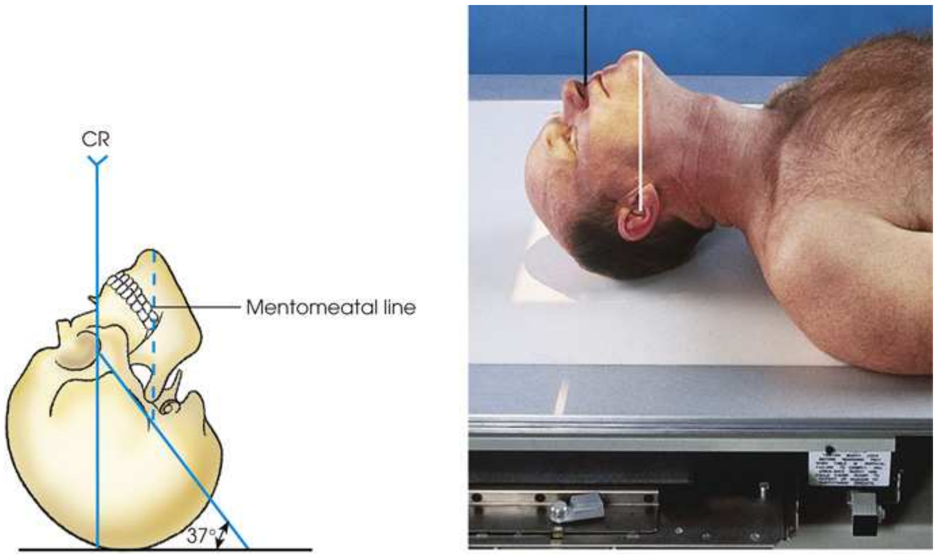


FIG. 11.112 Table radiography. Acanthioparietal facial bones: reverse Waters method with neck extended. MML is perpendicular to IR.

An illustration and a photo of a patient lying on an X-ray table with his head tilted upwards. The illustration depicts the position of the skull of the patient. The central ray enters the nasal cavity.

- The MML is approximately perpendicular to the plane of the IR.
- Adjust the head so that MSP is perpendicular to the plane of the IR.
- Immobilize the head.
- *Respiration:* Suspend.

Central ray

- Perpendicular to enter the acanthion and centered to the IR

Collimation

- Adjust the radiation field to extend about 1 inch (2.5 cm) beyond the lateral sides of the face, superiorly just to the skin shadow, and inferiorly to the chin. The exposure field should be no larger than 8 × 10 inches (18 × 24 cm). Place the side marker in the collimated exposure field.

Structures shown

The *reverse* Waters method shows the superior facial bones. The image is similar to that obtained with the Waters method, but the facial structures are considerably magnified (Fig. 11.113).

Evaluation Criteria

The following should be clearly seen:

n Evidence of proper collimation and presence of the side marker placed clear of anatomy of interest
n Entire orbits and facial bones
n No rotation or tilt, demonstrated by:
  ▫ Distances between lateral borders of the skull and orbits equal on each side
  ▫ MSP of head aligned with long axis of collimated field
n Petrous ridges projected below maxillary sinuses
n Soft tissue and bony trabecular detail

Alternative Acanthioparietal Projection

Many patients, including those being evaluated for acute injury, are often unable to hyperextend the neck far enough to place the OML 37 degrees to the IR and the MML perpendicular to the plane of the IR. In these patients, the acanthioparietal projection, or the reverse Waters projection, can be achieved by adjusting the central ray so that it enters the acanthion while remaining parallel with the MML (Fig. 11.114).

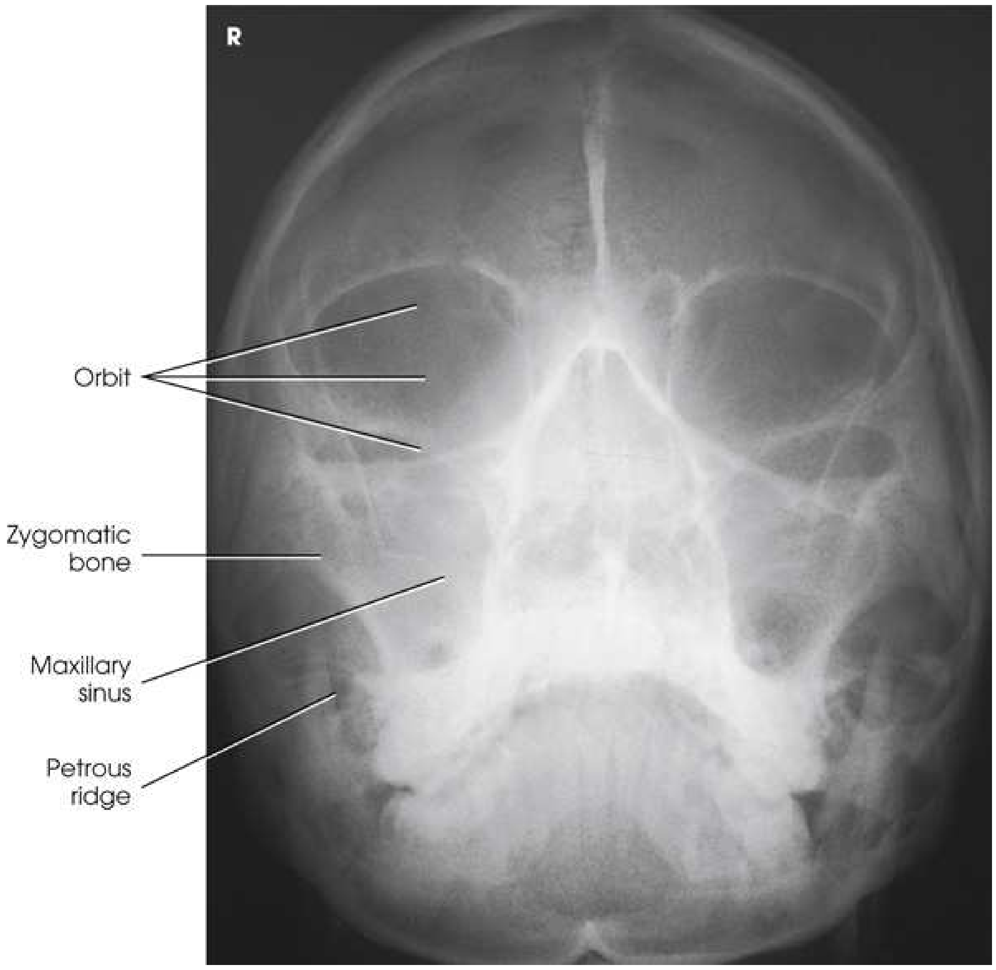


FIG. 11.113 Acanthioparietal facial bones: reverse Waters method.

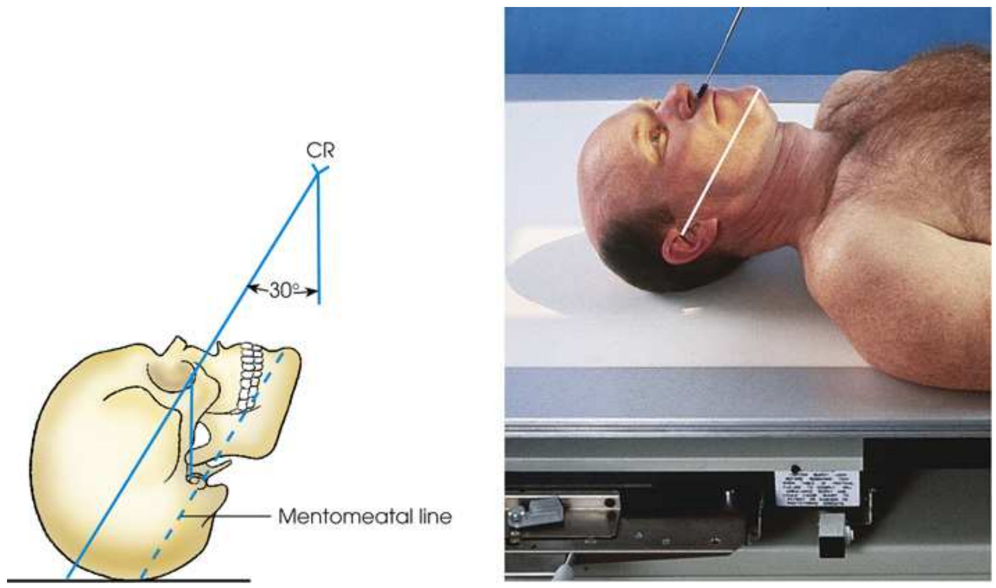


FIG. 11.114 Table radiography. Acanthioparietal facial bones: reverse Waters method with the CR parallel to MML.

An illustration and a photo of a patient lying on an X-ray table. The illustration depicts the position of the skull of the patient. The central ray enters the nasal cavity at an angle from the vertical below the skull.

Pa Axial Projection

Caldwell Method

Image receptor + grid: Positioned by manufacturer or department protocol for proper anatomy display orientation; CR plate: 10 × 12 inches (24 × 30 cm) lengthwise.

Position of patient

• Place the patient in a prone or a seated position.
• Center MSP of the patient's body to the midline of the grid.
• Rest the patient's forehead and nose on the table or against the upright bucky.
• Flex the patient's elbows, and place the arms in a comfortable position.

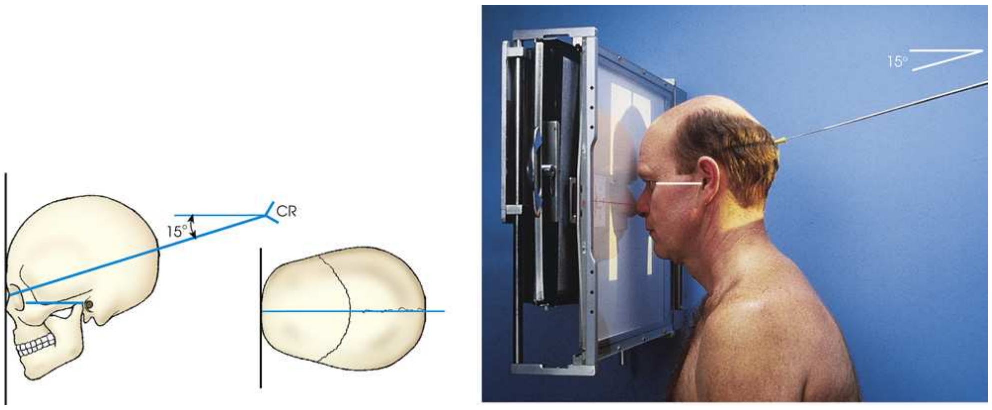


FIG. 11.115 Upright radiography, PA axial facial bones: Caldwell method.

Position of part

• Adjust the flexion of the patient's neck so that the OML is perpendicular to the plane of the IR.
• If the patient is obese or hypersthenic, a small radiolucent sponge may need to be placed in front of the forehead.
• Align MSP of the head perpendicular to the IR by adjusting the lateral margins of the orbits or the EAM equidistant from the tabletop.
• Immobilize the head, and center the IR to the nasion (Fig. 11.115).
• *Respiration:* Suspend.

Central ray

• Direct the central ray to exit the nasion at an angle of 15 degrees caudad.
• To show the orbital rims, in particular, the orbital floors, use a 30-degree caudal angle (sometimes referred to as the *exaggerated Caldwell*).
• Center the IR to the central ray.

Collimation

• Adjust the radiation field to extend about 1 inch (2.5 cm) beyond the lateral sides of the face, superiorly to include the supraorbital margins, and inferiorly to the chin. The exposure field should be no larger than 8 × 10 inches (18 × 24 cm). Place the side marker in the collimated exposure field.

Structures shown

The orbital rims, maxillae, nasal septum, zygomatic bones, and anterior nasal spine. When the central ray is angled 15 degrees caudad to the nasion, the petrous ridges are projected into the lower third of the orbits (Fig. 11.116). When the central ray is angled 30 degrees caudad, the petrous ridges are projected below the inferior margins of the orbits.

Evaluation Criteria

The following should be clearly seen:

n Evidence of proper collimation and presence of the side marker placed clear of anatomy of interest
n Entire orbits and facial bones
n No rotation or tilt, demonstrated by:
  ▫ Equal distances from lateral borders of skull to lateral borders of orbits on both sides
  ▫ MSP of head aligned with long axis of collimated field
n Symmetric petrous ridges lying in lower third of orbit
n Bony detail and surrounding soft tissues

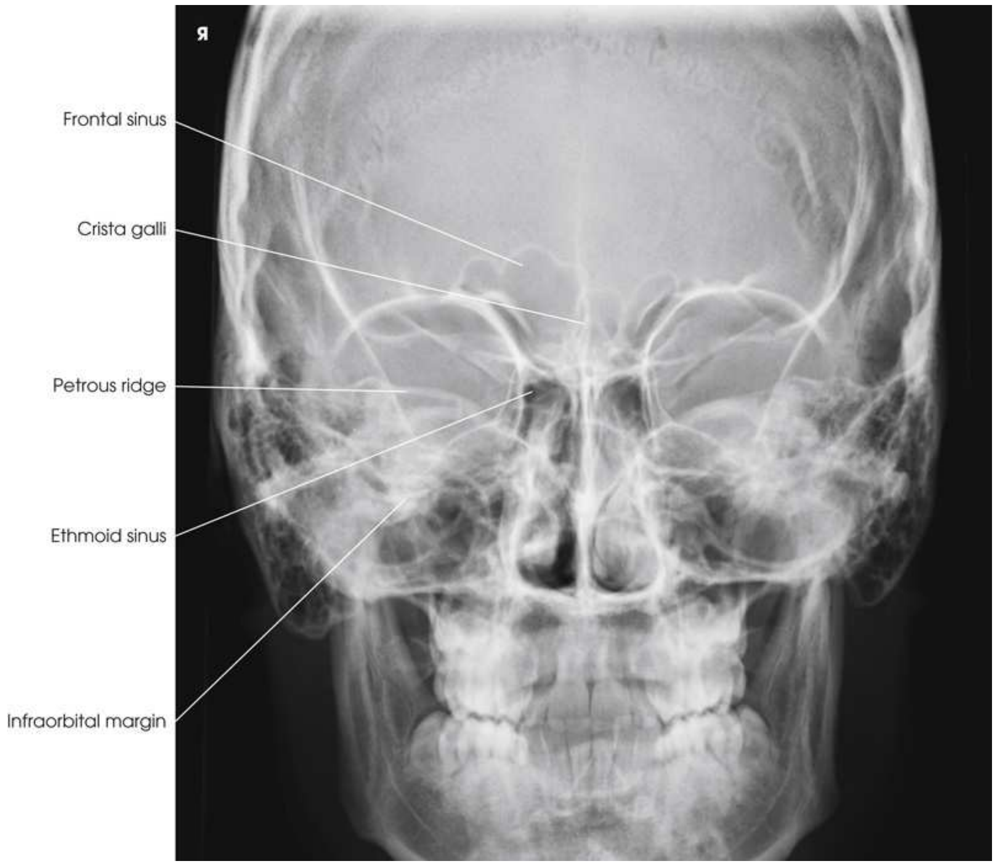


FIG. 11.116 PA axial facial bones: Caldwell method. Courtesy St. Bernard's Medical Center, Jonesboro, AR.

Nasal Bones

Lateral Projection

Right and left positions

Image receptor: Positioned by manufacturer or department protocol for proper anatomy display orientation; CR plate: 10 × 12 inches (24 × 30 cm), crosswise for two exposures on one IR.

Position of patient

- With the patient in a recumbent or upright anterior oblique position, adjust the rotation of the body so that MSP of the head can be placed horizontally.

Position of part

- Adjust the head so that MSP is parallel with the tabletop and the IPL is perpendicular to the tabletop.
- Adjust the flexion of the patient's neck so that the IOML is parallel with the transverse axis of the IR (Figs. 11.117 and 11.118).
- Support the mandible to prevent rotation.
- *Respiration:* Suspend.

Placement of image receptor

- When using a crosswise IR, slide the unmasked half of the IR under the frontonasal region and center it to the nasion (see Fig. 11.117). This centering allows space for the identification marker to be projected across the upper part of the IR. Tape the side marker (R or L) in position.

FIG. 11.117 Lateral nasal bones.

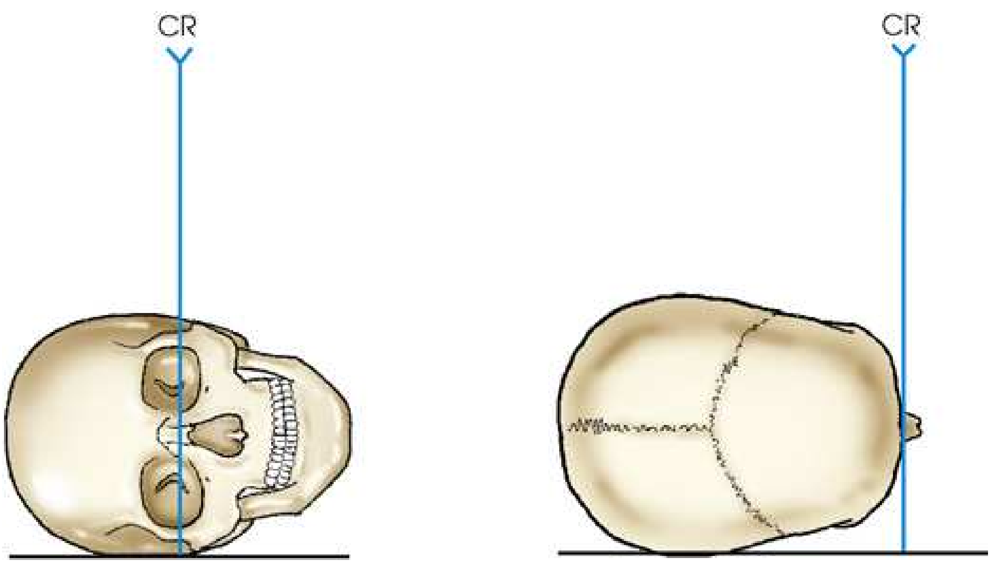


FIG. 11.118 Table radiography diagram: lateral nasal bones.

The anterior and posterior view of the human skull. The central ray is directed through the temporal bones in the anterior position. It is directed through the right extreme in the posterior position.

Central ray

- Perpendicular to the bridge of the nose at a point 1 inch (2.5 cm) distal to the nasion (see Fig. 11.118).

Collimation

- Adjust the radiation field to extend from the glabella to 1 inch (2.5 cm) inferior to the acanthion and 1 inch (2.5 cm) beyond the tip of the nose. The exposure field should be no larger than 3 × 3 inches (8 × 8 cm). Place the side marker in the collimated exposure field.

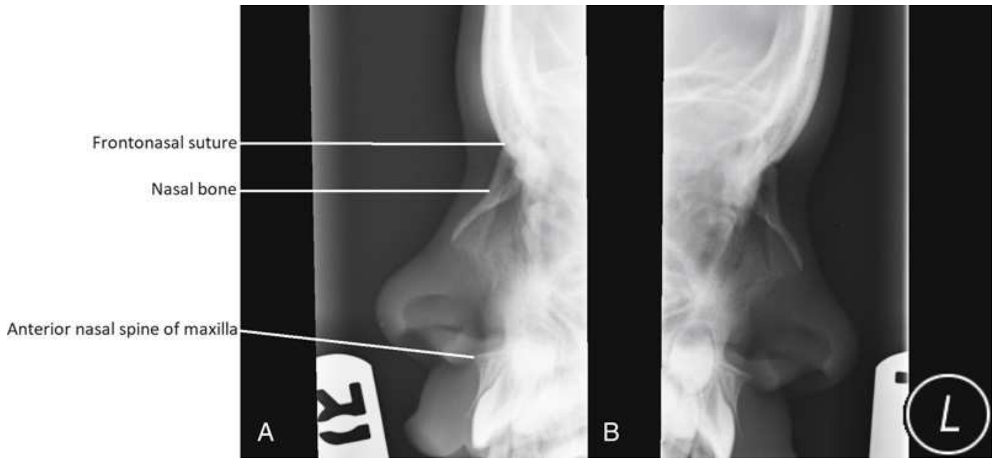


FIG. 11.119 Nasal bones. (A) Right lateral. (B) Left lateral. Courtesy St. Bernard's Medical Center, Jonesboro, AR.

Structures shown

Nasal bone and soft tissues of the nose closer to the IR (Fig. 11.119). Both sides are examined for comparison.

Evaluation Criteria

The following should be clearly seen:

- Evidence of proper collimation and presence of the side marker placed clear of anatomy of interest
- Nasal bones, anterior nasal spine, and frontonasal suture
- No rotation of nasal bones and soft tissue
- Soft tissue and bony trabecular detail

Zygomatic Arches

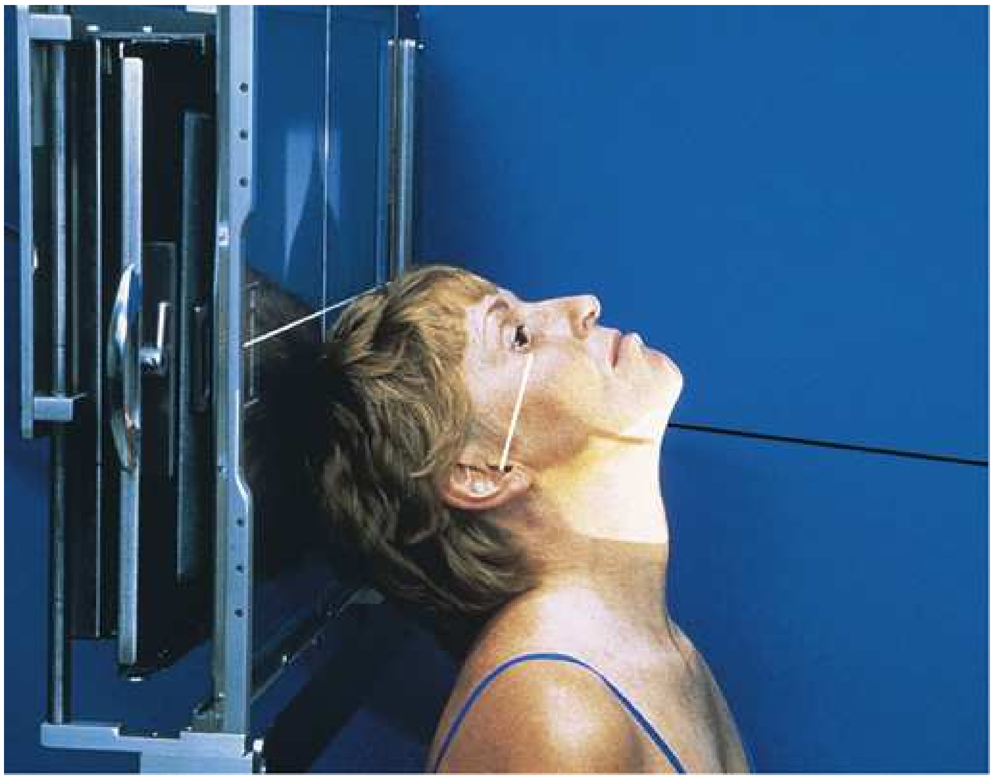


FIG. 11.120 SMV zygomatic arches, patient upright.

A patient stands with the back of her head against the image receptor and tilts her head up against the image receptor. The top of her head touches the receptor. The central ray is directed towards the throat.

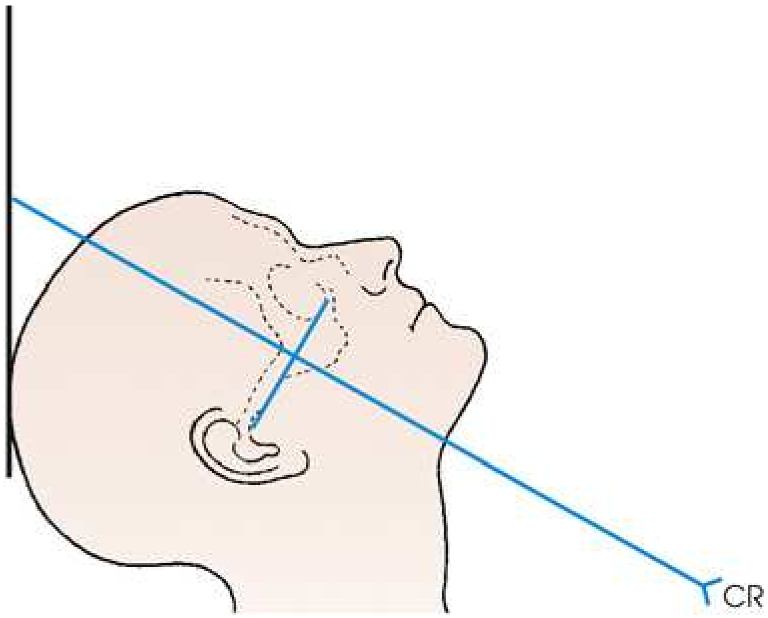


FIG. 11.121 Upright radiography diagram: SMV zygomatic arches.

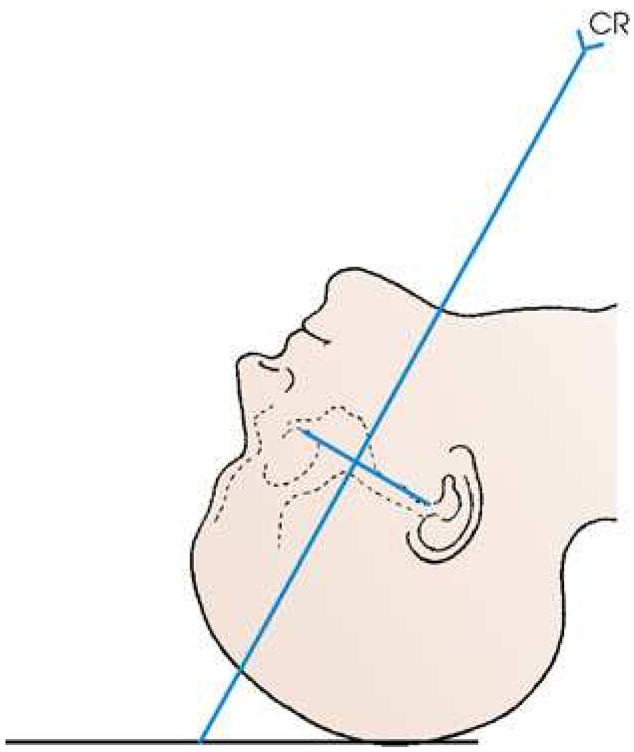


FIG. 11.122 Table radiography diagram: SMV zygomatic arches.

Submentovertical Projection

This projection is similar to the SMV projection described in the Skull Radiography section.

Image receptor + grid: Positioned by manufacturer or department protocol for proper anatomy display orientation; CR plate: 10 × 12 inches (24 × 30 cm) crosswise.

Position of patient

- Place the patient in a seated upright or supine position.
- When the supine position is used, elevate the patient's trunk on several firm pillows or a suitable pad to allow complete extension of the neck. Flex the patient's knees to relax the abdominal muscles.
- Center MSP of the patient's body to the midline of the grid device.

Position of part

- Hyperextend the patient's neck completely so that the IOML is as parallel with the plane of the IR as possible.
- Rest the patient's head on its vertex, and adjust the head so that MSP is perpendicular to the plane of the IR (Figs. 11.120–11.122).
- *Respiration:* Suspend.

Central ray

- Perpendicular to the IOML and entering MSP of the throat at a level approximately 1 inch (2.5 cm) posterior to the outer canthi.
- Center the IR to the central ray.

Collimation

- Adjust radiation field to extend 1 inch (2.5 cm) beyond the lateral sides of the face, superiorly to the chin, and inferiorly to the gonions. The exposure field should be no larger than 10 inches (24 cm) wide and 8 inches (18 cm) long. Place the side marker in the collimated exposure field.

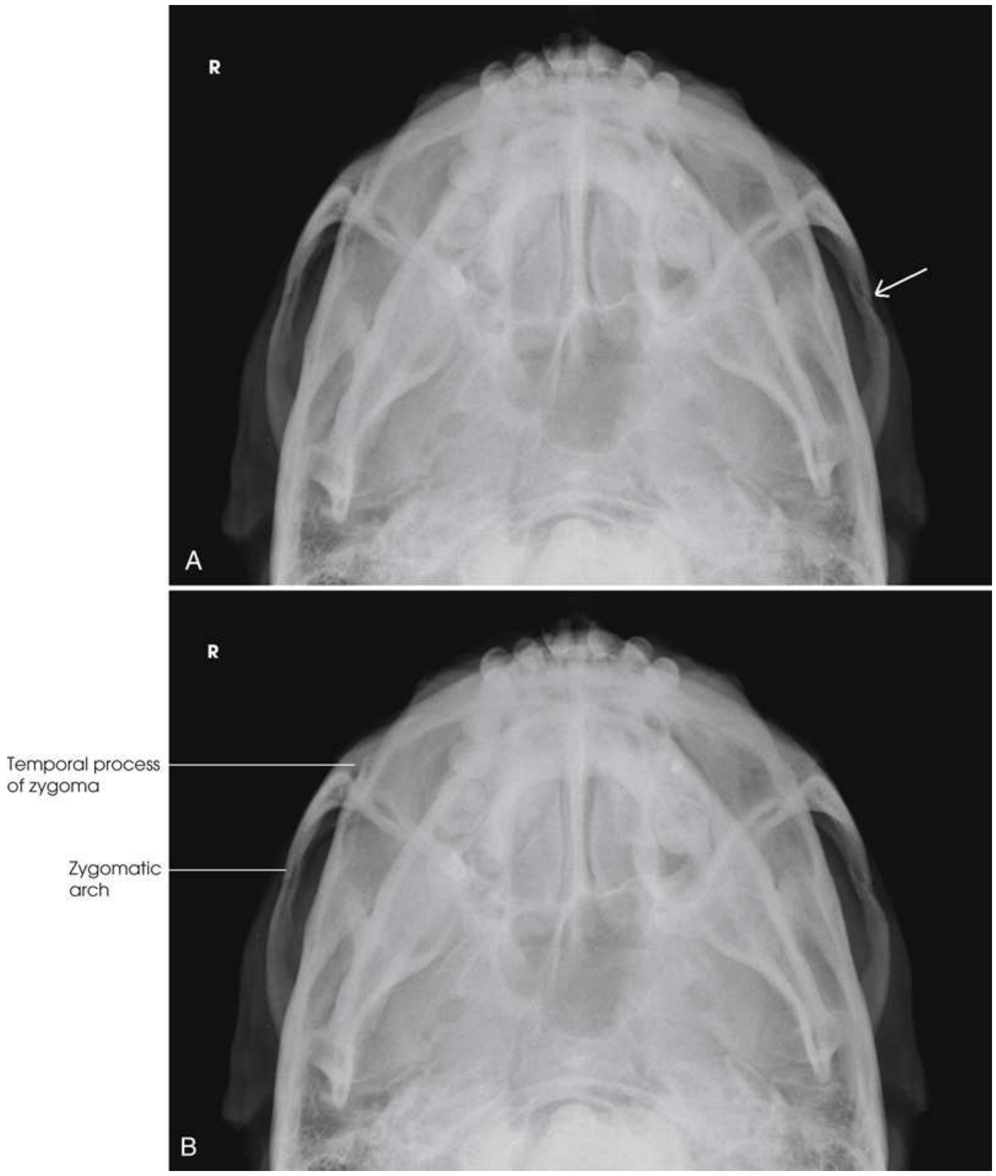


FIG. 11.123 (A) SMV projection showing normal zygomatic arch *(right)* and fracture *(arrow)* of left zygomatic arch. (B) SMV zygomatic arches. Courtesy St. Bernard's Medical Center, Jonesboro, AR.

Two X-ray images of the inferior skull. The zygomatic arch is visible in the first image. The second image shows a fracture on the zygomatic arches. The Temporal process of zygoma and the Zygomatic arch are labeled.

Structures shown

Bilateral symmetric SMV images of the zygomatic arches are shown, projected free of superimposed structures (Fig. 11.123). Unless very flat or traumatically depressed, the arches, being farther from the IR, are projected beyond the prominent parietal eminences by the divergent x-ray beam.

Evaluation Criteria

The following should be clearly seen:

n Evidence of proper collimation and presence of the side marker placed clear of anatomy of interest
n Zygomatic arches free from overlying structures

- No rotation or tilt of head, demonstrated by:
    - Zygomatic arches symmetric and without foreshortening
- Soft tissue and bony trabecular detail

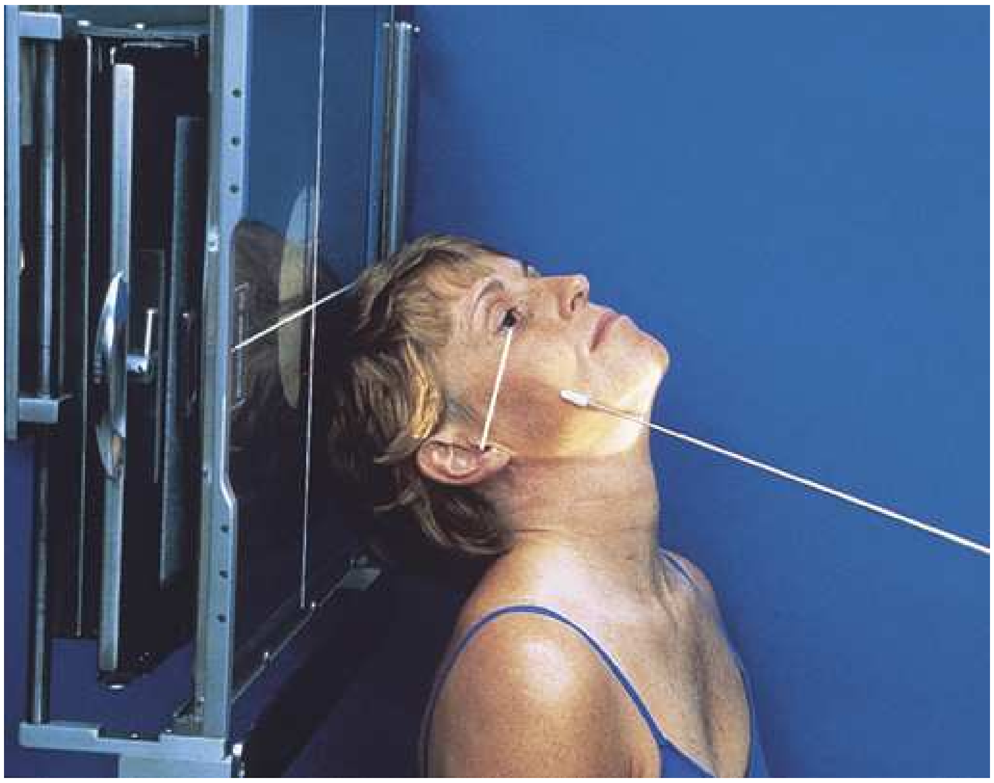


FIG. 11.124 Tangential zygomatic arch, patient upright.

A patient stands with the back of her head against the image receptor for capturing the tangential zygomatic position. The head is tilted upwards and the top of the head rests on the image receptor. The central ray is directed towards the center of the throat.

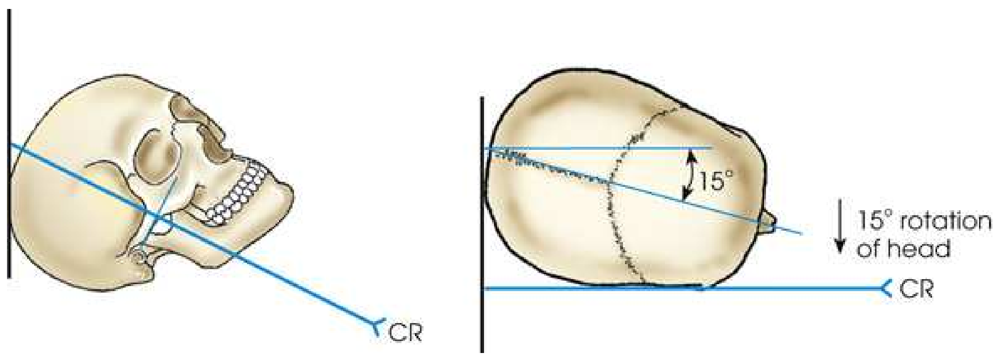


FIG. 11.125 Upright radiography diagram: tangential zygomatic arch.

The anterior and posterior view of the human skull tilted backwards. The central ray is directed through the jaw bones in the anterior position. It is directed through the axis of the skull in the posterior position.

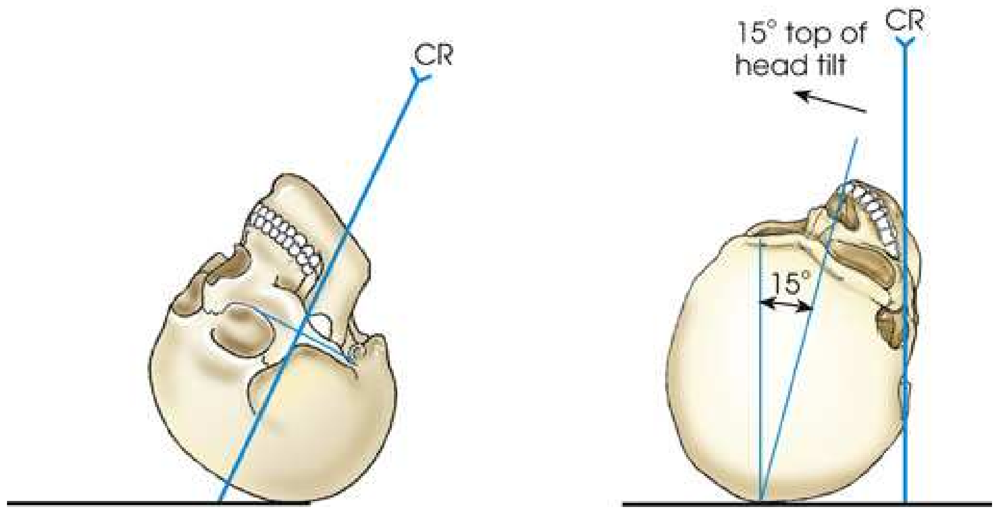


FIG. 11.126 Table radiography diagram: tangential zygomatic arch.

The anterior and posterior view of the human skull tilted backwards. The central ray is directed through the jaw bones in the anterior position. It is directed below the lower jaw in the posterior position. It is tilted at 15 degrees from the top of the skull.

Tangential Projection

Image receptor + grid: Positioned by manufacturer or department protocol for proper anatomy display orientation; CR plate: 10 × 12 inches (24 × 30 cm) lengthwise.

Position of patient

- Seat the patient with the back against a vertical grid device, or place the patient in the supine position with the trunk elevated on several firm pillows and the knees flexed to permit complete extension of the neck.

Position of part

Seated position

- Hyperextend the patient's neck, and rest the head on its vertex.
- Adjust the position of the patient's head so that the IOML is as parallel as possible with the plane of the IR.
- Rotate MSP of the head approximately 15 degrees toward the side being examined.
- Tilt the top of the head approximately 15 degrees away from the side being examined. This rotation and tilt ensure that the central ray is tangent to the lateral surface of the skull. The central ray skims across the lateral portion of the mandibular angle and the parietal bone to project the zygomatic arch onto the IR.
- Center the zygomatic arch to the IR (Figs. 11.124–11.126).

Supine position

- Rest the patient's head on its vertex.
- Elevate the upper end of the IR on sandbags, or place it on an angled sponge of suitable size.
- Adjust the elevation of the IR and the extension of the patient's neck so that the IOML is placed as nearly parallel with the plane of the IR as possible.
- Rotate and tilt MSP of the head approximately 15 degrees toward the side being examined (similar to the upright position).
- If the IOML is parallel with the plane of the IR, center the IR to the zygomatic arch; if not, displace the IR so that the midpoint of the IR coincides with the central ray (see Fig. 11.126).
- Attach a strip of adhesive tape to the inferior surface of the chin; draw the tape upward, and anchor it to the edge of the table or IR stand. This usually affords sufficient support. Do not put the adhesive surface directly on the patient's skin.
- *Respiration:* Suspend.

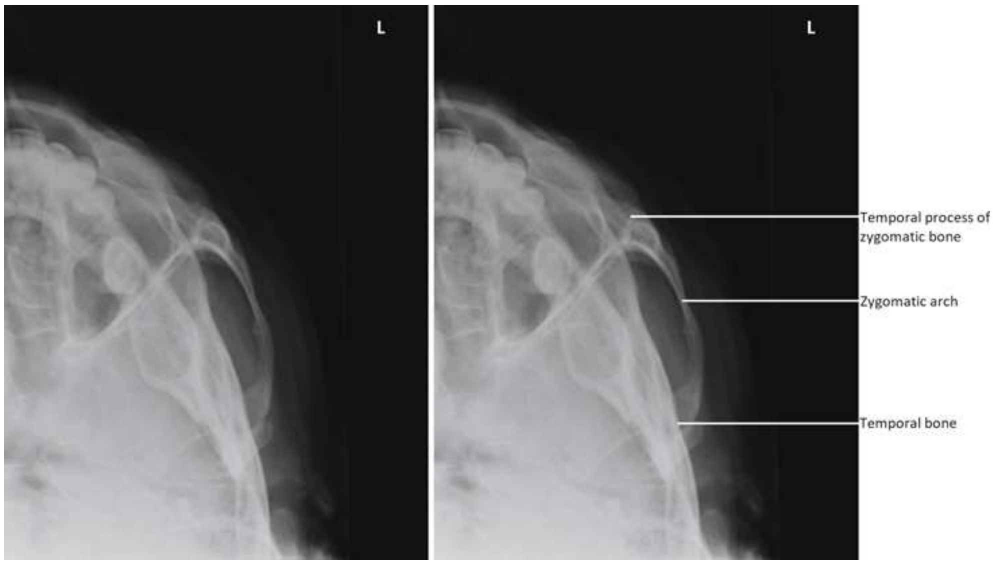


FIG. 11.127 Tangential zygomatic arch. Courtesy St. Bernard's Medical Center, Jonesboro, AR.

Two X-ray images of the zygomatic arch. The edges of the arch are smudged and the interior structures are prominent. The temporal process of zygomatic bone, zygomatic arch, and temporal bone are labeled.

Central ray

- Perpendicular to the IOML and centered to the zygomatic arch at a point approximately 1 inch (2.5 cm) posterior to the outer canthus.
- Centered to the IR.

Collimation

- Adjust the radiation field to 1 inch (2.5 cm) beyond the skin shadow of the affected cheek, superiorly to the tip of the nose, and inferiorly to the gonion. The exposure field should be no larger than 6 × 10 inches (18 × 24 cm). Place the side marker in the collimated exposure field.

Structures shown

A tangential image of one zygomatic arch is seen free of superimposition (Fig. 11.127). This projection is particularly useful in patients with depressed fractures or flat cheekbones.

Evaluation Criteria

The following should be clearly seen:

n Evidence of proper collimation and presence of the side marker placed clear of anatomy of interest
n Zygomatic arch free from overlying structures
n Soft tissue and bony trabecular detail

Ap Axial Projection

Modified Towne Method

Image receptor + grid: Positioned by manufacturer or department protocol for proper anatomy display orientation; CR plate: 10 × 12 inches (24 × 30 cm) crosswise.

Position of patient

- Place the patient in the seated-upright or supine position.
- Center MSP of the body to the midline of the grid.

Position of part

- Adjust the patient's head so that MSP is perpendicular to the midline of the grid.
- Adjust the flexion of the neck so that the OML is perpendicular to the plane of the IR (Figs. 11.128–11.130).
- *Respiration:* Suspend.

Central ray

• Directed to enter the glabella approximately 1 inch (2.5 cm) above the nasion at an angle of 30 degrees caudad.
• If the patient is unable to flex the neck sufficiently, adjust the IOML perpendicular with the IR and direct the central ray 37 degrees caudad.
• Center the IR to the central ray.

Collimation

• Adjust the radiation field to 1 inch (2.5 cm) beyond the skin shadow of the affected cheek, superiorly to the tip of the nose, and inferiorly to the gonion. The exposure field should be no larger than 6 × 10 inches (18 × 24 cm). Place the side marker in the collimated exposure field.

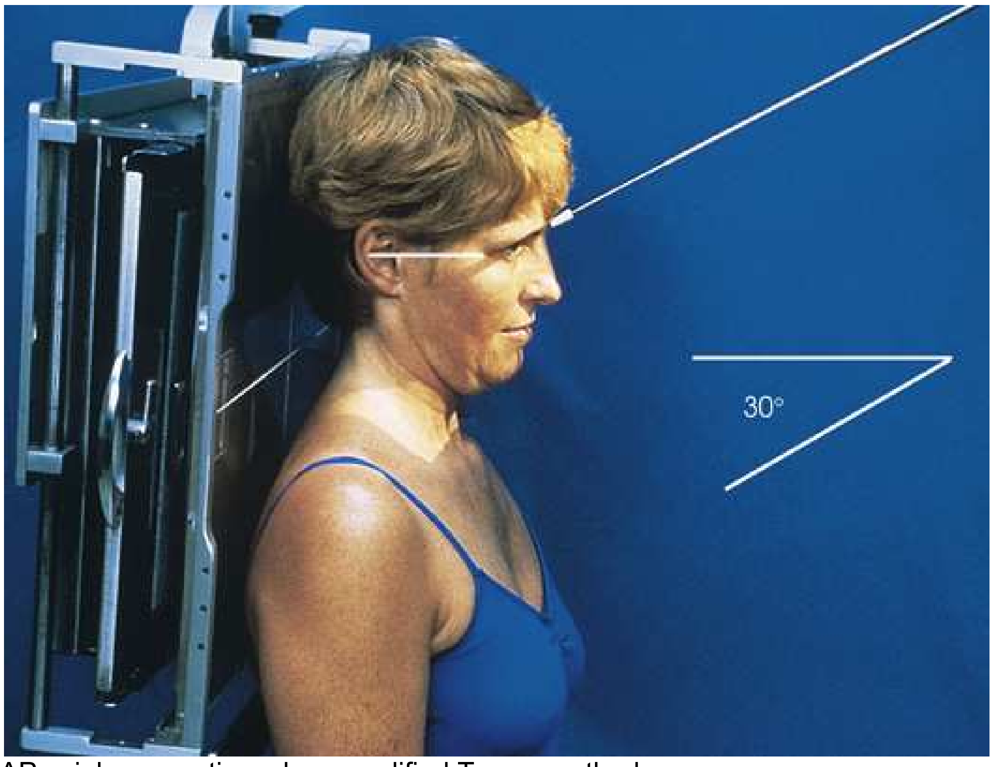


FIG. 11.128 AP axial zygomatic arches: modified Towne method.

Structures shown

A symmetric AP axial projection of both zygomatic arches is shown. The arches should be projected free of superimposition (Fig. 11.131).

Evaluation Criteria

The following should be clearly seen:

- Evidence of proper collimation and presence of the side marker placed clear of anatomy of interest
- No overlap of zygomatic arches by mandible
- No rotation or tilt, demonstrated by:
  - Symmetric arches
  - Zygomatic arches projected lateral to mandibular rami
  - MSP of head aligned with long axis of collimated field
- Soft tissue and bony trabecular detail

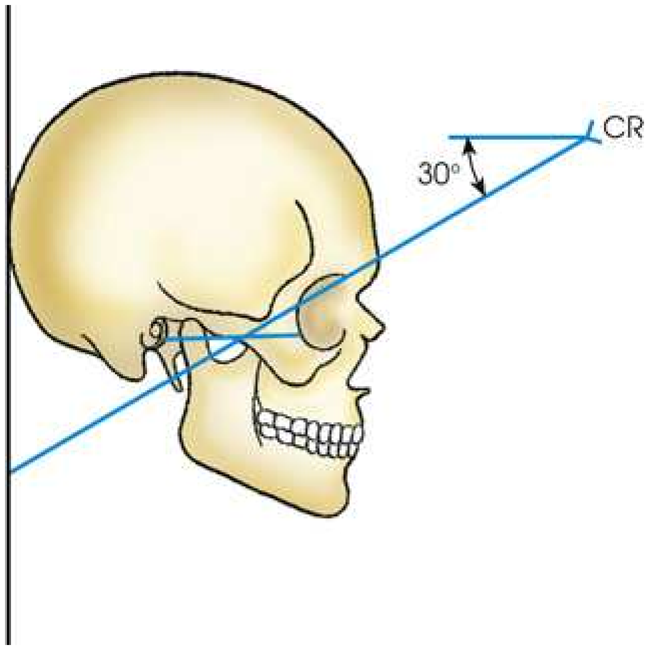


FIG. 11.129 Upright radiography diagram: modified Towne method.

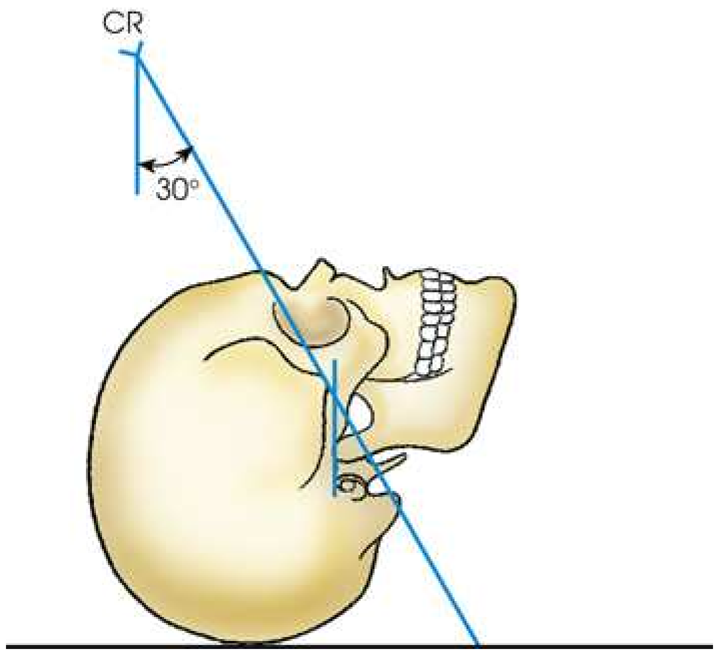


FIG. 11.130 Table radiography diagram: modified Towne method.

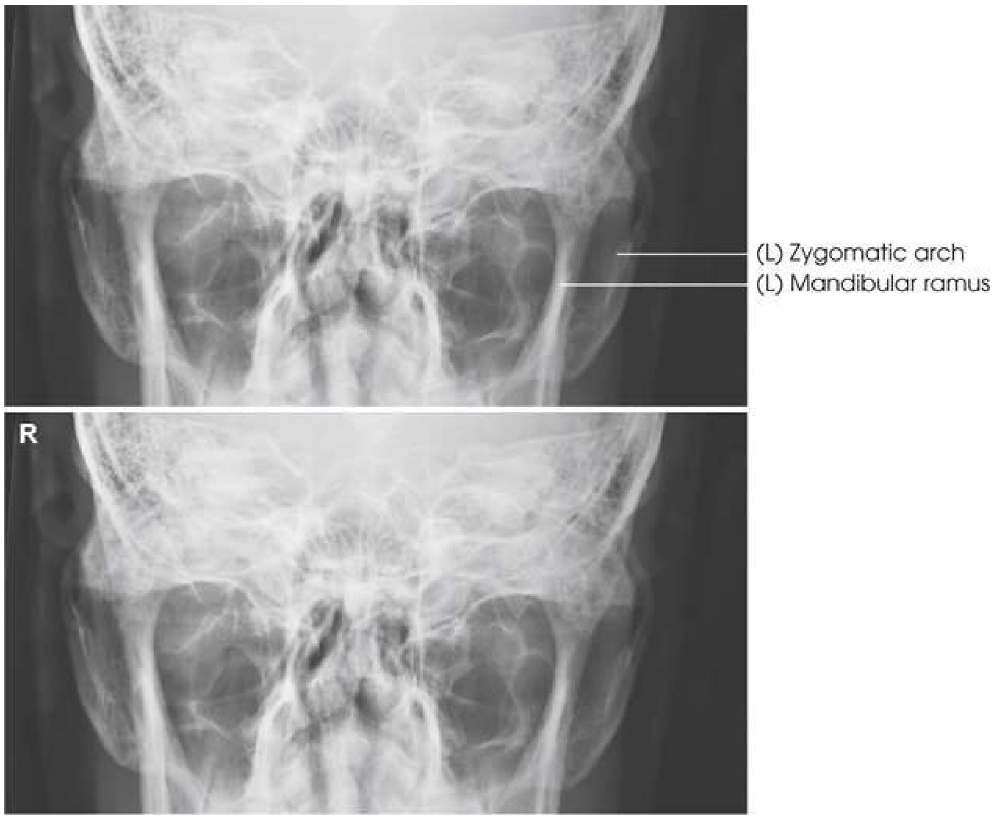


FIG. 11.131 AP axial zygomatic arches: modified Towne method.

Mandibular Rami

Pa Projection

Image receptor + grid: Positioned by manufacturer or department protocol for proper anatomy display orientation; CR plate: 10 × 12 inches (24 × 30 cm) lengthwise.

Position of patient

- Place the patient in the prone position, or seat the patient before a vertical grid device.

Position of part

- Rest the patient's forehead and nose on the IR. Adjust the OML to be perpendicular to the plane of the IR.
- Adjust the head so that its MSP is perpendicular to the plane of the IR (Fig. 11.132).
- Immobilize the head.
- *Respiration:* Suspend.

Central ray

- Perpendicular to exit the acanthion.
- Center the IR to the central ray.

FIG. 11.132 PA mandibular rami.

Collimation

- Adjust the radiation field to extend 1 inch (2.5 cm) beyond the lateral sides, above the TMJs and below the chin. The exposure field should be no larger than 8 × 10 inches (18 × 24 cm). Place the side marker in the collimated exposure field.

Structures shown

The mandibular body and rami (Fig. 11.133). The central part of the body is not well shown because of the superimposed spine. This radiographic approach is usually employed to show medial or lateral displacement of fragments in fractures of the rami.

FIG. 11.133 PA mandibular rami. Courtesy St. Bernard's Medical Center, Jonesboro, AR.

Evaluation Criteria

The following should be clearly seen:

- n Evidence of proper collimation and presence of the side marker placed clear of anatomy of interest
- n Entire mandible
- n No rotation or tilt, demonstrated by:
  - ▫ Mandibular body and rami symmetric on each side
  - ▫ MSP of head aligned with long axis of collimated field
- n Soft tissue and bony trabecular detail

Pa Axial Projection

Image receptor + grid: Positioned by manufacturer or department protocol for proper anatomy display orientation; CR plate: 10 × 12 inches (24 × 30 cm) lengthwise.

Position of patient

- Place the patient in the prone position, or seat the patient before a vertical grid device.

Position of part

- Rest the patient's forehead and nose on the IR holder.
- Adjust the OML to be perpendicular to the plane of the IR.
- Adjust the patient's head so that MSP is perpendicular to the plane of the IR (Fig. 11.134).
- Immobilize the patient's head.
- *Respiration:* Suspend.

Central ray

- Directed 20 or 25 degrees cephalad to exit at the acanthion.
- Center the IR to the central ray.

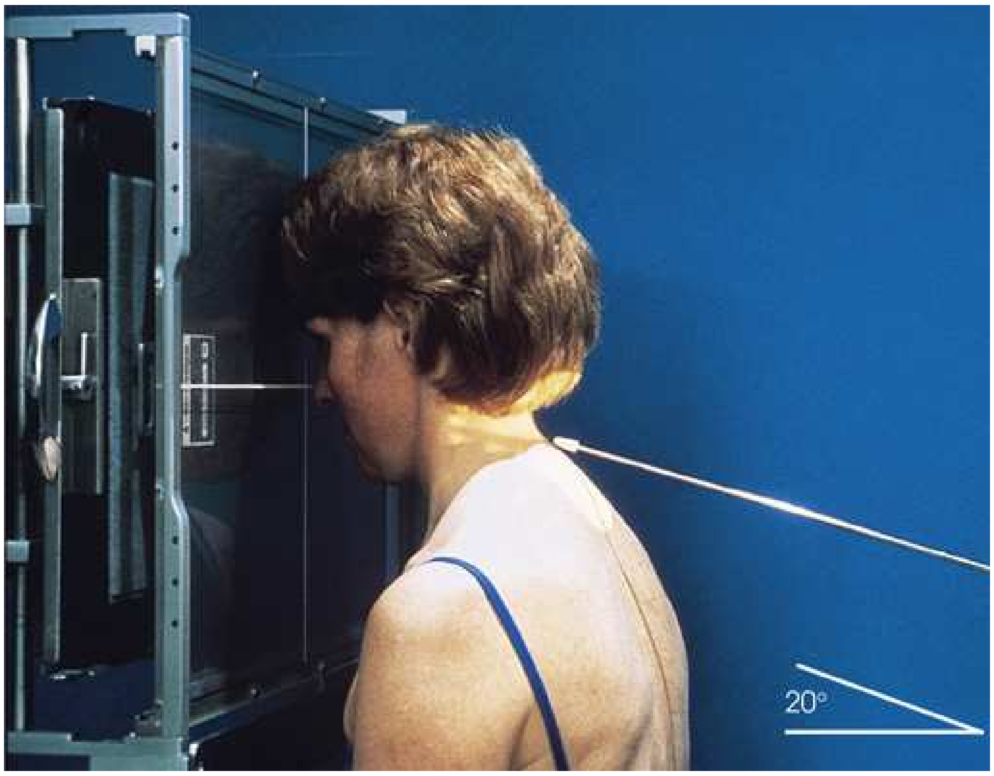


FIG. 11.134 PA axial mandibular rami.

Collimation

- Adjust the radiation field to extend 1 inch (2.5 cm) beyond the lateral sides, above the TMJs and below the chin. The exposure field should be no larger than 8 × 10 inches (18 × 24 cm). Place the side marker in the collimated exposure field.

Structures shown

The mandibular body and rami (Fig. 11.135). The central part of the body is not well shown because of the superimposed spine. This radiographic approach is usually employed to show medial or lateral displacement of fragments in fractures of the rami.

Evaluation Criteria

The following should be clearly seen:

n Evidence of proper collimation and presence of the side marker placed clear of anatomy of interest
n Entire mandible
n No rotation or tilt, demonstrated by:
  ▫ Mandibular body and rami symmetric on each side
  ▫ MSP of head aligned with long axis of collimated field
n Condylar processes
n Soft tissue and bony trabecular detail

FIG. 11.135 PA axial mandibular body and rami.

Mandibular Body

Pa Projection

Image receptor + grid: Positioned by manufacturer or department protocol for proper anatomy display orientation; CR plate: 10 × 12 inches (24 × 30 cm) lengthwise.

Position of patient

- Place the patient in the prone position, or seat the patient before a vertical grid device.

Position of part

- With MSP of the patient's head centered to the midline of the IR, rest the head on the nose and chin so that the anterior surface of the mandibular symphysis is parallel with the plane of the IR. This position places the AML nearly perpendicular to the IR plane.
- Adjust the patient's head so that MSP is perpendicular to the plane of the IR (Fig. 11.136).
- *Respiration:* Suspend.

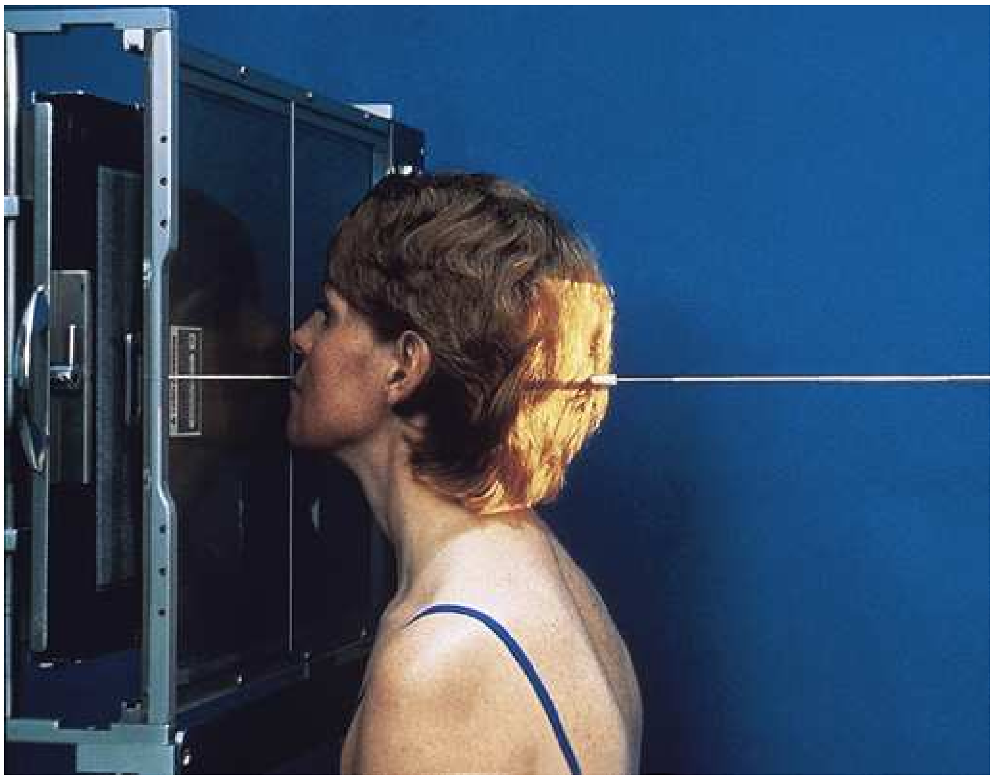


FIG. 11.136 PA mandibular body.

A patient stands in an upright position facing the image receptor. The head is tilted upwards and the chin of the patient is in contact with the receptor. The central ray is directed at the base of the skull.

Central ray

- Perpendicular to the level of the lips.
- Center the IR to the central ray.

Collimation

- Adjust the radiation field to extend 1 inch (2.5 cm) beyond the lateral sides, above the TMJs and below the chin. The exposure field should be no larger than 8 × 10 inches (18 × 24 cm). Place the side marker in the collimated exposure field.

Structures shown

The mandibular body (Fig. 11.137).

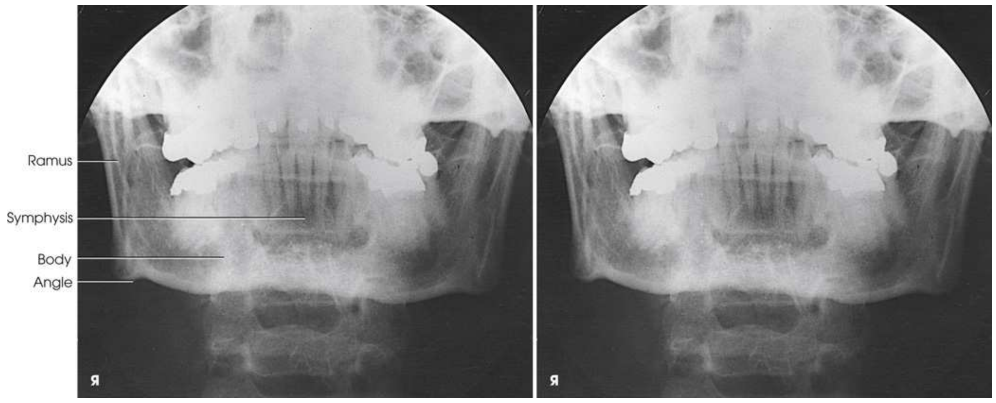


FIG. 11.137 PA mandibular body.

Evaluation Criteria

The following should be clearly seen:

n Evidence of proper collimation and presence of the side marker placed clear of anatomy of interest
n Entire mandible
n No rotation or tilt, demonstrated by:

▫ Mandibular body symmetric on each side
▫ MSP of head aligned with long axis of collimated field
n Soft tissue and bony trabecular detail

Pa Axial Projection

Image receptor + grid: Positioned by manufacturer or department protocol for proper anatomy display orientation; CR plate: 10 × 12 inches (24 × 30 cm) lengthwise.

Position of patient

- Place the patient in the prone position, or seat the patient before a vertical grid device.

Position of part

- With MSP of the patient's head centered to the midline of the IR, rest the head on the nose and chin so that the anterior surface of the mandibular symphysis is parallel with the plane of the IR. This position places the AML nearly perpendicular to the plane of the IR.
- Adjust the patient's head so that MSP is perpendicular to the plane of the IR (Fig. 11.138).
- *Respiration:* Suspend.

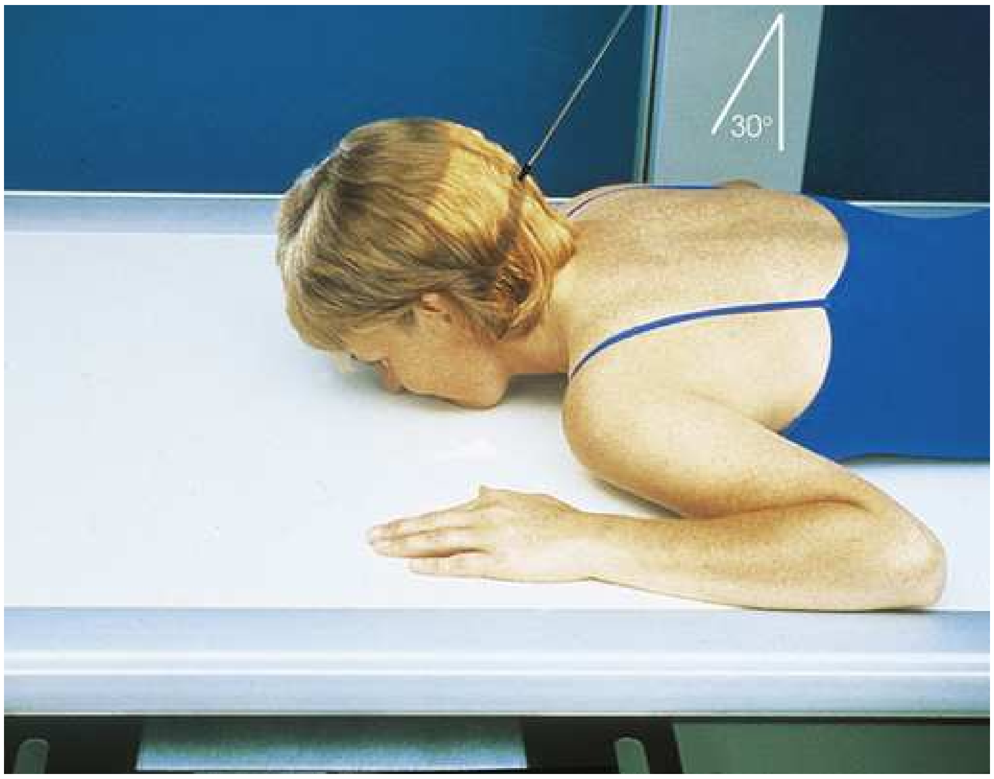


FIG. 11.138 PA axial mandibular body.

A patient lies down on the stomach on a table with the image receptor placed adjacent to her upper torso. The palms are placed on either side of the head on the table. The central ray is directed towards the base of the skull.

Central ray

- Directed midway between the TMJs at an angle of 30 degrees cephalad. Zanelli [10] recommended that better contrast around the TMJs could be obtained if the patient was instructed to fill the mouth with air for this projection.
- Center the IR to the central ray.

Collimation

- Adjust the radiation field to extend 1 inch (2.5 cm) beyond the lateral sides, above the TMJs and below the chin. The exposure field should be no larger than 8 × 10 inches (18 × 24 cm). Place the side marker in the collimated exposure field.

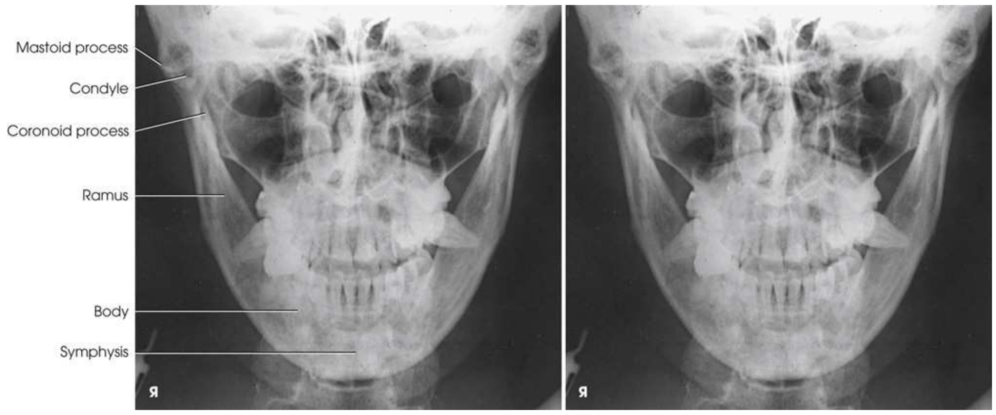


FIG. 11.139 PA axial mandibular body.

Structures shown

The mandibular body and TMJs (Fig. 11.139).

Evaluation Criteria

The following should be clearly seen:

- n Evidence of proper collimation and presence of the side marker placed clear of anatomy of interest
- n Entire mandible
- n TMJs just inferior to the mastoid process
- n No rotation or tilt, demonstrated by:
  - ▫ Symmetric rami
  - ▫ MSP of head aligned with long axis of collimated field
- n Soft tissue and bony trabecular detail

Mandible

Axiolateral And Axiolateral Oblique Projections

The goal of these projections is to place the desired portion of the mandible parallel with the IR.

Image receptor + grid: Positioned by manufacturer or department protocol for proper anatomy display orientation; CR plate: 10 × 12 inches (24 × 30 cm) lengthwise.

Position of patient

- Place the patient in the seated, semiprone, or semisupine position.

Position of part

- Place the patient's head in a lateral position with the IPL perpendicular to the IR. The mouth should be closed with the teeth together.
- Extend the patient's neck enough that the long axis of the mandibular body is parallel with the transverse axis of the IR to prevent superimposition of the cervical spine.

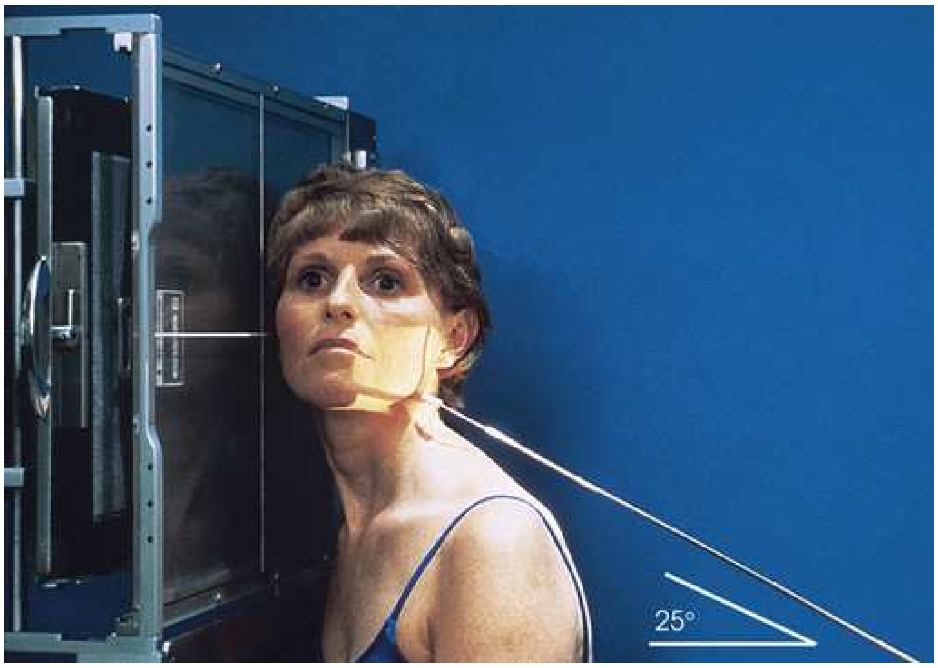


FIG. 11.140 Axiolateral mandibular ramus.

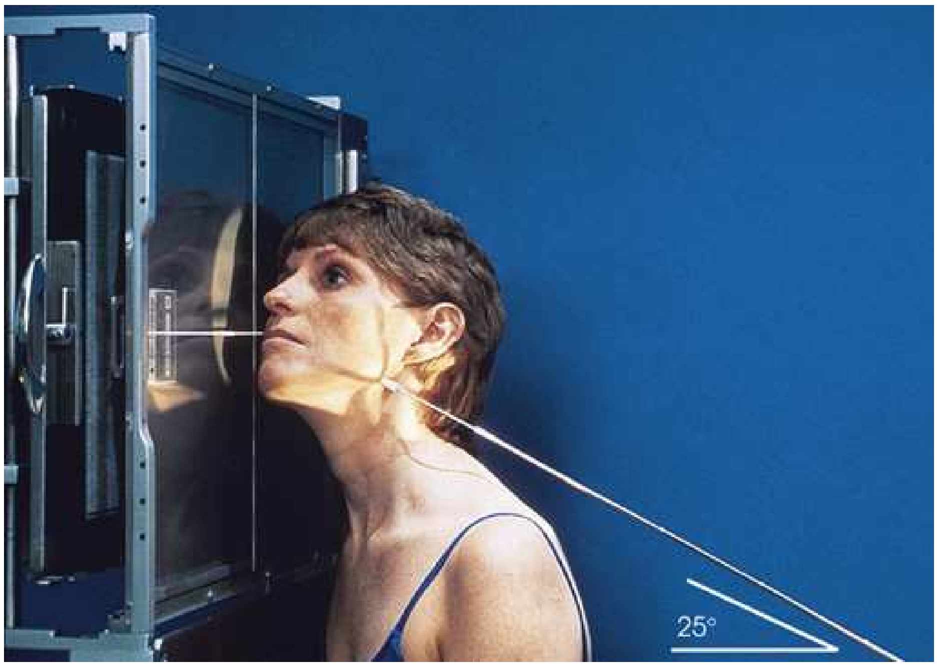


FIG. 11.141 Axiolateral oblique mandibular body.

- If the projection is to be performed on the tabletop, position the IR so that the complete body of the mandible is on the IR.
- Adjust the rotation of the patient's head to place the area of interest parallel to the IR, as follows.

Ramus

- Keep the patient's head in a true lateral position (Fig. 11.140).

Body

- Rotate the patient's head 30 degrees toward the IR (Fig. 11.141).

Symphysis

- Rotate the patient's head 45 degrees toward the IR (Fig. 11.142).
- *Respiration:* Suspend.

NOTE: When the patient is in the semisupine position, place the IR on a wedge device or wedge sponge (Fig. 11.143). Ensure that combined CR angle and midsagittal plane tilt equals 25 degrees.

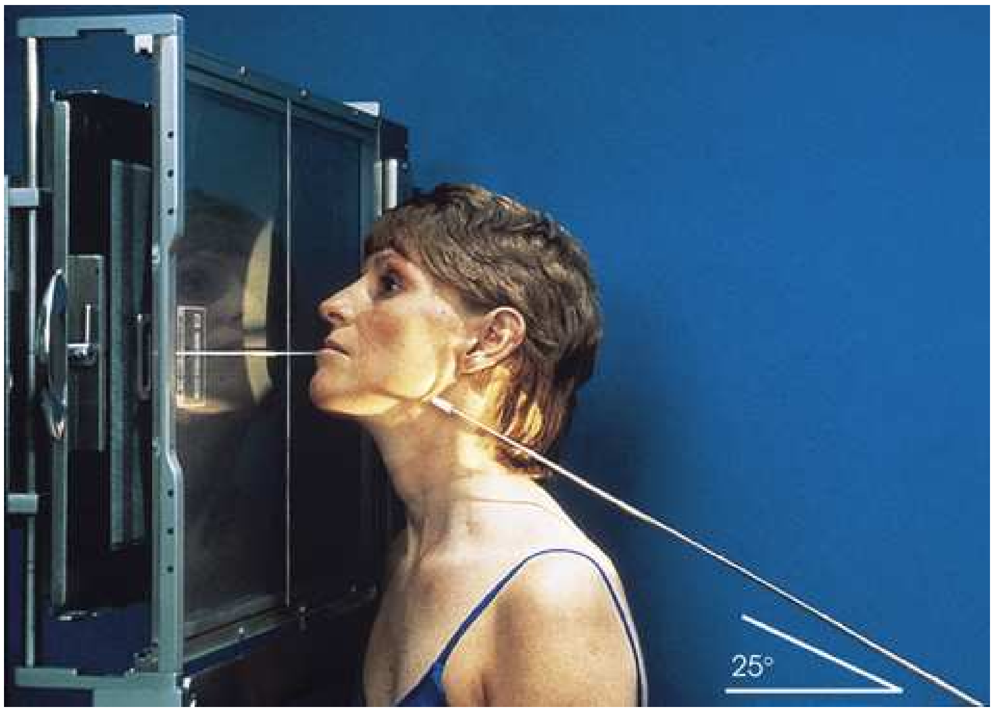


FIG. 11.142 Axiolateral oblique mandibular symphysis.

A patient stands facing the image receptor and rests the side of her head against the image receptor. The head is slightly tilted towards the top-right. The central ray is directed at a point below the lower jaw.

Central ray

- Directed 25 degrees cephalad to pass directly through the mandibular region of interest (see the note on p. 87).
- Center the IR to the central ray for projections done on upright grid units.

Collimation

- Adjust the radiation field to extend 1 inch (2.5 cm) beyond the anterior and inferior skin shadows and above the TMJ. The exposure field should be no larger than 8 × 10 inches (18 × 24 cm). Place the side marker in the collimated exposure field.

Structures shown

Each projection shows the region of the mandible that was parallel with the IR (Figs. 11.144–11.146).

FIG. 11.143 Semisupine axiolateral oblique mandibular body and symphysis.

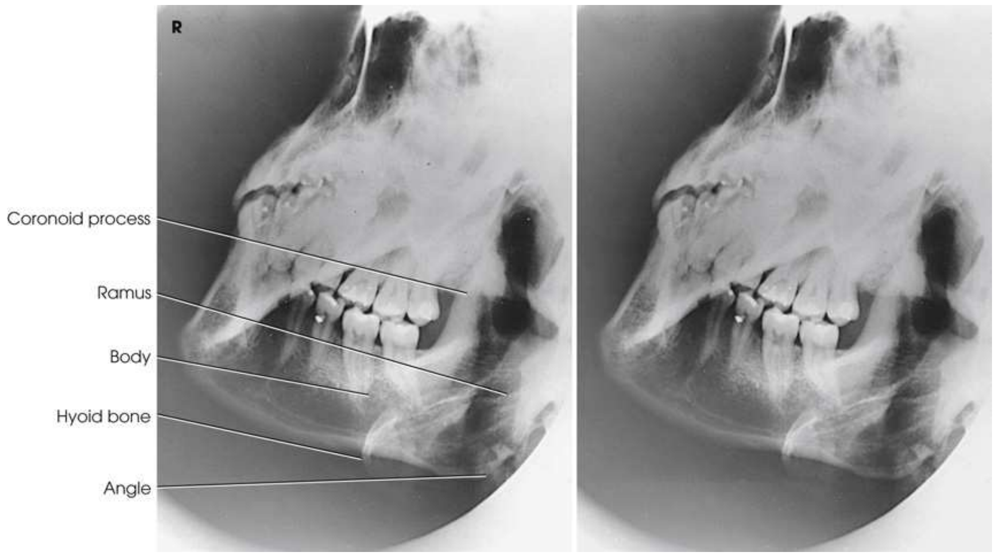


FIG. 11.144 Axiolateral oblique mandibular body.

Two X-ray images of the lateral view of the skull. The parts of the axiolateral oblique mandibular body are visible. The Coronoid process, R Ramus Body, Hyoid bone, and Angle are labeled on the first image.

Evaluation Criteria

The following should be clearly seen:

n Evidence of proper collimation and presence of the side marker placed clear of anatomy of interest
n Soft tissue and bony trabecular detail

Ramus and body

n No overlap of the ramus by the opposite side of the mandible
n No elongation or foreshortening of ramus or body
n No superimposition of the ramus by the cervical spine

Symphysis

n No overlap of the mentum region by the opposite side of the mandible
n No foreshortening of the mentum region

NOTE: To reduce the possibility of projecting the shoulder over the mandible when radiographing muscular or hypersthenic patients, adjust MSP of the patient's skull with an approximately 15-degree angle, open inferiorly. The cephalad angulation of 10 degrees of the central ray maintains the optimal 25-degree central ray/part angle relationship.

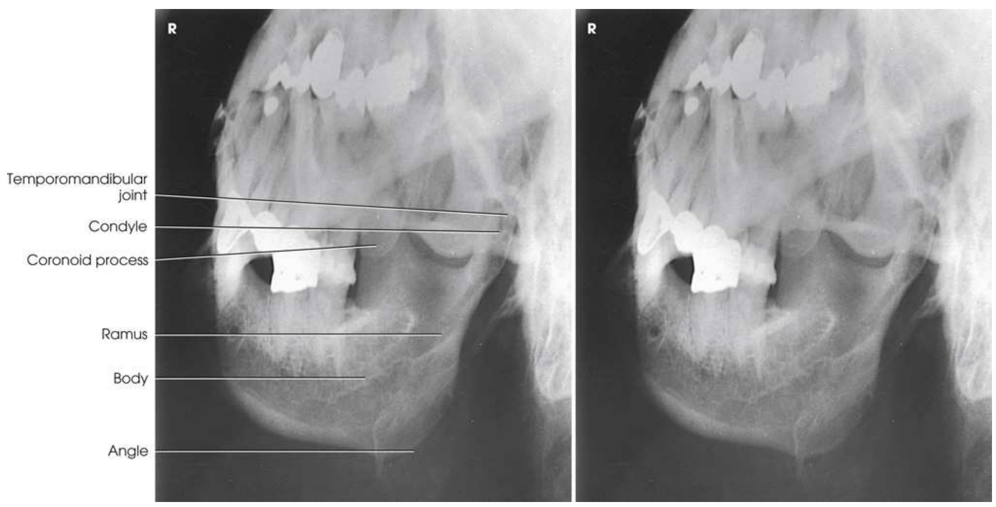


FIG. 11.145 Axiolateral mandibular ramus.

Two X-ray images of the axio lateral view of the skull. The parts of the axiolateral mandibular ramus are visible. The Temporomandibular joint, Condyle, Coronoid process, Ramus, Body, and Angle are labeled on the first image.

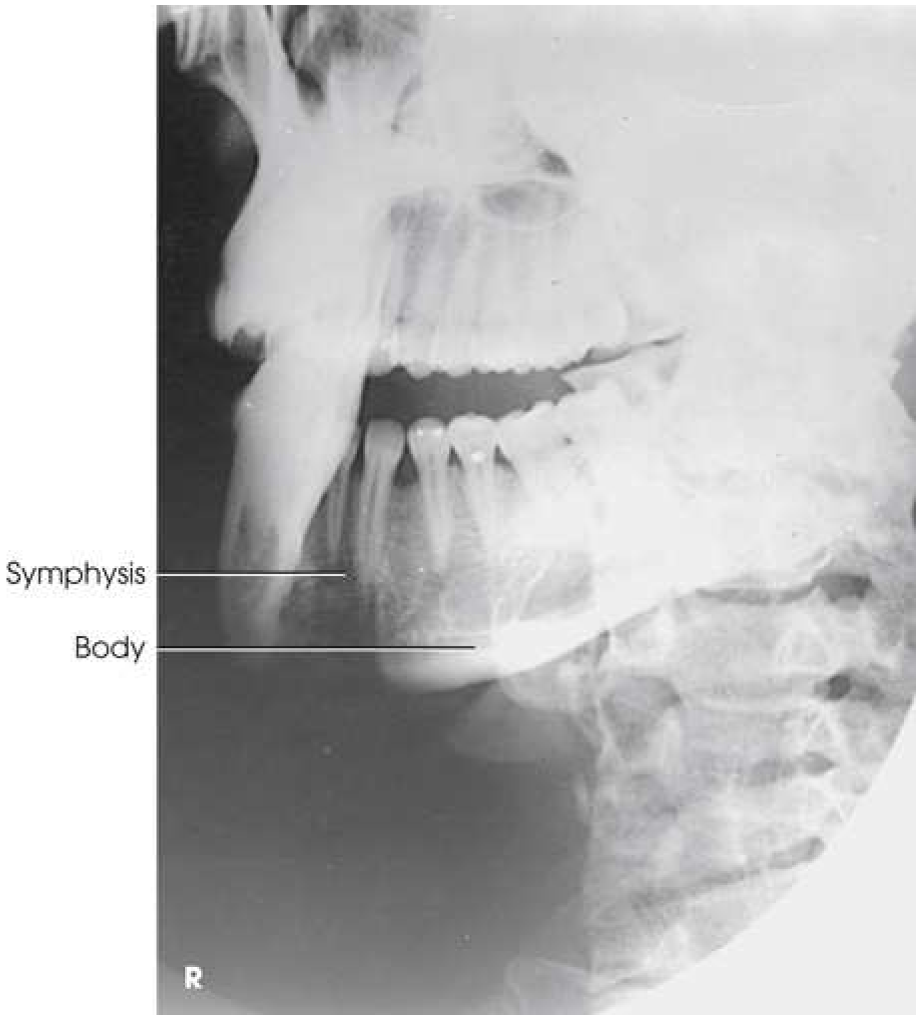


FIG. 11.146 Axiolateral oblique mandibular symphysis.

Submentovertical Projection

Image receptor + grid: Positioned by manufacturer or department protocol for proper anatomy display orientation; CR plate: 10 × 12 inches (24 × 30 cm) lengthwise.

Position of patient

- Place the patient upright in front of a vertical grid device or in the supine position. When the patient is supine, elevate the shoulders on firm pillows to permit complete extension of the neck.
- Flex the patient's knees to relax the abdominal muscles and relieve strain on the neck muscles.
- Center MSP of the body to the midline of the grid device.

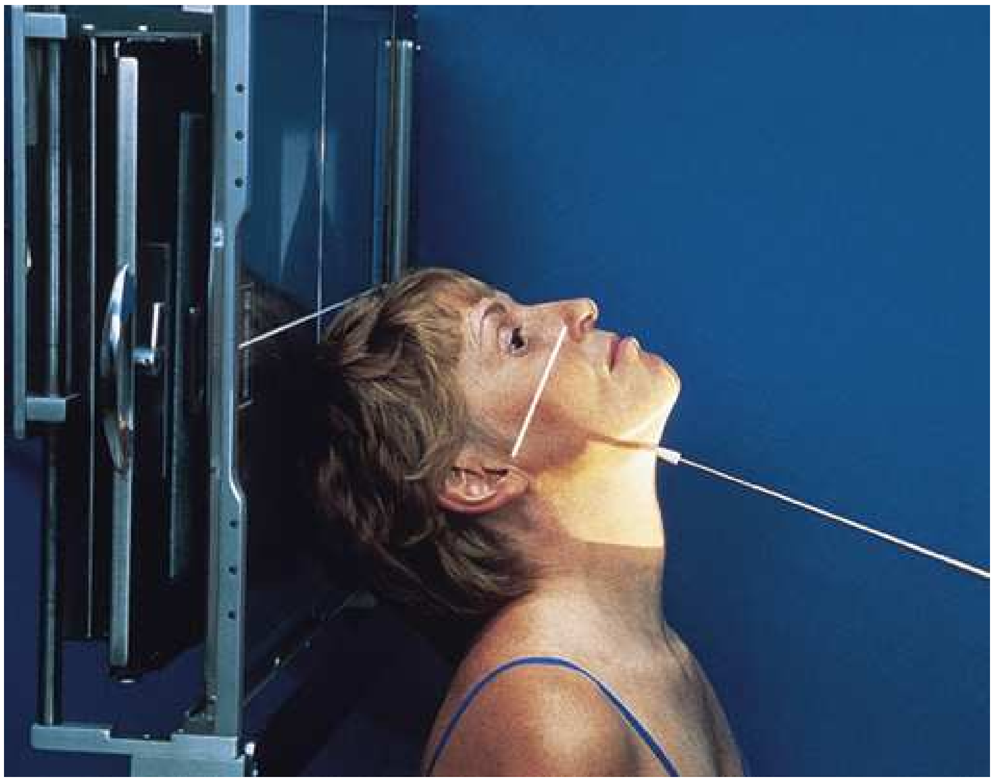


FIG. 11.147 SMV mandible.

A patient stands with the back of her head against the image receptor. Her head is tilted upwards. The top of her head is rested against the image receptor. The central ray is directed towards the center of the lower jaw.

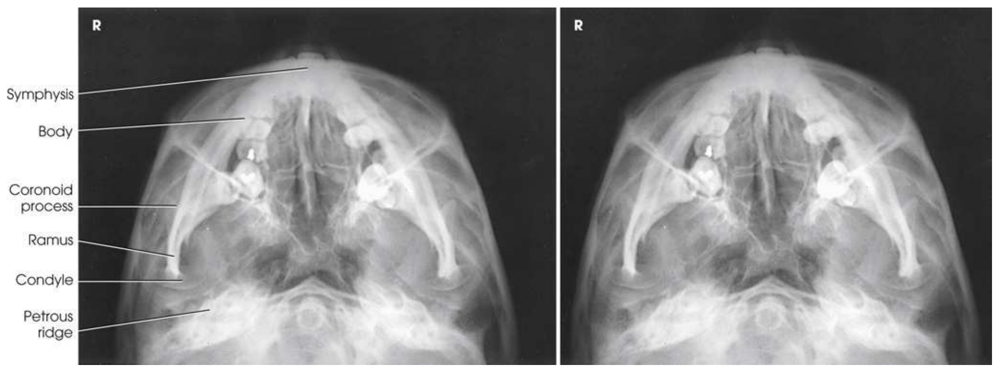


FIG. 11.148 SMV mandible.

Position of part

- With the neck fully extended, rest the head on its vertex and adjust the head so that MSP is vertical.
- Adjust the IOML as parallel as possible with the plane of the IR (Fig. 11.147).
- When the neck cannot be extended enough that the IOML is parallel with the IR plane, angle the *grid device* and place it parallel to the IOML.
- Immobilize the head.
- *Respiration:* Suspend.

Central ray

- Perpendicular to the IOML and centered midway between the angles of the mandible.

Collimation

- Adjust the radiation field to extend 1 inch (2.5 cm) beyond the lateral sides and above the tip of the nose. The exposure field should be no larger than 8 × 10 inches (18 × 24 cm). Place the side marker in the collimated exposure field.

Structures shown

SMV projection of the mandibular body shows the coronoid and condyloid processes of the rami (Fig. 11.148).

Evaluation Criteria

The following should be clearly seen:

- n Evidence of proper collimation and presence of the side marker placed clear of anatomy of interest
- n No rotation or tilt, demonstrated by:
  - ▫ Distance between the lateral border of the skull and the mandible equal on both sides
  - ▫ MSP of head aligned to long axis of collimated field
- n Condyles of the mandible anterior to the pars petrosal
- n Symphysis extending almost to the anterior border of the face so that the mandible is not foreshortened
- n Soft tissue and bony trabecular detail

Temporomandibular Articulations

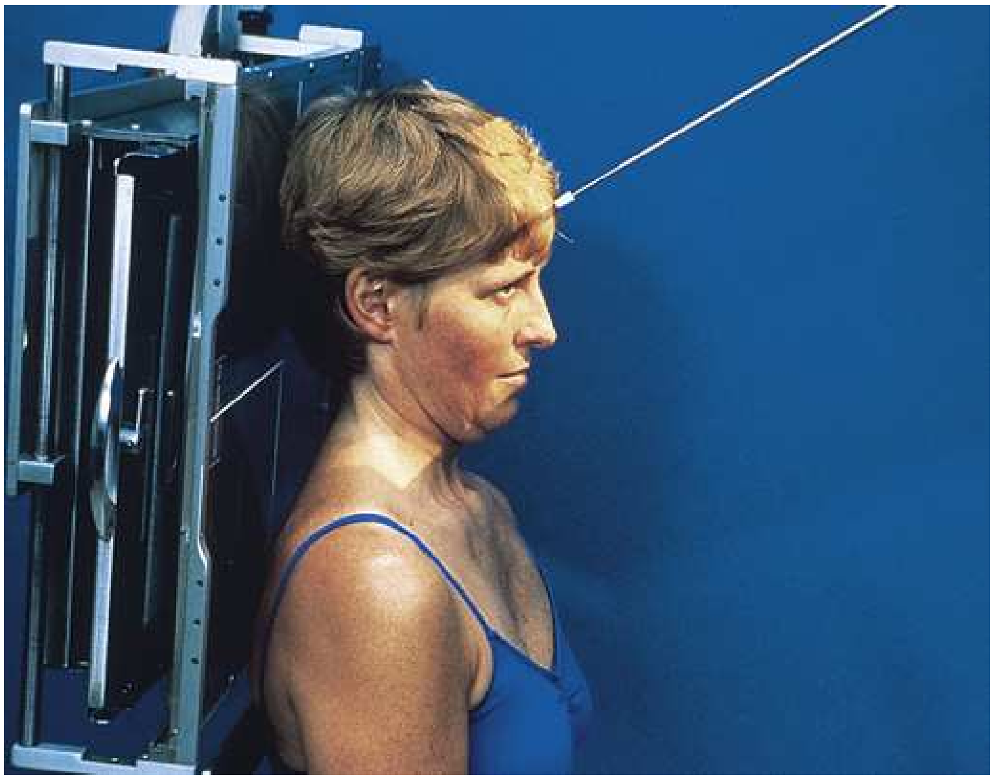


FIG. 11.149 AP axial TMJs.

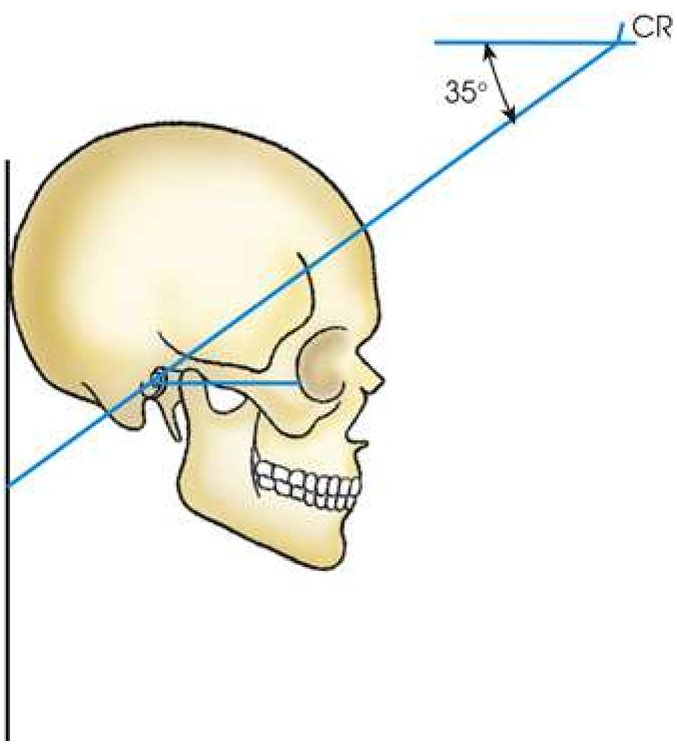


FIG. 11.150 Upright radiography diagram: AP axial TMJs.

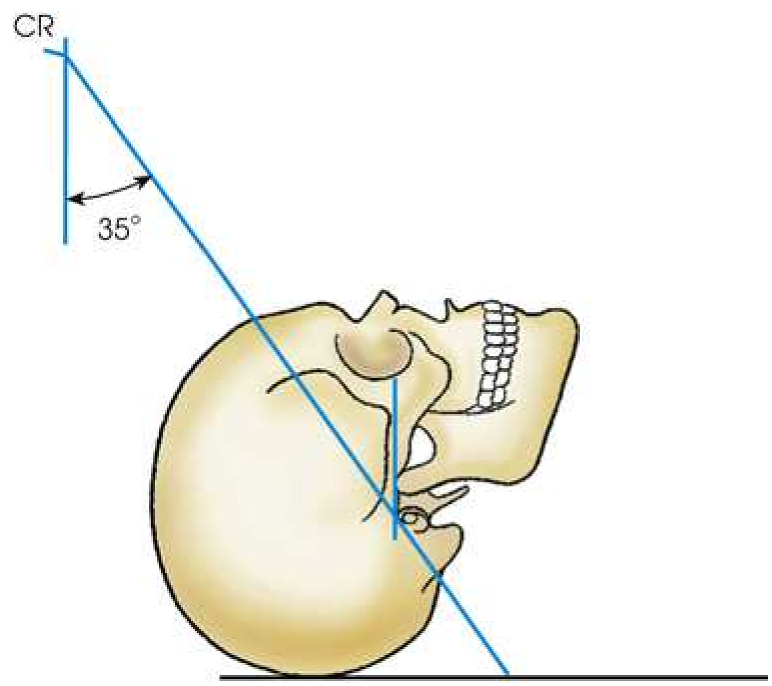


FIG. 11.151 Table radiography diagram: AP axial TMJs.

Ap Axial Projection

For radiography of the TMJs in the closed-mouth position, the *posterior teeth*, rather than the incisors, must be in contact. Occlusion of the incisors places the mandible in a position of protrusion, and the condyles are carried out of the mandibular fossae. In the open-mouth position, the mouth should be opened as wide as possible but not with the mandible protruded (jutted forward).

Because of the danger of fragment displacement, the open-mouth position should not be attempted in patients with recent injury. Trauma patients are examined without any stress movement of the mandible.

Image receptor + grid: Positioned by manufacturer or department protocol for proper anatomy display orientation; CR plate: 10 × 12 inch (24 × 30 cm) lengthwise.

Position of patient

- Place the patient in a supine or seated-upright position with the posterior skull in contact with the upright bucky.

Position of part

- Adjust the patient's head so that MSP is perpendicular to the plane of the IR.
- Flex the patient's neck so that the OML is perpendicular to the plane of the IR (Figs. 11.149–11.151).
- *Respiration:* Suspend.

Central ray

- Directed 35 degrees caudad, centered midway between the TMJs, and entering at a point approximately 3 inches (7.6 cm) above the nasion.
- Expose one image with the mouth closed; when not contraindicated, expose one image with the mouth open.
- Center the IR to the central ray.

Collimation

- Adjust the radiation field to extend 1 inch (2.5 cm) beyond the lateral sides, superiorly to the glabella, and inferiorly to the lips. The exposure field should be no larger than 8 × 10 inches (18 × 24 cm). Place the side marker in the collimated exposure field.

Structures shown

The condyles of the mandible and the mandibular fossae of the temporal bones (Figs. 11.152 and 11.153).

Evaluation Criteria

The following should be clearly seen:

n Evidence of proper collimation and presence of the side marker placed clear of anatomy of interest
n No rotation of head

- Minimal superimposition of petrosa on the condyle in the closed-mouth examination
- Condyle and temporomandibular articulation below pars petrosa in the open-mouth position
- Soft tissue and bony trabecular detail

FIG. 11.152 AP axial TMJs: mouth closed.

FIG. 11.153 AP axial TMJs: mouth open.

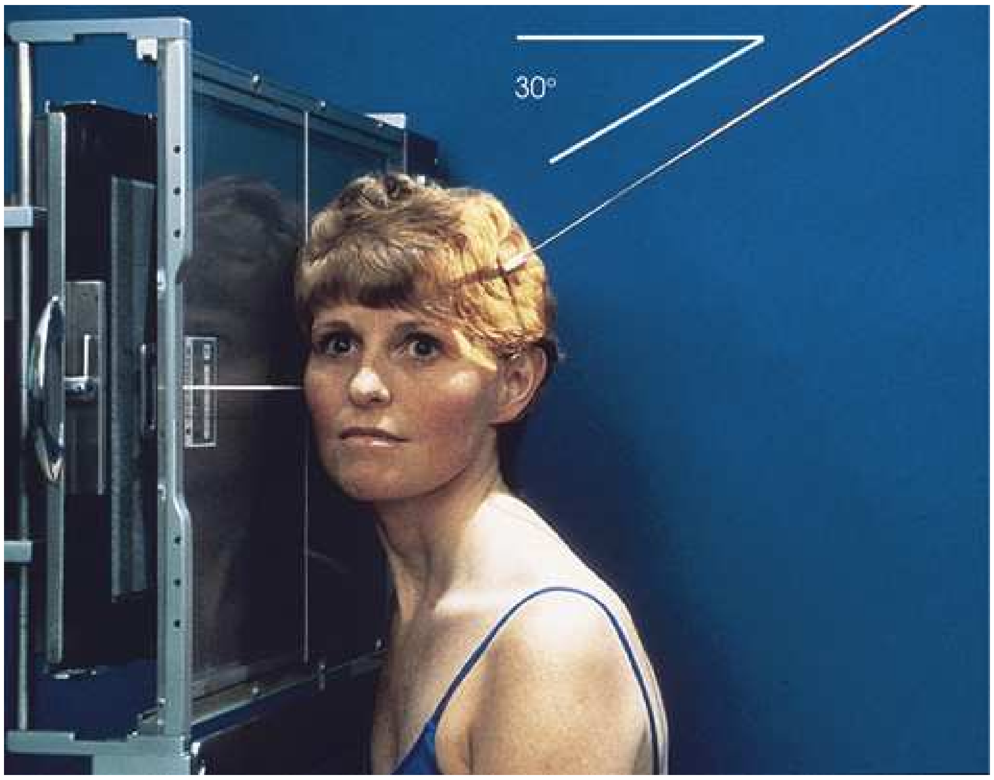


FIG. 11.154 Axiolateral TMJ: mouth closed.

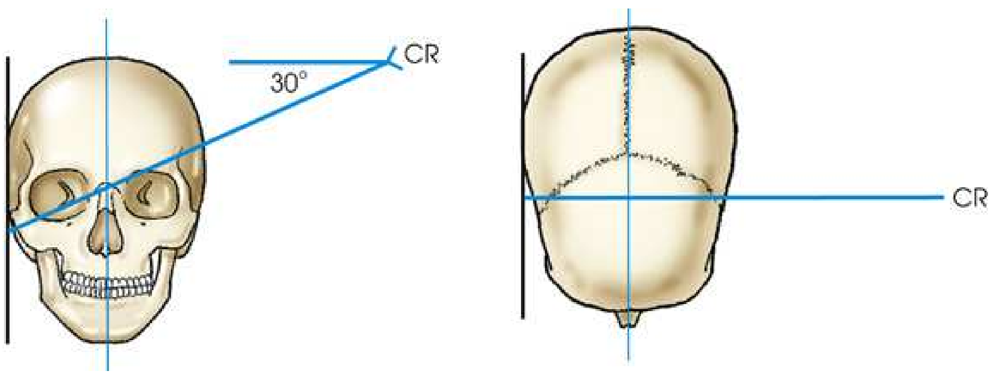


FIG. 11.155 Upright radiography diagram: axiolateral TMJ.

The anterior and posterior positions of a skull with the lateral side against an image receptor. The central ray is directed towards the occipital bones, at an angle 30 degrees away from a horizontal above the skull in the anterior position. The ray is directed towards the center of the axis of the skull in the posterior position.

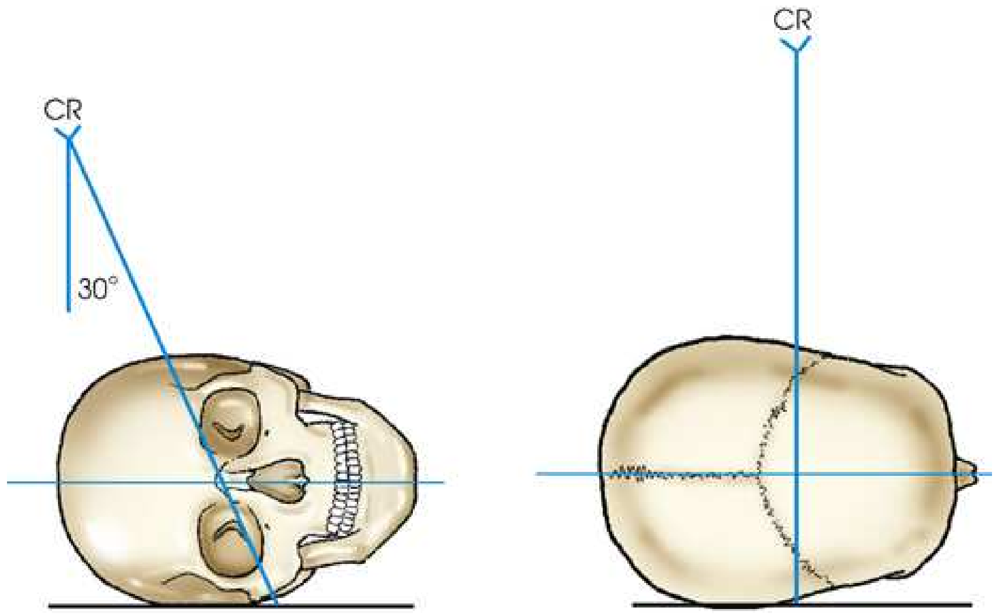


FIG. 11.156 Table radiography diagram: axiolateral TMJ.

The anterior and posterior positions of a skull lying on an image receptor. The central ray is directed towards the occipital bones, at an angle 30 degrees away from a horizontal above the skull in the anterior position. The ray is directed towards the center of the axis of the skull in the posterior position.

Axiolateral Projection

Right and left positions

This projection is sometimes called the *modified Schüller method* because it consists of approximately the same positioning details and CR orientation as the Schüller method for the petromastoid portion of the temporal bone, seen in the 10th edition of *Merrill's Atlas.*

Image receptor + grid: Positioned by manufacturer or department protocol for proper anatomy display orientation; CR plate: 10 × 12 inches (24 × 30 cm) crosswise.

Position of patient

- Put a mark on each cheek at a point ½ inch (1.3 cm) anterior to the EAM and 1 inch (2.5 cm) inferior to the EAM to localize the TMJ if needed.
- Place the patient in a semiprone position, or seat the patient before a vertical grid device.

Position of part

- Center a point ½ inch (1.3 cm) anterior to the EAM to the IR, and place the patient's head in the lateral position with the affected side closest to the IR.
- Adjust the patient's head so that MSP is parallel with the plane of the IR and the IPL is perpendicular to the IR plane (Figs. 11.154–11.156).
- Immobilize the head.
- *Respiration:* Suspend.
- After making the exposure with the patient's mouth closed, change the IR; then, unless contraindicated, have the patient open the mouth widely (Fig. 11.157).
- Recheck the patient's position, and make the second exposure.

Central ray

- Directed to the midpoint of the IR at an angle of 25 or 30 degrees caudad. The central ray enters about ½ inch (1.3 cm) anterior and 2 inches (5 cm) superior to the upside EAM.

Collimation

- Adjust the radiation field to extend 1 inch (2.5 cm) beyond the anterior skin line, posterior and inferior to the TMJs. The exposure field should be no larger than 8 × 10 inches (18 × 24 cm). Place the side marker in the collimated exposure field.

Structures shown

The TMJ when the mouth is open and closed (Figs. 11.158 and 11.159). Examine both sides for comparison.

Evaluation Criteria

The following should be clearly seen:

- n Evidence of proper collimation and presence of the side marker placed clear of anatomy of interest
- n TMJ anterior to the EAM
- n Condyle in mandibular fossa in the closed-mouth examination
- n Condyle inferior to the articular tubercle in the open-mouth examination if the patient is normal and able to open the mouth widely
- n Soft tissue and bony trabecular detail

FIG. 11.157 Axiolateral TMJ with mouth open.

A patient stands with her lateral face against an image receptor. Her mouth is open. The central ray is directed towards the center of the occipital bone at an angle 30 degrees away from the horizontal above the head.

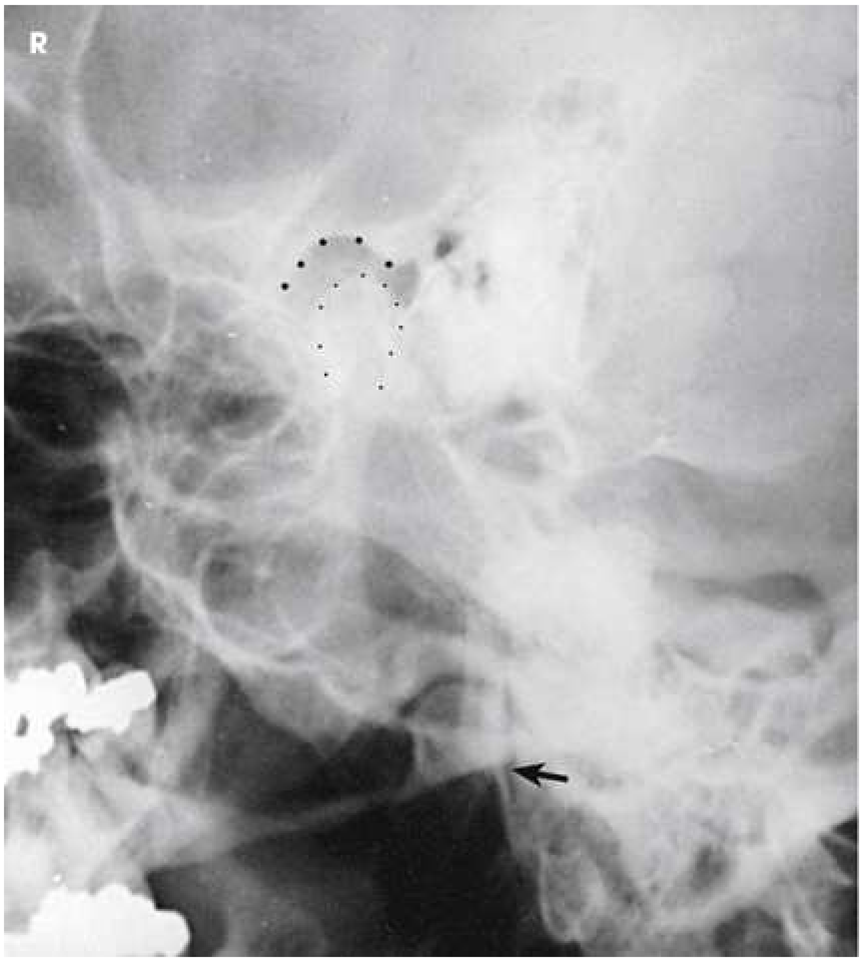


FIG. 11.158 Axiolateral TMJ, mouth closed. Mandibular condyle *(small dots)* and mandibular fossa *(large dots)* are shown. Mandibular condyle of side away from the IR is also seen *(arrow)*.

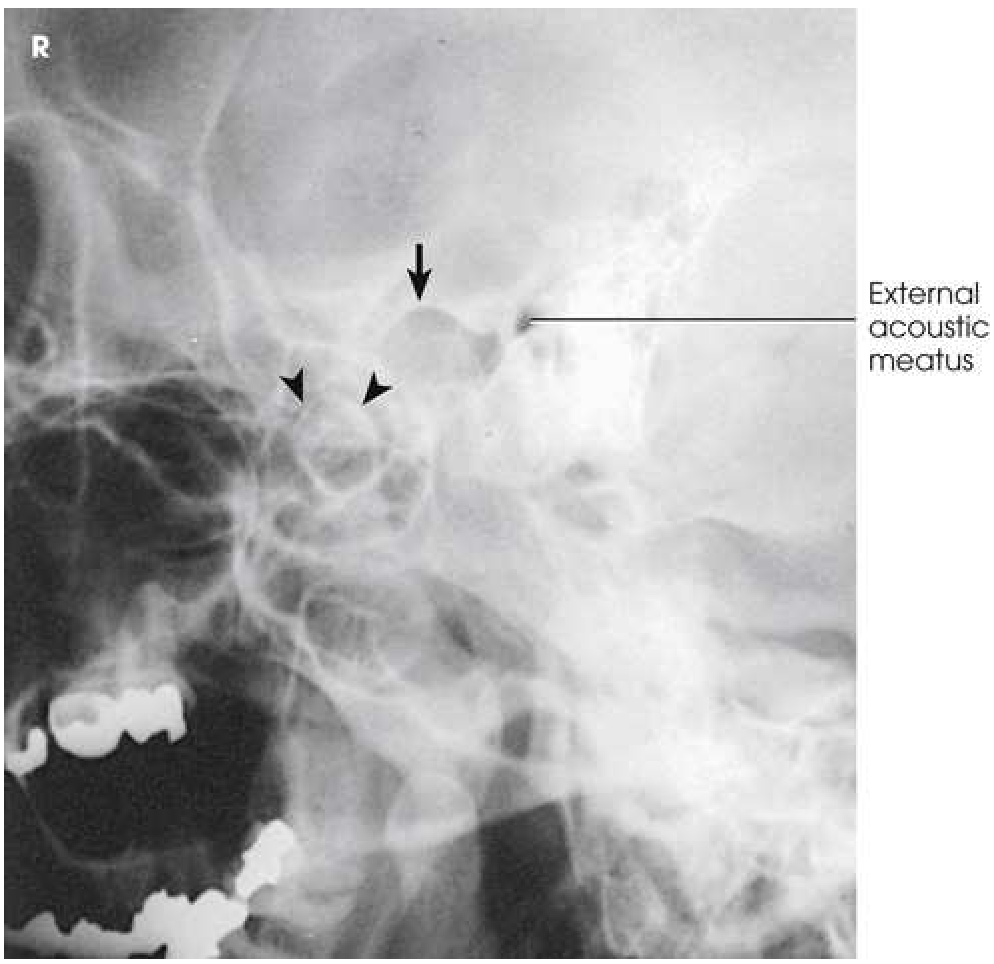


FIG. 11.159 Axiolateral TMJ, mouth open. Mandibular fossa *(arrow)* and mandibular condyle *(arrowheads)* are shown.

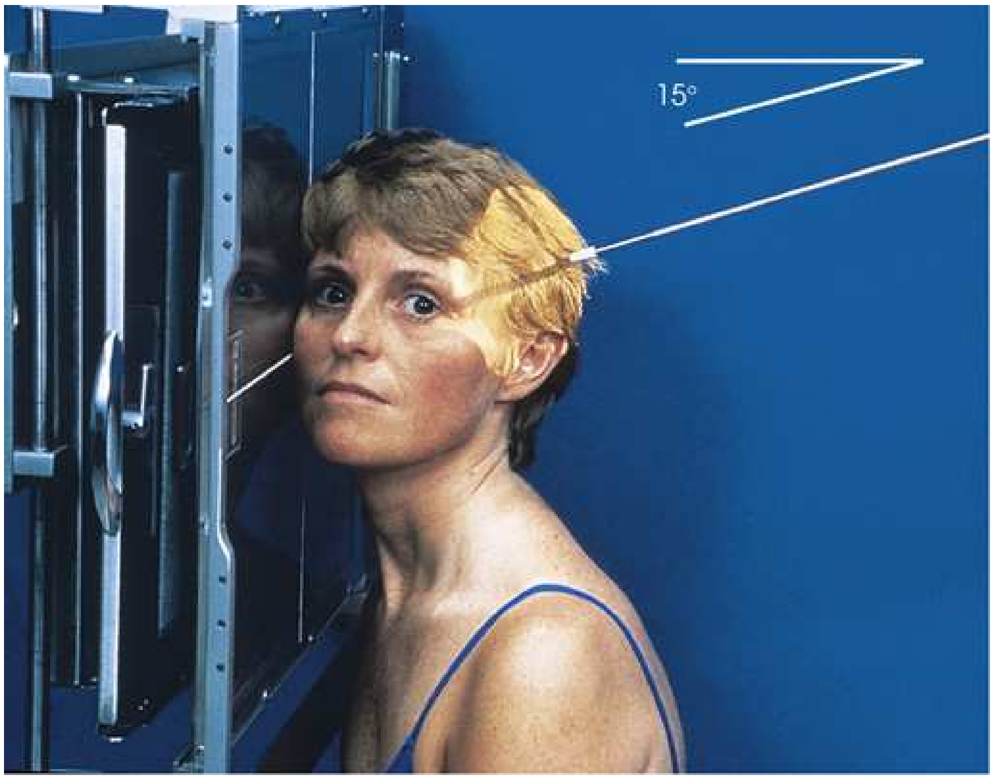


FIG. 11.160 Axiolateral oblique TMJ.

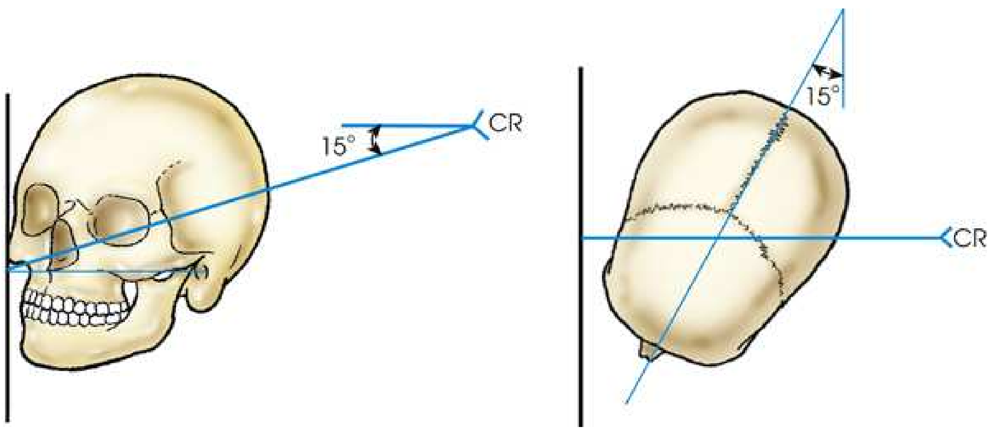


FIG. 11.161 Upright radiography diagram: axiolateral oblique TMJ.

The anterior and posterior positions of a skull with the lateral side against an image receptor. The skull is tilted towards right. The central ray is directed towards the occipital bones, at an angle 30 degrees away from a horizontal above the skull in the anterior position. The ray is directed towards the center of the axis of the skull in the posterior position.

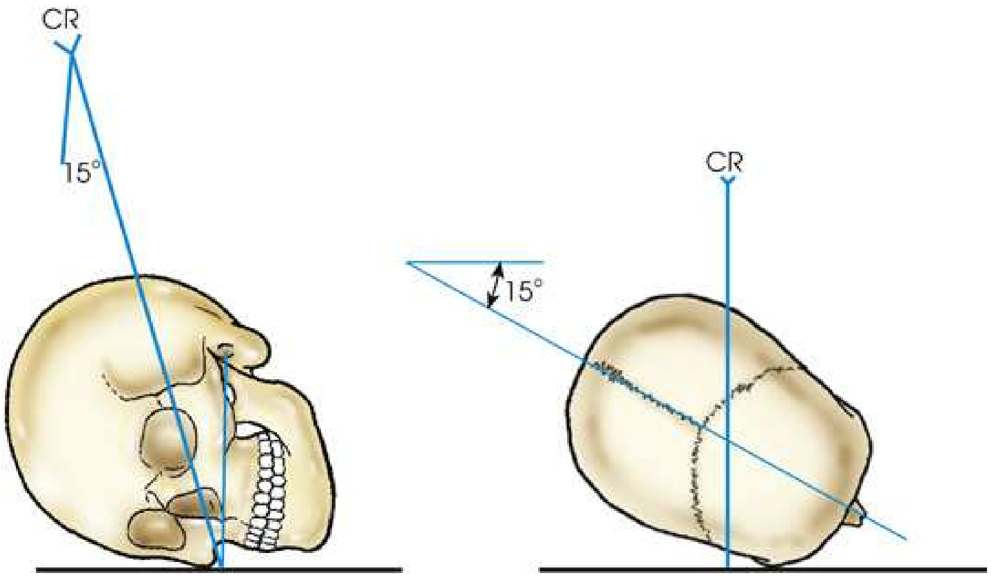


FIG. 11.162 Table radiography diagram: axiolateral oblique TMJ.

The anterior and posterior positions of a skull lying on an image receptor. The skull is tilted towards right. The central ray is directed towards the occipital bones, at an angle 30 degrees away from a horizontal above the skull in the anterior position. The ray is directed towards the center of the axis of the skull in the posterior position.

Axiolateral Oblique Projection

Right and left positions

This projection is sometimes called the *modified Law method* because it consists of approximately the same positioning details and CR orientation as the modified Law method for the petromastoid portion of the temporal bone, seen in the 10th edition of *Merrill's Atlas*.

Image receptor + grid: Positioned by manufacturer or department protocol for proper anatomy display orientation; CR plate: 10 × 12 inches (24 × 30 cm) crosswise.

Position of patient

- Place the patient in a semiprone position, or seat the patient before a vertical grid device.
- In TMJ examinations, make one exposure with the mouth closed, and when not contraindicated, make one exposure with the mouth open.
- Examine both sides for comparison.

Position of part

- Center a point ½ inch (1.3 cm) anterior to the EAM to the IR, and rest the patient's cheek on the grid device.
- Rotate MSP of the head approximately 15 degrees toward the IR.
- Adjust the IPL perpendicular to the plane of the IR.
- Adjust the flexion of the patient's neck so that the AML is parallel with the transverse axis of the IR (Figs. 11.160–11.162).
- Immobilize the head.
- *Respiration:* Suspend.
- After making the exposure with the mouth closed, change the IR and instruct the patient to open the mouth widely.
- Recheck the position of the AML, and make the second exposure.

Central ray

- Directed 15 degrees caudad and exiting through the TMJ closest to the IR. The central ray enters about 1½ inches (3.8 cm) superior to the upside EAM.

Collimation

- Adjust the radiation field to extend from the outer canthus to the posterior edge of the auricle and from the midparietal region to the inferior edge of the auricle. The exposure field should be no larger than 5 × 5 inches (12.5 × 12.5 cm). Place the side marker in the collimated exposure field.

Structures shown

Open-mouth and closed-mouth positions show the condyles and necks of the mandible. The images also show the relationship between the mandibular fossa and the condyle. The open-mouth position shows the mandibular fossa and the inferior and anterior excursion of the condyle. Both sides are examined for comparison (Fig. 11.163). The closed-mouth position shows fractures of the neck and condyle of the ramus.

Evaluation Criteria

The following should be clearly seen:

- Evidence of proper collimation and presence of the side marker placed clear of anatomy of interest
- Temporomandibular articulation
- Condyle lying in the mandibular fossa in the closed-mouth examination
- Condyle lying inferior to the articular tubercle in the open-mouth projection if the patient is normal and is able to open the mouth widely
- Soft tissue and bony trabecular detail

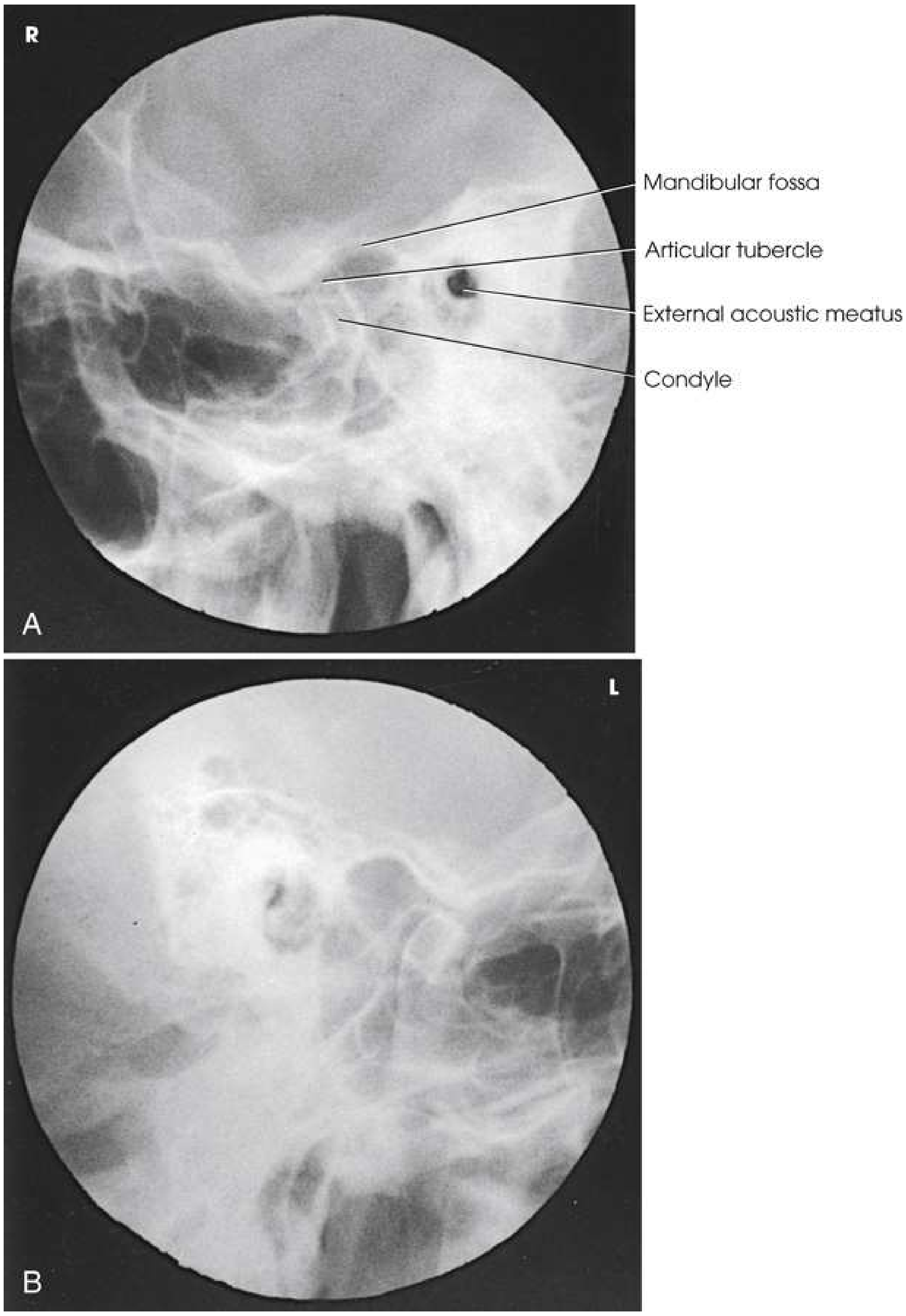


FIG. 11.163 Axiolateral oblique TMJ. (A) Mouth open, right side. (B) Mouth open, left side (same patient), showing more movement on left side.

Two circular X-ray images of the axiolateral oblique with the mouth open on the right side and left side. The Mandibular fossa, Articular tubercle, Condyle, and External acoustic meatus are labeled on the first image.

Mandible and TMJs

Panoramic Tomography of the Mandible

Panoramic tomography, *pantomography*, and *rotational tomography* are terms used to designate the technique employed to produce tomograms of curved surfaces. This technique of body-section radiography provides a panoramic image of the entire mandible, including the TMJ, and of both dental arches on one long, narrow image. Digital panorex units are capable of providing several images necessary for orthodontic and dental treatments, including three-dimensional images, cephalometric analysis, and surgical implant treatment planning.

Two types of equipment are available for pantomography. In the first type, the patient and the IR are rotated before a stationary x-ray tube. This type of machine consists of (1) a specially designed chair mounted on a turntable and (2) a second turntable to support a 4 × 10 inches (10 × 24 cm) IR. The seated and immobilized patient and the IR are electronically rotated in opposite directions at coordinated speeds. The x-ray tube remains stationary. In one machine, the exposure is interrupted in the midline.

FIG. 11.164 Digital panograph unit. Courtesy Gendex.

In the second type of unit, the x-ray tube and the IR rotate in the same direction around the seated and immobilized patient (Fig. 11.164). The x-ray tube and IR drum are attached to an overhead carriage that is supported by the vertical stand assembly. The chair of this unit is fixed to the base but can be removed to accommodate patients in wheelchairs. The attached head holder and radiolucent bite device center and immobilize the patient's head. A scale on the head holder indicates the jaw size. The latest digital technology offers 33 panoramic options.

In both types of equipment, the beam of radiation is sharply collimated at the tube aperture by a lead diaphragm with a narrow vertical slit. A corresponding slit diaphragm is fixed between the patient and the IR so that the patient and the IR (or the tube and the IR) rotate. Each narrow area of the part is recorded on the IR without overlap and without fogging from scattered and secondary radiation.

The scan (exposure) time varies from 10 to 20 seconds in different makes of equipment. Because of the slit diaphragm, however, radiation exposure to the patient at each fraction of a second is restricted to the skin surface that is passing before the narrow vertical slit aperture.

Panoramic tomography provides a distortion-free lateral image of the entire mandible (Fig. 11.165). It also affords the most comfortable way to position patients who have sustained severe mandibular or TMJ trauma, before and after splint wiring of the teeth. It must be supplemented with an AP, PA, or VSM projection to establish fragment position.

This tomographic technique is useful for general survey studies of various dental and facial bone abnormalities. It is also used to supplement rather than replace conventional periapical images, although digital units are capable of providing standard bitewing images as well as lateral TMJ images.

FIG. 11.165 Panoramic digital tomogram. Courtesy Gendex.

Sinus Radiography

Technical Considerations

The most important technical consideration for demonstration of potential pathology of the paranasal sinuses is to image the patient in the *upright* position whenever possible. The upright position is best for demonstration of air-fluid levels and to differentiate fluid from other pathologic conditions, as shown by the research by Cross [11] and Flecker. [12] Appropriate exposure factors are also necessary so that air, fluid, soft tissue, and bony tissues are all well visualized. An appropriate kVp and mAs combination and a well-collimated radiation field will ensure optimum digital image quality at the lowest possible patient dose.

The paranasal sinuses vary not only in size and form but also in position. The cells of one group frequently encroach on and resemble those of another group. This characteristic of the sinuses, together with their proximity to the vital intracranial organs, makes accurate radiographic demonstration of their anatomic structure of prime importance. The patient's head must be carefully placed in a sufficient number of positions so that the projections of each group of cavities are as free of superimposed bony structures as possible. The images must be of such quality that it is possible to distinguish the cells of several groups of sinuses and their relationship to surrounding structures.

Unless sinus images are almost perfect technically, they are of little diagnostic value. For this reason, a precise technical procedure is necessary in radiography of the paranasal sinuses. The first requirements are a small focal spot and IRs that are free of artifacts. As mentioned previously, the image contrast must markedly distinguish the sinuses from surrounding structures. The head must be carefully positioned and rigidly immobilized, and respiration must be suspended for the exposures.

The effect of body position and central ray angulation is shown in radiographs of a coconut held in position by head clamps. Fig. 11.166 shows a sharply defined air-fluid level. This coconut was placed in the vertical position, and the central ray was directed horizontally. Fig. 11.167 was also taken with the coconut in the vertical position, but the central ray was directed upward at an angle of 45 degrees to show gradual fading of the fluid line when the central ray is *not* horizontal. This effect is much more pronounced in actual practice because of structural irregularities. Fig. 11.168 was made with the coconut in the horizontal position and the central ray directed vertically. The resultant radiograph shows a homogeneous density throughout the cavity of the coconut, with no evidence of an air-fluid level.

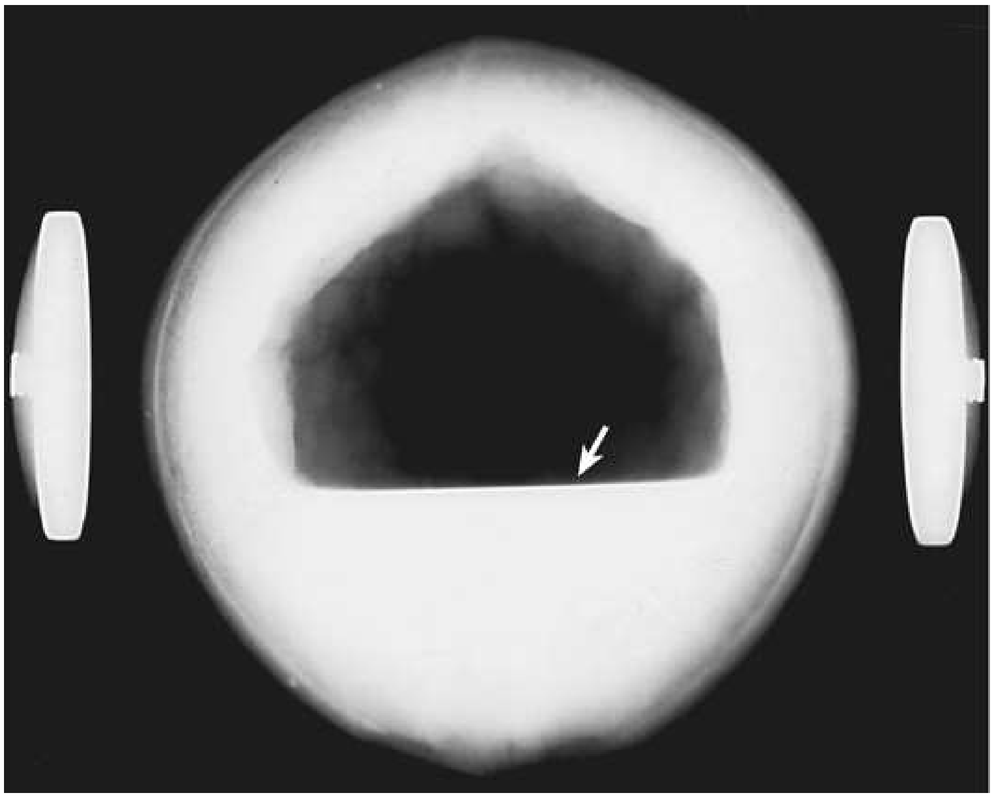


FIG. 11.166 Coconut, vertical position: horizontal central ray. Air-fluid level is shown *(arrow)*.

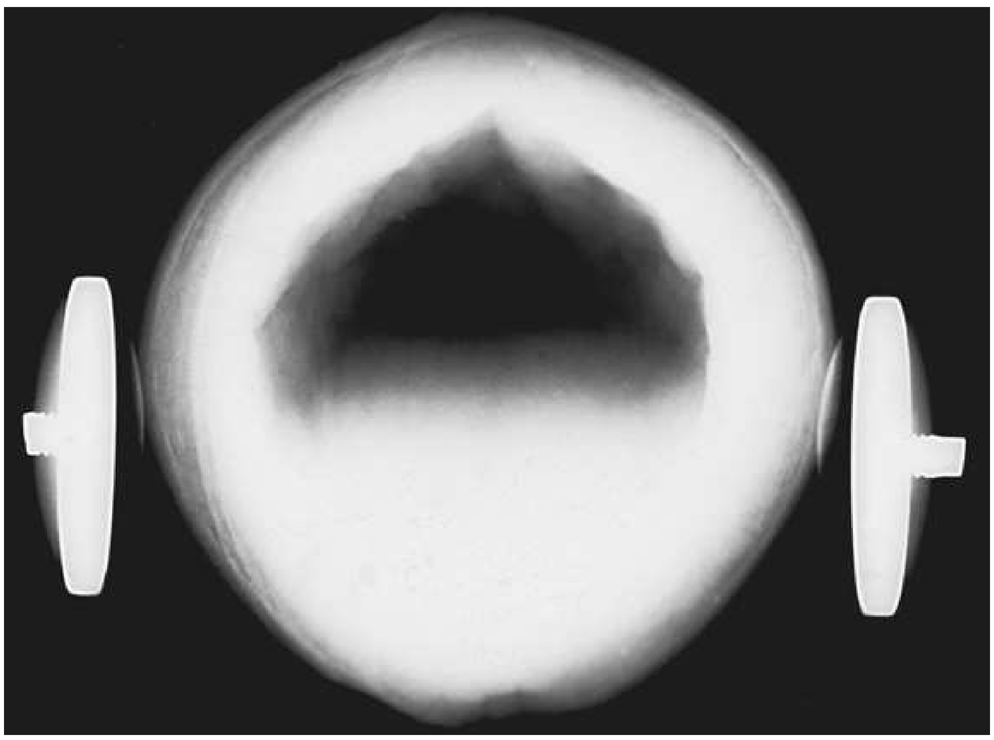


FIG. 11.167 Coconut, vertical position: central ray angled 45 degrees upward. Air-fluid level is not as sharp.

Exudate contained in the sinuses is not fluid in the usual sense of the word but is commonly a heavy, semigelatinous material. The exudate, rather than flowing freely, clings to the walls of the cavity and takes several minutes, depending on its viscosity, to shift position. For this reason, when the position of a patient is changed or the patient's neck is flexed or extended to position the head for special projections, *several minutes* should be allowed for the exudate to gravitate to the desired location before the exposure is made.

Although numerous sinus projections are possible, with each serving a special purpose, many are used only when required to show a specific lesion. The consensus is that five standard projections adequately show all of the paranasal sinuses in most patients. The following steps are observed in preparing for these projections:

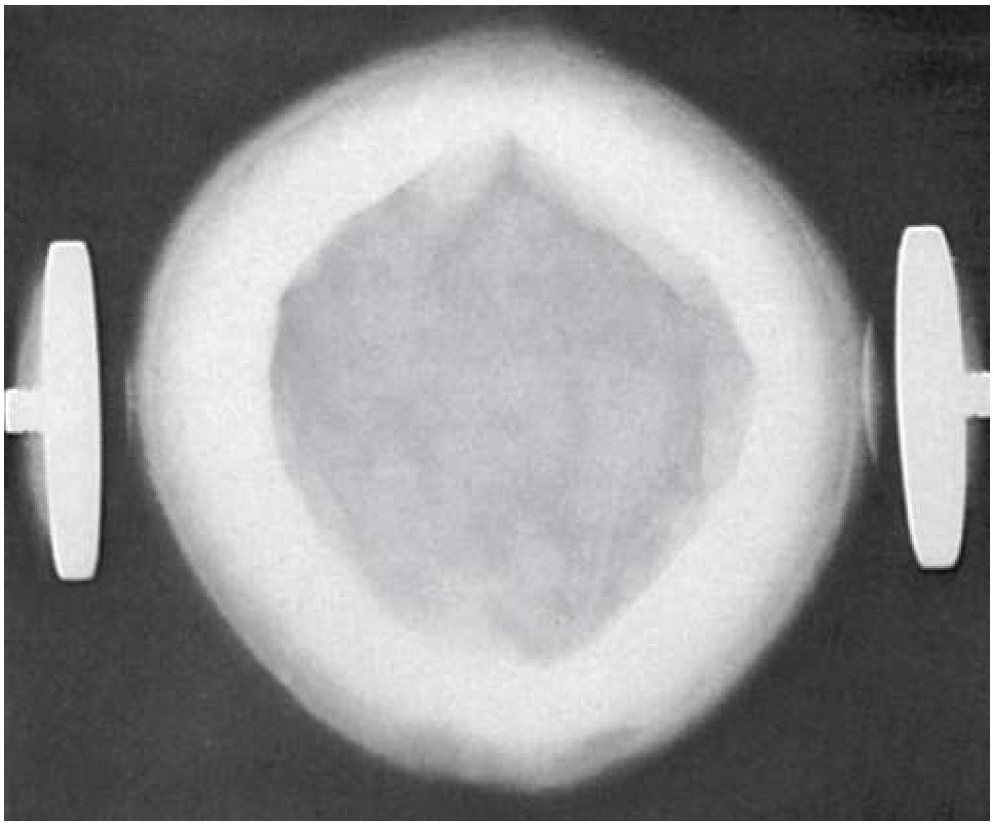


FIG. 11.168 Coconut, horizontal position: vertical central ray. No evidence of air-fluid level is seen.

- Use a suitable protractor to check and adjust the position of the patient's head to ensure accurate positioning.
- Have the patient remove all potential artifacts, such as dentures, hairpins, earrings and other facial piercings, and necklaces before proceeding with the examination.
- Because the patient's face is in contact with the IR holder or the IR itself for many of the images, these items should be cleaned before the patient is positioned.

Even with the most hygienic patients, the hair and face are naturally oily and leave a residue. If a patient is sick, the residue is worse. During positioning of the patient's head, the hair, mouth, nose, and eyes come in direct contact with the vertical grid device, tabletop, or IR. Medical asepsis can be promoted by placing a paper towel or sheet between the imaging surface and the patient. As standard procedure, the contacted area should be cleaned with a disinfectant before and after positioning.

Paranasal Sinuses

Lateral Projection

Right or left position

Image receptor + grid: Positioned by manufacturer or department protocol for proper anatomy display orientation; CR plate: 10 × 12 inches (24 × 30 cm) lengthwise.

Position of patient

- Seat the patient before a vertical grid device with the body placed in the RAO or LAO position so that the head can be adjusted in a true lateral position. This is the same basic position that is used for the lateral skull and facial bone positions.

Position of part

- Rest the side of the patient's head on the vertical grid device, and adjust the head in a true lateral position. MSP of the head is parallel with the plane of the IR, and the IPL is perpendicular to the plane of the IR.
- The IOML is positioned horizontally to ensure proper extension of the head. This position places the IOML perpendicular to the front edge of the vertical grid device (Fig. 11.169).
- *Respiration:* Suspend.

Central ray

- Directed *horizontal,* enter the patient's head

to 1 inch (1.3 to 2.5 cm) posterior to the outer canthus.
• Center the IR to the central ray.
• Immobilize the head.

Collimation

• Adjust the radiation field to extend 1 inch (2.5 cm) beyond the tip of the nose, superiorly to 3 inches (7.6 cm) above the nasion, inferiorly to the occlusal plane, and posteriorly to the auricle. The exposure field should be no larger than 8 × 10 inches (18 × 24 cm). Place the side marker in the collimated exposure field.

Structures shown

The AP and superoinferior dimensions of the paranasal sinuses, their relationship to surrounding structures, and the thickness of the outer table of the frontal bone (Fig. 11.170).

When the lateral projection is to be used for preoperative measurements, it should be made at a 72-inch (183-cm) SID to minimize magnification and distortion.

Evaluation Criteria

The following should be clearly seen:

- Evidence of proper collimation and presence of the side marker placed clear of anatomy of interest
- All four sinus groups, but the sphenoidal sinus is best demonstrated
- No rotation or tilt of sinus anatomy, as demonstrated by:
  - Sella turcica in profile
  - Superimposed orbital roofs
  - Superimposed mandibular rami
- Soft tissue, bony trabecular detail, and air-fluid levels, if present

NOTE: If the patient is unable to assume the upright body position, a lateral projection can be obtained using the dorsal decubitus position. The horizontal beam enables fluid levels to be seen. Positioning of the part is the same except for the IOML, which is vertical rather than horizontal.

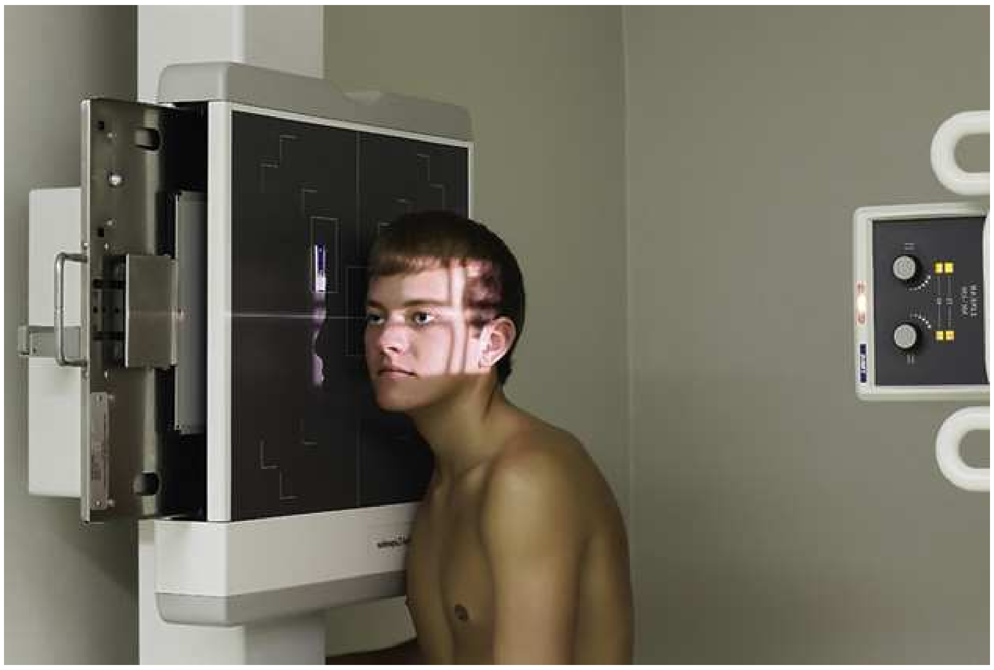


FIG. 11.169 Lateral sinuses.

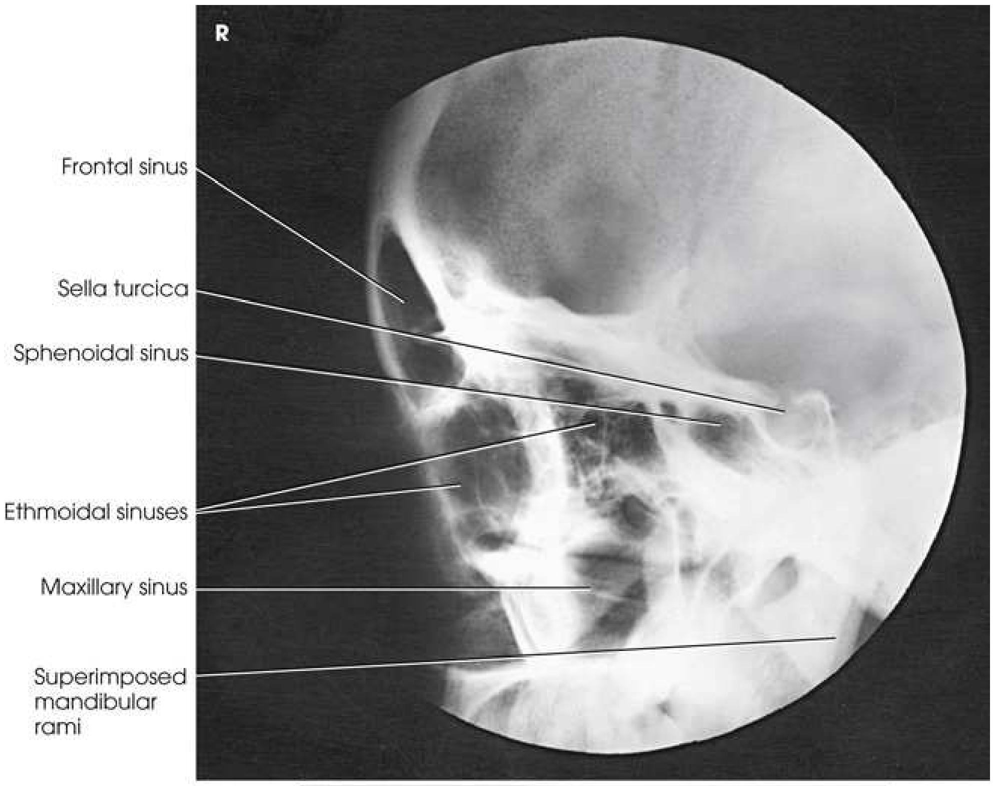


FIG. 11.170 Lateral sinuses.

Frontal and Anterior Ethmoidal Sinuses

Pa Axial Projection

Caldwell Method

Because sinus images should always be obtained with the patient in the upright body position and with a *horizontal* direction of the central ray, the Caldwell method is easily modified when a vertical grid device capable of angular adjustment is used. For the modification, all anatomic landmarks and localization planes remain unchanged.

Image receptor + grid: Positioned by manufacturer or department protocol for proper anatomy display orientation; CR plate: 10 × 12 inches (24 × 30 cm) lengthwise.

Position of patient

- Seat the patient facing a vertical grid device.
- Center MSP of the patient's body to the midline of the grid.

Position of part

Angled grid technique

- Before positioning the patient, tilt the vertical grid device down so that an angle of 15 degrees is obtained (Fig. 11.171A).
- Rest the patient's nose and forehead on the vertical grid device, and center the nasion to the IR.
- Adjust the MSP and OML of the patient's head perpendicular to the plane of the IR.
- This positioning places the OML perpendicular to the angled IR and 15 degrees from the horizontal central ray.
- Immobilize the head.
- *Respiration:* Suspend.

Vertical grid technique

- When the vertical grid device cannot be angled, extend the patient's neck slightly, rest the tip of the nose on the grid device, and center the nasion to the IR.
- Position the patient's head so that the OML forms an angle of 15 degrees with the horizontal central ray. For support, place a radiolucent sponge between the forehead and the grid device (see Figs. 11.171B and 11.172).
- Adjust the MSP of the patient's head perpendicular to the plane of the IR.
- Immobilize the head.
- *Respiration:* Suspend.

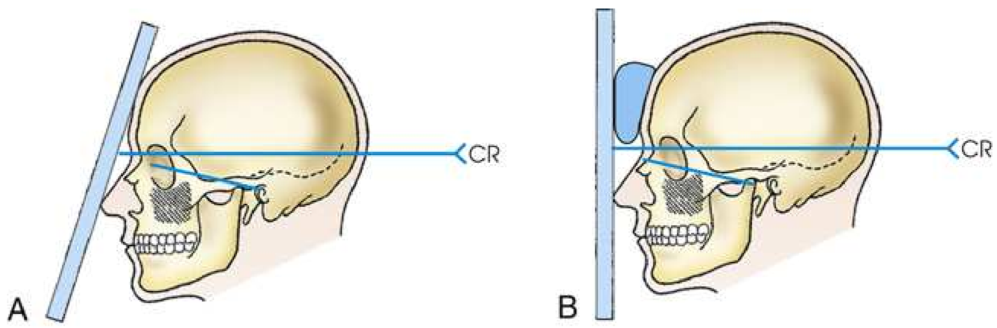


FIG. 11.171 Diagram of PA axial sinuses: Caldwell method. (A) IR tilted 15 degrees. (B) Same projection with vertical IR.

FIG. 11.172 PA axial sinuses: Caldwell method.

Central ray

- Directed *horizontal* to exit the nasion. The 15-degree relationship between the central ray and the OML remains the same for both techniques.
- Center the IR to the central ray.

NOTE: The *angled grid technique* is preferred because it brings the IR closer to the sinuses, increasing resolution. Angulation of the grid device provides a natural position for placement of the patient's nose and forehead.

Collimation

- Adjust the radiation field to extend 1 inch (2.5 cm) beyond the lateral skin shadows, superiorly to include just the shadow of the top of the head, and inferiorly to the occlusal plane. The exposure field should be no larger than 8 × 10 inches (18 × 24 cm). Place the side marker in the collimated exposure field.

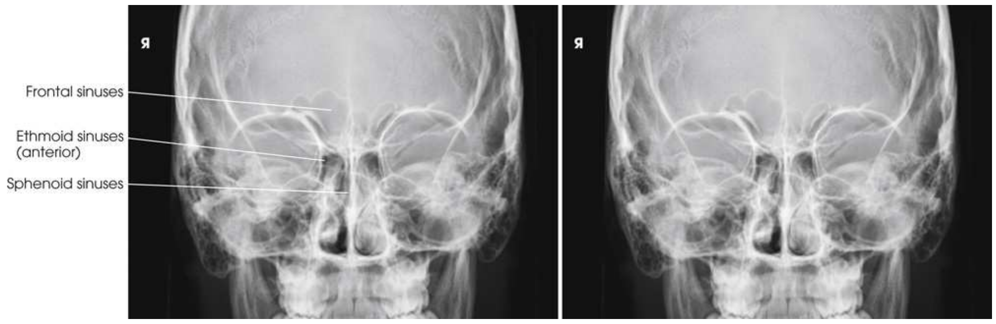


FIG. 11.173 PA axial sinuses: Caldwell method.

Structures shown

The frontal sinuses lying superior to the frontonasal suture, the anterior ethmoidal air cells lying on each side of the nasal fossae and immediately inferior to the frontal sinuses, and the sphenoidal sinuses projected through the nasal fossae just inferior to or between the ethmoidal air cells (Fig. 11.173). The dense petrous pyramids extend from the inferior third of the orbit inferiorly to obscure the superior third of the maxillary sinus. This projection is used primarily to show the frontal sinuses and anterior ethmoidal air cells.

Evaluation Criteria

The following should be clearly seen:

- Evidence of proper collimation and presence of the side marker placed clear of anatomy of interest
- Frontal sinuses lying above the frontonasal suture and the anterior ethmoidal air cells lying above the petrous ridges
- No rotation or tilt, demonstrated by:
  - Equal distance between the lateral border of the skull and the lateral border of the orbits
  - Petrous ridge symmetric on both sides
  - MSP of head aligned with long axis of collimated field
- Petrous ridge lying in the lower third of the orbit
- Soft tissue, bony trabecular detail, and air-fluid levels, if present

Maxillary Sinuses

Parietoacanthial Projection

Waters Method

Image receptor + grid: Positioned by manufacturer or department protocol for proper anatomy display orientation; CR plate: 10 × 12 inches (24 × 30 cm) lengthwise.

For the Waters method,[13, 14] the goal is to hyperextend the patient's neck just enough to place the dense petrosae immediately below the maxillary sinus floors (Fig. 11.174). When the neck is extended too little, the petrosae are projected over the inferior portions of the maxillary sinuses and obscure underlying pathologic conditions (Fig. 11.175). When the neck is extended too much, the maxillary sinuses are foreshortened, and the antral floors are not shown.

Position of patient

- Place the patient seated in an upright position, facing the vertical grid device.
- Center the MSP plane of the patient's head to the midline of the grid device.

Position of part

- Because this position is uncomfortable for the patient to hold, have the IR and equipment in position so that the examination can be performed quickly.
- Hyperextend the patient's neck to approximately the correct position, and then center the IR to the acanthion.

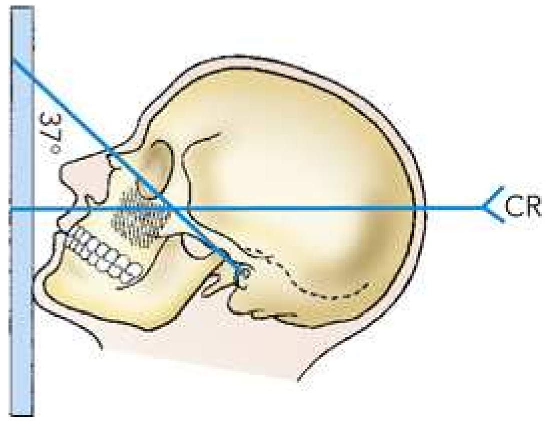


FIG. 11.174 Proper positioning diagram. Petrous ridges are projected below maxillary sinuses.

- Rest the patient's chin on the vertical grid device and adjust it so that the MSP is perpendicular to the plane of the IR.
- Using a protractor as a guide, adjust the head so that the OML forms an angle of 37 degrees from the plane of the IR (see Figs. 11.174 and 11.176). As a positioning check for the average-shaped skull, the MML line should be approximately perpendicular to the IR plane.
- Immobilize the head.
- *Respiration:* Suspend.

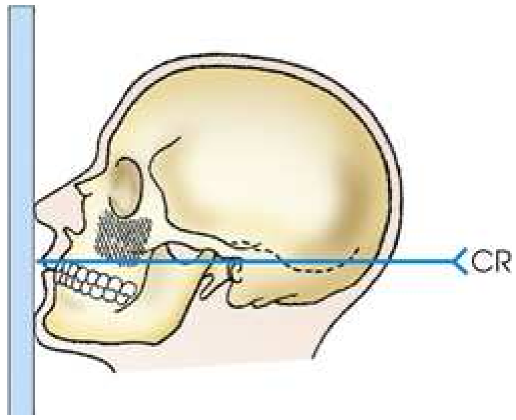


FIG. 11.175 Improper positioning diagram. Petrous ridges are superimposed on maxillary sinuses.

FIG. 11.176 Parietoacanthial sinuses: Waters method.

Central ray

- *Horizontal* to the IR and exiting the acanthion

Collimation

- Adjust the radiation field to extend 1 inch (2.5 cm) beyond the lateral skin shadows, superiorly to include just the shadow of the top of the head, and inferiorly to the occlusal plane. The exposure field should be no larger than 8 × 10 inches (18 × 24 cm). Place the side marker in the collimated exposure field.

Structures shown

The maxillary sinuses, with the petrous ridges lying inferior to the floor of the sinuses (Fig. 11.177). The frontal and ethmoidal air cells are distorted.

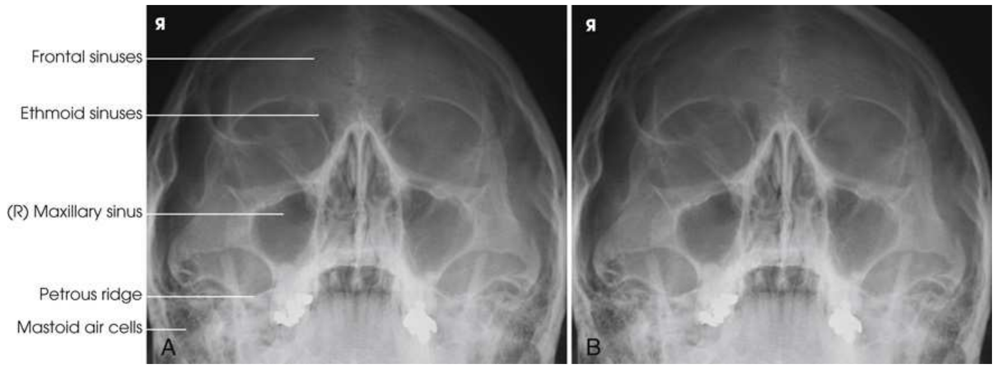


FIG. 11.177 (A) Parietoacanthial sinuses: Waters method. (B) Same projection.

The Waters method is also used to show the foramen rotundum. The images of these structures are seen, one on each side, just inferior to the medial aspect of the orbital floor and superior to the roof of the maxillary sinuses.

Evaluation Criteria

The following should be clearly seen:

n Evidence of proper collimation and presence of the side marker placed clear of anatomy of interest
n Maxillary sinuses
n OML in proper position (sufficient neck extension), as demonstrated by:
  - Petrous pyramids lying immediately *inferior* to the floor of the maxillary sinuses
n No rotation or tilt, demonstrated by:
  - Equal distance between the lateral border of the skull and the lateral border of the orbit on both sides
  - Orbits and maxillary sinuses symmetric on each side
  - MSP of head aligned with long axis of collimated field
n Soft tissue, bony trabecular detail, and air-fluid levels, if present

Maxillary and Sphenoidal Sinuses

Parietoacanthial Projection

Open-Mouth Waters Method

Image receptor + grid: Positioned by manufacturer or department protocol for proper anatomy display orientation; CR plate: 10 × 12 inches (24 × 30 cm) lengthwise.

This method provides an excellent demonstration of the sphenoidal sinuses projected through the open mouth. For patients who cannot be placed in position for the SMV projection, the *open-mouth Waters method* and lateral projections may be the only techniques to show the sphenoidal sinuses. Because the open-mouth position is uncomfortable for the patient to hold, the radiographer must have the IR and equipment in position to perform the examination quickly.

Position of part

- Hyperextend the patient's neck to approximately the correct position, and then position the IR to the acanthion.
- Rest the patient's chin on the vertical grid device, and adjust it so that MSP is perpendicular to the plane of the IR.
- Using a protractor as a guide, adjust the patient's head so that the OML forms an angle of 37 degrees from the plane of the IR. The MML would not be perpendicular (Fig. 11.178).
- Have the patient *slowly open the mouth wide open* while holding the position.
- Immobilize the head.
- *Respiration:* Suspend.

FIG. 11.178 Parietoacanthial sinuses: open-mouth Waters method.

Central ray

- *Horizontal* to the IR and exiting the acanthion.

Collimation

- Adjust the radiation field to extend 1 inch (2.5 cm) beyond the lateral skin shadows, superiorly to include just the shadow of the top of the head, and inferiorly to the occlusal plane. The exposure field should be no larger than 8 × 10 inches (18 × 24 cm). Place the side marker in the collimated exposure field.

Structures shown

The sphenoidal sinuses projected through the open mouth along with the maxillary sinuses (Fig. 11.179).

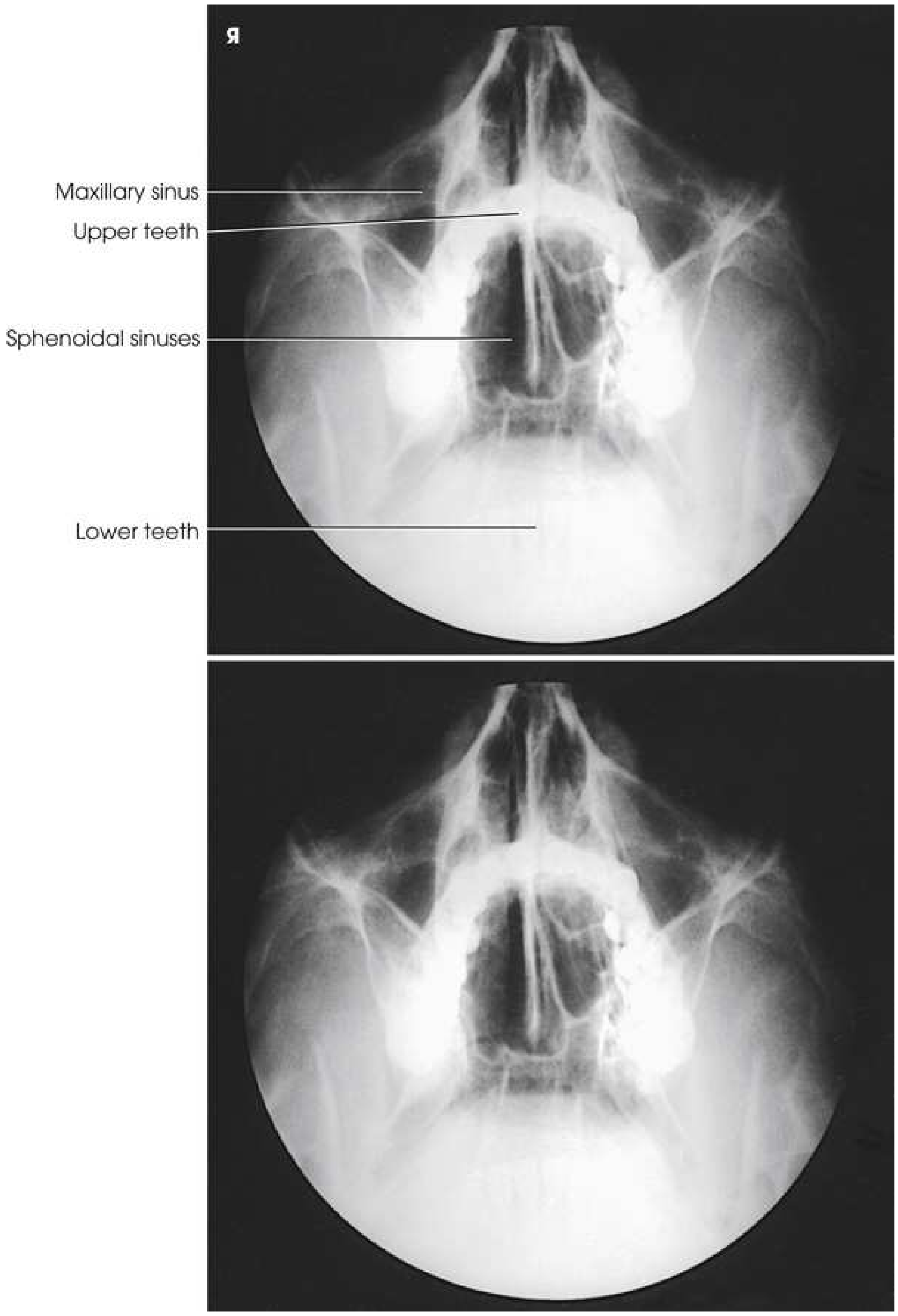


FIG. 11.179 Open-mouth Waters modification shows sphenoidal sinuses projected through open mouth along with maxillary sinuses.

Two X-ray images of the sphenoidal sinuses projected through open mouth and the maxillary sinuses are visible. The Maxillary sinus, Upper teeth, Sphenoidal sinuses, and Lower teeth are labeled in the first image.

Evaluation Criteria

The following should be clearly seen:

n Evidence of proper collimation and presence of the side marker placed clear of anatomy of interest
n Sphenoidal sinuses projected through the open mouth
n Maxillary sinuses
n OML in proper position (sufficient neck extension), as demonstrated by:
  ▫ Petrous pyramids lying immediately *inferior* to the floor of the maxillary sinuses
n No rotation or tilt, demonstrated by:
  ▫ Equal distance between the lateral border of the skull and the lateral border of the orbit on both sides
  ▫ Orbits and maxillary sinuses symmetric on each side
  ▫ MSP of head aligned with long axis of collimated field
n Soft tissue, bony trabecular detail, and air-fluid levels, if present

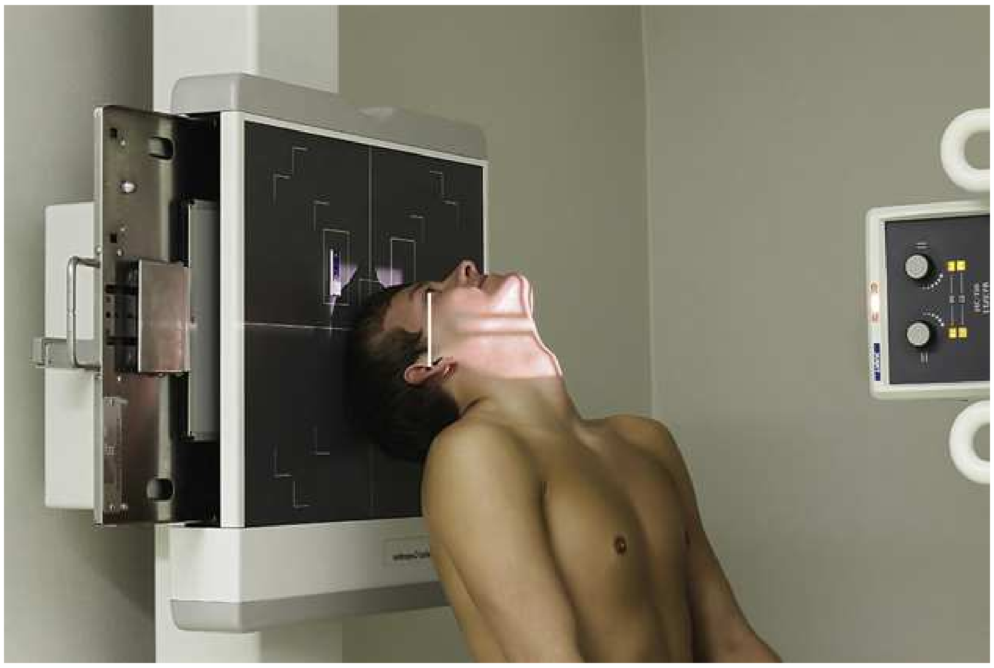


FIG. 11.180 SMV sinuses.

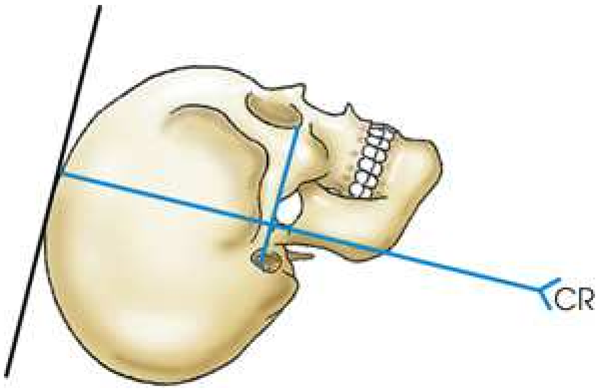


FIG. 11.181 Upright radiography diagram: SMV sinuses.

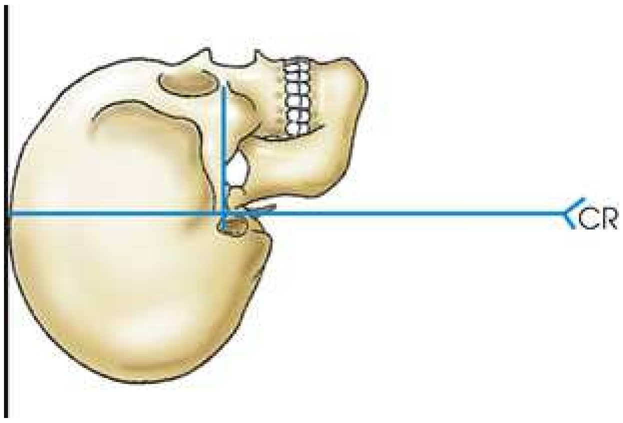


FIG. 11.182 Upright radiography diagram: SMV sinuses, preferred position of skull.

A skull is placed with the top resting against an image receptor in an upright position. The central ray passes through the axis of the skull perpendicular to the image receptor and parallel to the table.

Ethmoidal and Sphenoidal Sinuses

Submentovertical Projection

Image receptor + grid: Positioned by manufacturer or department protocol for proper anatomy display orientation; CR plate: 10 × 12 inches (24 × 30 cm), lengthwise.

Position of patient

The success of the SMV projection depends on placing the IOML as nearly parallel as possible with the plane of the IR and directing the central ray perpendicular to the IOML. The upright position is recommended for all paranasal sinus images and is more comfortable for the patient. The following steps are observed:

- Use a chair that supports the patient's back to obtain greater freedom in positioning the patient's body to place the IOML parallel with the IR.
- Seat the patient far enough away from the vertical grid device that the head can be fully extended (Fig. 11.180).
- If necessary to examine short-necked or hypersthenic patients, angle the vertical grid device downward to achieve a parallel relationship between the grid and the IOML (Fig. 11.181). The disadvantage of angling the vertical grid device is that the central ray is not horizontal, and air-fluid levels may not be shown as easily as when the central ray is truly horizontal.

Position of part

- Hyperextend the patient's neck as far as possible, and rest the head on its vertex. If the patient's mouth opens during hyperextension, ask the patient to keep the mouth closed to move the mandibular symphysis anteriorly.
- Adjust the patient's head so that the MSP is perpendicular to the midline of the IR.
- Adjust the tube so that the central ray is perpendicular to the IOML (Fig. 11.182; also see Figs. 11.180 and 11.181).
- Immobilize the patient's head. In the absence of a head clamp, place a suitably backed strip of adhesive tape across the tip of the chin and anchor it to the sides of the radiographic unit. Do not put the adhesive surface directly on the patient's skin.
- *Respiration:* Suspend.

Central ray

- *Horizontal* and perpendicular to the IOML through the sella turcica. The central ray enters on the MSP approximately ¾ inch (1.9 cm) anterior to the level of the EAM.

Collimation

- Adjust the radiation field to extend 1 inch (2.5 cm) beyond the tip of the nose and on the lateral sides. The exposure field should be no larger than 8 × 10 inches (18 × 24 cm). Place the side marker in the collimated exposure field.

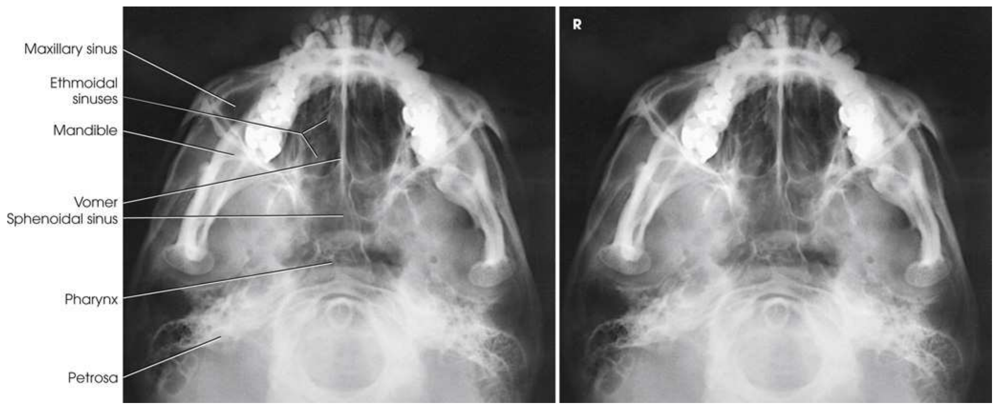


FIG. 11.183 SMV sinuses.

Two X-ray images of the S M V sinuses. The thorax, mandible, and teeth are visible. The Maxillary sinus, Ethmoidal sinuses Mandible, Vomer, Sphenoidal sinus, and Pharynx Petrosa are labeled in the first image.

Structures shown

A symmetric image of the anterior portion of the base of the skull. The sphenoidal sinus and ethmoidal air cells are shown (Fig. 11.183).

Evaluation Criteria

The following should be clearly seen:

- Evidence of proper collimation and presence of the side marker placed clear of anatomy of interest
- Sphenoid and ethmoid sinuses
- No tilt (MSP positioned perpendicular to IR), demonstrated by:
  - Equal distance from the lateral border of the skull to the mandibular condyles on both sides
- IOML positioned parallel to IR (sufficient neck extension), demonstrated by:
  - Superimposition of anterior frontal bone by mental protuberance
  - Insufficient neck extension will cause mandible to superimpose ethmoid sinuses.
- Mandibular condyles anterior to petrous pyramids

n Soft tissue, bony trabecular detail, and air-fluid levels, if present

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12: Trauma Radiography

OUTLINE

Summary of Projections

PROJECTIONS, POSITIONS, AND METHODS					
Page	Essential	Anatomy	Projection	Position	Method
124		Cervical vertebrae	Lateral	Dorsal decubitus	
125		Cervicothoracic vertebrae	Lateral	Dorsal decubitus	
126		Cervical vertebrae	AP axial	Supine	
137		Cervical intervertebral foramina	AP axial oblique	Supine	
128		Thoracic vertebrae	Lateral	Dorsal decubitus	
128		Lumbar vertebrae	Lateral	Dorsal decubitus	
129		Chest: *Lungs and heart*	AP	Supine	
131		Abdomen	AP	Supine	
133		Abdomen	AP or PA	R or L lateral decubitus	
134		Abdomen	Lateral	Dorsal decubitus	
135		Pelvis	AP	Supine	
136		Hip	Lateral	Supine	Danelius-Miller
137		Hip	Modified axiolateral	Supine	Clements-Nakayama
138		Skull	Lateral	Dorsal decubitus	
140		Skull	AP	Supine	
140		Skull	AP axial	Supine	Reverse Caldwell
140		Skull	AP axial	Supine	Reverse Towne
142		Facial bones	Acanthioparietal	Supine	Reverse Waters
143		Upper extremity	AP	Variable	
143		Upper extremity	Lateral	Variable	
146		Lower extremity	AP	Variable	
146		Lower extremity	Lateral	Variable	

Icons in the Essential column indicate projections frequently performed in the United States and Canada. Students should be competent in these projections.

AP, Anteroposterior; *L,* left; *LAO,* left anterior oblique; *PA,* posteroanterior; *R,* right; *RAO,* right anterior oblique.

Introduction

Trauma is defined as severe injury or damage to the body caused by an accident or violence. Victims of trauma require immediate and specialized care, which is commonly provided in larger hospitals within a specialized unit termed the *emergency department* (ED). Physicians and many nurses specialize in trauma care. Imaging professionals are essential to the diagnosis of injuries sustained during traumatic events, so extra study in this area of imaging is necessary. Trauma radiography can be an exciting and challenging environment for a properly prepared imaging professional.

These procedures can be intimidating and stressful for individuals unprepared for the innumerable injuries seen in the ED. The essential key to quality imaging procedures for trauma patients is proper study and preparation for imaging professionals.

Preparation for the trauma environment requires an understanding of the following: the most common traumatic injuries, the most commonly affected populations, types of trauma care facilities, specialized imaging equipment designed for imaging of trauma patients, the role of the imaging technologist as part of the ED team, and imaging procedures commonly performed on trauma patients. This chapter provides the information necessary to improve the skills and confidence of all imaging professionals caring for trauma patients.

Trauma Statistics

Trauma-related injuries affect persons in all age ranges. Fig. 12.1 shows trauma incidence by age and gender, as reported in the 2016 annual report of the American College of Surgeons' National Trauma Data Bank (NTDB). The database contains more than 7 million records from 747 hospitals and is the largest collection of data on US/Canadian trauma. These data show that trauma patients most commonly are male and range in age from teenagers to early adults. Fig. 12.2 shows the distribution of trauma injuries by cause; the most common are falls, followed by motor vehicle–traffic accidents (MVTAs). Firearms rank last as a cause of injury, however, the 2016 NTDB report also shows that firearms have the highest fatality rate. The data show the most common trauma patients and mechanisms of injury, but the imaging professional who chooses to work in the ED must be prepared to care for patients of every age exhibiting a vast array of injuries.

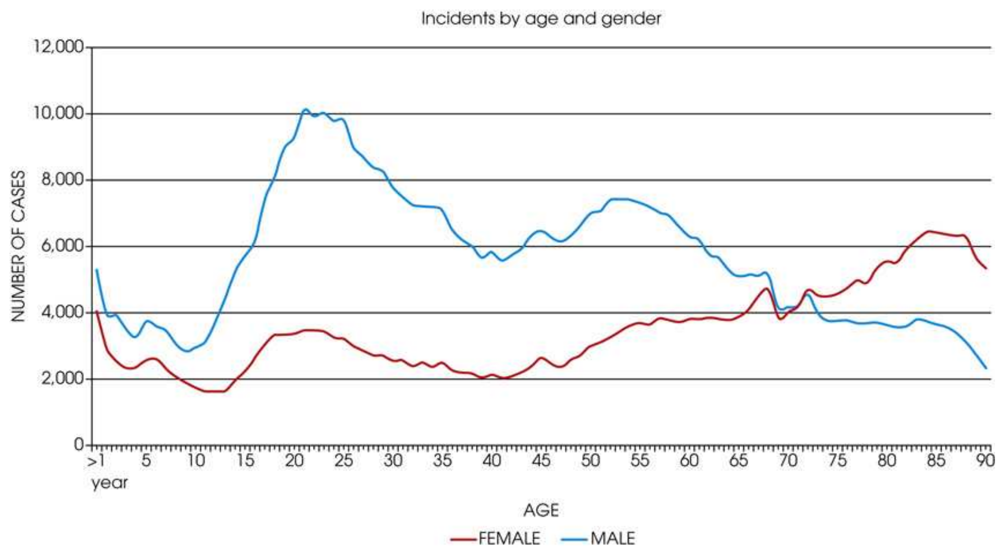


FIG. 12.1 NTDB annual report, 2016, table showing number of trauma incidents by age and gender. *NTDB*, National Trauma Data Bank. Reprinted by permission of the American College of Surgeons.

A graph showing the number of trauma incidents by age and gender. A curve denoting the number of incidents in males shows a sharp increase for age greater than 15. It reaches a highest value of 10000 for age 20 to 25. The curve decreases and rises above 7000 between age 50 to 55. It decreases gradually after age 60 years. A curve denoting the number of incidents in females shows a slight increase for age greater than 15. It reaches a highest value of 3500 for age 20 to 25. The curve decreases and rises again above 4500 between age 60 to 65. It continues the increasing trend and moves beyond 6000 for age greater than 80 years. Note: All data is approximate.

Many types of facilities provide emergency medical care, ranging from major medical centers to small outpatient clinics in rural areas. The term *trauma center* denotes a specific level of emergency medical care as defined by the American College of Surgeons Commission on Trauma (ACS COT). Four levels of care are defined. Level I is the most comprehensive, and Level IV is the most basic. A *Level I* trauma center is usually a university-based center, research facility, or large medical center. It provides the most comprehensive emergency medical care available with complete imaging capabilities and all types of specialty physicians available on site 24 hours/day. Imaging professionals are also available 24 hours/day. A *Level II* trauma center probably has all of the same specialized care available but is not a research or teaching hospital, and some specialty physicians may not be available on site. *Level III* trauma centers are usually located in smaller communities where Level I or Level II care is unavailable. Level III centers generally do not have all specialists available but can resuscitate, stabilize, assess, and prepare a patient for transfer to a larger trauma center. A *Level IV* trauma center may not be a hospital at all, but rather a clinic or other outpatient setting. These facilities usually provide care for minor injuries and offer stabilization, as well as transfer arrangements to a larger trauma center for patients with more serious injuries.

Trauma injuries can occur by several types of forces, including *blunt, penetrating, explosive,* and *heat*. Examples of blunt trauma are MVTAs, which include motorcycle accidents, collisions with pedestrians, falls, and aggravated assaults. Penetrating trauma events include gunshot wounds (GSWs), stab wounds, impalement injuries, and foreign body ingestion or aspiration. Explosive trauma causes injury by several mechanisms, including pressure shock waves, high-velocity projectiles, and burns. Heat trauma includes burn injuries, which may be caused by numerous agents, including fire, steam, hot water, chemicals, electricity, and frostbite.

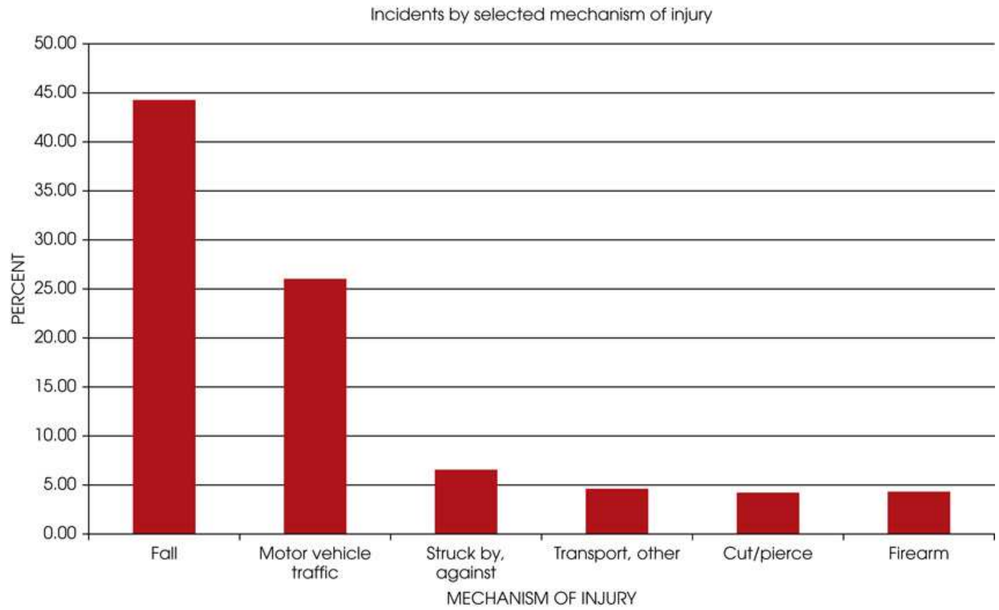


FIG. 12.2 NTDB annual report, 2016, table showing number of patients injured by each mechanism. *NTDB*, National Trauma Data Bank. Reprinted by permission of the American College of Surgeons.

A bar graph showing the number of patients injured by each mechanism. The percentage for each mechanism are as follows: Fall: 44, motor vehicle traffic: 26, struck by, against: 7, Transport and other: 4.5, cut or pierce: 4, firearm: 4.1. Note: All data is approximate.

Preliminary Considerations

Specialized Equipment

Time is a crucial element in the care of a trauma patient. To minimize the time needed to acquire diagnostic x-ray images, many EDs have dedicated radiographic equipment located in the department or immediately adjacent to the department. Trauma radiographs must be taken with minimal patient movement, requiring more maneuvering of the tube and image receptor (IR). Specialized trauma radiographic systems are available and are designed to provide greater flexibility in x-ray tube and IR maneuverability (Fig. 12.3). These specialized systems help minimize movement of the injured patient while imaging procedures are performed. In addition, some EDs are equipped with specialized beds or stretchers that have a movable tray to hold the IR. This type of stretcher allows for the use of a mobile radiographic unit and eliminates both the requirement and risk for transferring an injured patient to the radiographic table.

Computed tomography (CT) is widely used for imaging of trauma patients. In many cases, CT is the first imaging modality used, now that image acquisition has become almost instantaneous. (Refer to Chapter 25 in Volume 3 for a detailed explanation and description of CT.) The only major concern with CT imaging compared with radiography is the radiation dose. The debate centers on the exclusive use of CT, when lower-dose radiographs may be sufficient for a diagnosis. Patients who are at high risk and who are not good candidates for quality radiographs based on their injuries may be referred to CT first.

Mobile radiography is often a necessity in the ED. Many patients have injuries that prohibit transfer to a radiographic table, or their condition may be too critical to interrupt treatment. Trauma radiographers must be competent in performing mobile radiography on almost any part of the body and must be able to use accessory devices (e.g., grids, air-gap technique) to produce quality mobile images.

Mobile fluoroscopic units, usually referred to as *C-arms* because of their shape, are becoming more commonplace in EDs. C-arms are used for fracture reduction procedures, foreign body localization in extremities, and reduction of joint dislocations (Fig. 12.4).

An emerging imaging technology has the potential to have a significant effect on trauma radiography. The Statscan Critical Imaging System (Lodox Systems [Pty.], Ltd., Johannesburg, South Africa) is a relatively new imaging device that produces full-body imaging scans in approximately 13 seconds without the need to move the patient (Figs. 12.5 to 12.7). At present, approximately 17 of these systems are available worldwide. At a cost of approximately $450,000, this technology is an expensive addition to a trauma-imaging department.

Positioning aids are essential for quality imaging in trauma radiography. Sponges, sandbags, and tape used creatively are often the trauma radiographer's most useful tools. Most patients who are injured cannot hold the required positions because of pain or impaired consciousness. Other patients cannot be moved into the proper position because to do so would exacerbate their injury. Proper use of positioning aids assists in quick adaptation of procedures to accommodate the patient's condition.

Grids and IR holders are also an important part of trauma radiography because many projections require the use of a horizontal central ray. Grids should be inspected regularly because a damaged grid often causes image artifacts. IR holders enable the radiographer to perform cross-table lateral projections (dorsal decubitus position) on numerous body parts with minimal distortion. To prevent unnecessary exposure, ED personnel should not hold the IR.

FIG. 12.3 Dedicated C-arm-type trauma radiographic room with patient on the table. Courtesy Siemens Healthcare.

FIG. 12.4 Mobile fluoroscopic C-arm. Courtesy GE Healthcare.

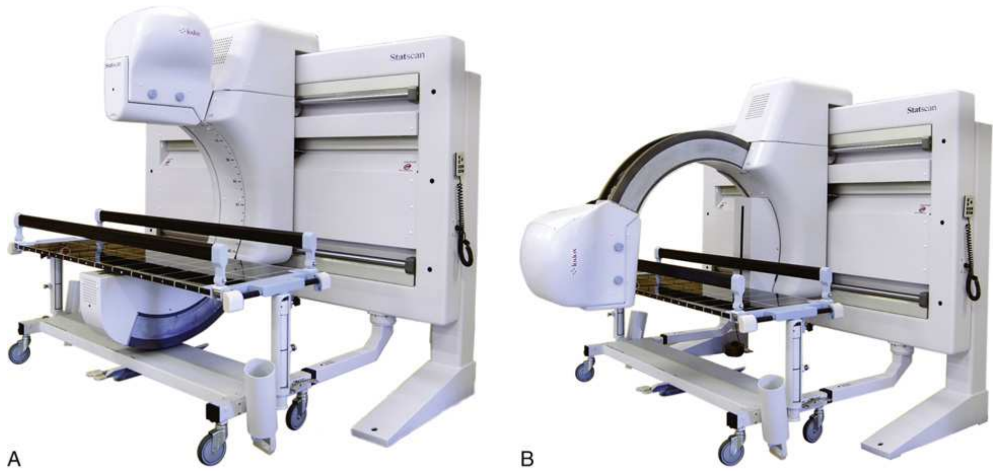


FIG. 12.5 (A) Statscan system configured for AP projection. (B) Statscan system configured for lateral projection. Courtesy Lodox Systems [Pty.], Ltd.

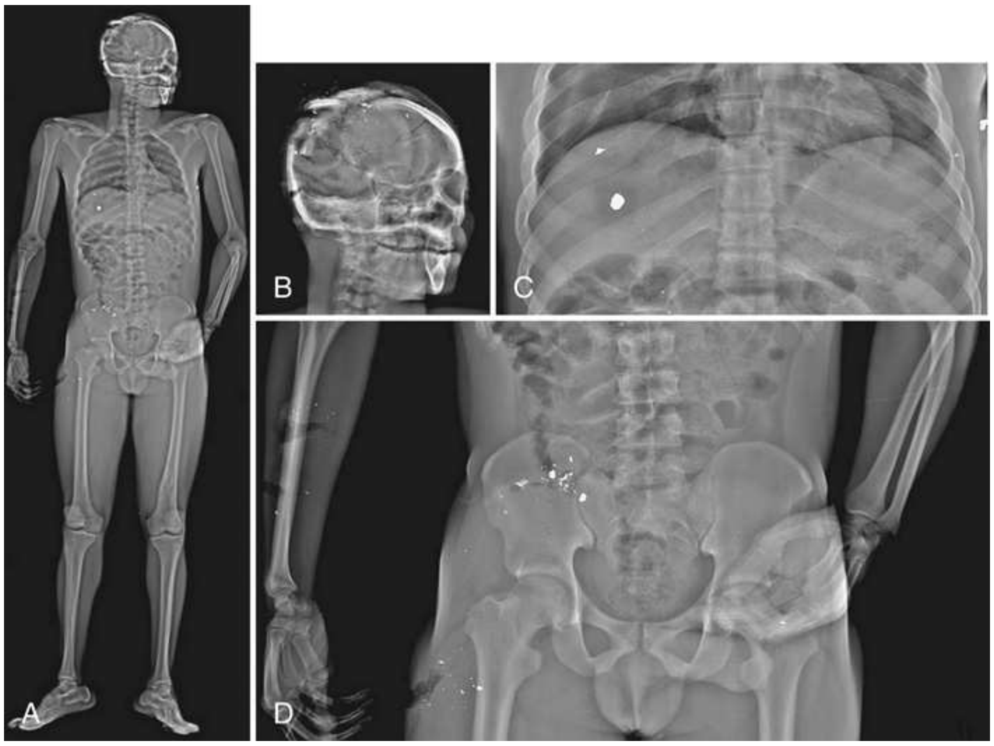


FIG. 12.6 Statscan of patient with multiple GSWs.(A) AP full-body scan—13 seconds required for acquisition. Shrapnel and projectile pathways identified by zooming in on areas of full-body scan. (B) Skull. (C) Diaphragm area. (D) Pelvis. Courtesy Lodox Systems [Pty.], Ltd.

Four statscan images of a patient with multiple GSWs. The first image is an anterior full-body scan, second one is a lateral skull scan, third one is a diaphragm scan, and the fourth one is a scan of the pelvic area.

FIG. 12.7 Statscan of motor vehicle-traffic accident victim with blunt trauma.(A) AP full-body scan. Tension pneumothorax shown without additional processing. (B) Zoomed lower pelvis showing multiple fractures *(arrows)*. (C) Zoomed bony thorax showing rib fractures *(arrows)*. Courtesy Lodox Systems [Pty.], Ltd.

Three statscan images of a patient with blunt trauma. The first one is an anterior full body scan, second one is a zoomed image of the pelvis with multiple fractures on the pelvic girdle denoted by arrows. The last one is a zoomed image of the thorax with fractured rib bones denoted by arrows.

Exposure Factors

Patient motion is always a consideration in trauma radiography. The shortest possible exposure time that can be set should be used in all procedures, except when a breathing technique is desired. Unconscious patients cannot suspend respiration for the exposure. Conscious patients are often in extreme pain and unable to cooperate for the procedure.

Radiographic exposure factor compensation may be required when exposures are made through immobilization devices such as a spine board or backboard. Most trauma patients arrive at the hospital with some type of immobilization device (Fig. 12.8). Pathologic changes should also be considered when technical factors are set. Internal bleeding in the abdominal cavity would absorb a greater amount of radiation than a bowel obstruction.

FIG. 12.8 (A) Typical backboard and neck brace used for trauma patients. (B) Backboard, brace, and other restraints are used on the patient throughout transport. (C) All restraints remain with and on the patient until all x-ray examinations are completed.

Three photographs depict the following: A backboard and neck brace used for trauma patients; a patient restrained with backboard, brace, and other restraints is carried into an helicopter; a patient is placed on an X-ray table with all the restraints.

Positioning of the Patient

The primary challenge of the trauma radiographer is to obtain a high-quality, diagnostic image on the first attempt when the patient is unable to move into the desired position. Many methods are available to adapt a routine projection and obtain the desired image of the anatomic part. To minimize the risk of aggravating the patient's condition, the x-ray tube and IR should be positioned, rather than the patient or the part. The stretcher can be positioned adjacent to the vertical Bucky or upright table as the patient's condition allows (Fig. 12.9). This location enables accurate positioning with minimal patient movement for cross-table lateral images (dorsal decubitus positions) on numerous parts of the body. In addition, the grid in the table or vertical Bucky is usually of a higher ratio than grids used for mobile radiography, so image contrast is improved. Another technique to increase efficiency while minimizing patient movement is to obtain all anteroposterior (AP) projections of the requested examinations while moving superiorly to inferiorly. All lateral projections of the requested examinations are then performed while moving inferiorly to superiorly. This method moves the x-ray tube in the most expeditious manner.

When radiographs are taken to localize a penetrating foreign object, such as metal, glass fragments, or bullets, entrance and exit wounds should be marked with a radiopaque marker that is visible on all projections (Fig. 12.10). Two exposures at right angles to each other will demonstrate the depth and path of the projectile.

FIG. 12.9 Stretcher positioned adjacent to vertical Bucky to expedite positioning. Note x-ray tube in position for lateral projections.

FIG. 12.10 Proper placement of radiopaque markers *(inside red circles)* on each side of bullet entrance wound. Red circles are "stickies" that contain radiopaque marker.

Radiographer's Role as Part of the Trauma Team

The role of the radiographer within the ED ultimately depends on the department protocol and staffing and the extent of emergency care provided at the facility. Regardless of the size of the facility, the primary responsibilities of a radiographer in an emergency situation include the following:

- Perform quality diagnostic imaging procedures as requested.
- Practice ethical radiation protection for self, patient, and other personnel.
- Provide competent patient care.

Ranking these responsibilities is impossible because they occur simultaneously, and all are vital to quality care in the ED.

Diagnostic Imaging Procedures

Producing a high-quality diagnostic image is an obvious role of any radiographer; a radiographer in the trauma environment has the added responsibility to perform that task efficiently. Efficiency and productivity are common and practical goals for the radiology department. In the ED, efficiency is often crucial to saving the patient's life. Diagnostic imaging in the ED is paramount to an accurate, timely, and often lifesaving diagnosis.

Radiation Protection

One of the most important duties and ethical responsibilities of the trauma radiographer is radiation protection of the patient, members of the trauma team, and the radiographer himself or herself. In critical care situations, members of the trauma team cannot leave the patient while imaging procedures are being performed. The trauma radiographer must ensure that the other team members are protected from unnecessary radiation exposure. Common practices should minimally include the following:

- Close collimation to the anatomy of interest to reduce scatter
- Gonadal shielding for patients of childbearing age (when doing so does not interfere with the anatomy of interest)
- Lead aprons for all personnel who remain in the room during the procedure
- Exposure factors that minimize patient dose and scattered radiation
- Announcement of impending exposure to allow unnecessary personnel to exit the room

Consideration must also be given to patients on nearby stretchers. If these patients are less than 6 feet away from the x-ray tube, appropriate shielding should be provided. Some of the greatest exposures to patients and medical personnel result from fluoroscopic procedures. If the C-arm fluoroscopic unit is used in the ED, special precautions should be in place to ensure that fluoroscopic exposure time is kept to a minimum and that all personnel are wearing protective aprons.

Patient Care

As with all imaging procedures, trauma procedures require a patient history. The patient may provide this history, if he or she is conscious, or the attending physician may inform the radiographer of the injury and the patient's status. If the patient is conscious, the radiographer should explain what he or she is doing in detail and in terms the patient can understand. The radiographer should listen to the patient's rate and manner of speech, which may provide insight into the patient's mental and emotional status. The radiographer should make eye contact with the patient to provide comfort and reassurance. A trip to the ED is an emotionally stressful event, regardless of the severity of injury or illness.

Radiographers are often responsible for the total care of the trauma patient while performing diagnostic imaging procedures. It is crucial that the radiographer constantly assess the patient's condition, recognize any signs of deterioration or distress, and report any change in the status of the patient's condition to the attending physician. The trauma radiographer must be knowledgeable in taking vital signs, as well as in knowing normal ranges, and must be competent in performing cardiopulmonary resuscitation (CPR), administering oxygen, and dealing with all types of medical emergencies. The radiographer must be prepared to perform these procedures when covered by a standing physician's order or as departmental policy allows. The radiographer should also be familiar with the location and contents of the adult and pediatric crash carts and should understand how to use the suctioning devices.

The CAB (*compressions, airway, and breathing*) of basic life support techniques must be constantly assessed during radiographic procedures. Visual inspection and verbal questioning enable the radiographer to determine whether the status of the patient changes during the procedure. Table 12.1 provides a guide for the trauma radiographer regarding changes in status that should be reported immediately to the attending physician. Table 12.1 also includes only the *common* injuries in which the radiographer may be the sole health care professional with the patient during the imaging procedure. Patients with multiple trauma injuries and those in respiratory or cardiac arrest usually are imaged with a mobile radiographic unit while ED personnel are present in the room. In these situations, the primary responsibility of the trauma radiographer is to produce quality images in an efficient manner while practicing ethical radiation protection measures.

TABLE 12.1

Guide for reporting patient status change

Noted symptom	Possible cause	When to report to physician immediately
Cool, clammy skin	Shock [a] Vasovagal reaction [b]	Other symptoms of shock present
Excessive sweating *(diaphoresis)*	Shock [a]	Other symptoms of shock present
Slurred speech	Head injury Stroke (cerebrovascular accident) [c] Drug or ethanol influence [d]	Accompanied by vomiting, especially if vomiting stops when patient is moved to different position
Agitation or confusion	Head injury Drug or ethanol influence [d]	Accompanied by vomiting, especially if vomiting stops when patient is moved to different position
Vomiting (without abdominal complaints) *(hyperemesis)*	Head injury Hyperglycemia [e] Drug or ethanol overdose	Position of patient abruptly stimulates vomiting or abruptly stops vomiting
Increased drowsiness *(lethargy)*	Shock [a] Head injury Hyperglycemia [e]	Other symptoms of shock present or accompanied by vomiting
Loss of consciousness (unresponsive to voice or touch)	Shock [a] Head injury Hyperglycemia [e]	Immediately
Pale or bluish skin pallor *(cyanosis)*	Airway compromise Hypovolemic shock	Immediately
Bluish nail beds	Circulatory compromise	Immediately
Patient complains of thirst	Shock [a] Hyperglycemia [e] Hypoglycemia	Other symptoms of shock present
Patient complains of tingling or numbness *(paresthesia)* or inability to move a limb	Spinal cord injury Peripheral nerve impairment	Accompanied by any symptoms of shock or altered consciousness
Seizures	Head injury	Immediately
Patient states that he or she cannot feel your touch *(paralysis)*	Spinal cord injury Peripheral nerve impairment	Accompanied by any symptoms of shock or altered consciousness
Extreme eversion of foot	Fracture of proximal femur or hip joint	Report only if x-ray request specifies “frog leg” lateral projection of hip. This movement would exacerbate patient’s injury and cause intense pain. Surgical lateral position should be substituted. Watch for changes in abdominal size and firmness.

Noted symptom	Possible cause	When to report to physician immediately
Increasing abdominal distention and firmness to palpation	Internal bleeding from pelvic fracture [f] or organ laceration	Immediately

[a] *Hypovolemic* or *hemorrhagic shock* is a medical condition in which levels of blood plasma in the body are abnormally low, such that the body cannot properly maintain blood pressure, cardiac output of blood, and normal amounts of fluid in the tissues. It is the most common type of shock in trauma patients. Symptoms include diaphoresis, cool and clammy skin, decrease in venous pressure, decrease in urine output, thirst, and altered state of consciousness.

[b] *Vasovagal reaction* is also called a vasovagal attack, situational syncope, and vasovagal syncope. It is a reflex of the involuntary nervous system or a normal physiologic response to emotional stress. Patients may complain of nausea, feeling flushed (warm), and feeling lightheaded. They may appear pale before they lose consciousness for several seconds.

[c] *Cerebrovascular accident* is commonly called a stroke and may be caused by thrombosis, embolism, or hemorrhage in the vessels of the brain.

[d] *Drugs or alcohol*. Patients under the influence of drugs, alcohol or both commonly present in the ED. In this situation, the usual symptoms of shock and head injury are unreliable. Be on guard for aggressive physical behaviors and abusive language.

[e] *Hyperglycemia* is also known as diabetic ketoacidosis. The cause is increased blood glucose levels. The patient may exhibit any combination of symptoms noted and has fruity-smelling breath.

[f] *Pelvic fractures* have a high mortality rate (mortality with open fractures may be 50%). Hemorrhage and shock are often associated with this type of injury.

Best Practices in Trauma Radiography

Radiography of the trauma patient seldom allows for the use of "routine" positions and projections. In addition, the trauma patient requires special attention to patient care techniques while difficult imaging procedures are performed. The following best practices provide some universal guidelines for the trauma radiographer.

1. ***Speed:*** Trauma radiographers must produce quality images in the shortest amount of time. Speed in performing a diagnostic examination is crucial to saving the patient's life. Many practical methods that increase examination efficiency without sacrificing image quality are introduced in this chapter.
2. ***Accuracy:*** Trauma radiographers must provide accurate images with a minimal amount of distortion and with the maximum amount of recorded detail. Alignment of the central ray, the part, and the IR is imperative in trauma radiography. Using the shortest exposure time minimizes the possibility of involuntary and uncontrollable patient motion on the image.
3. ***Quality:*** Quality does not have to be sacrificed to produce an image quickly. The patient's condition should not be used as an excuse for careless positioning and accepting less than high-quality images.
4. ***Positioning:*** Careful precautions must be taken to ensure that performance of the imaging procedure does not worsen the patient's injuries. The "golden rule" of two projections at right angles from one another still applies. As often as possible, the radiographer should position the tube and the IR, rather than the patient, to obtain the desired projections.
5. ***Practice standard precautions:*** Exposure to blood and body fluids should be expected in trauma radiography. The radiographer should wear gloves, mask, eye shields, and gown when appropriate. IR and sponges should be placed in nonporous plastic to protect them from body fluids. Hand hygiene should be performed frequently, especially between patients. All equipment and accessory devices should be kept clean and ready for use.
6. ***Immobilization:*** The radiographer should *never* remove any immobilization device without a physician's orders. The radiographer should provide proper immobilization and support to increase patient comfort and to minimize risk for motion.
7. ***Anticipation:*** Anticipating required special projections or diagnostic procedures for certain injuries makes the radiographer a vital part of the ED team. Patients requiring surgery generally require an x-ray of the chest. In facilities where CT is not readily available for emergency patients, fractures of the pelvis may require a cystogram to determine the status of the urinary bladder. The radiographer should know which procedures are often referred to CT first or for additional images. Being prepared for and understanding the necessity of these additional procedures and images instills confidence in and creates an appreciation for the role of the radiographer in the emergency setting.
8. ***Attention to detail:*** The radiographer should *never* leave a trauma patient (or any patient) unattended during imaging procedures. The patient's condition may change at any time, and it is the radiographer's responsibility to note these changes and report them immediately to the attending physician. If the radiographer cannot process images while maintaining eye contact with the patient, he or she should call for help. Someone must be with the injured patient at all times.
9. ***Attention to department protocol and scope of practice:*** The radiographer should know department protocols and practice only within his or her own competence and abilities. The scope of practice for radiographers varies from state to state and from country to country. The radiographer should study and understand the scope of his or her role in the emergency setting. The radiographer should not provide or offer a patient anything by mouth. The radiographer should always ask the attending physician before giving the patient anything to eat or drink, no matter how persistent the patient may be.
10. ***Professionalism:*** Ethical conduct and professionalism in all situations and with every person is a requirement of all health care professionals, but the conditions encountered in the ED can be particularly complicated. The radiographer should adhere to the Code of Ethics for radiologic technologists (see Chapter 1) and the radiography practice standards. The radiographer should be aware of the people present or nearby at all times when discussing a patient's care. The ED radiographer is exposed to countless tragic conditions. Emotional reactions are common and expected but must be controlled until emergency care of the patient is complete.

Radiographic Procedures in Trauma

The projections included in this chapter address the trauma-related positions and projections listed in the American Registry of Radiologic Technologists (ARRT) radiography examination content specifications and align with the American Society of Radiologic Technologists (ASRT) radiography curriculum.

Most Level I trauma centers have replaced conventional trauma skull and facial bone radiographs (e.g., AP, cross-lateral, reverse Caldwell and Towne, and reverse Waters) with CT scan of the head and/or facial bones (Fig. 12.11). Research articles continue to delineate the advantages of CT over radiography. The American College of Radiology (ACR) Appropriateness Criteria state that CT head without IV contrast is usually appropriate in closed head trauma on patients who meet the most widely accepted patient evaluation criteria scales—the Glasgow Coma Scale (GCS), the New Orleans Head CT Criteria, and the Canadian CT Head Rule. Many smaller facilities may not have CT readily available, thus, trauma skull positioning remains valuable knowledge for the radiographer.

Patient Preparation

Remembering that the patient has endured an emotionally disturbing and distressing event, in addition to the physical injuries he or she may have sustained, is important. If the patient is conscious, speak calmly and look directly into the patient's eyes while explaining the procedures that have been ordered. Assume that the patient can hear you, even if he or she does not respond. Check the patient thoroughly for items that might cause an artifact on the images. Explain what you are removing from the patient and why. Place all removed personal effects, especially valuables, in the proper container used by the facility (i.e., plastic bag) or in the designated secure area. Each facility has a procedure regarding proper storage of a patient's personal belongings. Know the procedure and follow it carefully.

FIG. 12.11 CT scan of skull showing displaced fracture *(white arrow)*. Intracranial air is present *(black open arrow)*. Courtesy Sunie Grossman, RT[R], St. Bernard's Medical Center, Jonesboro, AR.

A CT scan image of the human skull. A white arrow on the bottom-right side denotes a fracture. A black arrow on the same spot, pointing outward from the skull denotes the presence of intracranial air.

Breathing Instructions

Most injured patients have difficulty following the recommended breathing instructions for routine projections. For these patients, exposure factors should be set using the shortest possible exposure time to minimize motion on the radiograph, necessitating use of the large focal spot. The decrease in resolution from using a large focal spot is minimal compared with the significant loss of resolution due to patient motion. If a breathing technique is desired, this can be explained to a conscious trauma patient in the usual manner. If the patient is unconscious or unresponsive, careful attention should be paid to the rate and degree of chest wall movement. If inspiration is desired on the image, the exposure should be timed to correspond to the highest point of chest expansion. Conversely, if the routine projection calls for exposure on expiration, the exposure should be made when the patient's chest wall falls to its lowest point.

Immobilization Devices

A wide variety of immobilization devices are used to stabilize injured patients. Standard protocol is to perform radiographic images without removing immobilization devices. After injuries have been diagnosed or ruled out, the attending physician gives the order for immobilization devices to be removed or changed, or to remain in place.

Many procedures necessitate the use of some sort of immobilization to prevent involuntary and voluntary motion. Many patient care textbooks discuss prudent usage of such immobilization devices. The key issues in the use of immobilization in trauma are to avoid exacerbating the patient's injury and to avoid increasing his or her discomfort.

Image Receptor Size and Collimated Field

The orientation of the IR, image plate sizes, and recommended collimated field sizes are the same in trauma procedures as those specified for the routine projection of the anatomy of interest. Occasionally, the physician may request that more of a part be included, and then a larger IR or exposure field size is acceptable. When using flat panel digital radiography (DR) detectors, be sure to collimate to the anatomy of interest to provide optimal quality images and ethical radiation protection for the patient and other personnel who may be required to be in the room during the imaging procedures. Exposure of unnecessary tissue generates excessive scatter, which is a primary source of radiation exposure for radiographers and other health care professionals.

Central Ray, Part, and Image Receptor Alignment

Unless otherwise indicated for the procedure, the central ray should be directed perpendicular to the midpoint of the grid, IR, or both. Tips for minimizing distortion are detailed in the procedures in which distortion is a potential threat to image quality.

Image Evaluation

Ideally, trauma images should be of optimal quality to ensure prompt and accurate diagnosis of the patient's injuries. Evaluate images for proper positioning and technique as indicated in the routine projections. Allowances can be made when true right-angle projections (AP, posteroanterior [PA], and lateral) must be altered as a result of the patient's condition.

Documentation

Deviation from routine projections is necessary in many instances. Documenting the alterations in routine projections for the attending physician and radiologist is important, so that they can interpret the images properly. In addition, the radiographer often has to determine whether the anatomy of interest has been adequately shown and must perform additional projections (within the scope of the ordered examination) on an injured part to aid in proper diagnosis. Notations concerning additional projections are extremely helpful for the interpreting physicians.

See Addendum B for a summary of all abbreviations used in Volume 2.

Abbreviations Used in Chapter 12

CPR	Cardiopulmonary resuscitation
CR	Central ray
CVA	Cerebrovascular accident
EAM	External acoustic meatus
ED	Emergency department
GSW	Gunshot wound
IOML	Infraorbitomeatal line
IVU	Intravenous urography
KUB	Kidneys, ureters, and bladder
MCP	Midcoronal plane
MML	Mentomeatal line
MSP	Midsagittal plane
MVTA	Motor vehicle-traffic accident
OML	Orbitomeatal line
SID	Source-to-image receptor distance

Radiography

Cervical Spine

Lateral Projection [a]

Dorsal decubitus position

Trauma positioning tips

- *Always* perform this projection first, before any other projections. Level I centers may refer patients with indications for cervical spine imaging to CT first, depending on concomitant injuries.
- The *attending physician* or radiologist must review this image to rule out vertebral fracture or dislocation before other projections are performed.
- Use a 72-inch (183-cm) SID whenever attainable.
- Move the patient's head and neck as little as possible.
- *Shield gonads and other personnel in the room.*

Patient position considerations

- The patient is generally immobilized on a backboard and in a cervical collar.
- The patient should relax the shoulders as much as possible.
- The patient should look straight ahead without any rotation of the head or neck.
- Place IR in a holder at the top of the shoulder (Fig. 12.12).
- Check that the IR is perfectly vertical.

Central ray

- *Horizontal* and perpendicular to the IR. Centered to MCP at the level of C4.

Collimation

- Adjust the radiation field to include the sella turcica (located 2 inches [5 cm] anterior and superior to the external acoustic meatus [EAM]) to T1 (located 2 inches [5 cm] above the jugular notch). The AP field margins should extend 1 inch (2.5 cm) beyond the skin shadow. Place the side marker in the collimated exposure field.

Structures shown

The entire cervical spine, from sella turcica to the top of T1, must be shown in profile with minimal rotation and distortion (Fig. 12.13). Evidence of proper collimation should be visible. Cross-table lateral images of the cervical vertebrae demonstrate the height and alignment of the vertebral bodies and intervertebral disk spaces, as well as the zygapophyseal joints.

NOTE: If all seven cervical vertebrae, including the spinous process of C7 and the C7-T1 interspace, are not clearly visible, a lateral projection of the cervicothoracic region must be performed.

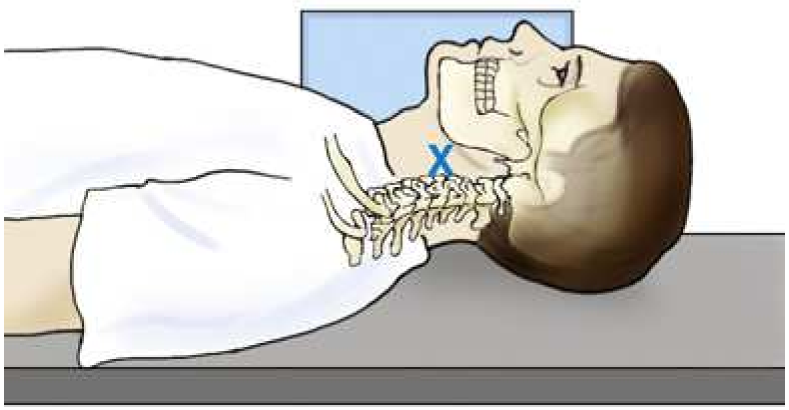


FIG. 12.12 Patient and image receptor positioned for trauma lateral projection of cervical spine using dorsal decubitus position. The X marks the central ray entrance point.

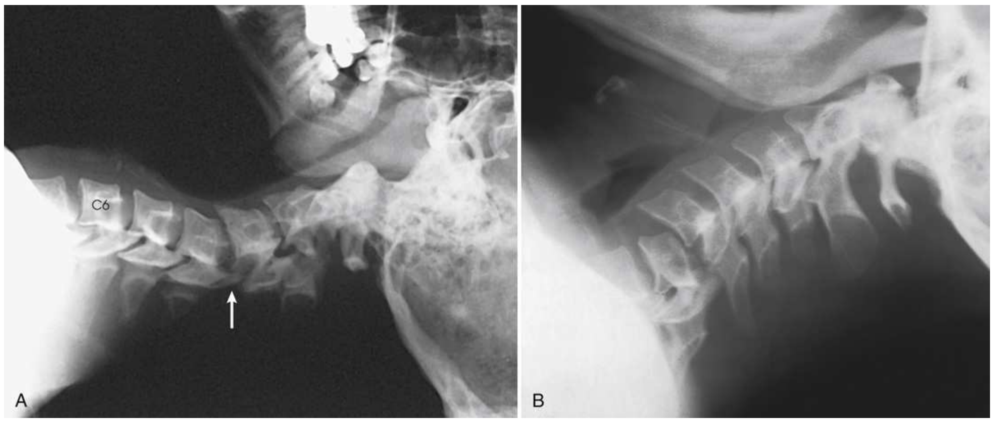


FIG. 12.13 Dorsal decubitus position lateral projection of cervical spine performed on a trauma patient. (A) Dislocation of C3 and C4 articular processes *(arrow)*. C7 is not well shown, so lateral projection of cervicothoracic vertebrae should also be performed. (B) Fracture of pedicles with dislocation of C5 and C6. Note superior portion of C7 shown on this image.

Cervicothoracic Region

Lateral Projection [b]

Dorsal decubitus position

This projection is often called the *swimmer's technique*.

Trauma positioning tips

- This projection should be performed if the entire cervical spine, including C7 and the interspace between C7 and T1, is not shown on the dorsal decubitus lateral projection. The patient must be able to move both arms. Do not move the patient's arms without permission from the attending physician and review of the lateral projection.
- If required and the patient is in stable condition, position the stretcher adjacent to a vertical Bucky to increase efficiency and obtain optimal image quality.
- *Shield gonads and other personnel in the room.*

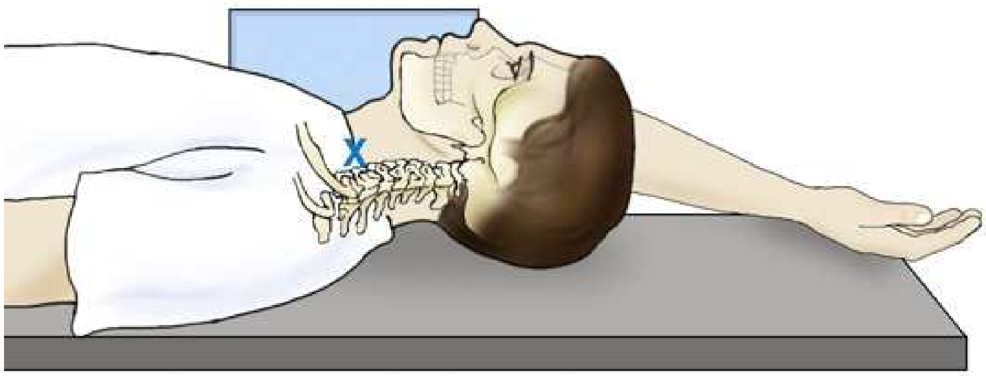


FIG. 12.14 Patient and image receptor positioned for trauma lateral projection of cervicothoracic vertebrae using dorsal decubitus position.

A patient lies on an X-ray table with the image receptor screen placed adjacent to his neck and chest. The patients right arm is rested at a position above his head. An X mark on below his cervix indicates the central ray entrance point.

Patient position considerations

- Position the patient supine, usually on a backboard and in a cervical collar.
- Have the patient depress the shoulder closest to the tube as much as possible. *Do not push on the patient's shoulder.*
- Instruct the patient to raise the arm closest to the grid IR over the head. Assist the patient as needed, but *do not use force or move the limb too quickly* (Fig. 12.14).
- Ensure that the patient is looking straight ahead without any rotation of the head or neck.
- Ensure that the grid IR is exactly vertical in the holder to prevent distortion.
- Instruct the patient to breathe normally, if he or she is conscious, and use a long exposure time technique to blur the overlying ribs.

Central ray

- *Horizontal* and perpendicular to the IR entering MCP at the level of the C7-T1 interspace, which is about 2 inches (5 cm) above the jugular notch.
- If the shoulders are aligned in the same horizontal plane, angle 3 to 5 degrees cephalic, enter the patient at MCP at the level of the C7-T1 interspace.

Collimation

- Adjust the radiation field to extend from the level of the mastoid tip to 1 inch (2.5 cm) below the jugular notch and no larger than 10 × 12 inches (24 × 30 cm). The entire soft tissues of the neck should also be included. Place the side marker in the collimated exposure field.

Structures shown

The lower cervical and upper thoracic vertebral bodies and spinous processes should be seen in profile between the shoulders. Exposure should be sufficient to demonstrate bony cortical margins and trabeculation, as well as soft tissues in the neck (Fig. 12.15). Evidence of proper collimation should be visible.

Compensating Filter

The use of a compensating filter can improve image quality, owing to the extreme difference in thickness between the upper thorax and the lower cervical spine.

NOTE: A grid is required to improve image contrast. If a breathing technique cannot be used, make the exposure with respiration suspended.

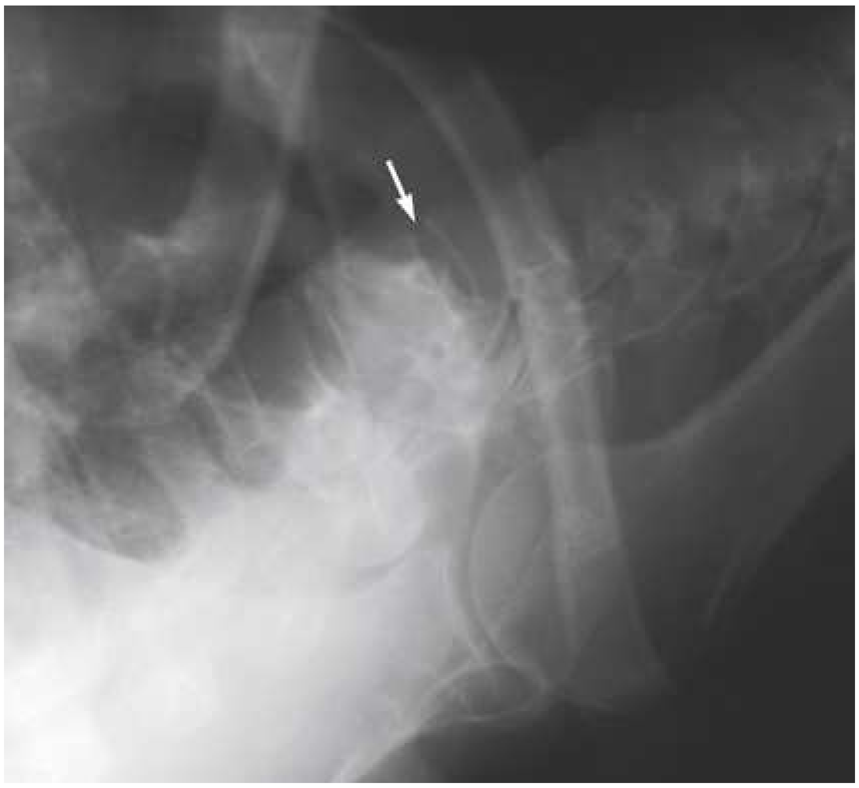


FIG. 12.15 Dorsal decubitus position lateral projection of cervicothoracic region performed on a trauma patient. Negative examination. Note excellent image of C7-T1 joint with use of Ferlic swimmer's filter *(arrow)*.

Cervical Spine

AP Axial Projection [c]

Trauma positioning tips

- *Do not perform this projection until the attending physician has reviewed the lateral projection.*
- This projection is usually performed after the lateral projection.
- If the patient is on a backboard and gurney, obtain proper assistance to safely lift the backboard and place the grid IR in position centered to MSP at the level of C4.
- Move the patient's head and neck as little as possible.
- *Shield gonads and other personnel in the room.*

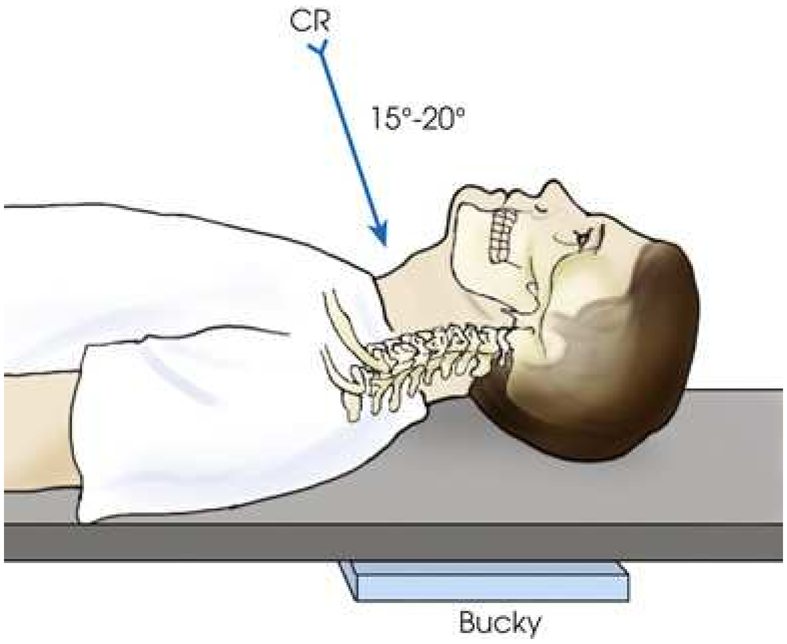


FIG. 12.16 Patient and image receptor positioned for trauma AP axial projection of cervical vertebrae. *CR*, Central ray.

A patient lies on an X-ray table with the image receptor placed below the table, right behind the neck. An arrow inclined at 15 degrees and 20 minutes, pointing to the cervical vertebrae indicates the central ray.

Patient position considerations

- Position the patient supine, usually on a backboard and in a cervical collar.
- Have the patient relax the shoulders as much as possible.
- Ensure that the patient is looking straight ahead without any rotation of the head or neck.

Central ray

- The central ray is directed 15 to 20 degrees cephalad to the center of the IR and enters MSP at slightly inferior to the thyroid cartilage. Exits at the level of C4 (Fig. 12.16).

Collimation

- Adjust the radiation field to 10 inches (25 cm) in length and 1 inch (2.5 cm) beyond the skin shadow on both sides. Place the side marker in the collimated exposure field.

Structures shown

C3 through T1 or T2, including interspaces and surrounding soft tissues, should be shown with minimal rotation and distortion. Exposure technique should show cortical margins and soft tissue shadows (Fig. 12.17). Evidence of proper collimation should be visible.

NOTE: If the patient is not on a backboard or an x-ray table, preferably the attending physician should lift the patient's head and neck while the radiographer positions the IR under the patient.

FIG. 12.17 AP axial projection of cervical vertebrae performed on an 11-year-old trauma patient. Cervical spine is completely dislocated between C2 and C3 *(arrow)*. The patient died on the x-ray table after x-ray examinations were performed.

AP Axial Oblique Projection

Trauma positioning tips

- *Do not perform this projection until the attending physician has reviewed the lateral projection.*
- If the patient is on a backboard, obtain appropriate help to safely lift the board and place the IR in position centered at the level of C4 and to adjacent mastoid process (about 3 inches [7.6 cm] lateral to MSP).
- Move the patient's head and neck as little as possible.
- Do not use a grid IR because the compound central ray angle results in grid cutoff. Some equipment does not allow the x-ray tube head to move in a compound angle. On these machines, only the 45-degree angle is used and a grid IR may be used to improve contrast.
- *Shield gonads and other personnel in the room.*

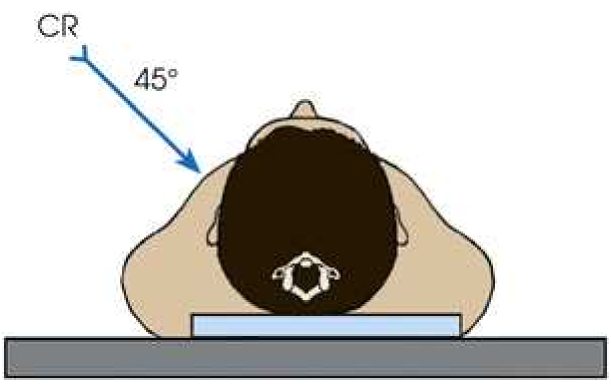


FIG. 12.18 Patient and IR positioned for trauma AP axial oblique projection of cervical vertebrae. Central ray *(CR)* is positioned 45 degrees mediolaterally and, if possible, 15 to 20 degrees cephalad.

A patient lies on an X-ray table with the image receptor placed behind his head. behind the neck. An arrow pointing to the cervical vertebrae indicates the central ray positioned 45 degrees mediolaterally.

Patient position considerations

- Position the patient supine, usually on a backboard and in a cervical collar.
- Have the patient relax the shoulders as much as possible.
- Ensure that the patient is looking straight ahead without any rotation of the head or neck.

Central ray

- Angled 45 degrees lateromedially. When a double angle is used, also angle 15 to 20 degrees cephalad.
- Enters slightly lateral to MSP at the level of the thyroid cartilage and passing through C4 (Fig. 12.18).

Collimation

- Adjust the radiation field to 12 inches (30 cm) in length and 1 inch (2.5 cm) beyond the skin shadow on both sides. Place the side marker in the collimated exposure field.

Structures shown

Cervical and upper thoracic vertebral bodies, pedicles, open intervertebral disk spaces, and open intervertebral foramina of the side that the central ray enters are shown. This projection provides excellent detail of the facet joints, and it is important in detecting subluxations and dislocations (Fig. 12.19). If the 15-degree cephalic angle is not used, the intervertebral foramina are foreshortened. Evidence of proper collimation should be visible.

NOTE: If the patient is not on a backboard or an x-ray table, preferably the attending physician should lift the patient's head and neck while the radiographer positions the IR under the patient.

FIG. 12.19 AP axial oblique projection of cervical vertebrae performed on a trauma patient using 45-degree angle. Radiograph was made using non-grid exposure technique. Negative image. Note excellent alignment of vertebral bodies and intervertebral foramen.

Thoracic and Lumbar Spine

Lateral Projections

Dorsal decubitus positions

Trauma positioning tips

- *Always* perform dorsal decubitus positions before AP projections of the spine because the attending physician should review the dorsal decubitus lateral projections to rule out vertebral fracture or dislocation *before* other projections are performed.
- Move the patient as little as possible.
- Use of a grid is necessary to improve image contrast. Use a vertical Bucky, if not working with a C-arm configured unit, to maximize positioning and for optimal image quality.
- *Shield gonads and other personnel in the room.*

Patient position considerations

- The patient is generally immobilized and on a backboard.
- Have the patient cross the arms over the chest to remove them from the anatomy of interest.
- *Thoracic spine:* Place the top of the IR 1.5 to 2 inches (3.8 to 5 cm) above the patient's relaxed shoulders. DR field projected size is from the jugular notch to the inferior costal margin and 7 inches (18 cm) in AP width, centered at the level of MCP.
- *Lumbar spine:* Center the IR at the level of the iliac crests (Fig. 12.20). DR field projected size extends from the xiphoid to the midsacrum and 8 inches (20 cm) in AP width, centered at the level of MCP.
- Ensure that the grid IR is perfectly vertical.

Central ray

- *Horizontal* and perpendicular to the longitudinal center of the IR and going through the spine.

Collimation

- Adjust the radiation field to 17 inches (43 cm) in length and 7 to 8 inches (18 to 20 cm) in the AP dimension. Place the side marker in the collimated exposure field.

Structures shown

For the thoracic spine, the image should include T3/T4 through L1. The lumbar spine image should, at a minimum, include T12 to the sacrum. The vertebral bodies should be seen in profile, with minimal rotation and distortion. Exposure should be sufficient to show cortical margins and bony trabeculation, as well as surrounding soft tissues (Fig. 12.21). Evidence of proper collimation should be visible.

NOTE: A lateral projection of the cervicothoracic spine must be performed to allow for visualization of the upper thoracic vertebrae in profile.

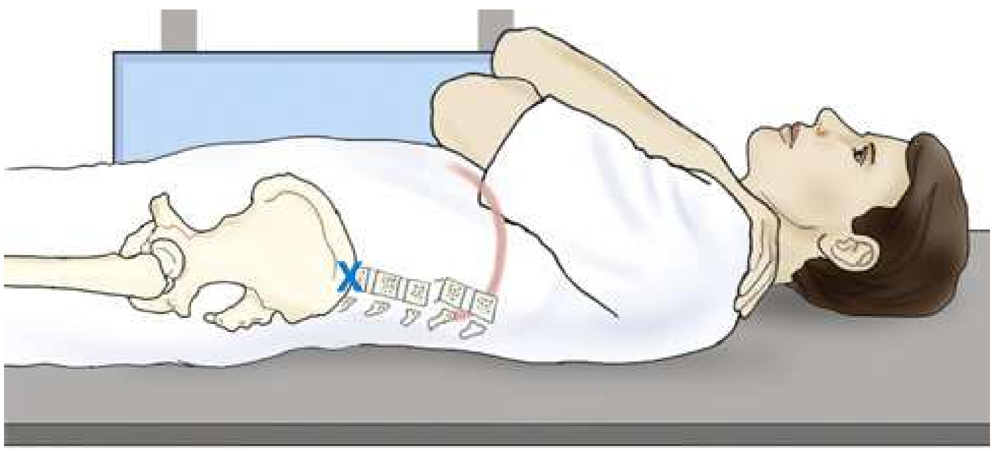


FIG. 12.20 Patient and image receptor positioned for trauma lateral projection of lumbar spine using dorsal decubitus position and vertical Bucky device.

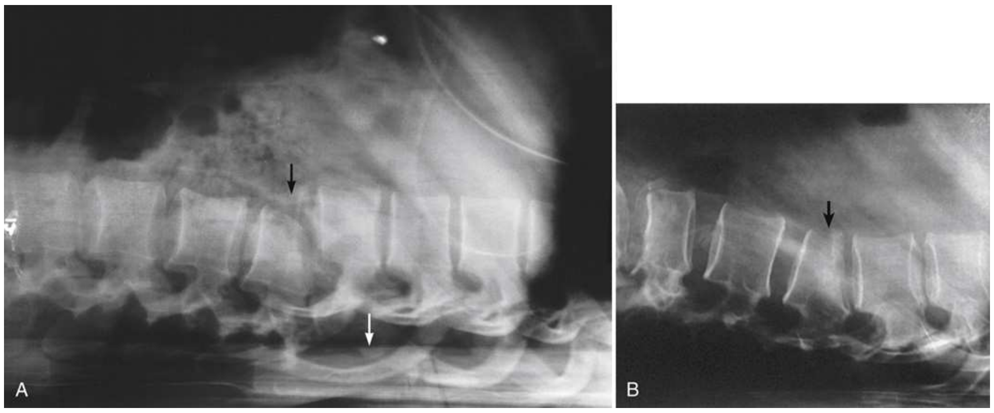


FIG. 12.21 Dorsal decubitus position lateral projection of lumbar spine performed on a trauma patient. (A) Fracture and dislocation of L2 *(black arrow)*. Note backboard *(white arrow)*. (B) Compression fracture of body of L2 *(arrow)*. This coned-down image provides better detail of fracture area.

Chest

AP Projection [d, e]

Trauma positioning tips

- Most trauma patients must be imaged in the supine position. If it is necessary to see air-fluid levels, a cross-table lateral x-ray beam (dorsal decubitus position) can be performed. (*Note:* Patients with chest trauma with suspected vascular injury may be referred to CT first.)
- Obtain help in lifting the patient to position the IR if the stretcher is not equipped with an IR tray or a C-arm configured trauma unit is not being used.
- Check for signs of respiratory distress or changes in level of consciousness during radiographic examination. *Report any changes to the attending physician immediately.*
- Assess the patient's ability to follow breathing instructions.
- Use the maximum SID possible to minimize magnification of the heart shadow.
- Use universal precautions if wounds, bleeding, or both are present, and protect the IR with plastic covering.
- Mark entrance and exit wounds with radiopaque indicators if evaluating a penetrating injury.
- Use of a grid improves image contrast.
- *Shield gonads and other personnel in the room.*

Patient position considerations

- Position the top of the IR 1.5 to 2 inches (3.8 to 5 cm) above the patient's shoulders.
- Move the patient's arms away from the thorax and out of the collimated field.
- Ensure that the patient is looking straight ahead, with the chin extended out of the collimated field.
- Check for rotation by determining whether the shoulders are equidistant to the IR or stretcher. This position places MCP parallel to the IR, minimizing image distortion.
- The exposure should be made at the end of deep inhalation. Breathing instructions are provided to the conscious patient, if possible, or to the medical personnel assisting with breathing for an unconscious patient.

Central ray

- Perpendicular to the center of the IR at MSP and at a level 3 inches (7.6 cm) below the jugular notch (Fig. 12.22).

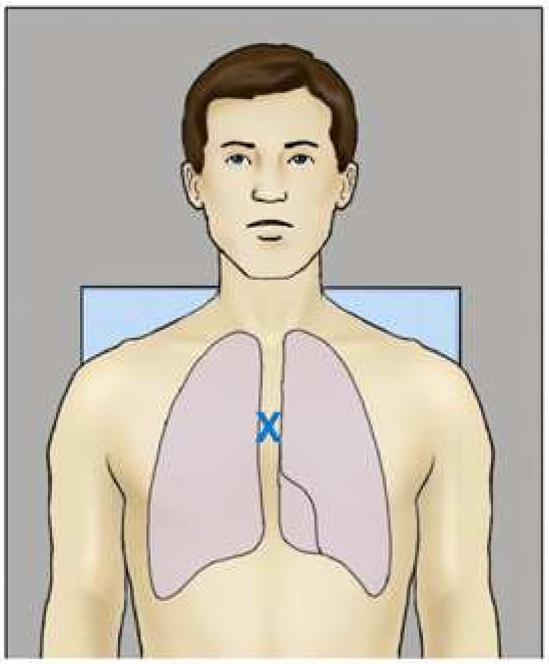


FIG. 12.22 Patient and image receptor *(IR)* positioned for trauma AP projection of chest. *CR,* Central ray.

Collimation

- Adjust the radiation field to no larger than 14 × 17 inches (35 × 43 cm), oriented to accommodate the patient's body habitus. On smaller patients, the exposure field should extend 1 inch (2.5 cm) beyond the skin shadows. Place the side marker in the collimated exposure field.

Structures shown

AP projection of the thorax is shown. The lung fields should be included in their entirety, with minimal rotation and distortion present. Adequate aeration of the lungs must be imaged to show the lung parenchyma (Fig. 12.23). Evidence of proper collimation should be visible.

NOTE: Fractured ribs are often incidentally diagnosed on AP chest images in the ED. Use of a grid and an adjustment in breathing instructions can improve rib visibility, if needed.

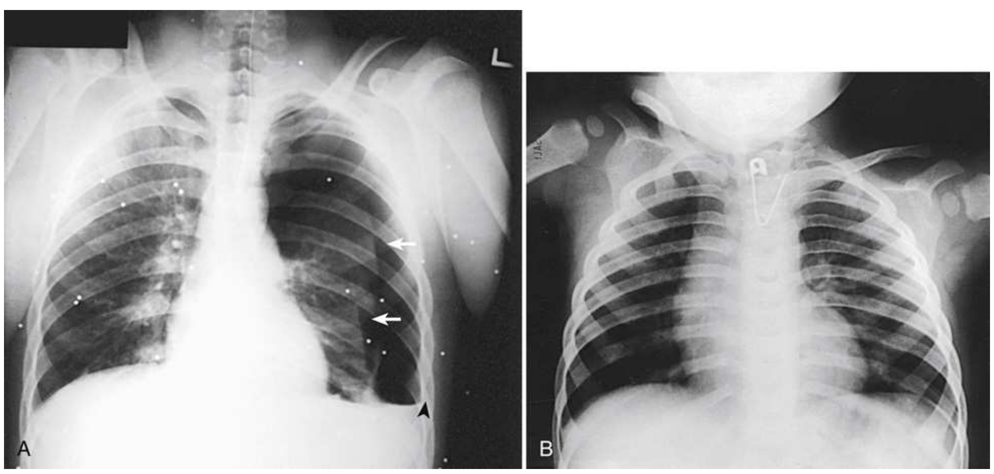


FIG. 12.23 AP upright projection of chest performed on a trauma patient. (A) Multiple buckshot in chest caused hemopneumothorax. *Arrows* show margin of collapsed lung with free air laterally. Arrowhead shows fluid level at costophrenic angle, left lung. (B) Open safety pin lodged in esophagus of a 13-month-old infant.

Abdomen

AP Projection [f, g]

Trauma positioning tips

- *Note:* Sonography is often used to evaluate abdominal trauma.
- Use of a grid provides optimal image quality. If not working with a C-arm configured unit, verify transfer to a standard x-ray table with the attending physician before moving the patient.
- Determine the possibility of fluid accumulation within the abdominal cavity to establish appropriate exposure factors.
- For patients with blunt force or projectile injuries, check for signs of internal bleeding during radiographic examination and *report any changes to the attending physician immediately*.
- Mark entrance and exit wounds with radiopaque markers if evaluating projectile injuries.
- Assess the ability of the patient to follow breathing instructions.
- Use standard precautions if wounds, bleeding, or both are present, and protect the IR with plastic covering if it is to come in contact with the patient.
- *Shield gonads, if possible, and other personnel in the room.*

Patient position considerations

- Ask ED personnel to assist in transferring the patient to the radiographic table, if possible.
- If not working with a C-arm-configured trauma unit and transfer is not advisable, obtain assistance to lift the patient carefully to position the grid IR under the patient, centered to the level of iliac crest (Fig. 12.24). (On patients with a long torso, a second AP projection of the upper abdomen may be required to show the diaphragm and lower ribs.)
- If the patient is on a stretcher, check that the grid IR is parallel with MCP. Correct tilting with sponges, sandbags, or rolled towels. The grid IR must be perfectly horizontal to prevent grid cutoff and image distortion. If you are unable to correct tilt on grid IR, angle the central ray to maintain part-IR-central ray alignment.
- Instruct the conscious patient to exhale and hold his or her breath for the exposure. Inform medical personnel assisting with breathing for an unconscious patient to suspend respiration for the exposure.

Central ray

- Perpendicular to the center of the IR entering the patient at MSP at the level of the iliac crests.

Collimation

- Adjust the radiation field to 17 inches (43 cm) in length on adult sthenic patients, and the width should be approximately 1 inch (2.5 cm) beyond the skin margin but no larger than the IR. Place the side marker in the collimated exposure field.

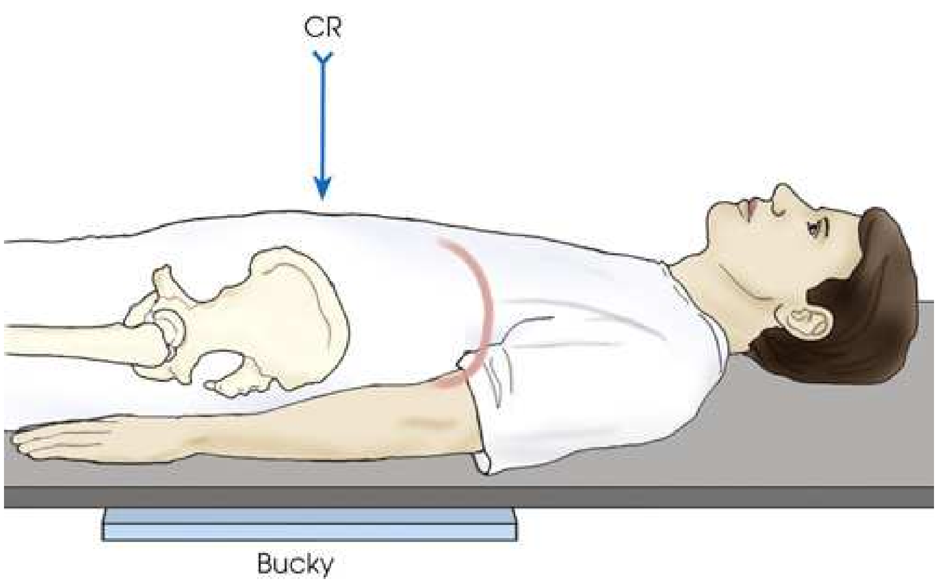


FIG. 12.24 Patient and image receptor positioned for trauma AP projection of abdomen. *CR*, Central ray.

Structures shown

AP projection of the abdomen is shown. The entire abdomen, including the pubic symphysis and/or diaphragm (depending upon the injury), should be included without distortion or rotation. Exposure should be adequate to show tissue interfaces, such as the lower margin of the liver, kidney shadows, psoas muscles, and transverse processes of lumbar vertebrae (Fig. 12.25). Evidence of proper collimation should be visible.

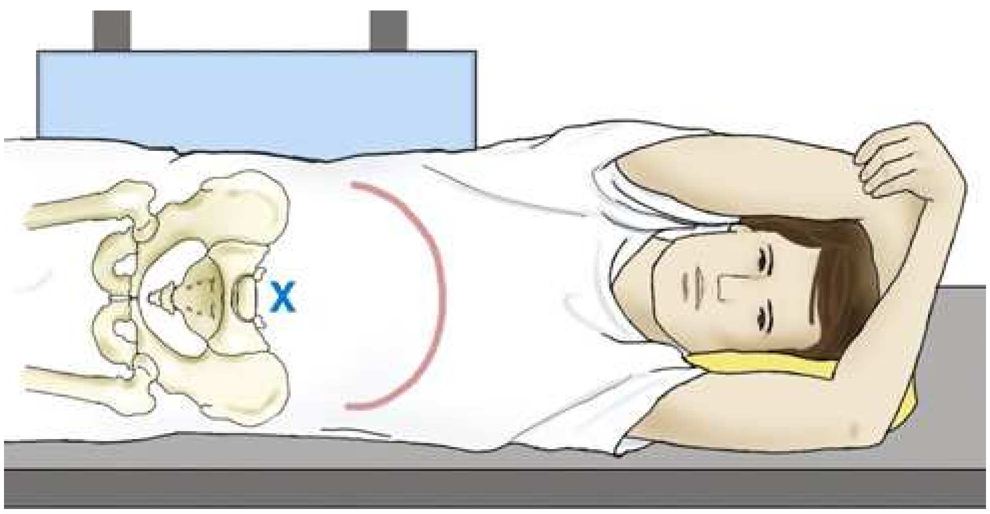
FIG. 12.25 AP projection of abdomen performed on a trauma patient. (A) Table knife in stomach along with other small metallic foreign bodies swallowed by the patient. (B) Coin in stomach swallowed by the patient.

AP Projection [h, i]

Left lateral decubitus position

Trauma positioning tips

- If not using a C-arm-configured unit, a vertical Bucky provides optimal image quality. If the patient must be imaged using a mobile radiographic unit, a grid IR is required.
- Verify with the attending physician that patient movement is possible and whether the image is necessary to assess fluid accumulation or free air in the abdominal cavity.
- The left lateral decubitus position shows free air in the abdominal cavity because the density of the liver provides good contrast for visualization of any free air.
- If fluid accumulation is of primary interest, the side down, or dependent side, must be elevated off the stretcher or table to be completely shown.
- Check for signs of internal bleeding during the radiographic examination and *report any changes to the attending physician immediately*.



Horizontal CR to center of IR

FIG. 12.26 Patient and image receptor positioned for trauma AP projection of abdomen using left lateral decubitus position and using vertical Bucky device.

- Use universal precautions if wounds, bleeding, or both are present, and protect the IR with plastic covering. Mark all entrance and exit wounds with radiopaque markers when imaging for penetrating injuries.
- *Shield gonads, if possible, and personnel in the room.*

Patient position considerations

- Carefully and slowly turn the patient into the recumbent left lateral position. Flex the knees to provide stability.
- If the image is being taken for visualization of fluid, carefully place a block under the length of the abdomen to ensure that the entire right side is visualized.
- Ensure that MCP is vertical to prevent image distortion.
- Center the IR 2 inches (5 cm) above the iliac crests to include the diaphragm (Fig. 12.26).
- The patient should be in the lateral position at least 5 minutes before the exposure to allow any free air to rise and be visualized.
- Instruct the patient to exhale and hold their breath for the exposure.

Central ray

- *Horizontal* and perpendicular to the IR, entering the patient at MSP at a level 2 inches (5 cm) above the iliac crests to include the diaphragm.

Collimation

- Adjust the radiation field to approximately 14 × 17 inches (35 × 43 cm). Collimate to 1 inch beyond the skin shadows on thinner adults and pediatric patients. Place the side marker in the collimated exposure field.

Structures shown

Air and fluid levels within the abdominal cavity are shown. This projection is especially helpful in assessing free air in the abdomen when an upright position cannot be used. Exposure should be adequate to show tissue interfaces, such as the lower margin of the liver, kidney shadows, psoas muscles, and the transverse processes of the lumbar vertebrae (Fig. 12.27). Evidence of proper collimation should be visible.

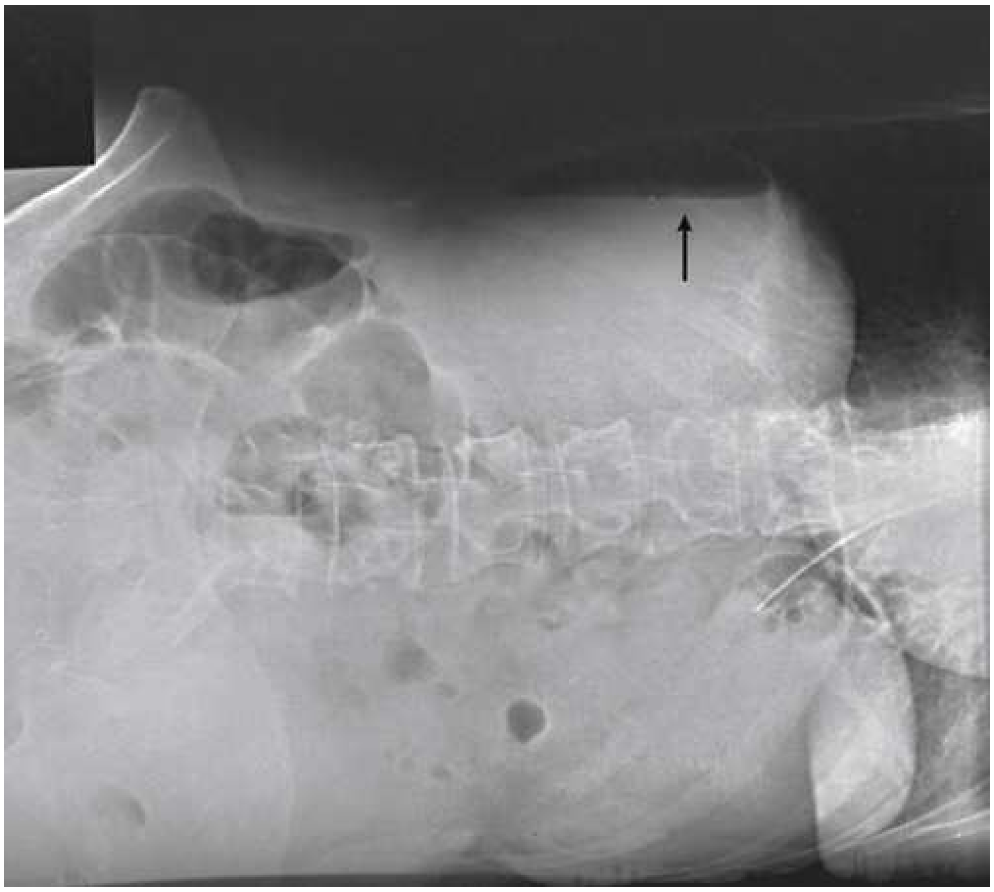


FIG. 12.27 Left lateral decubitus position AP projection of abdomen performed on a trauma patient. Free intraperitoneal air is seen on upper right side of abdomen *(arrow)*. Radiograph is slightly underexposed to show free air more easily.

Lateral Projection [j]

Dorsal decubitus position

Trauma positioning tips

- *Note:* This position is substituted for the lateral decubitus position in patients too injured or too ill to be turned onto their side.

- Verify whether the image is necessary to assess fluid accumulation or free air in the abdominal cavity. Exposure factors are often decreased for free air since the air must be visualized against the anterior tissues of the abdomen.
- If fluid accumulation is of primary interest, ensure that the IR is centered to the level of MCP.
- Check for signs of internal bleeding during the radiographic examination and *report any changes to the attending physician immediately.*
- Use universal precautions if wounds, bleeding, or both are present, and protect the IR with plastic covering. Mark all entrance and exit wounds with radiopaque markers when imaging for penetrating injuries.
- *Shield gonads, if possible, and personnel in the room.*

Patient position considerations

- Position the gurney with either side of the patient adjacent to the vertical Bucky device, with wheels locked. If mobile radiography is required, be sure that the grid IR is exactly vertical to avoid distortion.
- Center the IR 2 inches (5 cm) above the iliac crests to include the diaphragm (Fig. 12.28).
- Carefully position the patient's arms over his or her head or across the upper chest to remove them from the image.
- Ensure that MSP is perpendicular to avoid rotation.
- Instruct the patient to exhale and hold his or her breath for the exposure.

Central ray

- *Horizontal* and perpendicular to the IR, entering the patient at MCP at a level 2 inches (5 cm) above the iliac crests to include the diaphragm.

Collimation

- Adjust the radiation field to approximately 14 × 17 inches (35 × 43 cm). Collimate to 1 inch (2.5 cm) beyond the skin shadows on thinner adults and pediatric patients. Place the side marker in the collimated exposure field.

Structures shown

Air and fluid levels within the abdominal cavity are shown. This projection is especially helpful in assessing free air in the abdomen when an upright position cannot be used. Exposure should be adequate to show tissue interfaces and the prevertebral space (Fig. 12.29). Evidence of proper collimation should be visible.

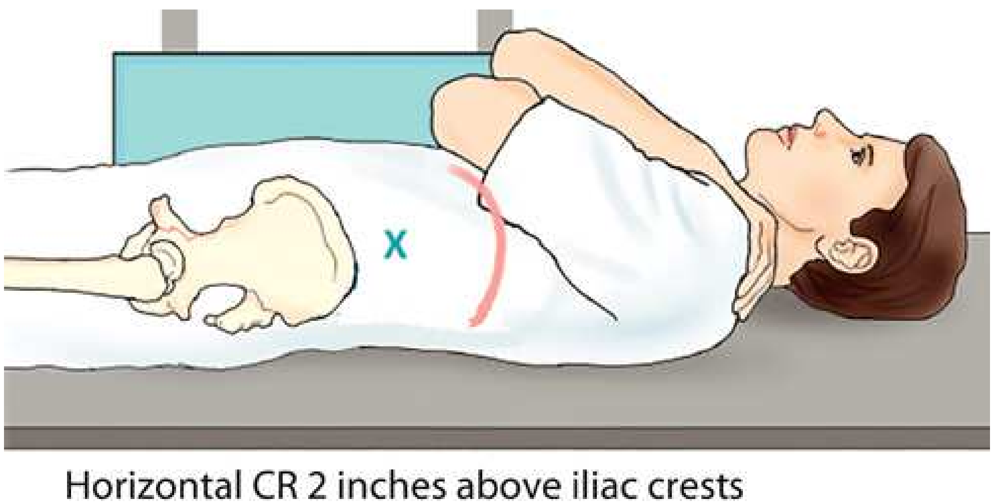


FIG. 12.28 Patient and image receptor positioned for trauma dorsal decubitus position, lateral projection of the abdomen. *CR*, Central ray.

FIG. 12.29 Dorsal decubitus, lateral projection of the abdomen. *Arrows* mark calcifications in the abdominal aorta.

Pelvis

Ap Projection [k, l]

Trauma positioning tips

- *Note:* Level I centers often refer patients with pelvic trauma to CT first because research has shown that CT is superior in showing fracture extent and associated visceral and vascular damage.
- Up to 50% of pelvic fractures are fatal due to vascular damage and shock. The mortality risk increases with the energy of the force and according to the health of the victim.
- Pelvic fractures have a high incidence of internal hemorrhage. Alert the attending physician immediately if the abdomen becomes distended and firm.
- Hemorrhagic shock is common with pelvic and abdominal injuries. Reassess the patient's level of consciousness repeatedly while performing radiographic examinations.
- *Do not* attempt internal rotation of the limbs for true AP projection of proximal femora on this projection.
- Collimate closely to reduce scatter radiation.
- Shield gonads, if possible, and other personnel in the room.

Patient position considerations

- The patient is supine, possibly on a backboard and with external immobilization.
- Obtain appropriate assistance to safely transfer the patient to the radiographic table to allow the use of a Bucky, if not working with a C-arm-configured unit.
- If unable to transfer the patient, use a grid IR positioned under the immobilization device or patient. Ensure that the grid IR is horizontal and parallel to MCP to minimize distortion and rotation.
- Position the grid IR centered at MSP at a level 2 inches (5 cm) inferior to the anterior superior iliac spine or 2 inches (5 cm) superior to the pubic symphysis.
- Instruct the patient to suspend respiration for the exposure, if possible.

Central ray

- Directed perpendicular to the center of the IR (Fig. 12.30). Carefully align to avoid distortion and grid cutoff.

Collimation

- Adjust the radiation field to approximately 14 × 17 inches (35 × 43 cm), and no larger than the IR. Adjust to 1 inch (2.5 cm) beyond the skin shadows on both sides on thinner adults or pediatric patients. Place the side marker in the collimated exposure field.

Structures shown

The pelvis and proximal femora should be shown in their entirety, with minimal rotation and distortion. Femoral necks are foreshortened, and lesser trochanters are seen. Exposure technique should show cortical margins, bony trabeculation, and soft tissue (Fig. 12.31). Evidence of proper collimation should be visible.

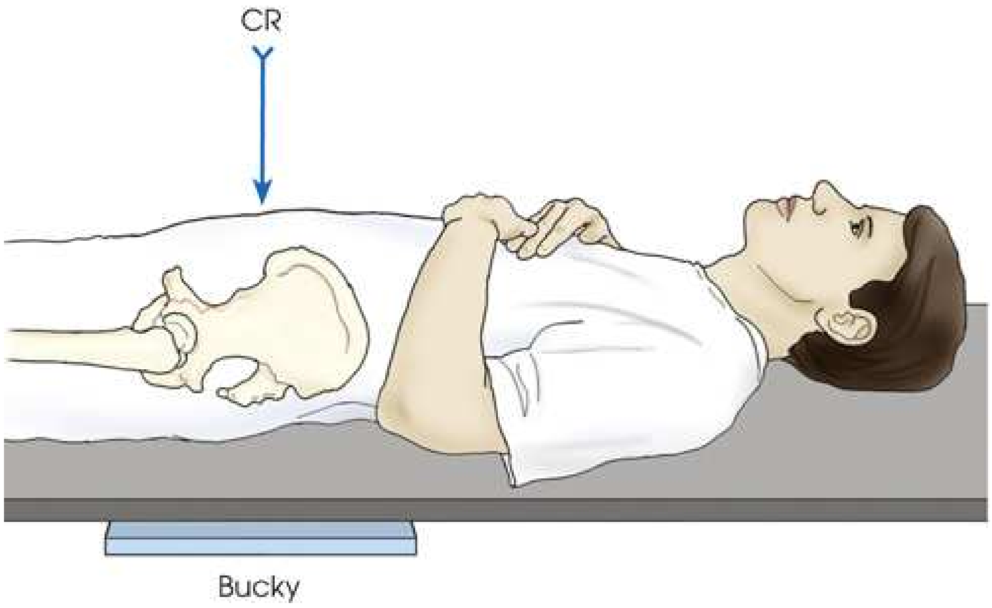


FIG. 12.30 Patient and image receptor positioned for trauma AP projection of pelvis. *CR*, Central ray.

FIG. 12.31 AP projection of pelvis performed on a trauma patient. (A) Entire right limb torn off after being hit by a car. Pelvic bone was disarticulated at pubic symphysis and sacroiliac joint. The patient survived. (B) Separation of pubic bones *(arrowheads)* anteriorly and associated fracture of left ilium *(arrow)*.

Hip

Axiolateral Projection m

Danelius-Miller Method

Trauma positioning tips

- This projection is often referred to as a “cross-table lateral” or “surgical lateral” hip.
- Use care and appropriate assistance to safely elevate the unaffected limb out of the collimated field.
- Do *not* attempt to internally rotate the affected limb.
- *Shield gonads, if possible, and other personnel in the room.*

Patient position considerations

- The patient is supine, possibly on a backboard and with external immobilization.

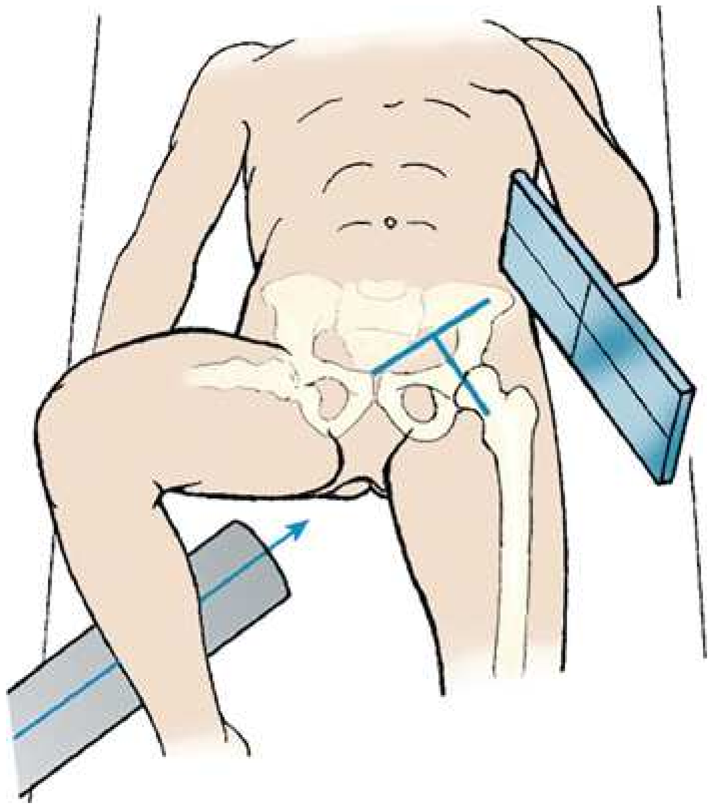


FIG. 12.32 Patient and image receptor positioned for cross-table lateral hip, axiolateral projection (Danelius-Miller method).

- Position a grid IR parallel with the femoral neck, centered to the most prominent portion of the greater trochanter and at a level to place the midline of the hip in the midline of the IR.
- Obtain appropriate assistance to safely elevate the unaffected limb, flex the knee, and position the thigh vertical, if possible.
- Support and immobilize the elevated limb. *Do not* rest on the collimator or tube housing, as this may cause injury to the patient or affect the central ray/IR relationship.
- If the patient is conscious, instruct them to suspend respiration for the exposure.

Central ray

- *Horizontal* and perpendicular to the center of the IR (Fig. 12.32). Carefully align to avoid distortion and grid cutoff.

Collimation

- Adjust the radiation field to approximately 10 × 12 inches (24 × 30 cm), and no larger than the IR. Adjust to 1 inch (2.5 cm) beyond the skin shadows on the anterior and posterior sides on thinner adults or pediatric patients. Place the side marker in the collimated exposure field.

Structures shown

The acetabulum, head, neck, and trochanters of the femur. Exposure technique should show cortical margins, bony trabeculation, and soft tissue (Fig. 12.33). Any orthopedic appliance should be seen in its entirety. Evidence of proper collimation should be visible.

FIG. 12.33 Axiolateral projection of the hip (Danelius-Miller method).

Modified Axiolateral Projection [n]

Clements-Nakayama Modification

Trauma positioning tips

- *Note:* This modification is used on patients with suspected bilateral hip fractures, bilateral hip arthroplasty, or limited movement of the unaffected limb.
- Position a grid IR aligned parallel to the femoral neck at a height to place the center of the hip on the IR.
- Tilt the top of the grid IR back (away from the hip) 15 degrees.
- *Shield gonads, if possible, and other personnel in the room.*

Patient position considerations

- The patient is supine, possibly on a backboard and with external immobilization.
- *Do not* attempt internal rotation of the limb.

Central ray

- Directed 15 degrees posteriorly and aligned perpendicular to the femoral neck and grid IR (Fig. 12.34).

Collimation

- Adjust the radiation field to approximately 10 × 12 inches (24 × 30 cm), and no larger than the IR. Adjust to 1 inch (2.5 cm) beyond the skin shadows on both sides on thinner adults or pediatric patients. Place the side marker in the collimated exposure field.

Structures shown

The acetabulum and the head, neck, and trochanters of the femur in lateral profile. Exposure technique should show cortical margins, bony trabeculation, and soft tissue (Fig. 12.35). Any orthopedic appliance should be seen in its entirety. Evidence of proper collimation should be visible.

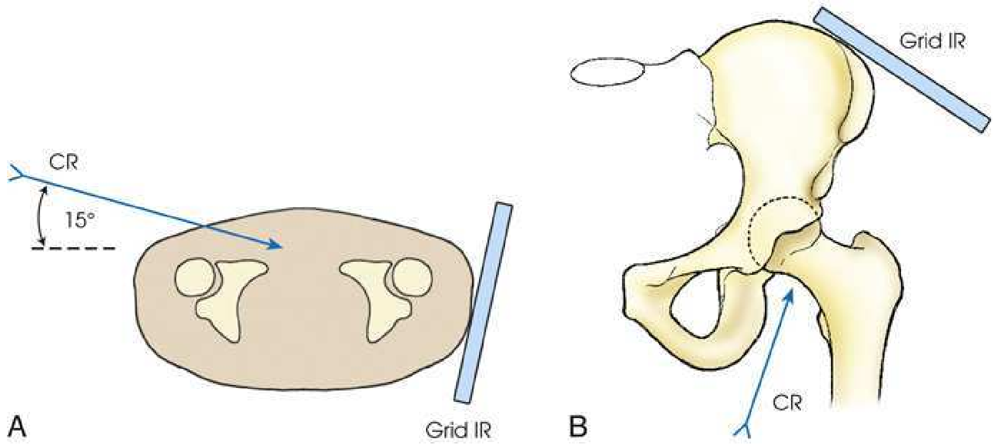


FIG. 12.34 Central ray (CR) and image receptor *(IR)* angles for Clements-Nakayama method for trauma hip. (A) CR angles 15 degrees posteriorly with grid top tilted 15 degrees away from the patient. (B) CR enters at femoral neck.

Two illustrations showing Clements-Nakayama method for positioning the central ray and image receptor on a hip. In the first one The central ray is at 15 degrees and the grid top is 15 degrees away from the patient's horizontal position. In the second one the image receptor is placed on the top-right pelvis and the central ray is directed towards the femoral neck.

FIG. 12.35 Clements-Nakayama method with 15-degree central ray angulation.

Skull

Lateral Projection º

Dorsal decubitus position

Trauma positioning tips

- *Note:* Patients with head injuries are often referred to CT imaging first because of its superiority in showing associated soft tissue and vascular damage.
- Robinson et al. [1] recommended using the dorsal decubitus lateral projection to show traumatic sphenoid sinus effusion (Fig. 12.36). The group stated that this finding may be the only clue to the presence of a basal skull fracture.
- Because the scalp and face are vascular, these areas tend to bleed profusely. Protect IRs with plastic covering and practice universal precautions.
- A grid IR is used for this projection. Elevate the patient's head on a radiolucent sponge *only after cervical injury, such as fracture or dislocation, has been ruled out.*

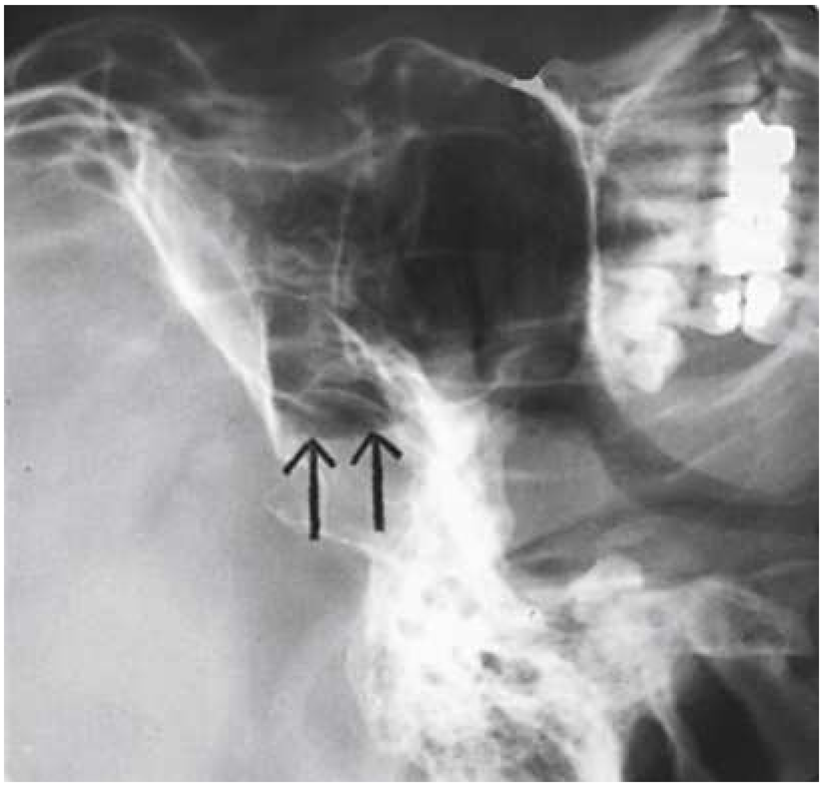


FIG. 12.36 Dorsal decubitus, lateral skull showing sphenoid sinus effusion *(arrows)*.

- Vomiting is a symptom of intracranial injury. *If a patient begins to vomit, logroll him or her to a lateral position to prevent aspiration, and alert the attending physician immediately.*
- *Alert the attending physician immediately if there is any change in the patient's level of consciousness or if the pupils are unequal.*
- Collimate closely to reduce scatter radiation. Recommend visualizing 1 inch of light beyond skin line. Check vertex, anterior, posterior, and base of skull to ensure entire anatomy of interest is included.
- Correctly place the side marker in light field.
- *Shield gonads and other personnel in the room. Shield thyroid and thymus glands on children.*

Patient position considerations

- Have the patient relax the shoulders.
- After cervical spine injury has been ruled out, the patient's head may be positioned to align the interpupillary line perpendicular to the IR and MSP vertical.
- If the patient is wearing a cervical collar, carefully minimize rotation and tilt of the cranium.
- Ensure that the grid IR is vertical.

Central ray

- *Horizontal* and perpendicular to a point 2 inches (5 cm) above the EAM (Fig. 12.37).

Collimation

- Adjust the radiation field to 12 inches (30 cm) in the AP dimension and 10 inches (24 cm) in the superoinferior dimension. Place the side marker in the collimated exposure field.

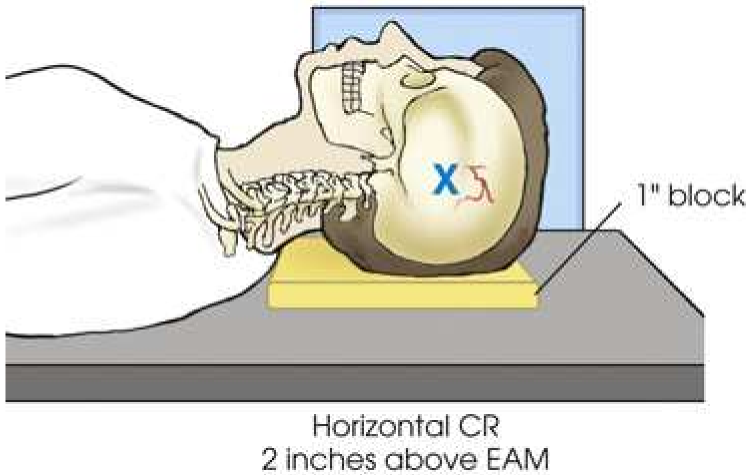


FIG. 12.37 Patient and image receptor positioned for trauma lateral projection of cranium using dorsal decubitus position. Note sponge in place to raise head to show posterior cranium (after checking lateral cervical spine radiograph). *CR*, Central ray; *EAM*, external acoustic meatus.

Structures shown

A profile image of the superimposed halves of the cranium is seen with detail of the side closer to the IR shown (Fig. 12.38). With some injuries, air-fluid levels can be shown in the sphenoid sinuses. Evidence of proper collimation should be visible.

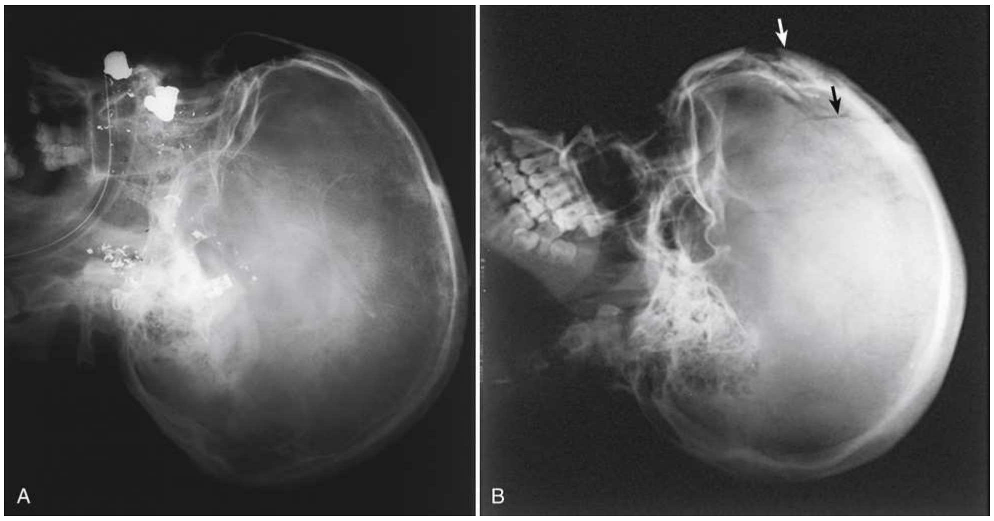


FIG. 12.38 Dorsal decubitus position lateral projection of cranium performed on a trauma patient. (A) Two gunshot wounds entering at level of C1 and traveling forward to face and lodging in area of zygomas. Note bullet fragments in external acoustic meatus area. (B) Multiple frontal skull fractures *(arrows)* caused by hitting windshield during a motor vehicle accident (MVA).

Ap and Ap Axial Projections [1]

Reverse Caldwell Method and Towne Method [p]

Trauma positioning tips

- Profuse bleeding should be anticipated with head and facial injuries. Use universal precautions and protect IRs and sponges with plastic.
- Cervical spine injury should be ruled out before attempting to position the head.
- AP and reverse Caldwell demonstrate the anterior cranium. The AP axial projection, Towne method, shows the posterior cranium.
- Vomiting is a symptom of an intracranial injury. If a patient begins to vomit, logroll him or her to a lateral position to prevent aspiration and alert the attending physician immediately.

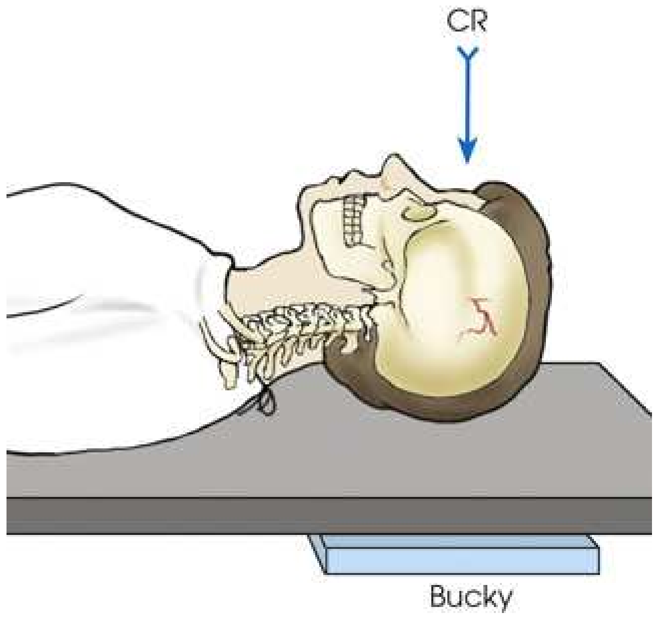


FIG. 12.39 Patient and image receptor positioned for trauma AP projection of cranium. *CR*, Central ray.

- Alert the attending physician if the patient's level of consciousness decreases or if pupils are unequal.
- A grid IR or Bucky should be used to ensure proper image contrast.
- *Shield gonads and other personnel in the room.*

Patient position considerations

- If not using a C-arm-configured unit, and if the patient's condition allows, obtain appropriate assistance to safely transfer the patient to the x-ray table using the immobilization device and proper transfer techniques. Transfer allows the use of the Bucky and minimizes risk of injury to the patient when positioning the IR.
- If the patient is not transferred to the radiographic table, the grid IR should be placed under the immobilization device. If no such device is present, the *attending physician* should carefully lift the patient's head and neck while the radiographer positions the grid IR under the patient.

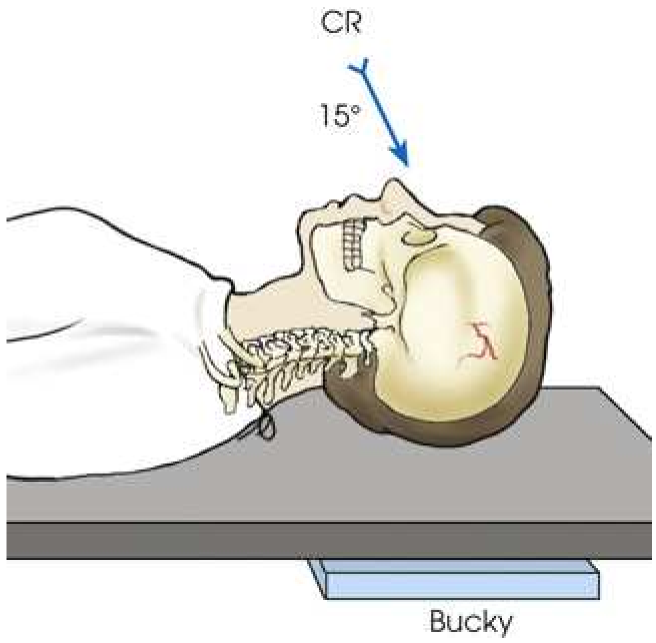


FIG. 12.40 Patient, image receptor, and central ray (CR) angled 15 degrees cephalad for trauma AP axial, reverse Caldwell of the cranium.

- *AP and AP axial (reverse Caldwell)*: Position the patient's head to place the orbitomeatal line (OML) and MSP perpendicular to the IR.
- *AP axial (Towne method)*: Position the patient's head to place OML or infraorbitomeatal line (IOML) and MSP perpendicular to the IR. If the patient is wearing a cervical collar, the OML or IOML cannot be positioned perpendicularly, thus, the central ray angle may have to be increased to 60 degrees caudad to maintain a 30-degree angle to OML maintained.

Central ray

- *AP projection*: Perpendicular to MSP at the nasion (Fig. 12.39).

- *AP axial projection (reverse Caldwell):* Angled 15 degrees cephalad entering MSP at the nasion (Fig. 12.40).
- *AP axial projection (Towne method):* Angled 30 degrees caudad to the OML or 37 degrees to the IOML (Fig. 12.41). The central ray passes through the EAM and exits the foramen magnum.

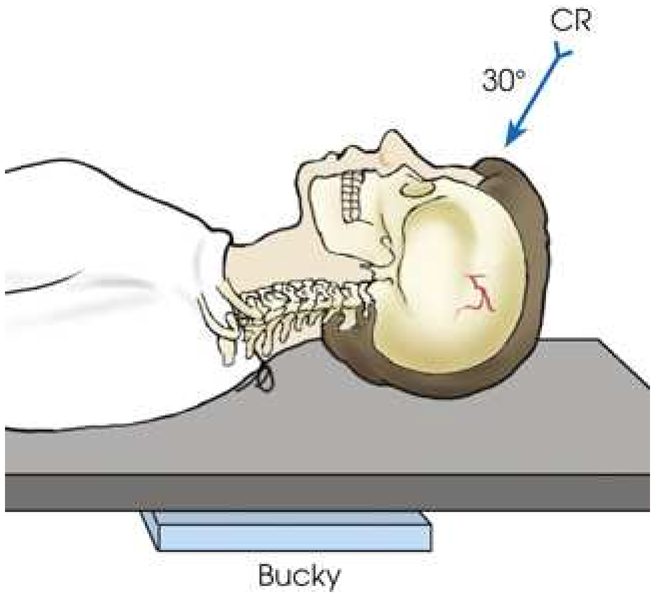


FIG. 12.41 Patient and image receptor positioned for trauma AP axial projection, Towne method, of cranium using 30-degree central ray *(CR)* angulation.

Collimation

- Adjust the radiation field to 10 × 12 inches (24 × 30 cm). Check for light extending approximately 1 inch beyond the skin shadows surrounding the cranium. Place the side marker in the collimated exposure field.

Structures shown

AP and reverse Caldwell demonstrate the anterior cranium (Fig. 12.42). The reverse Caldwell demonstrates the petrous ridges in the lower third of the magnified orbits (Fig. 12.43). AP axial projection, Towne method, shows the posterior cranium and foramen magnum (Fig. 12.44). Cranium should be demonstrated without tilt or rotation. Exposure should demonstrate penetration of cranial bones and surrounding soft tissues. Evidence of proper collimation should be visible.

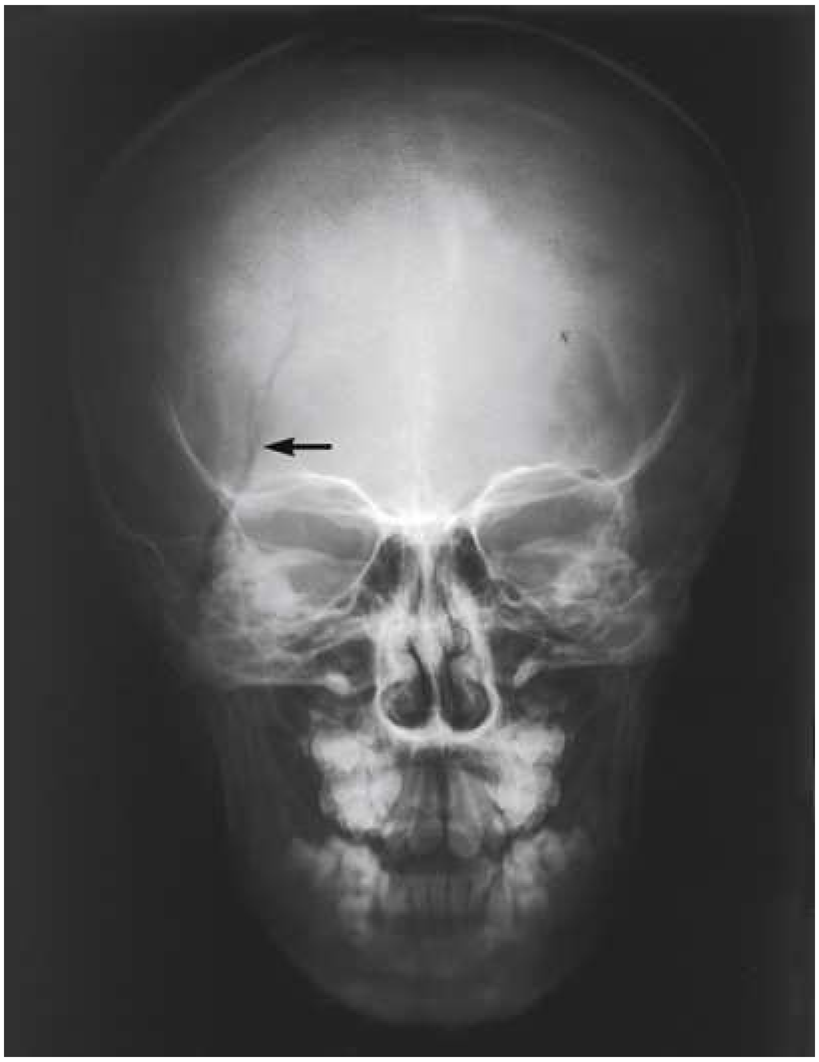


FIG. 12.42 AP projection of cranium performed on a trauma patient. Fracture of occipital bone *(arrow)*.

FIG. 12.43 AP axial, reverse Caldwell of cranium. Note screws (anterior and lateral surfaces) from recent surgery. Petrous ridges are slightly too low in the orbits, most likely due to misalignment of orbitomeatal line with image receptor plane. Slight rotation and tilt also present.

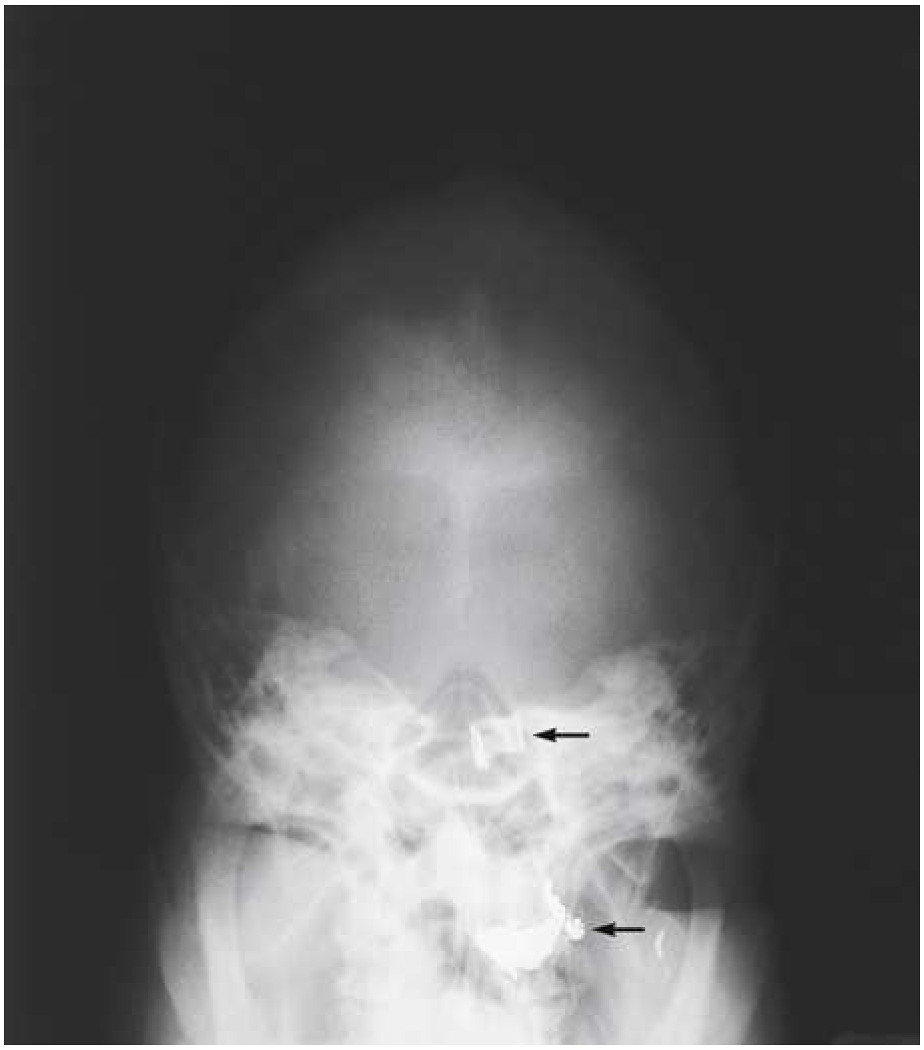


FIG. 12.44 AP axial projection, Towne method, performed on a trauma patient with gunshot wound to the head. Metal clip *(upper arrow)* indicates entrance of bullet on anterior cranium. Flattened bullet and fragments *(lower arrow)* are lodged in area of C2.

Facial Bones

Acanthioparietal Projection q

Reverse Waters Method

Trauma positioning tips

- Anticipate profuse bleeding with facial trauma. Protect IRs with plastic covering and practice universal precautions.
- Cervical spine injury should be ruled out before positioning of the head is attempted.
- *Alert the attending physician if the patient's level of consciousness decreases or if pupils are unequal.*
- A grid IR or Bucky is used to ensure proper image contrast.
- *Shield gonads and other personnel in the room.*

Patient position considerations

- If required and if the patient's condition allows, carefully and slowly transfer the patient to the x-ray table using the immobilization device and proper transfer techniques. Transfer allows use of the Bucky and minimizes risk for injury to the patient when the IR is positioned.
- If mobile radiography must be used, the grid IR should be placed under the immobilization device. If no such device is present, the *attending physician* should carefully lift the patient's head and neck while the radiographer positions the grid IR under the patient.
- Trauma patients are often unable to hyperextend the neck far enough to allow placement of the OML 37 degrees to the IR and the MML perpendicular to the plane of the IR. In these patients, the acanthioparietal projection, or the reverse Waters projection, can be achieved by adjusting the central ray so that it enters the acanthion while remaining parallel with the MML.
- MSP should be perpendicular to prevent rotation.

Central ray

- Angled cephalad until it is parallel with MML. Enters at the acanthion (Fig. 12.45).

Collimation

- Adjust the radiation field to 10 × 12 inches (24 × 30 cm). Check that the light field extends 1 inch (2.5 cm) beyond the lateral sides of the face and 1 inch (2.5 cm) above the superior orbital margins and inferiorly to the tip of the chin. Place the side marker in the collimated exposure field.

Structures shown

The superior facial bones are shown (Fig. 12.46). The image should be similar to the parietoacanthial projection or routine Waters method and should show symmetry of the face. Evidence of proper collimation should be visible.

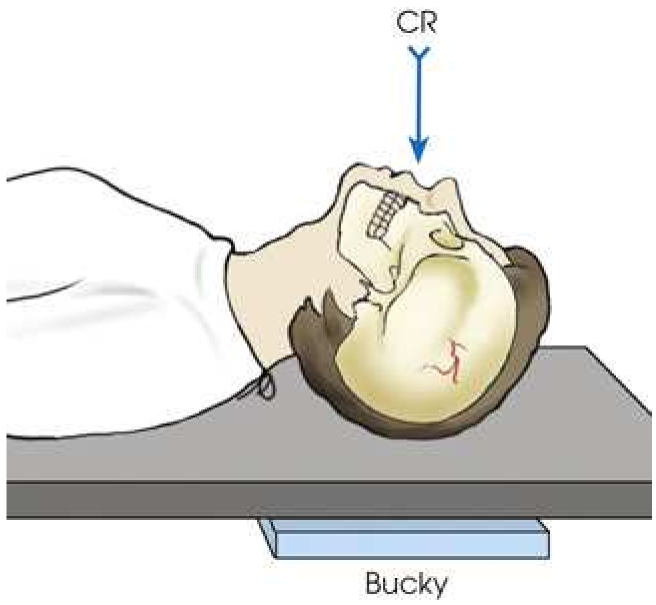


FIG. 12.45 Central ray *(CR)* aligned parallel to mentomeatal line for trauma acanthioparietal projection, reverse Waters method, of cranium.

FIG. 12.46 Acanthioparietal projections, reverse Waters method, performed on trauma patients to show facial bones. (A) Fracture of right orbital floor *(arrow)* with blood-filled maxillary sinus (note no air is in sinus). The patient hit face on steering wheel during MVA. (B) Blowout fracture of left orbital floor *(arrow)* with blood-filled maxillary sinus (note no air is in sinus). Patient was hit with a fist.

Upper Extremity

Trauma positioning tips

- Use standard precautions, and cover IRs and positioning aids in plastic if wounds are present.
- When lifting an injured limb, support it at both joints and lift slowly. Lift only enough to place the IR under the part—sometimes only 1 to 2 inches (2.5 to 5 cm). Always obtain help in lifting injured limbs and positioning the IRs to minimize patient discomfort.
- If the limb is severely injured, *do not* attempt to position for true AP or lateral projections. Expose the two projections, 90 degrees apart, while moving the injured limb as little as possible.

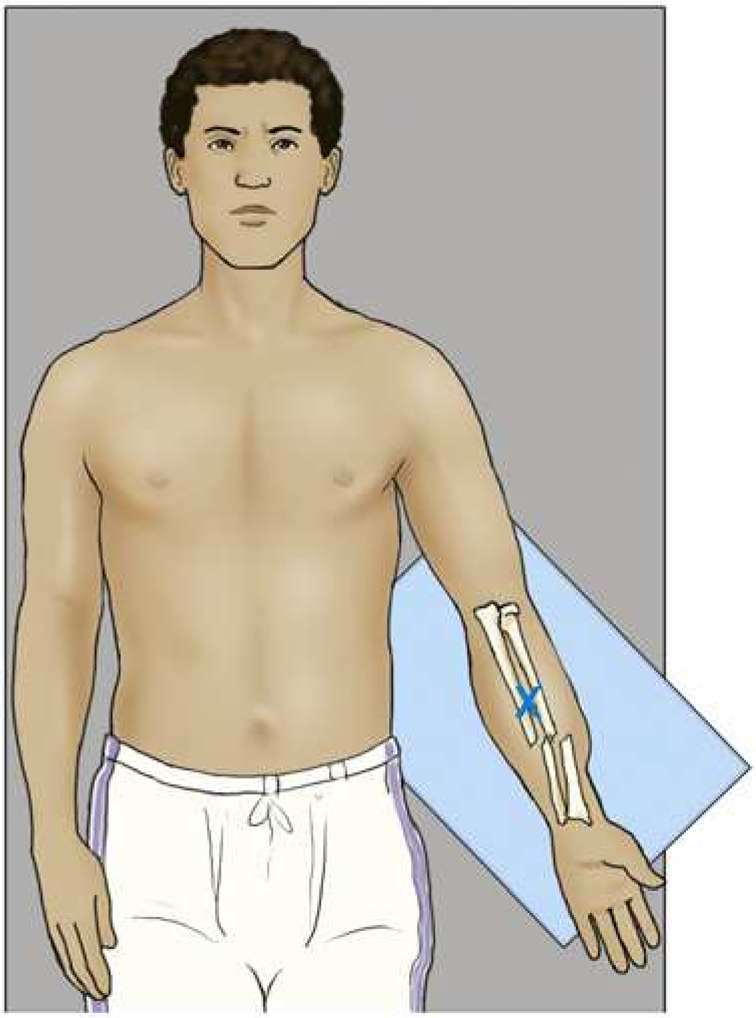


FIG. 12.47 Patient and image receptor *(IR)* positioned for trauma AP projection of forearm. *CR*, Central ray.

- Check the patient's status during radiographic examination. Shock can occur from crushing injuries to extremities.
- Long bone radiographs must include both joints on the image.
- Separate examinations of the adjacent joints *may be required* if injury indicates. Do not attempt to "short cut" by performing only one projection of the long bone.
- *Shield gonads and other personnel in the room.*

Patient position considerations

- If possible, demonstrate the desired position for a conscious patient. Assist the patient in attempting to assume the position, rather than moving the injured limb.
- If the patient is unable to position the limb close to that required, move the IR and x-ray tube to obtain the desired projection (Figs. 12.47 to 12.50).

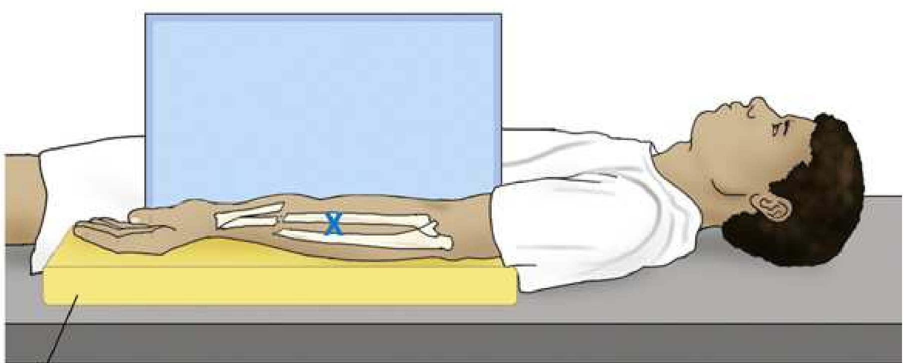


FIG. 12.48 Patient and image receptor *(IR)* positioned for trauma cross-table lateral projection of forearm. *CR*, Central ray.

FIG. 12.49 AP projection of forearm performed on a trauma patient. Fracture of midportion of radius and ulna *(arrows)*.

FIG. 12.50 Cross-table lateral projection of forearm performed on a trauma patient. Gunshot wound to forearm with fracture of radius and ulna and extensive soft tissue damage.

- Shoulder injuries should be initially imaged "as is" without rotating the limb. The "reverse" PA oblique projection of the scapular Y (an AP oblique) is useful in showing dislocation of the glenohumeral joint with minimal patient movement. The patient's affected side is elevated 45 degrees and supported in position (Figs. 12.51 and 12.52).
- If imaging while the patient is still on a stretcher, check to ensure that the IR is perfectly horizontal to minimize image distortion.
- The central ray must be directed perpendicular to the IR to minimize distortion.
- Immobilization techniques for the IR and upper limb are useful in obtaining an optimal image with minimal patient discomfort.

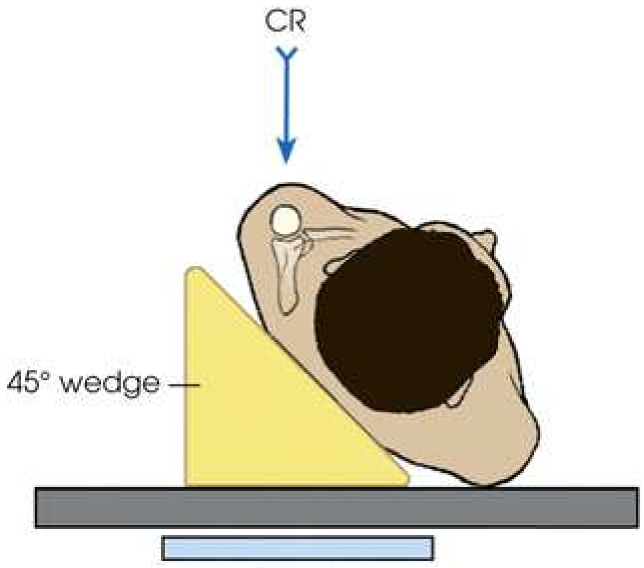


FIG. 12.51 Patient and image receptor positioned for trauma AP oblique projection of shoulder to show scapular Y. (Reverse of PA oblique, scapular Y—see Chapter 6.) *CR*, Central ray.

A patient lies on an X-ray table with the image receptor placed behind his shoulders, below the table. A wedge is used to incline and lift his shoulders to the right. The central ray is directed towards the center of the left shoulder.

Structures shown

Images of the anatomy of interest, 90 degrees from one another, should be shown. Exposure technique should be sufficient to visualize cortical margins, bony trabeculation, and surrounding soft tissues. Both joints should be included in projections of long bones. Projections of adjacent joints must be centered to the joint to show the articular ends properly (Figs. 12.53 and 12.54). Evidence of proper collimation should be visible.

FIG. 12.52 AP oblique projection of shoulder (reverse of PA oblique, scapular Y) performed on a trauma patient. Several fractures of scapula *(arrows)* with significant displacement.

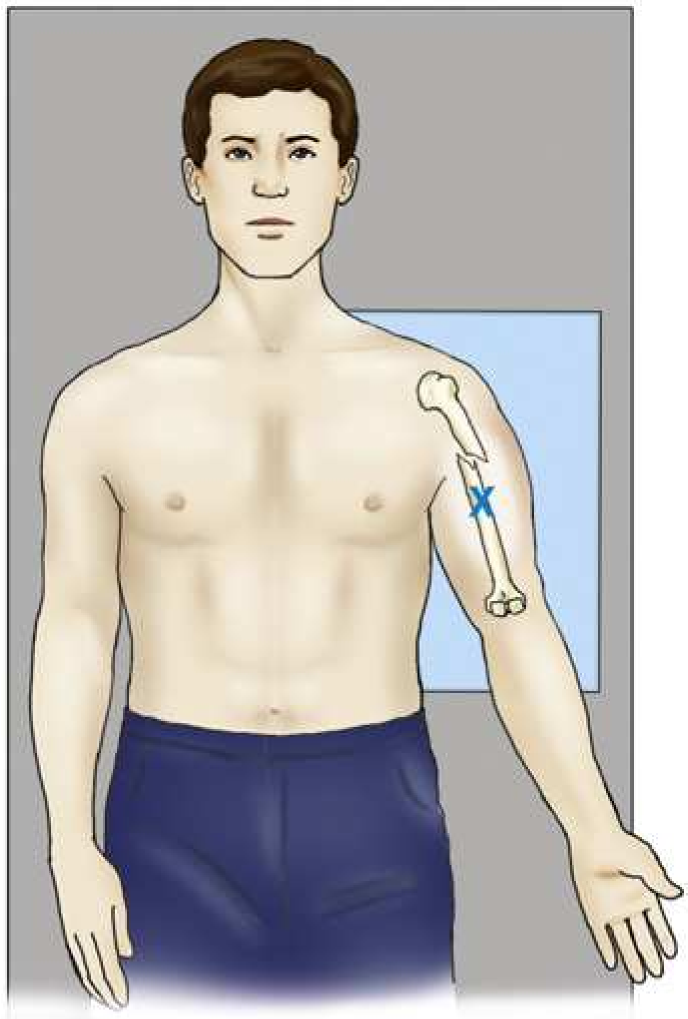


FIG. 12.53 Patient and image receptor *(IR)* positioned for trauma AP projection of humerus. *CR*, Central ray.

FIG. 12.54 AP projection of humerus performed on a trauma patient. Fracture of midshaft of humerus.

Lower Extremity

Trauma positioning tips

- Use standard precautions, and cover IRs and positioning aids in plastic if open wounds are present.
- Immobilization devices are often present with injuries to the lower extremities, especially in cases with suspected femoral fractures. *Perform image procedures with immobilization in place, unless directed to remove them by the attending physician.*
- When lifting an injured extremity, support at both joints and lift slowly. Lift only enough to place the IR under the part—sometimes only 1 to 2 inches (2.5 to 5 cm). Always obtain help in lifting injured extremities and in positioning IRs to minimize patient discomfort (Fig. 12.55).
- If the extremity is severely injured, *do not* attempt to position it for true AP and lateral projections. Take two projections, 90 degrees apart, moving the injured extremity as little as possible.
- Long bone examinations must include both joints. Separate images may be required.
- Examinations of adjacent joints may be required if the condition indicates. The central ray and IR must be properly centered to the joint of interest to show the anatomy properly.
- Check on patient status during radiographic examination. Shock can occur with severe injuries to the lower extremities.
- A grid IR should be used on thicker anatomic parts, such as the femur.
- *Shield gonads and other personnel in the room.*

Patient position considerations

- Demonstrate or describe the desired position for the patient and allow him or her to attempt to assume the position, rather than moving the injured extremity. Assist the patient as needed.
- If the patient is unable to position the extremity close to the required true position, move the IR and x-ray tube to obtain projection (Figs. 12.56 and 12.57).
- If imaging while the patient is still on a stretcher, check to ensure that the IR is perfectly horizontal to minimize image distortion.
- The central ray must be directed perpendicular to the IR to minimize distortion.
- Immobilization techniques for the IR and lower extremity are extremely useful in obtaining optimal quality with minimal patient discomfort.

FIG. 12.55 Proper method of lifting lower extremity for placement of image receptor (for AP projection) or placement of elevation blocks (for cross-table lateral). Lift only high enough to place IR or blocks underneath. Note that two hands are used to lift this patient with a broken leg gently.

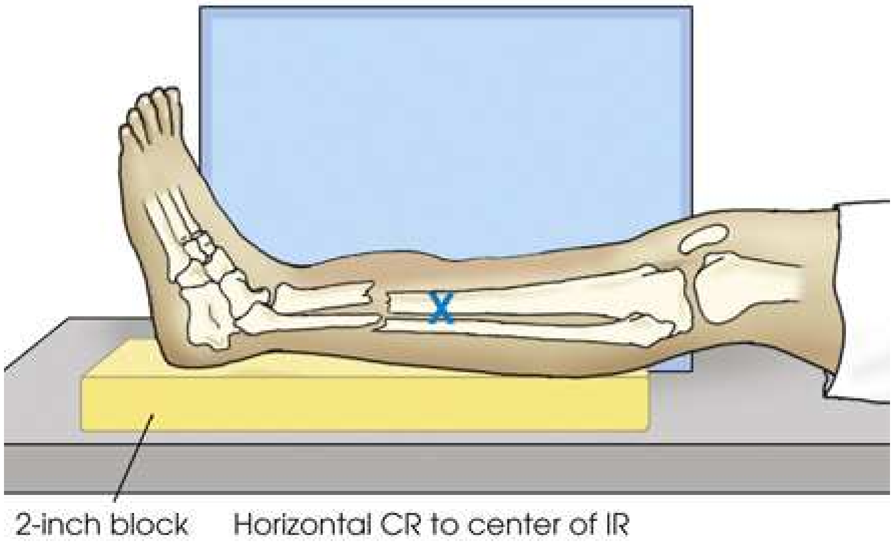


FIG. 12.56 Patient and image receptor *(IR)* positioned for trauma cross-table lateral projection of lower leg. IR and central ray *(CR)* may be moved superiorly or inferiorly to center for other portions of lower extremity. Note positioning blocks placed under extremity to elevate it so that all anatomy of interest is seen.

FIG. 12.57 Cross-table lateral projection of lower extremity performed on a trauma patient. (A) Dislocation of tibia from talus *(double arrows)* and fracture of fibula *(arrow)*. (B) Complete fracture and displacement of femur. Proximal femur is seen in AP projection, and distal femur is rotated 90 degrees at fracture point, resulting in lateral projection. Note artifacts caused by immobilization devices.

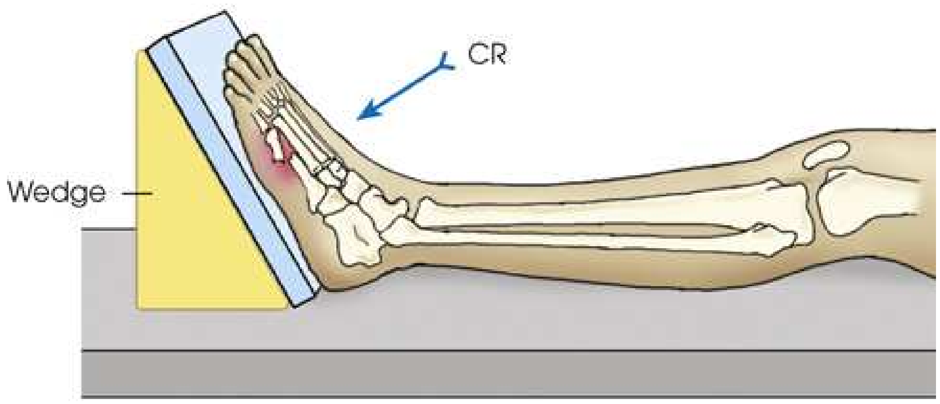


FIG. 12.58 Patient and image receptor *(IR)* positioned for trauma AP projection of foot or toes. IR is supported with sandbags for positioning against foot. *CR*, Central ray.

FIG. 12.59 AP projection of foot performed on a trauma patient. (A) Fracture and dislocation of tarsal bones with exposure technique adjusted for optimal image of this area. (B) Gunshot wounds to great toe.

Structures shown

Images of the anatomy of interest, 90 degrees from each other, should be shown. Exposure technique should be sufficient to visualize cortical margins, bony trabeculation, and surrounding soft tissues. Both joints should be included in examinations of long bones. Images of articulations must be properly centered to show anatomy properly (Figs. 12.58 and 12.59). Evidence of proper collimation should be visible.

Other Imaging Procedures in Trauma

Follow-up imaging procedures by other modalities are often warranted when radiography reveals a traumatic injury. In many instances, however, radiography is *not* the modality used first for detection of injuries sustained in a trauma. Because of this fact, most trauma centers have CT readily available or a dedicated unit for trauma cases (Figs. 12.60 to 12.63). The role of sonography in trauma imaging has increased significantly, and it provides the advantage of yielding a great deal of diagnostic information without radiation exposure. Magnetic resonance imaging (MRI) has also increased in its utility in trauma imaging, primarily owing to decreased scan times provided by newer scan protocols and techniques.

Computed Tomography

In many major trauma centers, CT is readily available for emergency imaging. This fact has influenced the decision-making policies associated with diagnostic imaging of trauma. CT is the first imaging modality used for trauma to the following parts of the body:

- Head and brain
- Cervical spine
- Thorax
- Pelvis

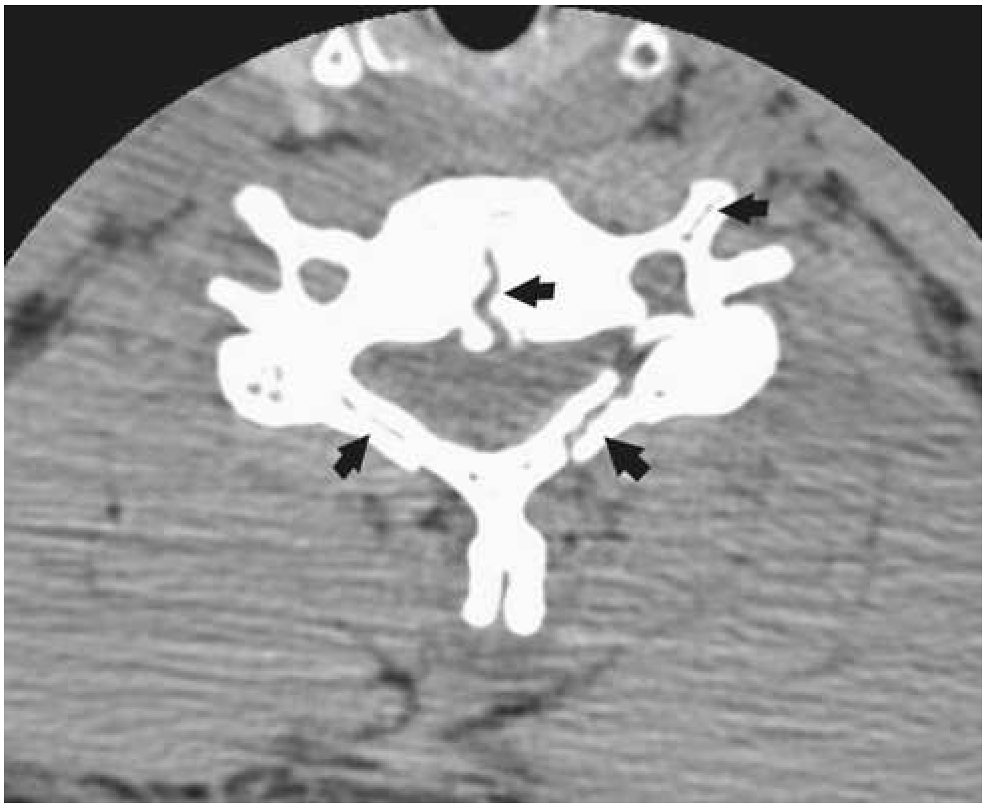


FIG. 12.60 CT scan of C5 showing multiple fractures *(arrows)* resulting from a fall from a tree. Courtesy Sunie Grossman, RT[R], St. Bernard's Medical Center, Jonesboro, AR.

FIG. 12.61 CT scan of pelvis showing fracture of left ilium *(arrow)* with fragment displacement. Clothing and backboard artifacts are evident. Courtesy St. Bernard's Medical Center, Jonesboro, AR.

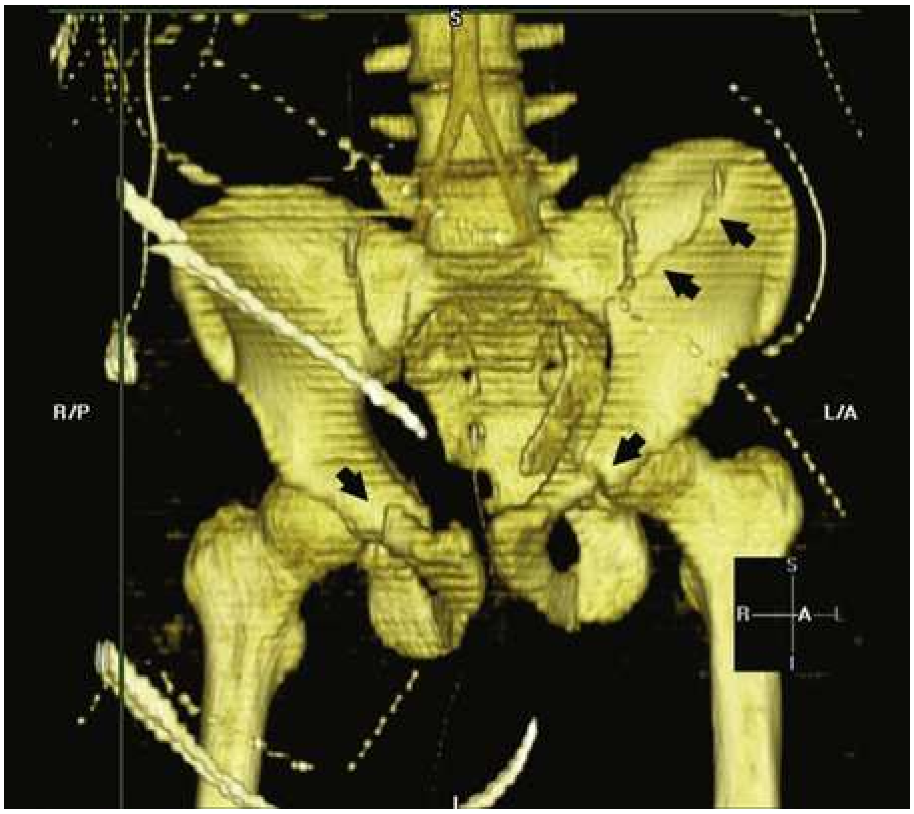


FIG. 12.62 Three-dimensional reconstruction of pelvis from the patient in Fig. 12.52. Multiple pelvic fractures are well visualized *(arrows)*. Courtesy St. Bernard's Medical Center, Jonesboro, AR.

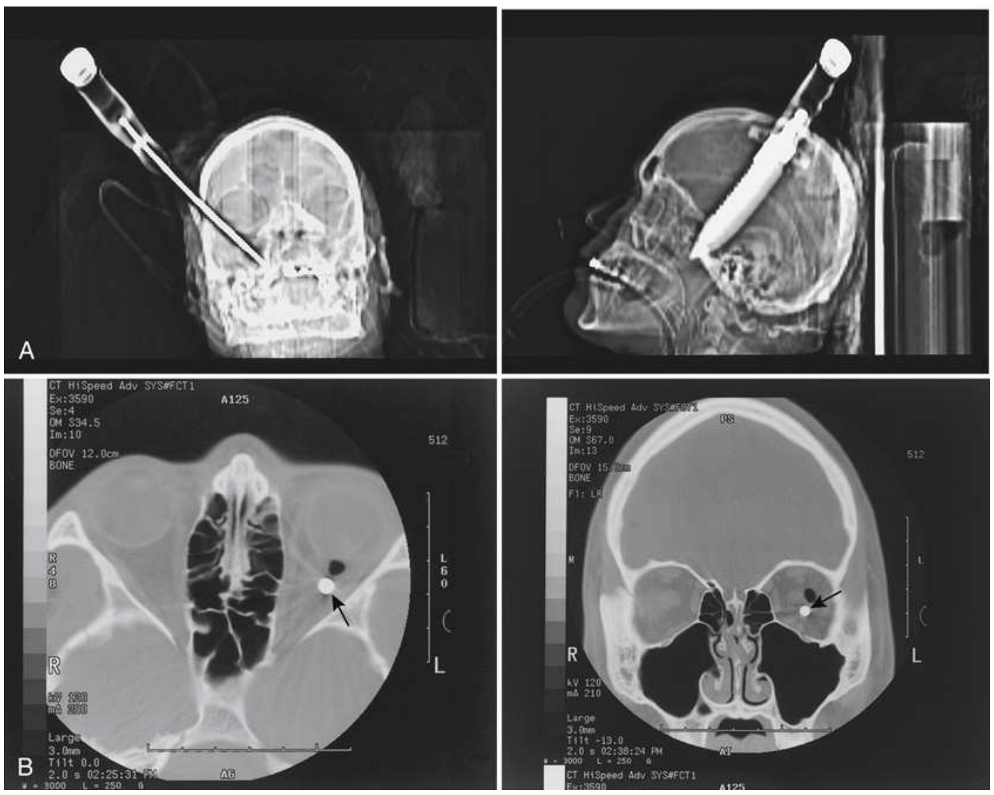


FIG. 12.63 (A) AP and lateral computer tomography (CT) scout images of cranium. Note knife placement in cranium. Conventional cranium radiographs were not obtained on this trauma patient. The patient was sent directly to CT scanner for these images and sectional images before going to surgery. The patient recovered and returned home. (B) Axial and coronal CT sectional images of cranium at level of the eye. The patient was shot in the left eye with a BB gun. Note BB *(arrow)*. Adjacent black area is air. The patient now has monocular vision. A, Courtesy Tony Hofmann, RT[R][CT], Shands Hospital School of Radiologic Technology, Jacksonville, FL; B, courtesy Mark H. Layne, RT[R].

Four scan images arranged side-by-side. In A, a knife is inserted through the cranium above the temple at an angle. In B, a knife is inserted through the cranium along the axis of the skull. In C, an axial view of the skull reveals wounds on the left eye. The coronal view of the same skull is provided.

The GCS is often the diagnostic indicator for the necessity of a head CT scan. The GCS is used to provide an objective and consistent neurologic evaluation. The highest possible score is 15, and the lowest possible score is 3. The GCS score and other head injury signs and symptoms, such as headache, loss of consciousness, posttraumatic amnesia, and seizure, are used to determine whether a head CT scan is required. Patients with cervical spine injuries are often referred to CT first—especially patients with multiple injuries and associated symptoms of cord injury. CT of the thorax is often the first imaging modality used in cases of suspected aortic dissection. Chest radiography is still the gold standard for many emergency cases involving the thorax, but because of time factors, patients with certain types of force trauma are sent directly to the CT scanner. CT of the pelvis is often performed in place of radiography because CT shows the extent of pelvic fractures better than radiography and offers the advantage of showing injuries to the pelvic organs and vasculature simultaneously.

Diagnostic Medical Sonography

The role of sonography in emergency imaging is evolving and increasing rapidly. Focused abdominal sonography in trauma (FAST) has been recognized as a valuable trauma diagnostic imaging tool. Research continues to assess the role of sonography in trauma imaging, and a wide variety of procedures have been studied so far, such as pediatric fracture reduction; chest and thoracic trauma, specifically pneumothorax and hemorrhage in the abdomen and pelvis; cranial trauma in infants; and superficial musculoskeletal sprains and tears. Advantages of sonography in trauma include lack of radiation exposure and improved efficiency of image access. The disadvantage is that sonography image quality is critically operator-dependent, and the ED physician may be uncomfortable with image interpretation, requiring the presence of a radiologist.

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[a] See Mobile Lateral Projection in Vol. 3, Chapter 20, pp. 24-25.

[b] See Chapter 9, Vol. 1, pp. 460-461, for a complete description.

[c] See Standard Projection in Vol. 1, Chapter 9, pp. 445-446.

[d] See Standard Projection in Vol. 1, Chapter 3, pp. 119-120.

[e] See Mobile Projection in Vol. 3, Chapter 20, pp. 10-11.

[f] See Standard Projection in Vol. 1, Chapter 4, pp. 138-139.

[g] See Mobile Projection in Vol. 3, Chapter 20, pp. 14-15.

[h] See Standard Projection in Vol. 1, Chapter 4, pp. 140-141.

[i] See Mobile Projection in Vol. 3, Chapter 20, pp. 16-17.

[j] See Standard Projection in Vol. 1, Chapter 4, p. 143.

[k] See Standard Projection in Vol. 1, Chapter 8, pp. 393-394.

[l] See Mobile Projection in Vol. 3, Chapter 20, pp. 18-19.

[m] See Standard Projection in Vol. 1, Chapter 8, pp. 406-407.

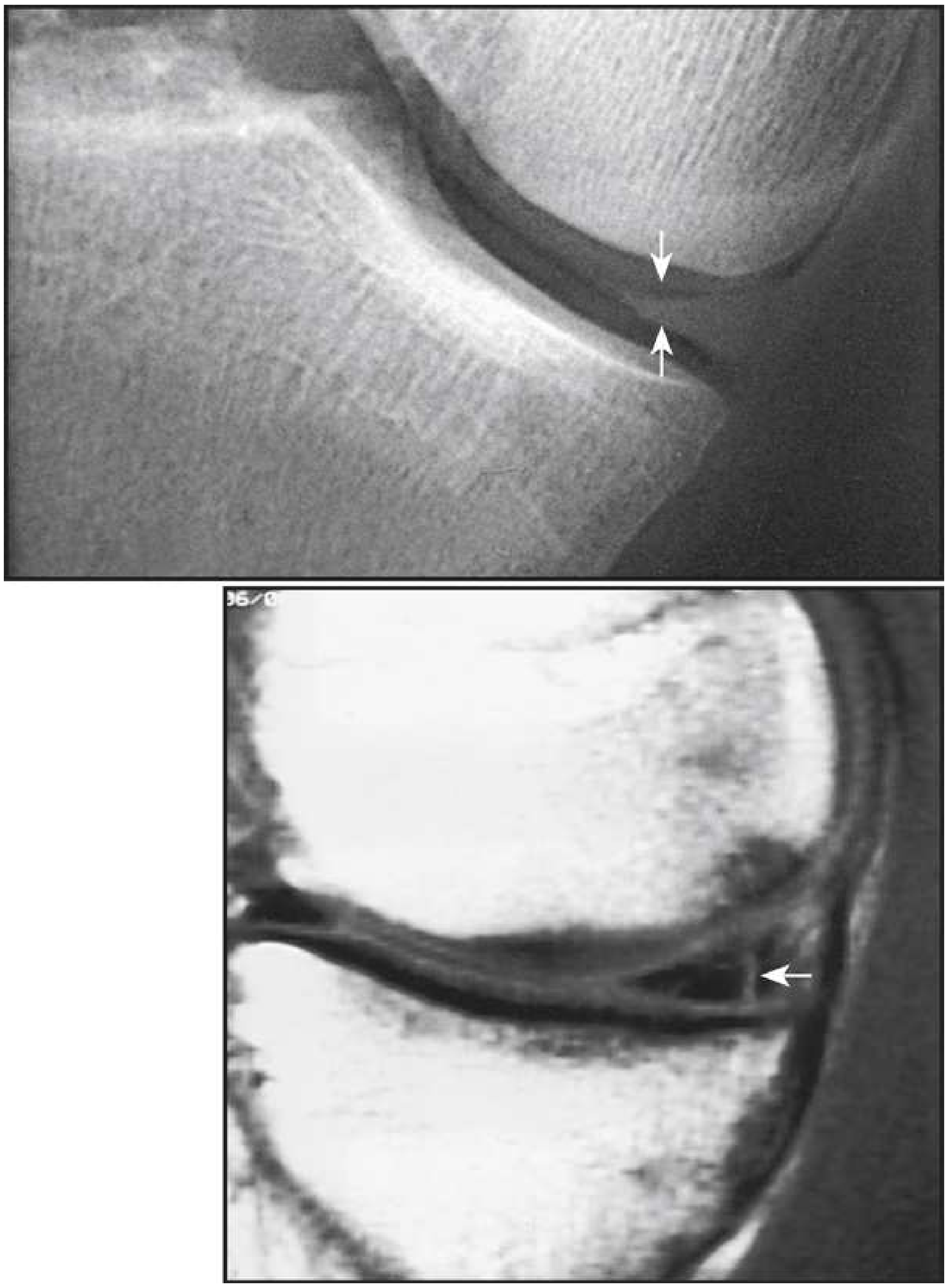
[n] See Standard Projection in Vol. 1, Chapter 8, pp. 408-409.

[o] See Standard Projection in Vol. 2, Chapter 11, pp. 34-37.

[p] See Standard Projection in Vol. 2, Chapter 11, pp. 38-49.

[q] See Standard Projection in Vol. 2, Chapter 11, pp. 65-66.

13: Contrast Arthrography



OUTLINE

Overview

Contrast computed tomography (CT), shoulder magnetic resonance imaging (MRI) with and without contrast, and ultrasound (US) have drastically reduced the need for radiographic contrast arthrography (Fig. 13.1). Radiography of joints is still recommended as the initial imaging for many of the joints once imaged using contrast arthrography, yet the most recent recommendations by the American College of Radiology (ACR) rank radiographic contrast arthrography from very low to not at all as an appropriate diagnostic tool. Exceptions include the following:

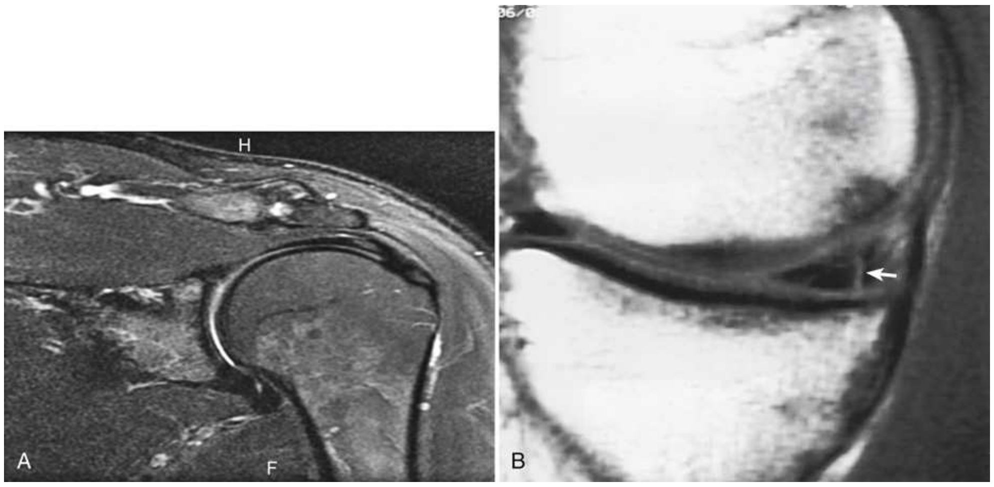


FIG. 13.1 (A) Non–contrast-enhanced MRI of shoulder. (B) Non–contrast-enhanced MRI of knee, showing torn medial meniscus *(arrow)*.

FIG. 13.2 Bilateral opaque arthrogram of bilateral congenital hip dislocations.

- Contraindications for administration of gadolinium or lack of expertise for US exams [1]
- Aspiration in suspected septic or inflammatory arthropathies of the shoulder [1]
- After knee arthroplasty as a routine follow-up or for complications [2]
- To rule out the hip as the referred pain source after other negative imaging [3]

Arthrography (Greek *arthron,* meaning "joint") is radiography of a joint or joints. *Pneumoarthrography, opaque arthrography,* and *double-contrast arthrography* are terms used to denote radiologic examinations of the soft tissue structures of joints (menisci, ligaments, articular cartilage, bursae) after injection of one or two contrast agents into the capsular space. A gaseous medium is used in pneumoarthrography, a water-soluble iodinated medium is used in opaque arthrography (Fig. 13.2), and a combination of gaseous and a water-soluble iodinated medium is used in double-contrast arthrography. Although contrast studies may be performed on any encapsulated joint, the shoulder is the most frequent site of investigation. The joints discussed in this chapter—shoulder, knee, and hip—are the ones most likely to be imaged using radiographic contrast arthrography. Other joints may be imaged occasionally with arthrography. As noted previously, MRI, CT, and US are the modalities most likely to be used to demonstrate pathologies of the joints and associated soft tissues.

Arthrogram examinations are usually performed with a local anesthetic. The injection is made under careful aseptic conditions, usually in a combination fluoroscopic-radiographic examining room that has been carefully prepared in advance. The sterile items required, particularly the length and gauge of the needles, vary according to the part being examined. The sterile tray and the nonsterile items should be set up on a conveniently placed instrument cart or a small two-shelf table (Fig. 13.3).

FIG. 13.3 Sterile arthrogram tray.

Summary of Pathology

Condition	Definition
Developmental dysplasia of the hip	Denotes a wide spectrum of congenital hip abnormalities, ranging from acetabular dysplasia, joint laxity, and subluxation to complete dislocation
Dislocation	Displacement of a bone from a joint
Joint capsule tear	Rupture of the joint capsule
Ligament tear	Rupture of the ligament
Meniscus tear	Rupture of the meniscus
Rotator cuff tear	Rupture of any muscle of the rotator cuff

After aspirating any effusion, the radiologist injects the contrast agent or agents and manipulates the joint to ensure proper distribution of the contrast material. The examination is usually performed by fluoroscopy and spot images. Conventional radiographic images may be obtained when special images, such as an axial projection of the shoulder or an intercondyloid fossa position of the knee, are desired.

Abbreviations Used in Chapter 13

ACR	American College of Radiology
DDH	Developmental dysplasia of the hip
MRI	Magnetic resonance imaging
PA	Posteroanterior

See Addendum B for a summary of all abbreviations used in Volume 2.

Shoulder Arthrography

Arthrography of the shoulder is performed primarily for the evaluation of partial or complete tears in the rotator cuff or glenoid labrum, persistent pain or weakness, and frozen shoulder. A single-contrast technique (Fig. 13.4) or a double-contrast technique (Fig. 13.5) may be used.

The usual injection site is approximately ½ inch (1.3 cm) inferior and lateral to the coracoid process. Because the joint capsule is usually deep, use of a spinal needle is recommended.

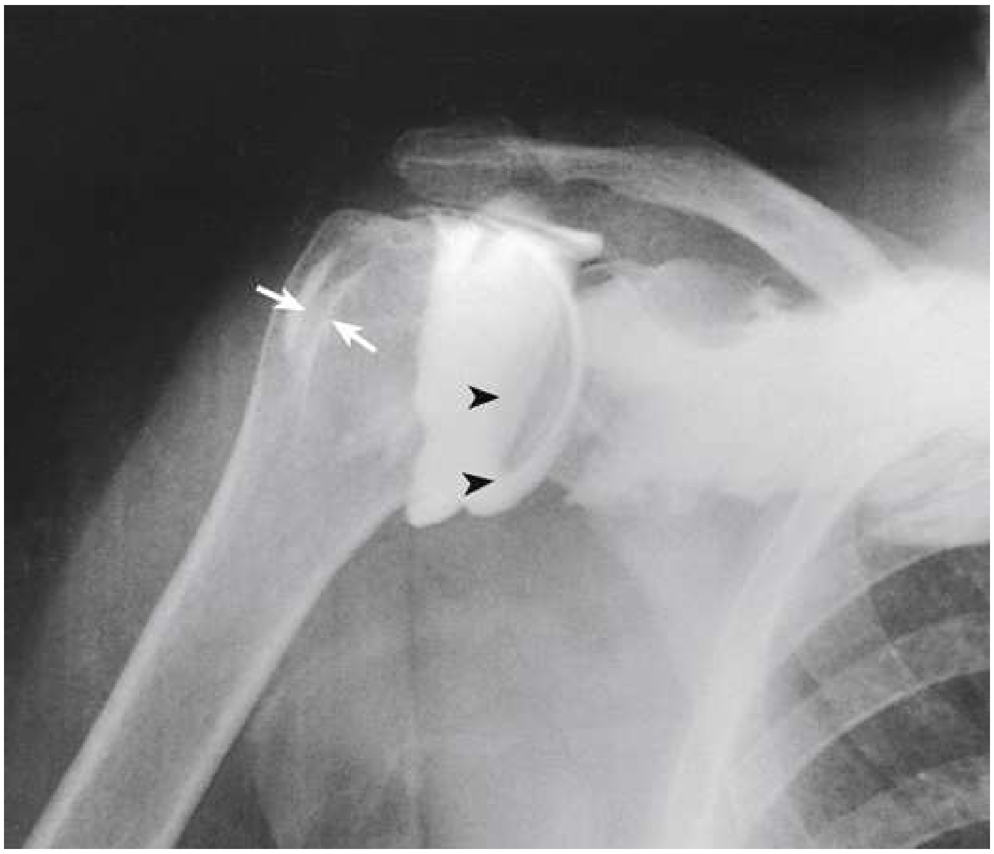


FIG. 13.4 Normal AP single-contrast shoulder arthrogram with contrast medium surrounding the biceps tendon sleeve and lying in the intertubercular (bicipital) groove *(arrows)*. The axillary recess is filled but has normal medial filling defect *(arrowheads)*, created by the glenoid labrum.

For a single-contrast arthrogram (Fig. 13.6), approximately 10 to 12 mL of positive contrast medium is injected into the shoulder. For double-contrast examinations, approximately 3 to 4 mL of positive contrast medium and 10 to 12 mL of air are injected into the shoulder.

FIG. 13.5 Normal AP double-contrast shoulder arthrogram.

FIG. 13.6 Single-contrast arthrogram showing a rotator cuff tear *(arrowheads)*.

The projections most often used are the anteroposterior (AP) (internal and external rotation), 30-degree AP oblique, axillary (Figs. 13.7 and 13.8), and tangential. (See Volume 1, Chapter 6, for a description of patient and part positioning).

FIG. 13.7 Normal axillary single-contrast shoulder arthrogram.

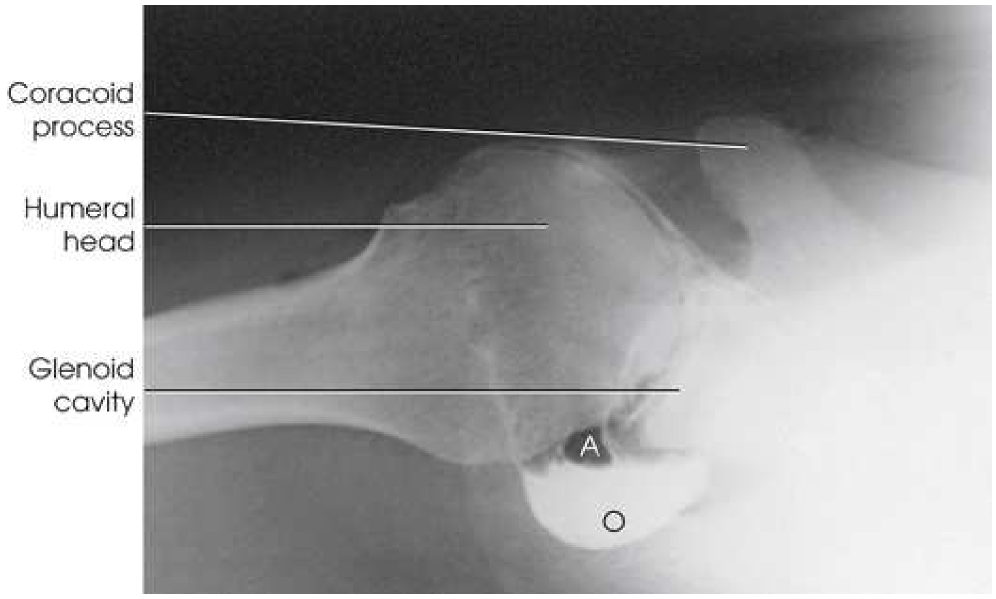


FIG. 13.8 Normal axillary double-contrast shoulder arthrogram projection of patient in supine position. Opaque medium *(O)* and air-created *(A)* density are seen anteriorly.

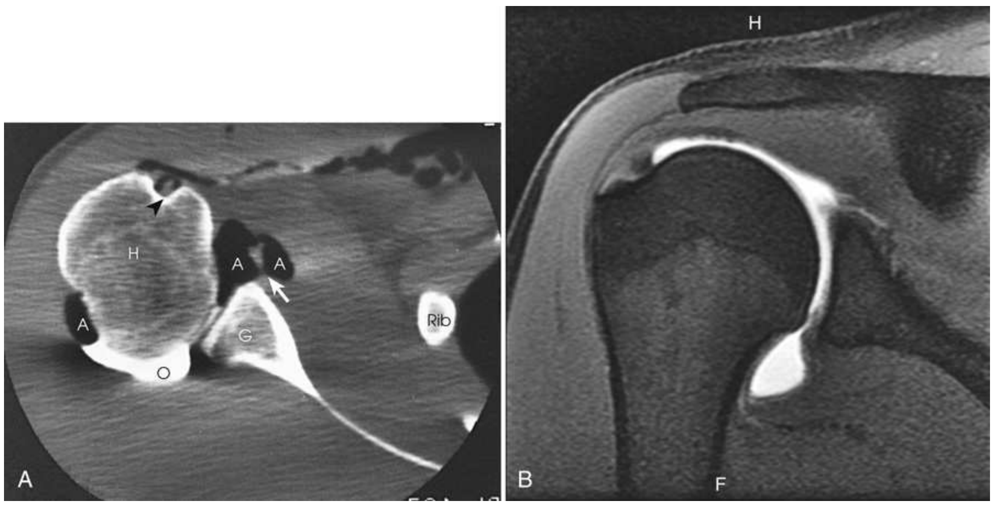


FIG. 13.9 (A) CT shoulder arthrogram. Radiographic arthrogram in this patient was normal (see Fig. 13.5). CT shoulder arthrogram shows small chip fracture *(arrow)* on the anterior surface of the glenoid cavity. Head of humerus *(H)*, air surrounding biceps tendon *(arrowhead)*, air contrast medium *(A)*, opaque contrast medium *(O)*, and glenoid portion of scapula *(G)* are evident. (B) MRI arthrogram of shoulder with injection of gadolinium contrast medium.

A C T shoulder arthrogram and an M R I arthrogram of the shoulder. In A, the Head of humerus, air surrounding biceps tendon, air contrast medium, opaque contrast medium, and glenoid portion of scapula are denoted. In B, the M R I arthrogram the Head of humerus is visible.

After double-contrast shoulder arthrography is performed, CT may be used to examine some patients. CT images may be obtained at approximately 5-mm intervals through the shoulder joint. In shoulder arthrography, CT has been found to be sensitive and \reliable in diagnosis. Radiographs and CT scans of the same patient are presented in Figs. 13.5 and 13.9. Shoulder arthrography is increasingly performed with MRI, with injection of gadolinium contrast medium into the joint capsule (see Fig. 13.9B).

Contrast Arthrography of the Knee

Vertical Ray Method

Contrast arthrography of the knee by the vertical ray method requires the use of a stress device. The following steps are taken:

- Place the limb in the frame to widen or "open up" the side of the joint space under investigation. This widening, or spreading, of the intrastructural spaces permits better distribution of the contrast material around the meniscus.
- After the contrast material is injected, place the limb into the stress device (Fig. 13.10). To delineate the medial side of the joint, place the stress device just above the knee, and then laterally stress the lower leg.

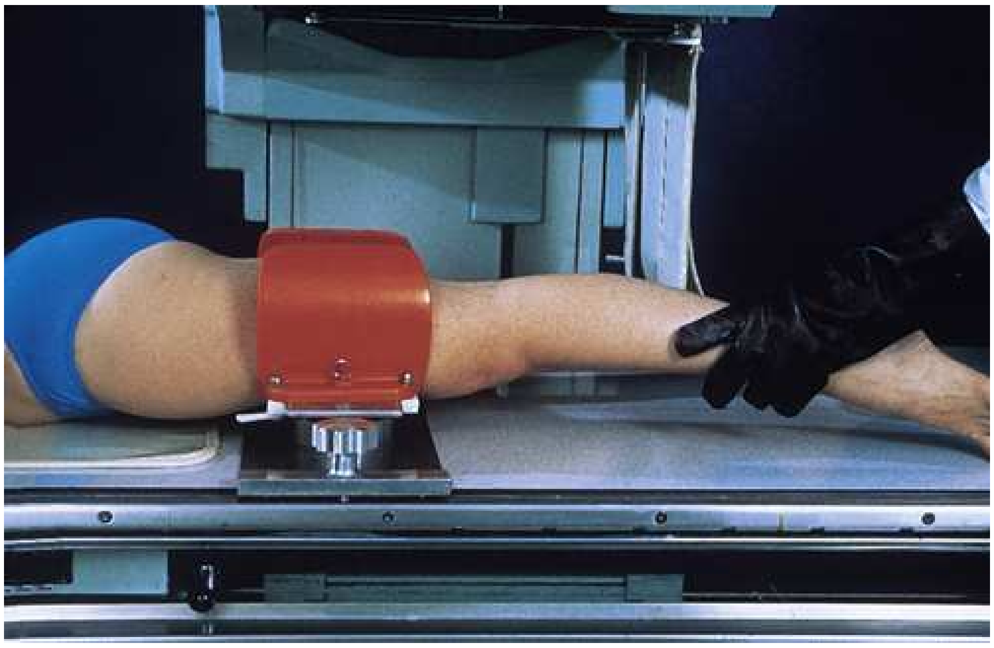


FIG. 13.10 Patient lying on lead rubber for gonad shielding and positioned in stress device on fluoroscopic table.

- When contrast arthrograms are to be made by conventional radiography, turn the patient to the prone position and fluoroscopically localize the centering point for each side of the joint. The mark ensures accurate centering for closely collimated studies of each side of the joint. The images obtained of each side of the joint usually consist of an AP projection and a 20-degree right and left AP oblique projection.
- Obtain the oblique position by leg rotation or by central ray angulation (Fig. 13.11).
- On completion of these studies, remove the frame and perform lateral and intercondyloid fossa projections.

NOTE: Anderson and Maslin [4] recommended that tomography be used in knee arthrography. In addition, the technique can frequently be used for other contrast-filled joint capsules.

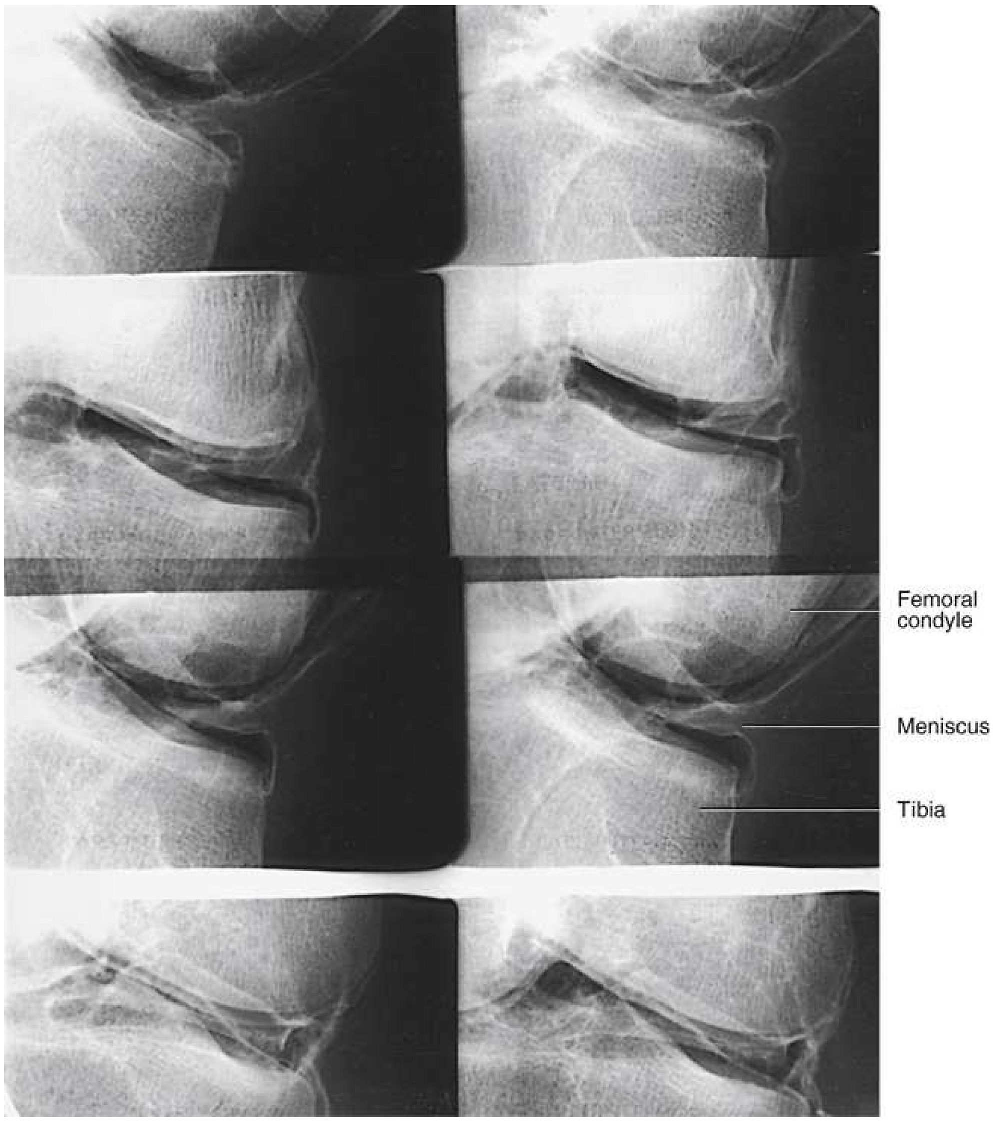


FIG. 13.11 Vertical ray double-contrast knee arthrogram.

Double-Contrast Arthrography of the Knee

Horizontal Ray Method

The horizontal central ray method of performing double-contrast arthrography of the knee was first described by Andrén and Wehlin [5] and later by Freiberger et al. [6] These investigators found that using a horizontal x-ray beam position and a comparatively small amount of each of the two contrast agents (gaseous medium and water-soluble iodinated medium) improved double-contrast delineation of the knee joint structures. With this technique, the excess of the heavier iodinated solution drains into the dependent part of the joint, leaving only the desired thin opaque coating on the gas-enveloped uppermost part—the part under investigation.

FIG. 13.12 Image showing a tear *(arrow)* in the medial meniscus.

Medial meniscus

- Adjust the patient into a semiprone position that places the posterior aspect of the medial meniscus uppermost (Fig. 13.12).
- To widen the joint space, manually stress the knee.
- Draw a line on the medial side of the knee and direct the central ray along the line and centered to the meniscus.
- With rotation toward the supine position, turn the leg 30 degrees for each of the succeeding five exposures.
- Direct the central ray along the localization line for each exposure, ensuring that it is centered to the meniscus.

FIG. 13.13 Normal lateral meniscus *(arrows)*.

Lateral meniscus

- Adjust the patient into a semiprone position that places the posterior aspect of the lateral meniscus uppermost (Fig. 13.13).
- To widen the joint space, manually stress the knee.
- As with the medial meniscus, make six images on one image receptor (IR).
- With movement toward the supine position, rotate the leg 30 degrees for each of the consecutive exposures, from the initial prone oblique position to the supine oblique position.
- Adjust the central ray angulation as required to direct it along the localization line and center it to the meniscus.

NOTE: To show the cruciate ligaments after imaging of the menisci is completed,[7] the patient sits with the knee flexed 90 degrees over the side of the radiographic table. A firm cotton pillow is placed under the knee and is adjusted so that some forward pressure can be applied to the leg. With the patient holding a grid IR in position, a closely collimated lateral projection is made.

Hip Arthrography

Hip arthrography is most often performed on children in a surgery suite by an orthopedic surgeon. Arthrography is used to evaluate lateral femoral head displacement and after closed reduction to ensure that there is no folding or impingement of soft tissues (see Fig. 13.2, pretreatment, and Figs. 13.14 and 13.15, posttreatment). In adults, the primary use of hip arthrography is to detect a loose hip prosthesis or to confirm the presence of infection. The cement used to fasten hip prosthesis components has barium sulfate added to make the cement and the cement-bone interface radiographically visible (Fig. 13.16). Although the addition of barium sulfate to cement is helpful in confirming proper seating of the prosthesis, it makes evaluation of the same joint by arthrography difficult.

Because cement and contrast material may appear similar in radiographic images (Figs. 13.17 and 13.18), subtraction images are recommended (Fig. 13.19). Chapter 27 in Volume 3 explains subtraction techniques. A common puncture site for hip arthrography is $\frac{1}{4}$ inch (0.6 cm) distal to the inguinal crease and $\frac{1}{4}$ inch (0.6 cm) lateral to the palpated femoral pulse. A spinal needle is useful for reaching the joint capsule.

FIG. 13.14 AP opaque arthrogram showing treated congenital right hip dislocation in the same patient as in Fig. 13.2.

FIG. 13.15 Axiolateral "frog" right hip of a patient treated for congenital dislocation of the hip.

FIG. 13.16 AP hip radiograph showing radiopaque cement *(arrows)* used to secure a hip prosthesis.

FIG. 13.17 AP hip arthrogram showing hip prosthesis in proper position. Cement with radiopaque additive is difficult to distinguish from contrast medium used to perform arthrography *(arrows)*.

FIG. 13.18 AP hip radiograph after injection of contrast medium.

FIG. 13.19 Digital subtraction hip arthrogram in the same patient as in Fig. 13.18. Contrast medium around a prosthesis in the proximal lateral femoral shaft *(arrows)* indicates that the prosthesis is loose. Lines on the medial and lateral aspects of the femur *(arrowheads)* are subtraction registration artifacts caused by slight patient movement during injection of contrast medium. (See Chapter 27 for a description of subtraction technique.)

A digital subtraction arthrograph of the hip taken after the injection of a contrast medium. A prosthesis is fixed to the hip joint. Arrows on the image point to illuminating parts around the prosthesis indicating that the prosthesis is loose.

Other Joints

Essentially, any joint can be evaluated by arthrography. A wrist arthrogram is included here as an example (Fig. 13.20).

FIG. 13.20 Opaque arthrogram of wrist, showing rheumatoid arthritis.

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14: Myelography and Other Central Nervous System Imaging

Rebecca H. Keith

OUTLINE

Anatomy

For descriptive purposes, the central nervous system (CNS) is divided into two parts: (1) the *brain,* [a] which occupies the cranial cavity, and (2) the *spinal cord,* which is suspended within the vertebral canal.

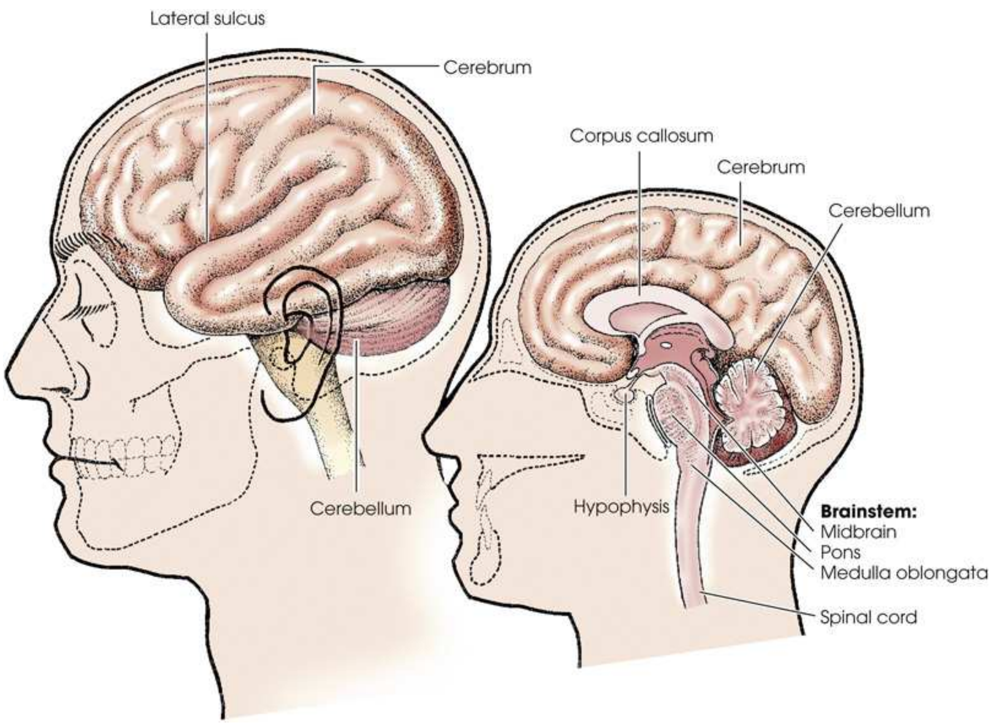

FIG. 14.1 Lateral surface and midsection of brain.

Two illustrations of the lateral view of the brain. The first one depicts the cerebellum above the brainstem and the lateral sulcus on the surface of the brain. The second one depicts the cerebrum, cerebellum and the corpus collosum below the cerebrum. The brainstem emerges from the center and consists of pons, medula oblongata, and midbrain. The spinal cord extends from the brainstem.

Brain

The brain is composed of an outer portion of gray matter called the *cortex* and an inner portion of *white matter.* The brain consists of the *cerebrum, cerebellum,* and *brain stem,* which is continuous with the spinal cord after leaving the cranial cavity (Fig. 14.1). The brain stem consists of the *midbrain, pons,* and *medulla oblongata.*

The cerebrum is the largest part of the brain and is referred to as the *forebrain.* Its surface is convoluted by shallow sulci and deeper grooves (*fissures*) that divide it into lobes and lobules. There are four lobes of the cerebrum, each named for its location within the cranium: the frontal lobe, parietal lobe, occipital lobe, and temporal lobe. The stemlike portion that connects the cerebrum to the pons and cerebellum is termed the *midbrain.* The cerebellum, pons, and medulla oblongata make up the *hindbrain.*

A deep cleft, called the *longitudinal sulcus* (interhemispheric fissure), separates the cerebrum into *right* and *left hemispheres,* which are closely connected by bands of nerve fibers, or commissures. The largest commissure between the cerebral hemispheres is the *corpus callosum.* The corpus callosum is a midline structure inferior to the longitudinal sulcus. Each cerebral hemisphere contains a fluid-filled cavity called a *lateral ventricle.* At the diencephalon, or second portion of the brain, the pair of oval-shaped gray matter masses of the thalamus surround the *third ventricle.* Inferior to the diencephalon is the *pituitary gland,* the master endocrine gland of the body. The pituitary gland resides in the hypophyseal fossa of the sella turcica.

The cerebellum, the largest part of the hindbrain, is separated from the cerebrum by a deep transverse cleft. The hemispheres of the cerebellum are connected by a median constricted area called the *vermis.* The surface of the cerebellum contains numerous transverse sulci that account for its cauliflower-like appearance. The tissues between the curved sulci are called *folia.* The pons, which forms the upper part of the hindbrain, is the commissure, or bridge, between the cerebrum, cerebellum, and medulla oblongata. The medulla oblongata, which extends between the pons and spinal cord, forms the lower portion of the hindbrain. All the fiber tracts between the brain and spinal cord pass through the medulla.

Spinal Cord

The spinal cord is a slender, elongated structure consisting of an inner gray, cellular substance, which has a butterfly shape on the transverse section and an outer white, fibrous substance (Figs. 14.2 and 14.3). The cord extends from the brain, where it is connected to the medulla oblongata at the level of the foramen magnum, to the approximate level of the space between the first and second lumbar vertebrae. The spinal cord ends in a pointed extremity called the *conus medullaris* (see Fig. 14.3). The *filum terminale* is a delicate fibrous strand that extends from the terminal tip and attaches the cord to the upper coccygeal segment.

In an adult, the spinal cord is 18 to 20 inches (46 to 50 cm) long and is connected to 31 pairs of spinal nerves. Each pair of spinal nerves arises from two roots (dorsal and ventral) at the sides of the spinal cord. The nerves are transmitted through the intervertebral and sacral foramina. Spinal nerves below the termination of the spinal cord extend inferiorly through the vertebral canal. These nerves resemble a horse's tail and are referred to as the *cauda equina.* The spinal cord and nerves work together to transmit and receive sensory, motor, and reflex messages to and from the brain.

Meninges

The brain and spinal cord are enclosed in three continuous protective membranes called *meninges.* The inner sheath, called the *pia mater* (Latin, meaning "tender mother"), is highly vascular and closely adherent to the underlying brain and cord structure.

The delicate central sheath is called the *arachnoid.* This membrane is separated from the pia mater by a comparatively wide space called the *subarachnoid space,* which is widened in certain areas. These areas of increased width are called *subarachnoid cisterns.* The widest area is the cisterna magna (cisterna cerebellomedullaris). This triangular cavity is situated in the lower posterior fossa between the base of the cerebellum and the dorsal surface of the medulla oblongata. The subarachnoid space is continuous with the ventricular system of the brain and communicates with it through the foramina of the fourth ventricle. The ventricles of the brain and the subarachnoid space contain *cerebrospinal fluid* (CSF). CSF is the tissue fluid of the brain and spinal cord; it surrounds and cushions the structures of the CNS.

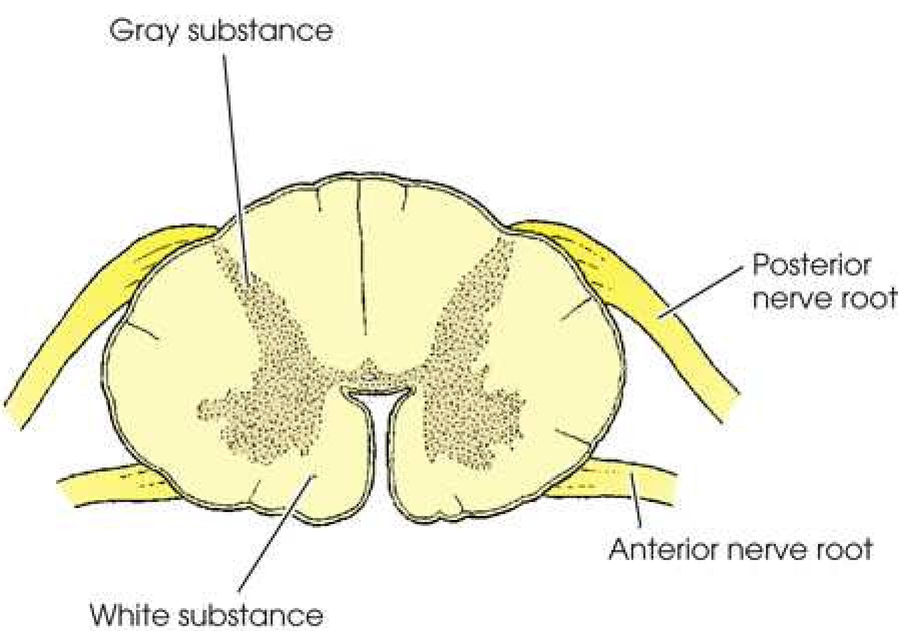

FIG. 14.2 Transverse section of spinal cord.

A transverse view of the spinal cord has a H shaped gray substance and a surrounding white substance. The posterior nerve root and the anterior nerve root rise from the top and the bottom portion respectively.

The outermost sheath, called the *dura mater* (Latin, meaning "tough mother"), forms the strong fibrous covering of the brain and spinal cord. The dura is separated from the arachnoid by the *subdural space* and from the vertebral periosteum by the *epidural space.* These spaces do not communicate with the ventricular system. The dura mater is composed of two layers throughout its cranial portion. The outer layer lines the cranial bones, serving as periosteum to their inner surface. The inner layer protects the brain and supports the blood vessels. The inner layer also has four partitions that provide support and protection for the various parts of the brain. One of these partitions, the *falx cerebri,* runs through the longitudinal fissure and provides support for the cerebral hemispheres. The *tentorium cerebelli* is a tent-shaped fold of dura that separates the cerebrum and cerebellum. Changes in the normal positions of these structures often indicate pathology. The dura mater extends below the spinal cord (to the level of the second sacral segment) to enclose the spinal nerves, which are prolonged inferiorly from the cord to their respective exits. The lower portion of the dura mater is called the *dural sac.* The dural sac encloses the cauda equina.

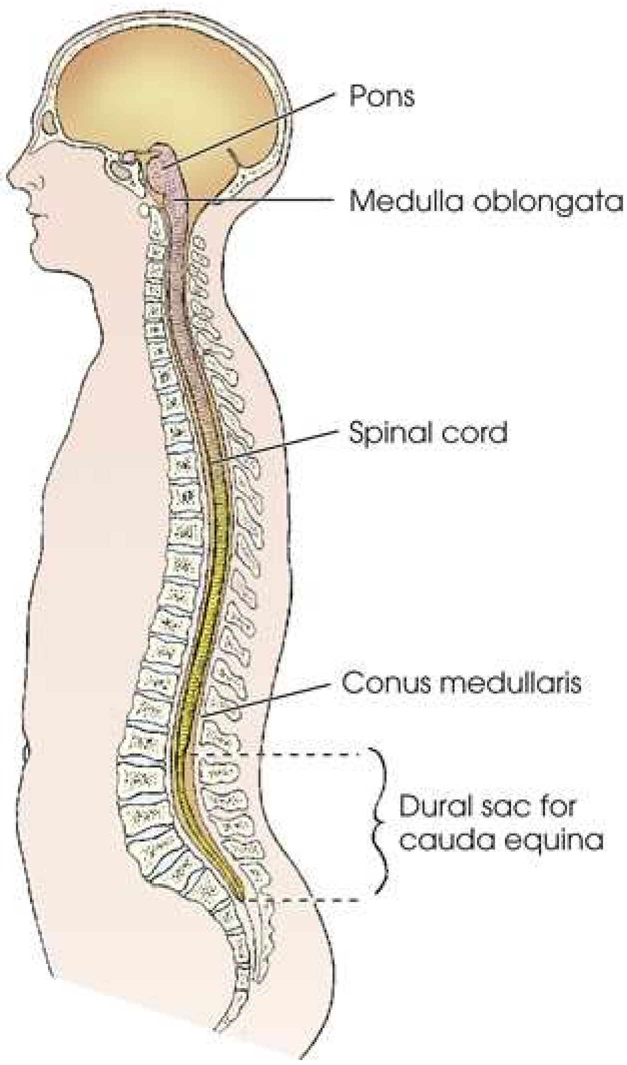

FIG. 14.3 Sagittal section showing spinal cord.

The lateral view of the head and upper body. The Pons lies at the base of the brain, followed by the medula oblongata. The spinal cord starts at the base of the brain and ends at the lumbar region. The Conus medullaris and Dural sac for cauda equina are at the end of the spinal cord.

Ventricular System

The ventricular system of the brain consists of four irregular, fluid-containing cavities that communicate with one another through connecting channels (Figs. 14.4 through 14.6). The two upper cavities are an identical pair and are called the *right* and *left lateral ventricles.* They are situated, one on each side of the midsagittal plane, in the inferior medial part of the corresponding hemisphere of the cerebrum.

Each lateral ventricle consists of a central portion called the *body* of the cavity. The body is prolonged anteriorly, posteriorly, and inferiorly into horn-like portions that give the ventricle an approximate U shape. The prolonged portions are known as the *anterior, posterior, or occipital,* and *inferior or temporal horns.* Each lateral ventricle is connected to the third ventricle by a channel called the *interventricular foramen*, or foramen of Monro, through which it communicates directly with the third ventricle and indirectly with the opposite lateral ventricle.

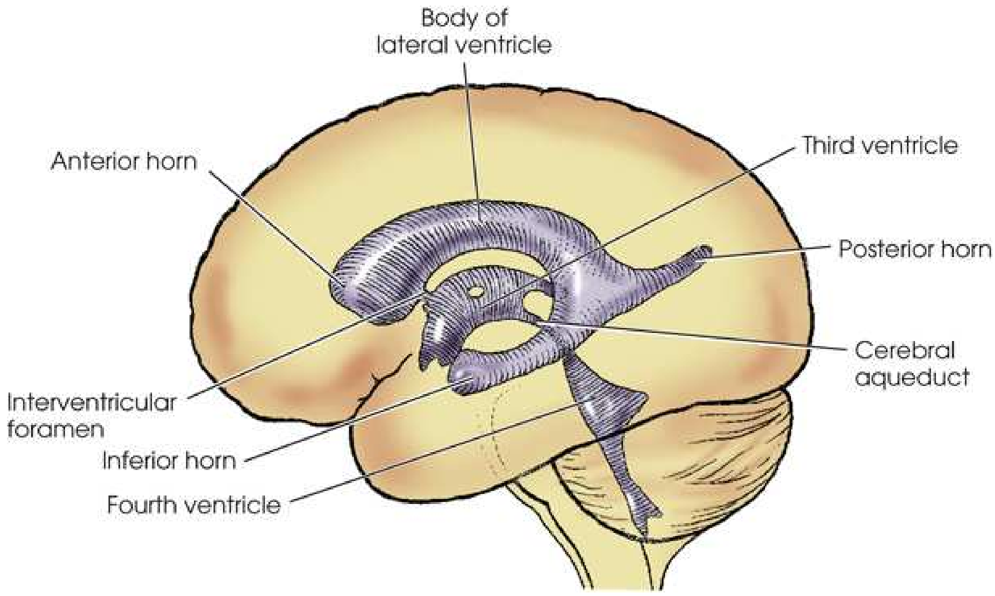

FIG. 14.4 Lateral aspect of cerebral ventricles in relation to surface of brain.

The lateral view of the cerebral ventricles of the brain. The lateral ventricle is a horn like U shaped structure at the center. It is extends into the anterior horn on the left and the posterior horn on the right. It is connected to a quadrilateral-shaped third ventricle through the intraventricular foramen. It is connected to the diamond-shaped fourth ventricle on the hind brain through the cerebral aqueduct.

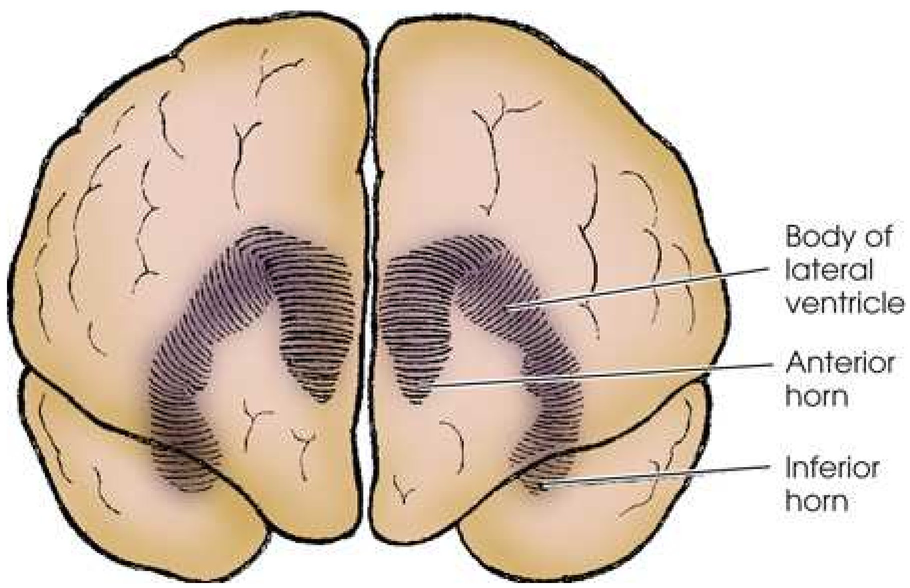

FIG. 14.5 Anterior aspect of lateral cerebral ventricles in relation to surface of brain.

The anterior view of the brain with the cerebrum ventricles. The ventricles are in the shape of m with the center between the two cerebral hemispheres. The lateral ventricle lies on the right hemisphere. The anterior horn is on the left end and the posterior horn is on the right end.

The *third ventricle* is a slit-like cavity with a quadrilateral shape. It is situated in the midsagittal plane just inferior to the level of the bodies of the lateral ventricles. This cavity extends anteroinferiorly from the pineal gland, which produces a recess in its posterior wall, to the optic chiasm, which produces a recess in its anteroinferior wall.

The interventricular foramina, one from each lateral ventricle, open into the anterosuperior portion of the third ventricle. The cavity is continuous posteroinferiorly with the fourth ventricle by a passage known as the *cerebral aqueduct,* or aqueduct of sylvius.

The *fourth ventricle* is diamond-shaped and located in the area of the hindbrain. The fourth ventricle is anterior to the cerebellum and posterior to the pons and the upper portion of the medulla oblongata. The distal, pointed end of the fourth ventricle is continuous with the central canal of the medulla oblongata. CSF exits the fourth ventricle into the subarachnoid space via the *median aperture* (foramen of Magendie) and the *lateral apertures* (foramen of Luschka). The central canal continues inferiorly to the conus medullaris and functions to carry CSF and nutrients throughout the spinal cord (Fig. 14.7).

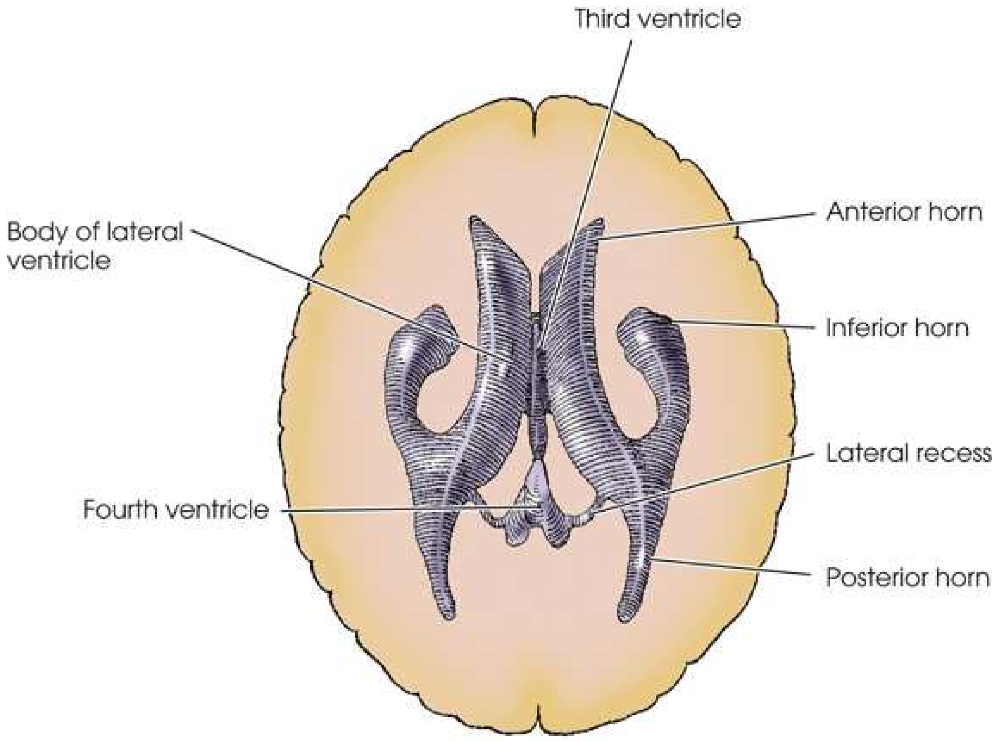

FIG. 14.6 Superior aspect of cerebral ventricles in relation to surface of brain.

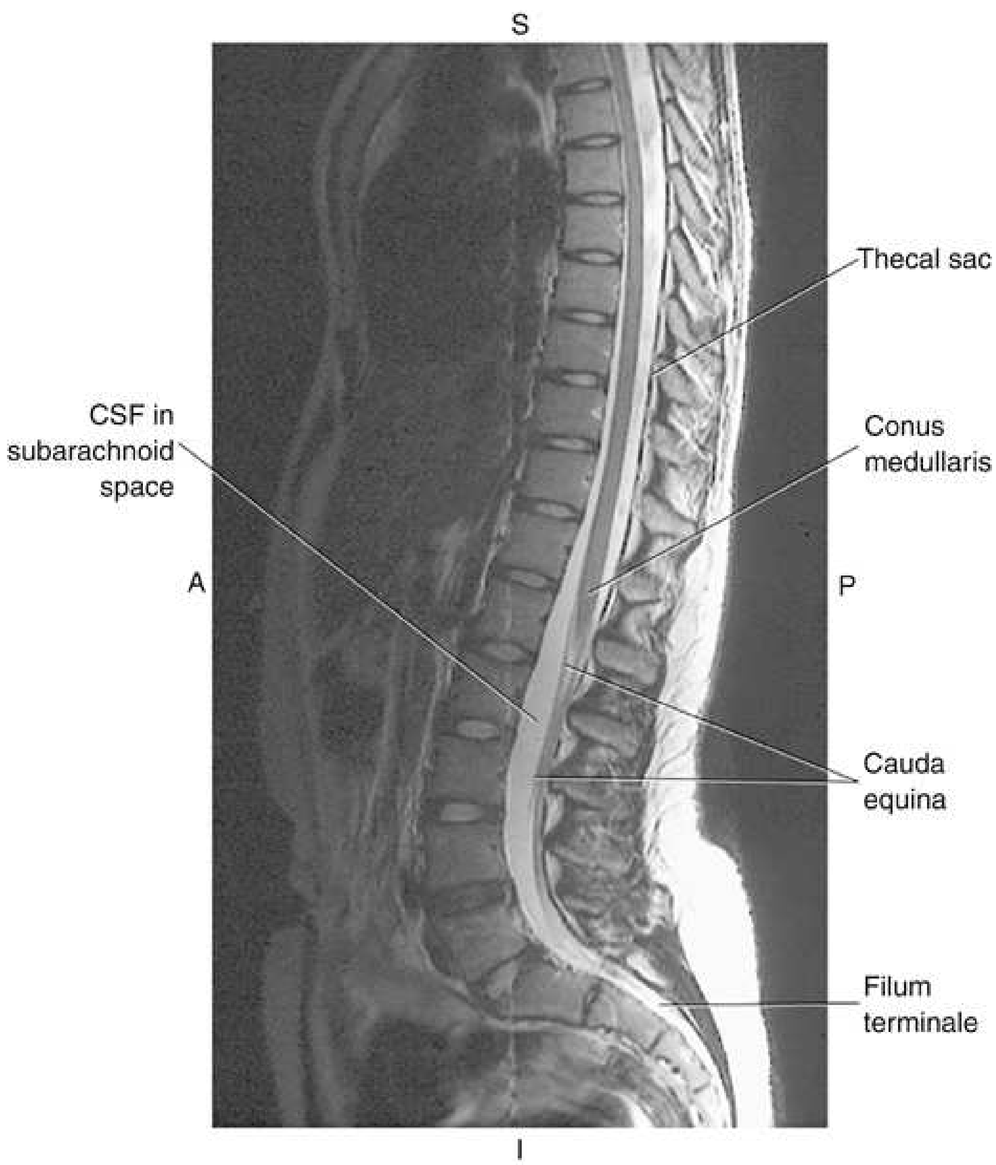

FIG. 14.7 Mid-sagittal T2-weighted magnetic resonance image demonstrating spinal cord within the vertebral canal, along with thecal sac and *cerebrospinal fluid (CSF)* flowing in the subarachnoid space.

Radiography

Plain Radiographic Examination

Neuroradiologic assessment should begin with noninvasive imaging procedures. Radiographs of the cerebral and visceral cranium and the vertebral column may be obtained to show bony anatomy. In traumatized patients (see Chapters 9 and 12), radiographs are obtained to detect bone injury, subluxation, or dislocation of the vertebral column and to determine the extent and stability of the bone injury. Computed tomography (CT) is often employed first in a trauma setting due to its speed and ability to demonstrate both soft tissue and bony anatomy (see Chapter 25).

For a traumatized patient with possible CNS involvement, a cross-table lateral cervical spine radiograph may be obtained to rule out fracture or misalignment of the cervical spine. Approximately two-thirds of significant pathologic conditions affecting the spine can be detected on this initial image. Care must be taken to image the entire cervical spine adequately, including the C7–T1 articulation. Employing the Swimmer's technique (see Chapter 9) may be necessary to show this anatomic region radiographically.

After the cross-table lateral radiograph has been checked and cleared by a physician or advanced practitioner, the following cervical spine projections should be obtained: AP, bilateral AP oblique (trauma technique may be necessary), and AP to show the dens. A vertebral arch, or pillar image, of the cervical spine may provide additional information about the posterior portions of the cervical vertebrae (see Chapter 9). An upright lateral cervical spine radiograph may also be requested to show alignment of the vertebrae better and to assess the normal lordotic curvature of the spine.

Radiographs of the spine should always be obtained before myelography. Routine images of the vertebral column are helpful in assessing narrowed disk spaces because of degeneration of the disk, osteoarthritis, postoperative changes in the spine, and other pathologies of the vertebral column. Because the contrast agents used in myelography may obscure some anomalies, noncontrast spinal images complement the myelographic examination and often provide additional information.

Routine skull images may be obtained when the possibility of a skull fracture exists. In trauma patients, a cross-table lateral or upright lateral skull radiograph may be obtained to show air-fluid levels in the sphenoid sinus. In many instances, these air-fluid levels may be the initial indication of a basilar skull fracture. A noncontrast head CT is indicated in head trauma patients who experience a loss of consciousness or other neurologic symptoms. In addition, skull images are helpful in diagnosing reactive bone formation and general alterations in the skull resulting from various pathologic conditions, including Paget disease, fibrous dysplasia, hemangiomas, and changes in the sella turcica.

Myelography

Myelography (Greek, *myelos*, "marrow; the spinal cord") is the general term applied to radiologic examination of the CNS structures situated within the vertebral canal. This examination is performed by introducing a nonionic, water-soluble contrast medium into the subarachnoid space by spinal puncture, most commonly at the L2–L3 or L3–L4 interspace or into the thecal sac via a lateral C1–C2 puncture. Injections into the subarachnoid space are termed *intrathecal injections*. A tilting table facilitates the positioning of the contrast medium to the desired region.

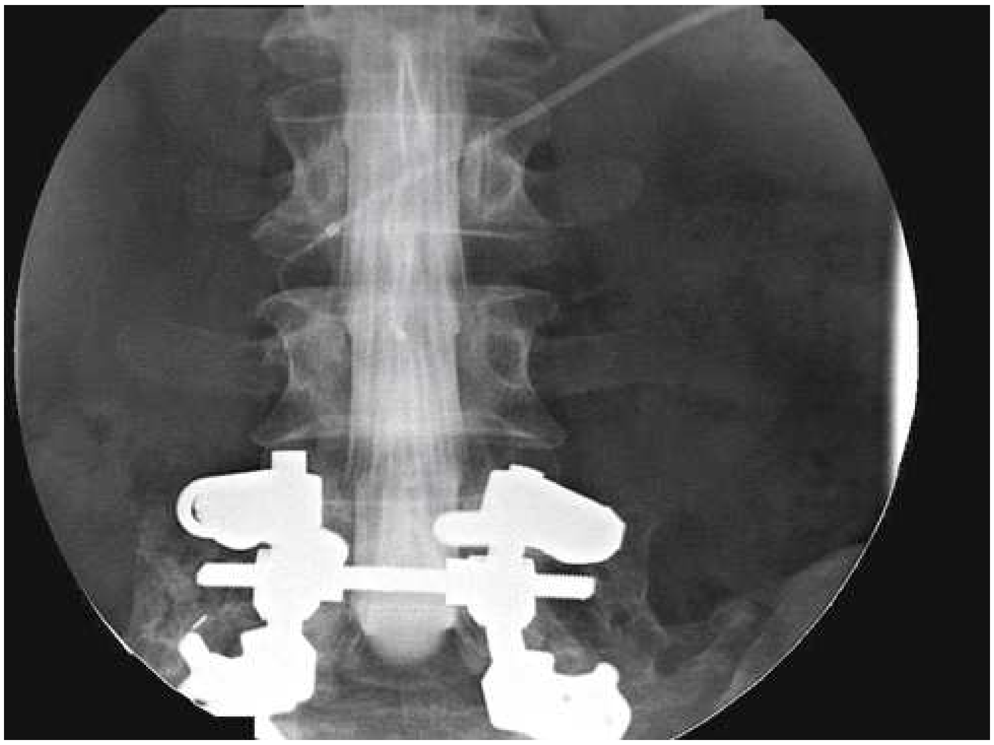

FIG. 14.8 Myelogram using nonionic water-soluble contrast medium (iopamidol) on a postsurgical patient.

Most myelograms are performed on an outpatient basis, with patients recovering for approximately 4 to 8 hours after the procedure before being released to return home. In many parts of the United States, magnetic resonance imaging (MRI) (see Chapter 26) has largely replaced myelography. Myelography continues to be the preferred examination method for assessing disk disease in patients with contraindications to MRI, such as pacemakers or metallic posterior spinal fusion rods.

Myelography is employed to show extrinsic spinal cord compression caused by a herniated disk, bone fragments, or tumors and spinal cord swelling resulting from traumatic injury. These encroachments appear radiographically as a deformity in the subarachnoid space or an obstruction of the passage of the column of contrast medium within the subarachnoid space. Myelography is also useful for identifying a narrowing of the subarachnoid space by evaluating the dynamic flow patterns of the CSF. Myelography may also demonstrate CSF leak and be used for surgical planning.

Contrast Media

A non–water-soluble iodinated ester (iophendylate [Pantopaque]) was introduced in 1942. Because the body could not absorb it, this lipid-based contrast medium required removal after the procedure. Frequently, some contrast remained in the canal and could be seen on non-contrast radiographs of patients who had the myelography procedure before the introduction of the newer medium. Iophendylate was used in myelography for many years but is no longer commercially available. The first water-soluble nonionic iodinated contrast agent, metrizamide, was introduced in the late 1970s. Thereafter, water-soluble contrast media quickly became the agents of choice. Nonionic water-soluble contrast media provides good visualization of nerve roots (Fig. 14.8) and allows for good enhancement for follow-up CT of the spine, often immediately following the radiographic myelogram. In addition, the body readily absorbs these agents. Over the past two decades, nonionic water-soluble agents, including iopamidol (Isovue) and iohexol (Omnipaque), have become the most commonly used agents for myelography. To reduce the chance of infection, single-dose vials are recommended. Improvements in nonionic contrast agents have resulted in fewer side effects.

Technologists who perform myelography should be educated regarding the use of contrast media. Intrathecal administration of ionic contrast media may cause severe and fatal neurotoxic reactions. Because vials of ionic and nonionic agents may look similar, radiology departments are encouraged to store contrast media for myelography separately from other agents. Proper medication guidelines must be followed when intrathecal agents are administered. Contrast vials should be checked three times and checked with the physician or advanced practitioner performing the examination. They should be kept until the procedure has been completed. All appropriate documentation must be completed.

Preparation of the Examining Room

One of the radiographer's responsibilities is to prepare the examination room before the patient's arrival. The radiographic equipment should be checked. Because the procedure involves aseptic technique, the table and overhead equipment must be cleaned. The footboard should be attached to the table, and the padded shoulder supports should be placed and ready for adjustment to the patient's height. The fluoroscopy tower should be locked so that it cannot accidentally come in contact with the spinal needle, sterile field, or both (Fig. 14.9).

The spinal puncture and injection of contrast medium are performed in the radiology department utilizing sterile technique. The Centers for Disease Control and Prevention (CDC) requires that surgical masks be worn when a catheter is being placed or material injected into the spinal canal or subdural space. Subcutaneous and intramuscular local anesthetic is administered. Under fluoroscopic observation, placement of the 20- to 25-gauge spinal needle in the subarachnoid space is verified and the nonionic iodinated contrast medium injected. The sterile tray and the nonsterile items required for this initial procedure should be ready for convenient placement.

FIG. 14.9 Patient set up with shoulder supports and fluoroscopy tower in locked position.

Examination Procedure

Premedication of the patient for myelography may be necessary, depending on the patient. The patient should be well hydrated, however, because a nonionic water-soluble contrast medium is used. To reduce apprehension and prevent alarm at unexpected maneuvers during the procedure, the radiographer should explain the details of myelography to the patient before the examination begins. The patient should be informed that the angulation of the examining table will change repeatedly and acutely. The patient should also be told why their head must be maintained in a fully extended position when the table is tilted to the Trendelenburg position. The radiographer must ensure that the patient will be safe when the table is acutely angled and that everything possible is being done to avoid causing unnecessary discomfort. Most facilities require an informed consent form to be completed and signed by the patient and physician. The risks and benefits of the procedure and of possible alternatives should be addressed.

Scout images, including a cross-table lateral lumbar spine prone (Fig. 14.10), are often requested. Some physicians/practitioners prefer to have the patient placed on the table in the prone position for the spinal puncture. Alternately, some physicians/practitioners have the patient adjusted in the lateral position, with the spine flexed to widen the interspinous spaces for easier introduction of the needle.

FIG. 14.10 Lateral scout projection of cross-table lumbar spine myelogram.

The physician/practitioner may withdraw CSF for laboratory analysis. Approximately 9 to 12 mL of nonionic contrast medium is slowly injected under intermittent imaging. After completing the injection, the physician removes the spinal needle. Travel of the column of contrast medium is observed and controlled fluoroscopically. Angulation of the table allows gravity to direct the contrast medium to the area of interest. Spot images are taken throughout the procedure. The radiographer obtains images at the level of any blockage or distortion in the outline of the contrast column. Conventional radiographic studies, with the central ray directed vertically or horizontally, may be performed as requested by the radiologist. The *conus projection* is used to show the *conus medullaris*. For this projection, the patient is placed in the AP position with the central ray centered to T12–L1. A 10 × 12-inch (24 × 30-cm) exposure field is used. Cross-table lateral radiographs are obtained using a crosswise image receptor with a grid and close collimation (Figs. 14.11 through 14.15).

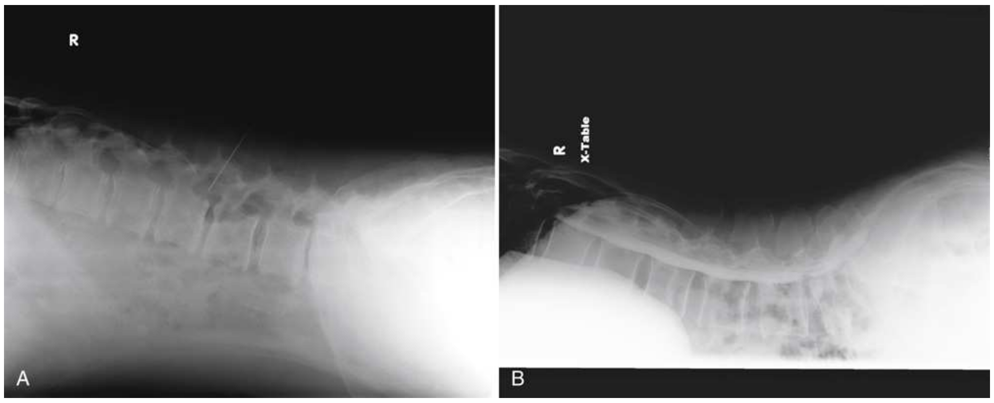

FIG. 14.11 (A) Lumbar myelogram. Cross-table lateral showing needle tip in the subarachnoid space. (B) Lumbar myelogram. Cross-table lateral showing contrast enhancement.

The position of the patient's head must be guarded as the contrast medium column nears the cervical area to prevent the medium from passing into the cerebral ventricles. Acute extension of the head compresses the cisterna magna and prevents further ascent of the contrast medium. Because the cisterna magna is situated posteriorly, neither forward nor lateral flexion of the head will compress the cisternal cavity. The technologist should employ proper radiation protection practices, including wearing lead gloves if support of the patient's head during fluoroscopy is deemed necessary.

After completion of the procedure, the patient must be monitored in an appropriate recovery area. Most physicians/practitioners recommend that the patient's head and shoulders be elevated 30 to 45 degrees during recovery. Bed rest for several hours is recommended, and fluids are encouraged. The puncture site must be examined before the patient is released from the recovery area. If the myelogram is performed on an outpatient basis, the patient should be instructed regarding limitations, including no driving, and warning signs of adverse reactions.

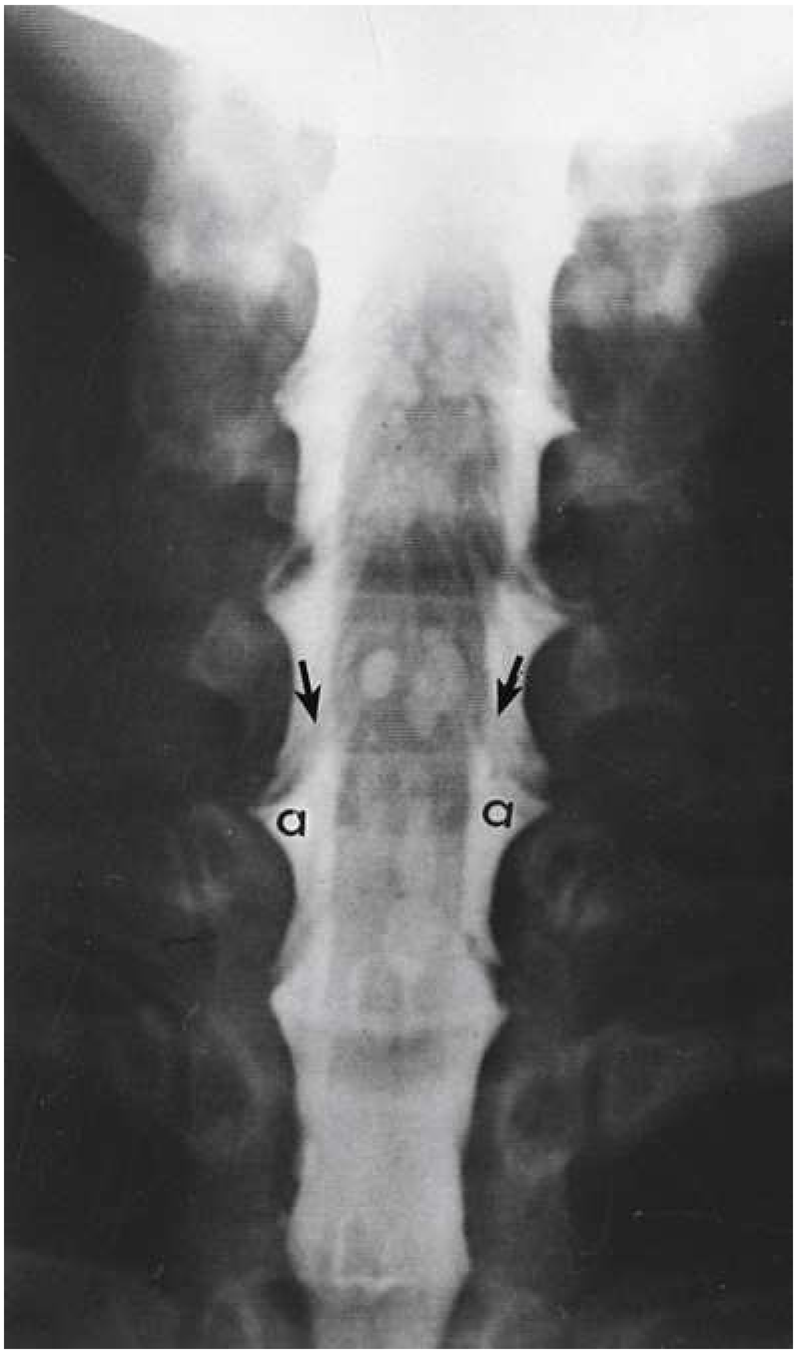

FIG. 14.12 Cervical myelogram. AP projection showing symmetric nerve roots *(arrows)* and axillary pouches *(a)* on both sides and spinal cord.

FIG. 14.13 Myelogram. Prone cross-table lateral projection showing dentate ligament and posterior nerve roots *(arrow)*.

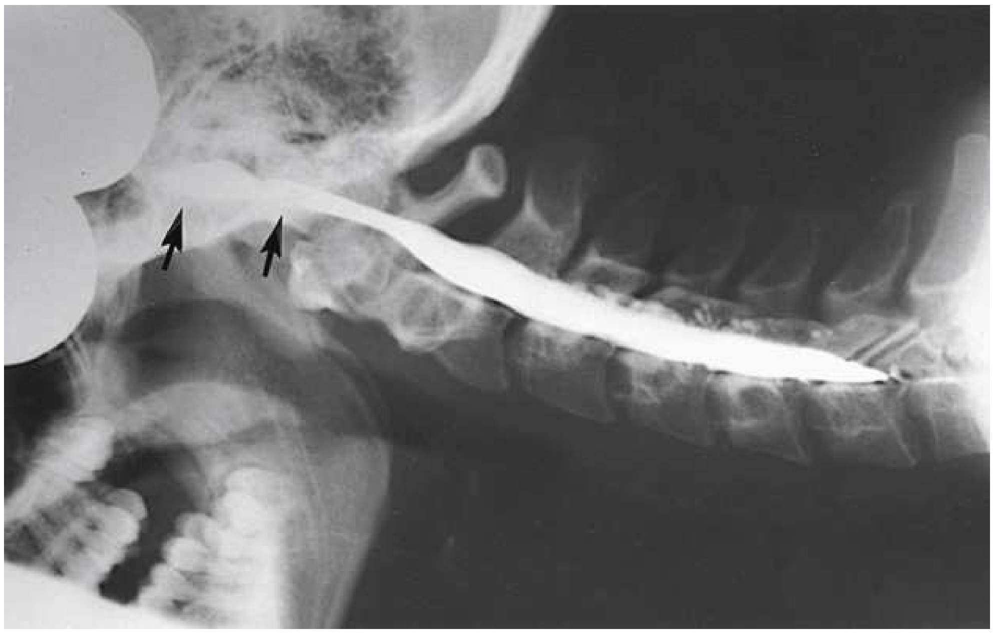

FIG. 14.14 Myelogram. Prone, cross-table lateral projection showing contrast medium passing through the foramen magnum and lying against the lower clivus *(arrows)*.

FIG. 14.15 Myelogram. Lateral projection showing narrowing of the subarachnoid space *(arrow)*.

Lumbar Puncture

For some diagnoses, a *lumbar puncture* is performed under fluoroscopic guidance. This procedure involves a similar setup to myelography, but without the contrast administration steps. In this procedure, the spinal needle is inserted, and CSF is withdrawn for laboratory analysis, or medication may be given intrathecally. Lumbar puncture exams may be performed for diagnostic means, such as in infections (meningitis), demyelinating diseases (multiple sclerosis), bleeding (subarachnoid hemorrhage), in situations when the pressure around the brain and spinal cord must be measured (increased intracranial pressure), and to inject medications. Alternately, lumbar punctures may be performed for treatment purposes, such as to relieve increased spinal pressure, to give anesthesia, or during a blood patch (CSF leak) (Fig. 14.16).

Vertebral Augmentation

Vertebral augmentation includes several percutaneous techniques aimed at stabilizing weakened vertebral bodies. Vertebroplasty, kyphoplasty, and mesh-container-plasty are interventional radiology procedures used to treat spinal osteoporotic compression fractures and other pathologies, such as bone weakened by neoplasia of the vertebral bodies that do not respond to conservative treatment. Vertebral compression fractures (VCFs) are common, especially in older patients with a history of osteoporosis. Estimates indicate that osteoporosis causes more than 700,000 vertebral fractures per year in the United States. About half of these fractures occur silently without any pain. Some fractures are extremely painful, however, and severely limit the patient's quality of life. The morbidity of symptomatic VCFs is significant, causing chronic pain, sleep loss, depression, and a loss of the ability to perform activities of daily living. Vertebral augmentation is used in cases of severe pain that does not improve over many weeks of conservative treatment.

Percutaneous vertebroplasty is defined as the injection of a radiopaque bone cement (e.g., polymethyl methacrylate) into a painful compression fracture under fluoroscopic guidance. This procedure is typically performed in the special procedures suite or the operating room with the patient sedated but awake. A specialized trocar needle is advanced into the fractured vertebral body under fluoroscopy (Fig. 14.17). Intraosseous venography using nonionic contrast media is performed to confirm needle placement. When the physician is satisfied with the needle placement, the cement is injected (Fig. 14.18). The cement stabilizes fracture fragments and leads to reduction in pain. Postprocedural imaging includes AP and lateral projections of the spine to confirm cement position (Fig. 14.19). A CT scan may also be performed.

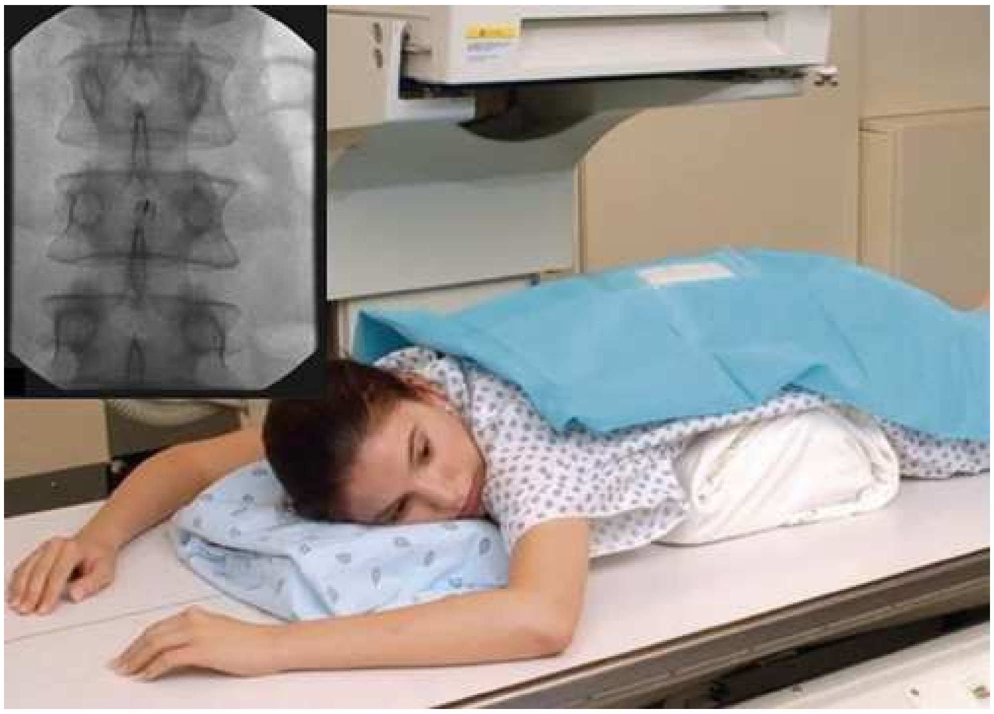

FIG. 14.16 Prone position for lumbar puncture and myelography. Fluoroscopic image demonstrating spinal needle localization.

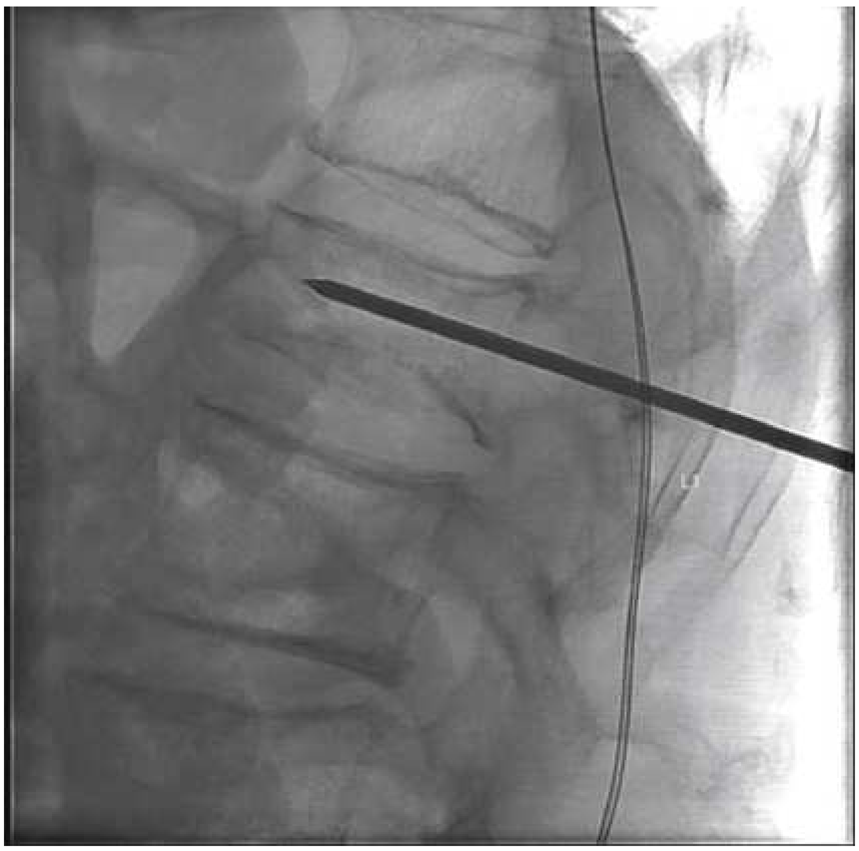

FIG. 14.17 Lateral projection of a compressed vertebral body with bone needle in place.

FIG. 14.18 Bone cement injected during vertebroplasty under image guidance.

Percutaneous kyphoplasty differs from vertebroplasty in that a balloon catheter is used to expand the compressed vertebral body to near its original height before injection of the bone cement. Inflation of the balloon creates a pocket for the placement of the cement. Kyphoplasty can help restore the spine to a more normal curvature and reduce hunchback deformities.

Percutaneous mesh-container-plasty utilizes a bone expansion brace to cut the bone tissues. After the brace is withdrawn, a mesh container is advanced into the cavity and the cement is injected into the container. This technique restores vertebral body height and strengthens bony trabeculae.

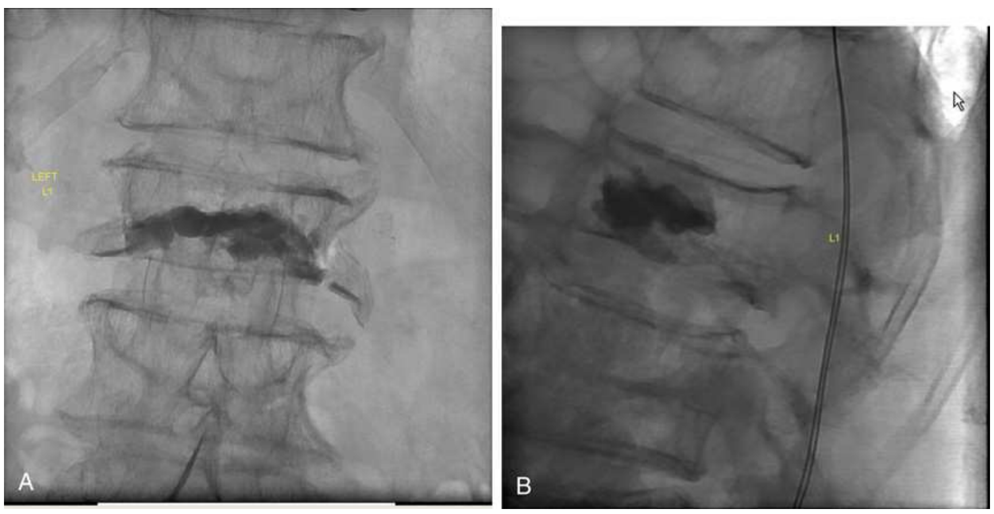

FIG. 14.19 (A) and (B) AP and lateral projections show bone cement in L1.

The success of these procedures is measured by significant reduction of pain, reduced disability, and improved quality of life reported by the patient. With proper patient selection and technique, success rates of 80% to 90% have been reported. Vertebral augmentation procedures have risks of serious complications, however. Major complications occur in less than 1% of patients treated for compression fractures. The most common complication is leakage of the cement before it hardens. Pulmonary embolism and death, although rare, have been reported. Patients should be encouraged to discuss risks, benefits, and alternatives with their physicians. Technologists who perform these procedures need to be properly educated and ensure that informed consent has been documented.

Other Neuroradiographic Procedures

Provocative Diskography

Diskography is a procedure performed under fluoroscopic guidance to determine whether the disc is the source of a patient's chronic back pain. The examination is performed with a small quantity of water-soluble nonionic iodinated medium injected into the center of the disk. Diskography is used in the investigation of internal disk lesions, such as rupture of the nucleus pulposus, which cannot be shown by other imaging procedures (Fig. 14.20). Patients are given only a local anesthetic so that they remain fully conscious and able to inform the physician about pain when the needles are inserted and the injection is made. Attempts are made to replicate the patient's chronic pain during the injection. CT is usually performed after diskography to look for clefts or tears. Spinal fusion is often recommended based on a positive provocation of pain. The need for this procedure should be carefully evaluated because there is controversy regarding the sensitivity and specificity of the examination. Some authors have suggested that diskography may increase the chance of later disk disruption. MRI and CT have largely replaced diskography.

Interventional Pain Management

Image-guided interventional pain management is becoming a common treatment for chronic back pain that does not respond to conservative treatment. Pretreatment assessment of the patient's pain and a thorough history are necessary. Fluoroscopy, CT, and ultrasonography are often used to confirm needle placement. Interventional pain management physicians perform a variety of injections using corticosteroids and local anesthetics to reduce inflammation and improve symptoms. Procedures can be performed at all levels of the spine and include facet injections, nerve root blocks, and epidural steroid injections. Various needle types can be used, but needles with a stylet are most common to prevent tissue from being trapped in the lumen. Size and tip configuration are determined by the physician. Patients are placed in the prone position (Fig. 14.21). A pillow placed under the pelvis may help with patient comfort. C-arm fluoroscopy is commonly used to determine needle placement. The C-arm may have to be rotated several times to identify the needle path. Images are taken to document the procedure, needle position, and contrast distribution. PA and lateral projections are needed to confirm needle depth. The tip of the needle and an identifiable bony landmark must be included in the images. The precise nature of the injections is thought to improve patient outcomes compared with blind injections. The success of the treatment is based on the patient's self-report of pain reduction.

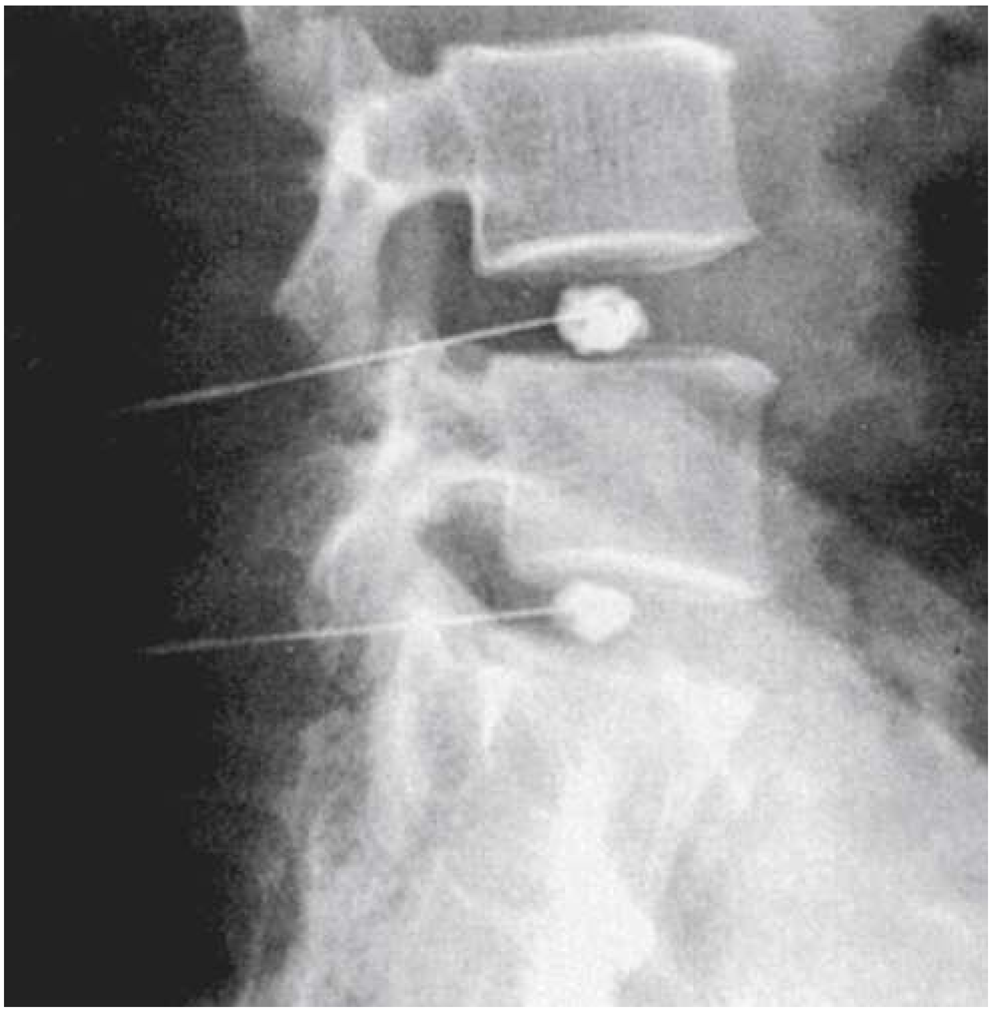

FIG. 14.20 Lumbar diskogram showing normal nucleus pulposus of round contour type.

FIG. 14.21 Patient set up with C-arm for pain management injection.

Definition of Terms

arachnoid: Thin delicate membrane surrounding the brain and spinal cord.
brain: Portion of the CNS contained within the cranium.
cauda equina: Collection of nerves located in the spinal canal inferior to the spinal cord.
cerebellum: Part of the brain located in the posterior cranial fossa behind the brain stem.
cerebral aqueduct: Opening between the third and fourth ventricles.
cerebrum: Largest uppermost portion of the brain.
conus medullaris: Most inferior portion of the spinal cord.
cortex: Outer surface layer of the brain.
CSF: Cerebrospinal fluid—the fluid that flows through and protects the ventricles, subarachnoid space, brain, and spinal cord.
dura mater: Tough outer layer of the meninges, which lines the cranial cavity and spinal canal.
epidural space: Outside or above the dura mater.
falx cerebri: Fold of dura mater that separates the cerebral hemispheres.
filum terminale: Threadlike structure that extends from the distal end of the spinal cord.
hindbrain: Portion of the brain within the posterior fossa; it includes the pons, medulla oblongata, and cerebellum.
intrathecal injection: Injection into the subarachnoid space of the spinal canal.
kyphoplasty: Interventional radiology procedure used to treat vertebral body compression fractures using a specialized balloon and bone cement.
lumbar puncture: Procedure involving the insertion of a spinal needle into the subdural space to remove CSF for laboratory analysis, relieve pressure, or to inject medication (also known as spinal tap).
pons: Oval-shaped area of the brain anterior to the medulla oblongata.
spinal cord: Extension of the medulla oblongata that runs through the spinal canal to the upper lumbar vertebrae.
tentorium cerebelli: Layer of dura that separates the cerebrum and cerebellum.
vermis: Wormlike structure that connects the two cerebellar hemispheres.
vertebroplasty: Interventional radiology procedure used to treat vertebral body compression fractures by stabilizing bone fragments with cement.

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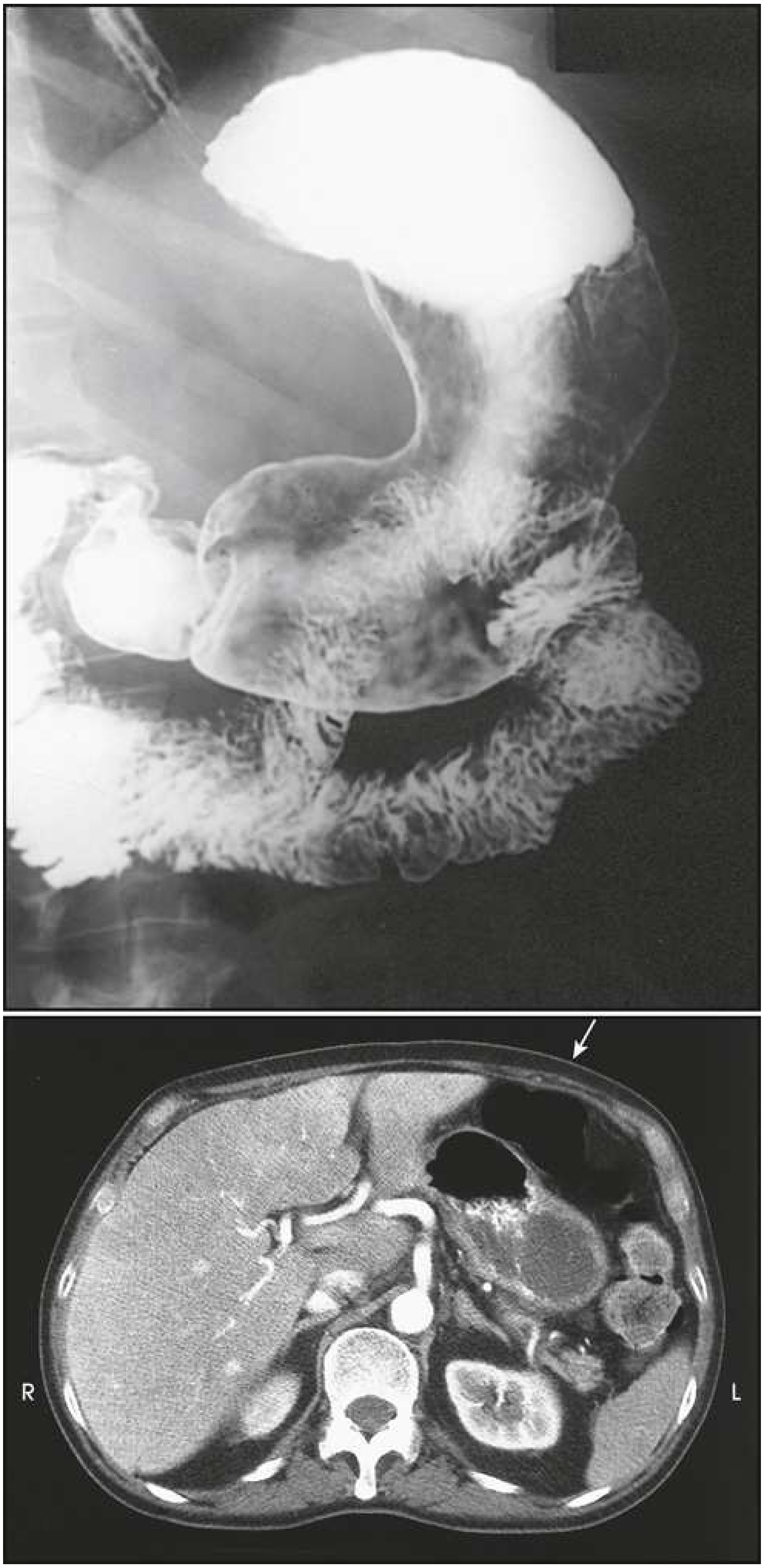
[a] Many italicized words are defined at the end of the chapter.

15: Digestive System



Salivary Glands, Alimentary Canal, And Biliary System

OUTLINE

Summary of Projections

PROJECTIONS, POSITIONS, AND METHODS					
Page	**Essential**	**Anatomy**	**Projection**	**Position**	**Method**
201		Parotid gland	Tangential		
203		Parotid and submandibular glands	Lateral	R or L	
207		Soft palate, pharynx, larynx, and cervical esophagus	Lateral	Upright/seated R or L	
208		Soft palate, pharynx, larynx, and cervical esophagus	AP	Upright/seated	
218		Esophagus	AP or PA		
218		Esophagus	AP or PA oblique	RAO or LPO	
218		Esophagus	Lateral	R or L	
223		Stomach and duodenum	PA		
225		Stomach and duodenum	PA axial		
226		Stomach and duodenum	PA oblique	RAO	
228		Stomach and duodenum	AP oblique	LPO	
230		Stomach and duodenum	Lateral	R only	
232		Stomach and duodenum	AP		
234		Superior stomach and distal esophagus	PA oblique	RAO	WOLF
237		Small intestine	PA or AP		
250		Large intestine	PA		
251		Large intestine	PA axial		
253		Large intestine	PA oblique	RAO	
254		Large intestine	PA oblique	LAO	
255		Large intestine	Lateral	R or L	
256		Large intestine	AP		
257		Large intestine	AP axial		
258		Large intestine	AP oblique	LPO	
259		Large intestine	AP oblique	RPO	
261		Large intestine	AP or PA	R lateral decubitus	
263		Large intestine	PA or AP	L lateral decubitus	
265		Large intestine	Lateral	R or L ventral decubitus	
266		Large intestine	AP, PA, oblique, lateral	Upright	
272		Percutaneous transhepatic cholangiography	AP/AP oblique	Supine/RPO	
274		Postoperative (T-tube) cholangiography	AP/AP oblique	Supine/RPO	
276		Endoscopic retrograde cholangiopancreatography	AP/AP oblique	Supine/RPO	

Icons in the Essential column indicate projections frequently performed in the United States and Canada. Students should be competent in these projections.

AP, Anteroposterior; *L,* left; *LAO,* left anterior oblique; *LPO,* left posterior oblique; *PA,* posteroanterior; *R,* right; *RAO,* right anterior oblique; *RPO,* right posterior oblique.

Anatomy

Digestive System

The *digestive system* consists of two parts: the *accessory glands* and the *alimentary canal*. The accessory glands, which include the *salivary glands, liver, gallbladder,* and *pancreas,* secrete digestive enzymes into the alimentary canal. The alimentary canal is a musculomembranous tube that extends from the mouth to the anus. The regions of the alimentary canal vary in diameter according to functional requirements. The greater part of the canal, which is about 29 to 30 ft (8.6 to 8.9 m) long, lies in the abdominal cavity. The component parts of the alimentary canal (Fig. 15.1) are the *mouth,* in which food is masticated and converted into a bolus by insalivation; the *pharynx* and *esophagus,* which are the organs of swallowing; the *stomach,* in which the digestive process begins; the *small intestine,* in which the digestive process is completed; and the *large intestine,* which is an organ of egestion and water absorption that terminates at the *anus.*

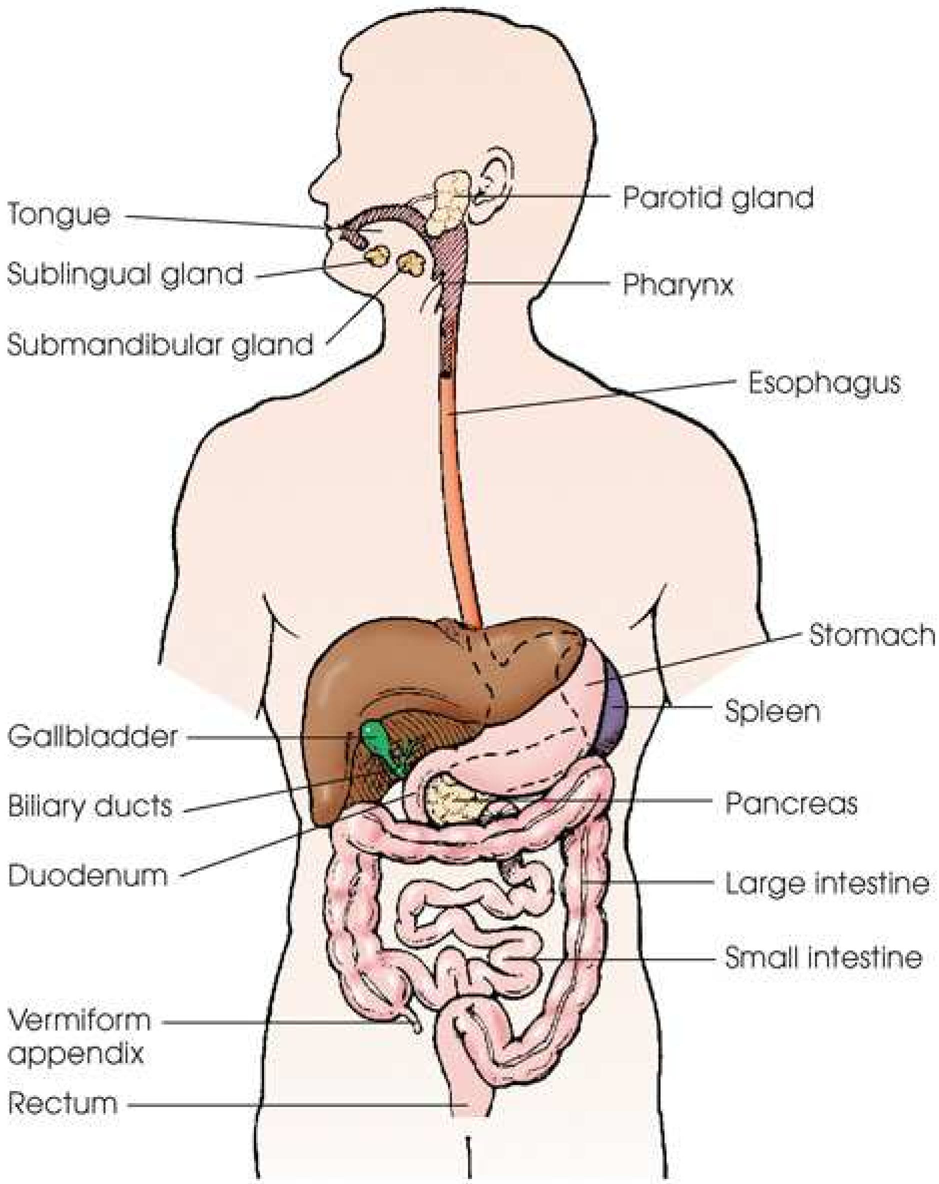


FIG. 15.1 Alimentary canal and accessory organs, with liver lifted to show gallbladder.

The alimentary canal of a human body with the organs labeled starting from top to bottom. The Tongue, Sublingual gland, Submandibular gland, Gallbladder, Biliary ducts, Duodenum, Vermiform appendix and Rectum are labeled on the left. The Parotid gland, Pharynx, Esophagus, Stomach, Spleen, Pancreas, Large intestine, and small intestine are labeled on the right.

Mouth

The *mouth,* or *oral cavity,* is the first division of the digestive system (Fig. 15.2). It encloses the dental arches and receives the saliva secreted by the salivary glands. The cavity of the mouth is divided into (1) the *oral vestibule,* the space between the teeth and the cheeks, and (2) the *oral cavity,* or mouth proper, the space within the dental arches. The roof of the oral cavity is formed by the hard and soft palates. The floor is formed principally by the tongue, and it communicates with the pharynx posteriorly via the *oropharynx*.

The *hard palate* is the anteriormost portion of the roof of the oral cavity. The hard palate is formed by the horizontal plates of the maxillae and palatine bones. The anterior and lateral boundaries are formed by the inner wall of the maxillary alveolar processes, which extend superiorly and medially to blend with the horizontal processes. The height of the hard palate varies considerably, and it determines the angulation of the inner surface of the alveolar process. The angle is less when the palate is high and is greater when the palate is low.

The *soft palate* begins behind the last molar and is suspended from the posterior border of the hard palate. Highly sensitive to touch, the soft palate is a movable musculomembranous structure that functions chiefly as a partial septum between the mouth and the pharynx. At the center of the inferior border, the soft palate is prolonged into a small, pendulous process called the *uvula*. On each side of the uvula, two arched folds extend laterally and inferiorly. The *anterior arches* project forward to the sides of the base of the tongue. The *posterior arches* project posteriorly to blend with the posterolateral walls of the pharynx. The triangular space between the anterior and posterior arches is occupied by the palatine *tonsil*.

The *tongue* is situated in the floor of the oral cavity, with its base directed posteriorly and its *apex* directed anteriorly (Fig. 15.3; see Fig. 15.2). The tongue is freely movable. The tongue is composed of numerous muscles and is covered with a mucous membrane that varies in complexity in the different regions of the organ. The extrinsic muscles of the tongue form the greater part of the oral floor. The mucous membrane covering the undersurface of the tongue is reflected laterally over the remainder of the floor to the gums. This part of the floor lies under the free anterior and lateral portions of the tongue and is called the *sublingual space*. Posterior movement of the free anterior part of the tongue is restricted by a median vertical band, or fold, of mucous membrane called the *frenulum of the tongue,* which extends between the undersurface of the tongue and the sublingual space. On each side of the frenulum, extending around the outer limits of the sublingual space and over the underlying salivary glands, the mucous membrane is elevated into a crest-like ridge called the *sublingual fold.* In the relaxed state, the two folds are quite prominent and are in contact with the gums.

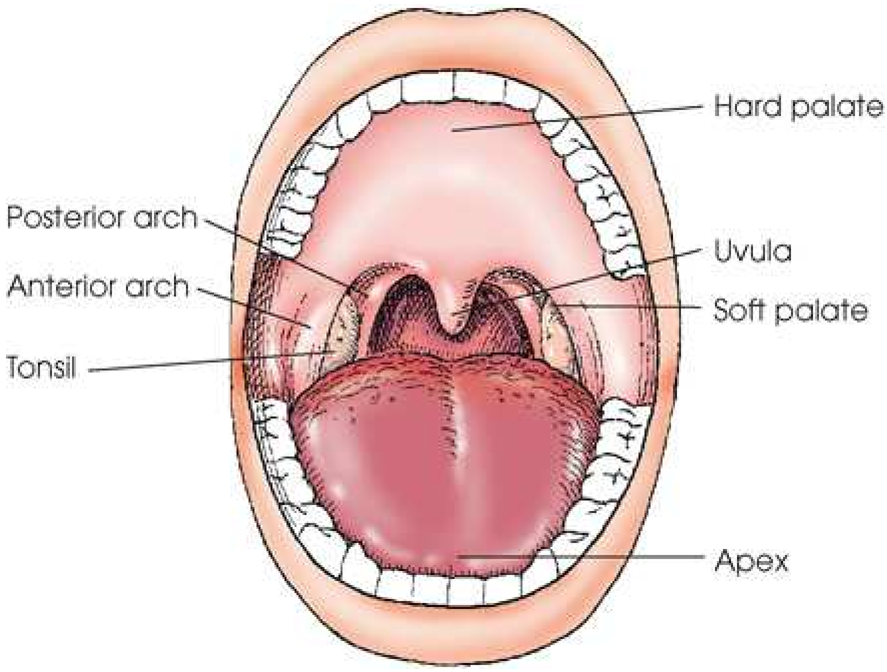


FIG. 15.2 Anterior view of oral cavity.

The *teeth* serve the function of *mastication,* the process of chewing and grinding food into small pieces. During mastication, the teeth cut, grind, and tear food, which is then mixed with saliva and swallowed, and later digested. The saliva softens the food, keeps the mouth moist, and contributes digestive enzymes.

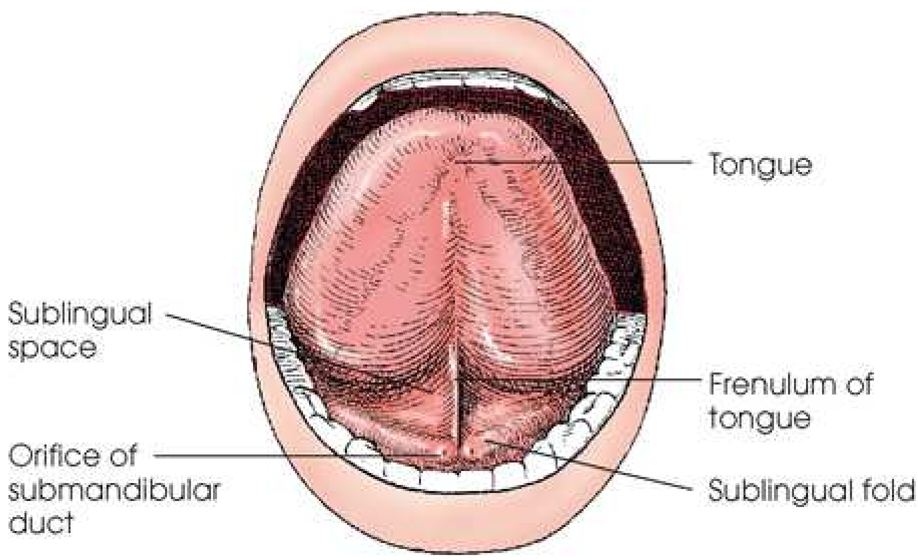


FIG. 15.3 Anterior view of undersurface of tongue and floor of mouth.

The anterior view of the undersurfaces of the oral cavity showing the teeth on lower jaw and tongue. The Sublingual space, Orifice of submandibular duct, tongue, Frenulum of tongue, and Sublingual fold are labeled.

Salivary Glands

The three pairs of salivary glands produce approximately 1 L of saliva each day. The glands are named the *parotid, submandibular,* and *sublingual* (Fig. 15.4). Each gland is composed of numerous lobes, and each lobe contains small lobules. The whole gland is held together by connective tissue and a fine network of blood vessels and ducts. The minute ducts of the lobules merge into larger tributaries, which unite and form the large efferent duct that conveys the saliva from the gland to the mouth.

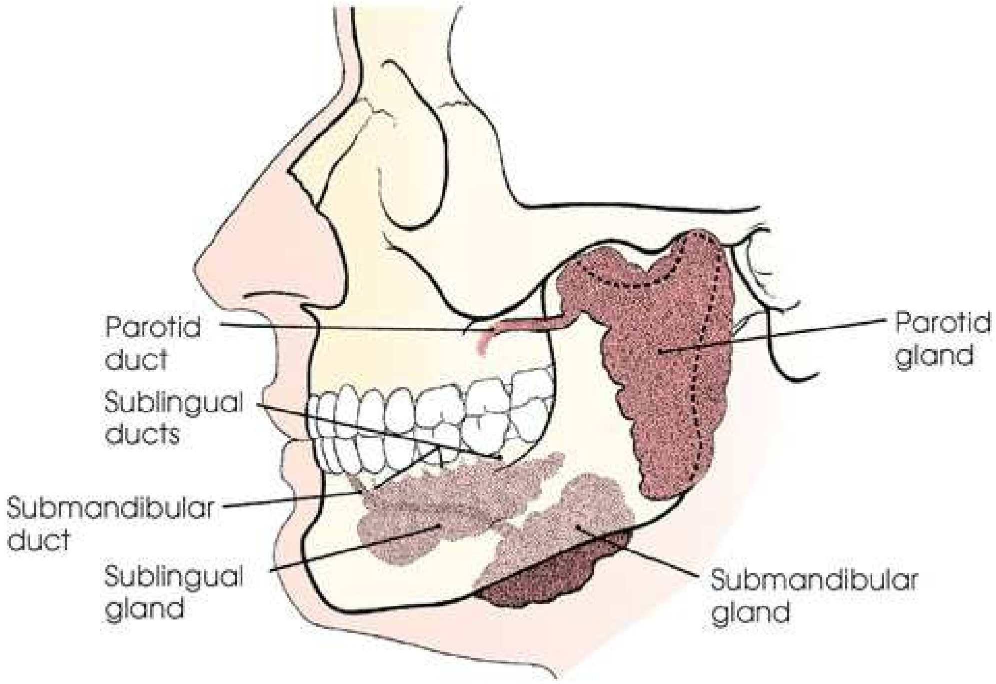


FIG. 15.4 Salivary glands from left lateral aspect.

The lateral view of the face with the teeth, both jaws and parts of salivary gland visible. The Parotid duct, Sublingual ducts, Submandibular duct, Parotid gland, Submandibular gland, and Sublingualgland are labeled.

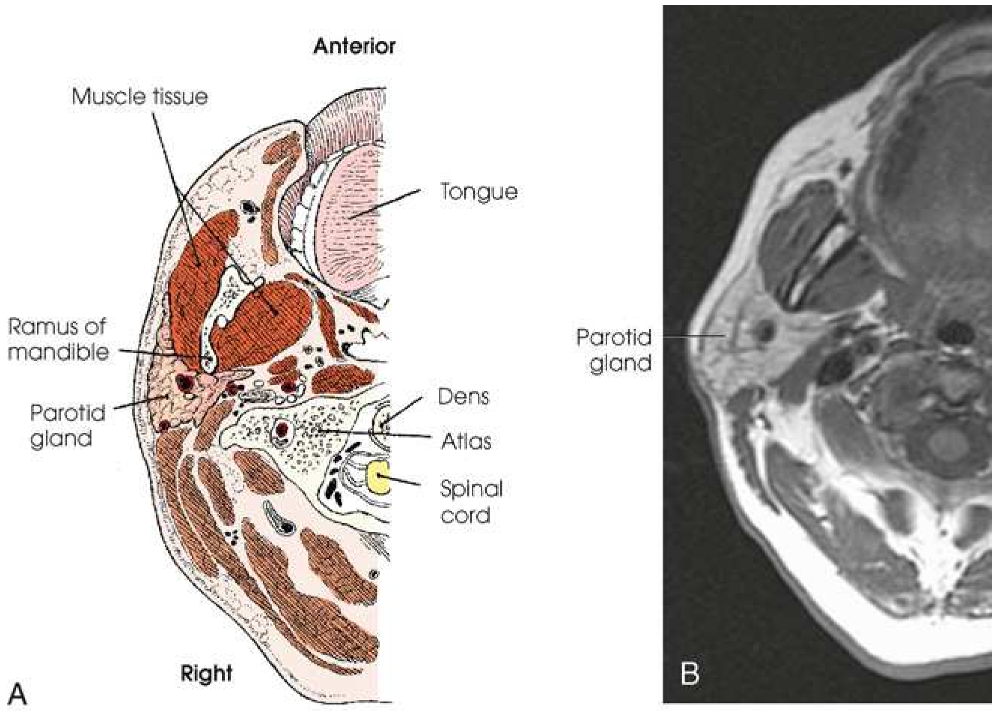


FIG. 15.5 (A) Horizontal section of face, showing relationship of parotid gland to mandibular ramus. Auricle is not shown. (B) Axial MRI of parotid gland. B, Courtesy J. Louis Rankin, BS, RT[R][MR].

A Horizontal section of face (A) and the axial M R I of parotid gland (B). A shows the relationship of parotid gland to mandibular ramus. The Muscle tissue, Ramus of mandible, and Parotid gland are labeled on the left. The Tongue, Dens, Atlas, and Spinal cord are labeled on the right.

Each of the *parotid glands,* the largest of the salivary glands, consists of a flattened superficial portion and a wedge-shaped deep portion (Fig. 15.5). The superficial part lies immediately anterior to the external ear and extends inferiorly to the mandibular ramus and posteriorly to the mastoid process. The deep, or retromandibular, portion extends medially toward the pharynx. The *parotid duct* runs anteriorly and medially to open into the oral vestibule opposite the second upper molar.

The *submandibular glands* are large, irregularly shaped glands. On each side, a submandibular gland extends posteriorly from a point below the first molar almost to the angle of the mandible (Fig. 15.6). Although the upper part of the gland rests against the inner surface of the mandibular body, its greater portion projects below the mandible. The *submandibular duct* extends anteriorly and superiorly to open into the mouth on a small papilla at the side of the frenulum of the tongue.

The *sublingual glands,* the smallest pair, are narrow and elongated in form (see Fig. 15.6). These glands are located in the floor of the mouth beneath the sublingual fold. Each is in contact with the mandible laterally and extends posteriorly from the side of the frenulum of the tongue to the submandibular gland. Numerous small *sublingual ducts* exist. Some of these ducts open into the floor of the mouth along the crest of the sublingual fold, and others open into the submandibular duct. The main sublingual duct opens beside the orifice of the submandibular duct.

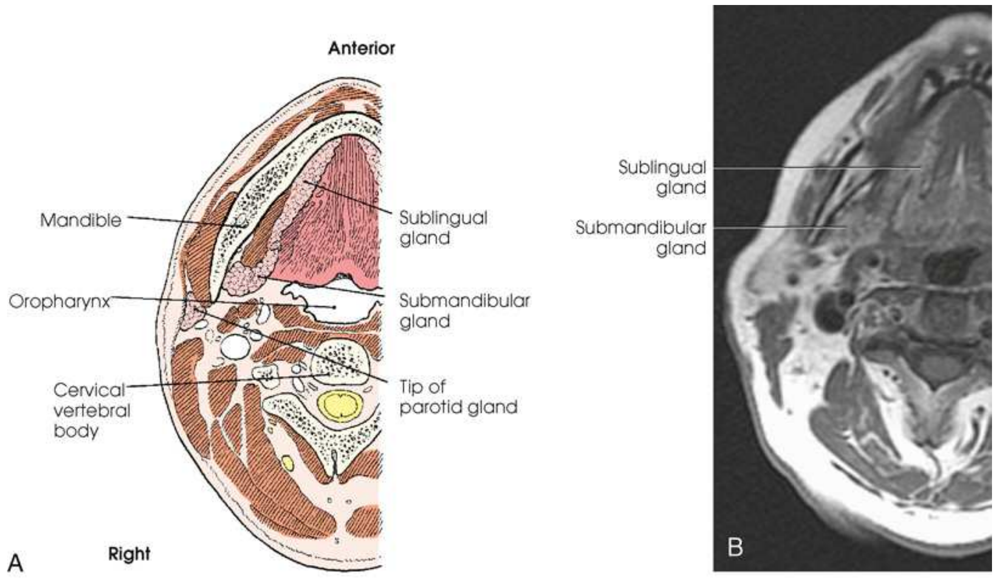


FIG. 15.6 (A) Horizontal section of face, showing relationship of submandibular and sublingual glands to surrounding structures. Auricle is not shown. (B) Axial MRI of submandibular and sublingual glands. B, Courtesy J. Louis Rankin, BS, RT[R][MR].

A horizontal section of face (A) and the axial M R I of parotid gland (B). A shows the relationship of submandibular and sublingual glands to surrounding structures. The Mandible, Oropharynx, Cervical, vertebral body, Sublingual gland, Submandibular gland, Tip of parotid gland are labeled. The Sublingual gland and Submandibular gland are labeled.

Pharynx

The *pharynx* serves as a passage for air and food and is common to the respiratory and digestive systems (Figs. 15.7 and 15.8). The pharynx is a musculomembranous, tubular structure situated in front of the vertebrae and behind the nose, mouth, and larynx. Approximately 5 inches (13 cm) in length, the pharynx extends from the undersurface of the body of the sphenoid bone and the basilar part of the occipital bone inferiorly to the level of the disk between the sixth and seventh cervical vertebrae, where it becomes continuous with the esophagus. The pharyngeal cavity is subdivided into nasal, oral, and laryngeal portions.

The *nasopharynx* lies posteriorly above the *soft* and *hard* palates. (The upper part of the hard palate forms the floor of the nasopharynx.) Anteriorly, the nasopharynx communicates with the posterior apertures of the nose. Hanging from the posterior aspect of the soft palate is a small conical process, the *uvula*. On the roof and posterior wall of the nasopharynx, between the orifices of the auditory tubes, the mucosa contains a mass of lymphoid tissue known as the *pharyngeal tonsil* (or *adenoids* when enlarged). Hypertrophy of this tissue interferes with nasal breathing and is common in children. This condition is well shown in a lateral radiographic image of the nasopharynx.

The *oropharynx* is the portion extending from the soft palate to the level of the *hyoid bone*. The base, or root, of the tongue forms the anterior wall of the oropharynx. The *laryngeal pharynx* lies posterior to the larynx, its anterior wall being formed by the posterior surface of the larynx. The laryngeal pharynx extends inferiorly and is continuous with the esophagus.

The air-containing nasal and oral pharynges are well visualized in lateral images except during the act of phonation, when the soft palate contracts and tends to obscure the nasal pharynx. An opaque medium is required to show the lumen of the laryngeal pharynx, although it can be distended with air during the *Valsalva maneuver* (an increase in intrathoracic pressure produced by forcible expiration effort against the closed glottis).

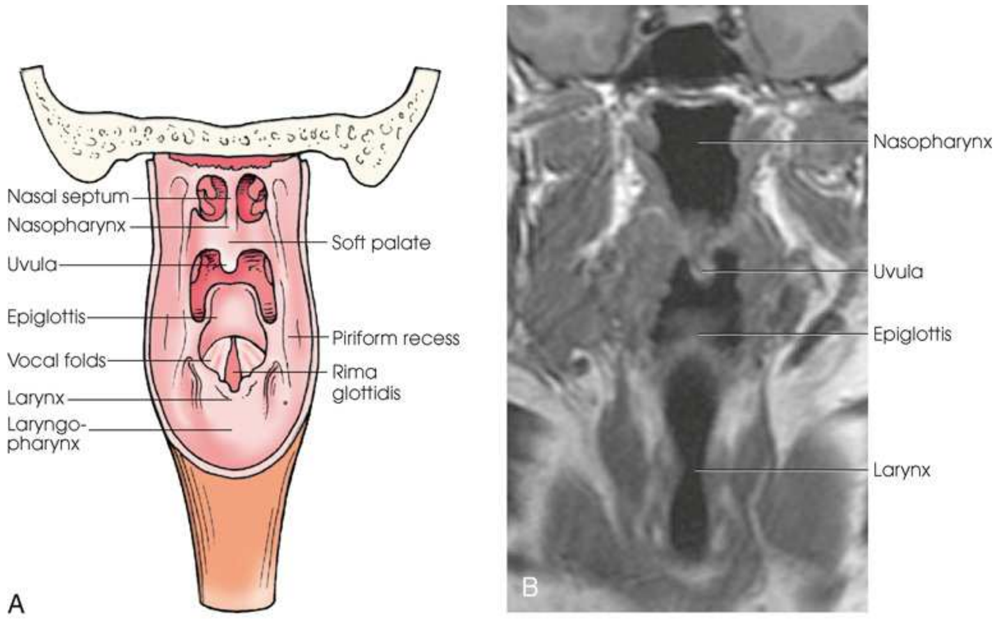


FIG. 15.7 (A) Interior posterior view of neck. (B) Coronal MRI of neck. B, Courtesy J. Louis Rankin, BS, RT[R][MR].

The illustration of interior posterior view of neck (A) and a coronal M R I of the neck (B). The Nasal septum, Nasopharynx, Uvula, Epiglottis, Vocal folds, Larynx, Soft palate, Piriform recess, Rima glottidis and Laryngopharynx are labeled in the illustration. The Nasopharynx, Uvula, Epiglottis, and Larynx are visible in the M R I scan.

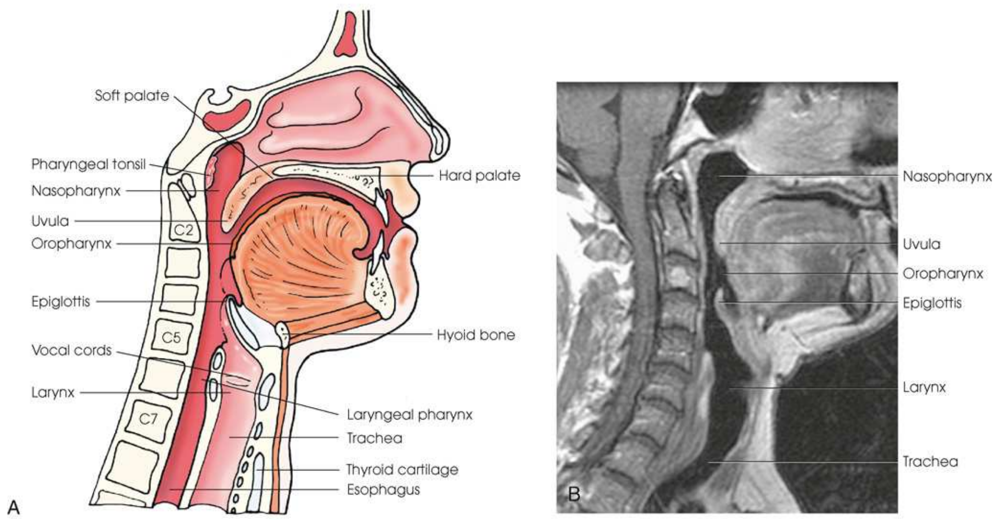


FIG. 15.8 (A) Sagittal section of face and neck. (B) Sagittal MRI of neck. B, Courtesy J. Louis Rankin, BS, RT[R][MR].

A sagittal view of the face (A) and neck and the M R I scan of the neck in sagittal view (B). The Soft palate, Pharyngeal tonsil, Nasopharynx, Uvula, Oropharynx, Epiglottis, Vocal cords, and Larynx, Hard palate, trachea, Hyoid bone Laryngeal pharynx, Thyroid cartilage and Esophagus are labeled in the sagittal view. The Nasopharynx, Uvula, Oropharynx, Epiglottis, Larynx, and Trachea are visible in the M R I scan.

Larynx

The larynx is the organ of voice (Figs. 15.9 and 15.10; see Figs. 15.7 through 15.10). Serving as the air passage between the pharynx and the trachea, the larynx is also one of the divisions of the respiratory system.

The larynx is a movable, tubular structure; is broader above than below; and is approximately 1½ inches (3.8 cm) in length. Situated below the root of the tongue and in front of the laryngeal pharynx, the larynx is suspended from the hyoid bone and extends from the level of the superior margin of the fourth cervical vertebra to its junction with the trachea at the level of the inferior margin of the sixth cervical vertebra. The thin, leaf-shaped *epiglottis* is situated behind the root of the tongue and the hyoid bone and above the laryngeal entrance. It has been stated that the epiglottis serves as a trap to prevent leakage into the larynx between acts of swallowing. The *thyroid cartilage* forms the laryngeal prominence, or *Adam's apple*.

The inlet of the larynx is oblique, slanting posteriorly as it descends. A pouch-like fossa called the *piriform recess* is located on each side of the larynx and external to its orifice. The piriform recesses are well shown as triangular areas on frontal projections when insufflated with air (Valsalva maneuver) or when filled with an opaque medium.

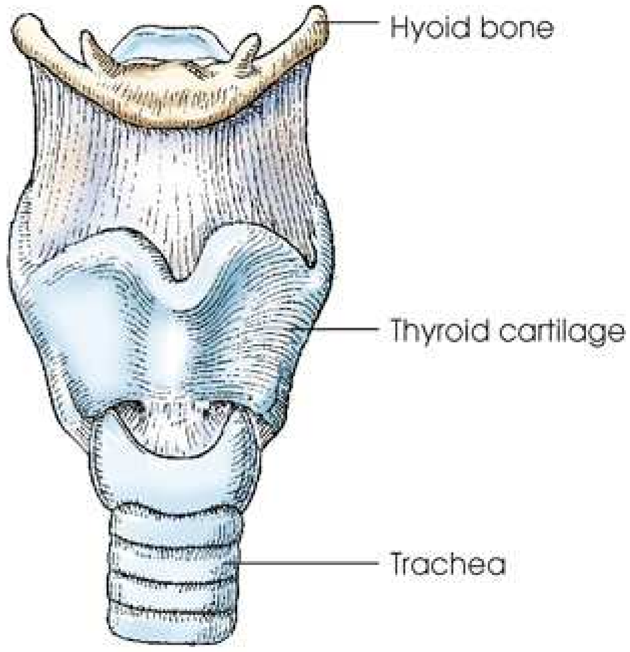


FIG. 15.9 Anterior aspect of larynx.

The entrance of the larynx is guarded superiorly and anteriorly by the epiglottis and laterally and posteriorly by folds of mucous membrane. These folds, which extend around the margin of the laryngeal inlet from their junction with the epiglottis, function as a sphincter during swallowing. The *laryngeal cavity* is subdivided into three compartments by two pairs of mucosal folds that extend anteroposteriorly from its lateral walls. The superior pairs of folds are the *vestibular folds,* or false vocal cords. The space above them is called the *laryngeal vestibule*. The lower two folds are separated from each other by a median fissure called the *rima glottidis*. They are known as the *vocal folds,* or true vocal folds (see Fig. 15.10). The vocal cords are vocal ligaments that are covered by the vocal folds. The ligaments and the rima glottidis constitute the vocal apparatus of the larynx and are collectively referred to as the *glottis*.

Esophagus

The *esophagus* is a long, muscular tube that carries food and saliva from the laryngopharynx to the stomach (see Fig. 15.1). The adult esophagus is approximately 10 inches (24 cm) long and ¾ inch (1.9 cm) in diameter. The esophagus begins at the inferior border of the cricoid cartilage, which is approximately at the level of the sixth cervical vertebra (C6). The esophagus terminates at the cardiac opening of the stomach, at about the level of the eleventh thoracic vertebra (T11) (Fig. 15.11). Similar to the rest of the alimentary canal, the esophagus has a wall composed of four layers. Beginning with the outermost layer and moving in, the layers are as follows:

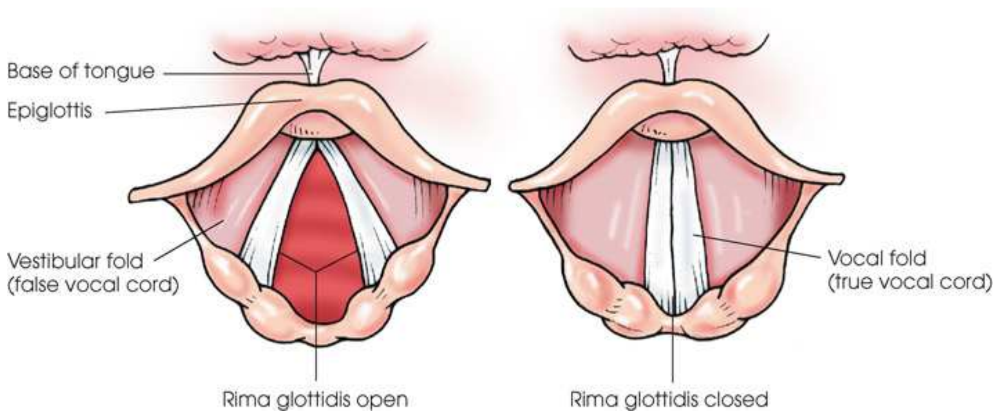


FIG. 15.10 Superior aspect of larynx (open and closed true vocal folds).

Two illustrations of the superior view of larynx. On the left, the true vocal folds are open. The Base of tongue, Epiglottis, Vestibular fold (false vocal cord) and Rima glottidis open are visible. On the right, true vocal folds are closed the Rima glottidis is also closed.

- Fibrous layer
- Muscular layer
- Submucosal layer
- Mucosal layer

The *esophagus* lies in the midsagittal plane (MSP) and is divided into three major sections with four natural narrowed areas or constrictions (Fig. 15.12A and B). The *cervical esophagus* begins at its first natural constriction, the *pharyngoesophageal constriction* occurs at the junction to the pharynx. The cervical portion of the esophagus is about 1.2 to 2 inches (3 to 5 cm) long, stretching from C6 to T1. The middle portion is the *thoracic esophagus*, which measures about 7 to 8.7 inches (18 to 22 cm) in length. The thoracic esophagus features two constrictions. The first occurs where the aortic arch and left main stem bronchus cross the esophagus, the *aortobronchial constriction,* and the second is where the left atrium of the heart compresses the esophagus. The *abdominal esophagus* measures about 1.2 to 2.4 inches (3 to 6 cm) long and begins at the final natural narrowing, the *diaphragmatic constriction*.

The esophagus descends the thorax parallel and anterior to the thoracic vertebrae and posterior to the trachea and heart (see Fig. 15.11). As the esophagus nears the diaphragm, it shifts anteriorly and to the left, crossing from the right side of the thoracic aorta to lie anterior to it. The esophagus then passes through the diaphragm at the *esophageal hiatus,* at the approximate level of T10. Finally, the esophagus curves sharply left, increases in diameter, and joins the stomach at the *esophagogastric junction,* which is at the level of the T11. The expanded portion of the terminal esophagus, which lies in the abdomen, is called the *cardiac antrum*.

The proximal and distal ends of the esophagus are bordered by sphincters that regulate the passage of materials. The *upper esophageal sphincter (UES)* is at its junction with the pharynx and functions to prevent air from entering the esophagus during respiration. Relaxation of the UES allows trapped air to escape the esophagus and stomach, commonly termed belching or burping. The distal sphincter is explained with the stomach anatomy.

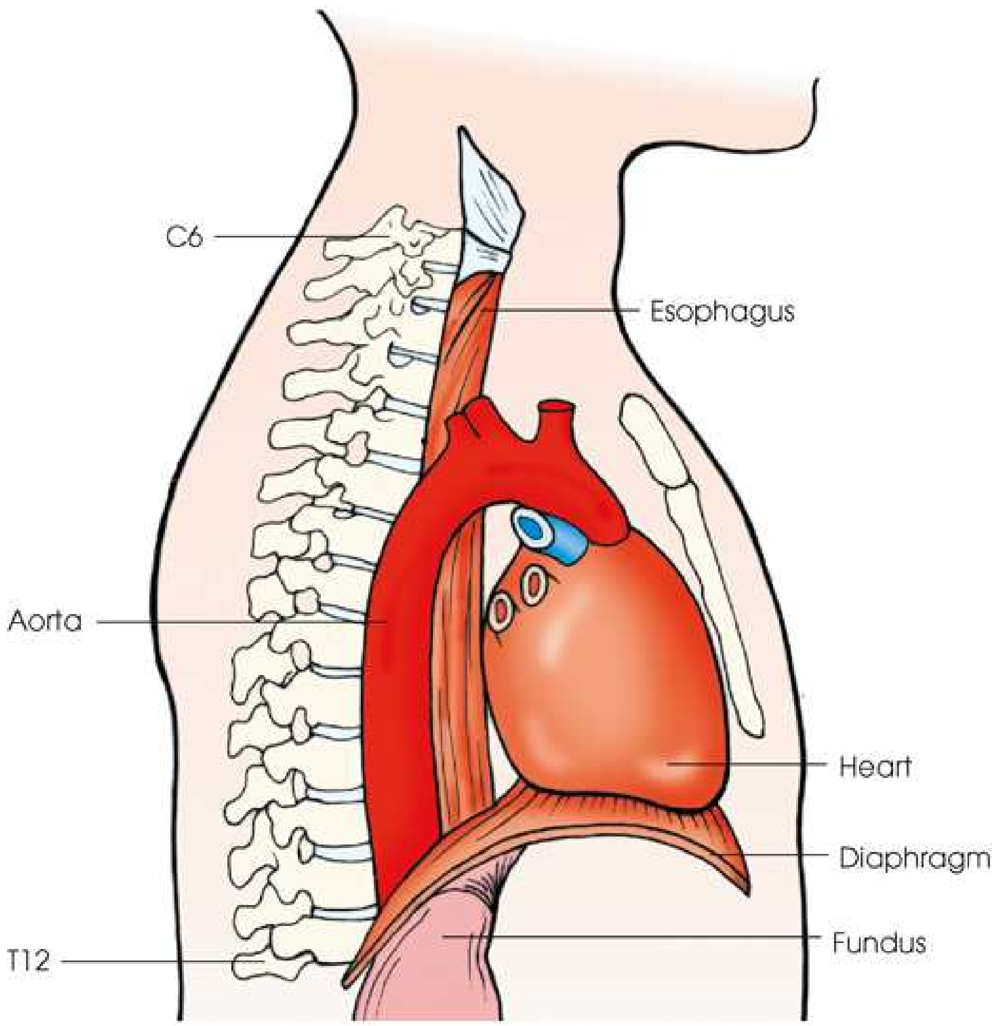


FIG. 15.11 Lateral view of thorax shows esophagus positioned anterior to vertebral bodies and posterior to trachea and heart.

A lateral view of the Thorax. The vertebral column from C 6 to T 12 are visible. The esophagus positioned anterior to vertebral bodies and posterior to trachea and heart. The diaphragm and fundus are positioned below.

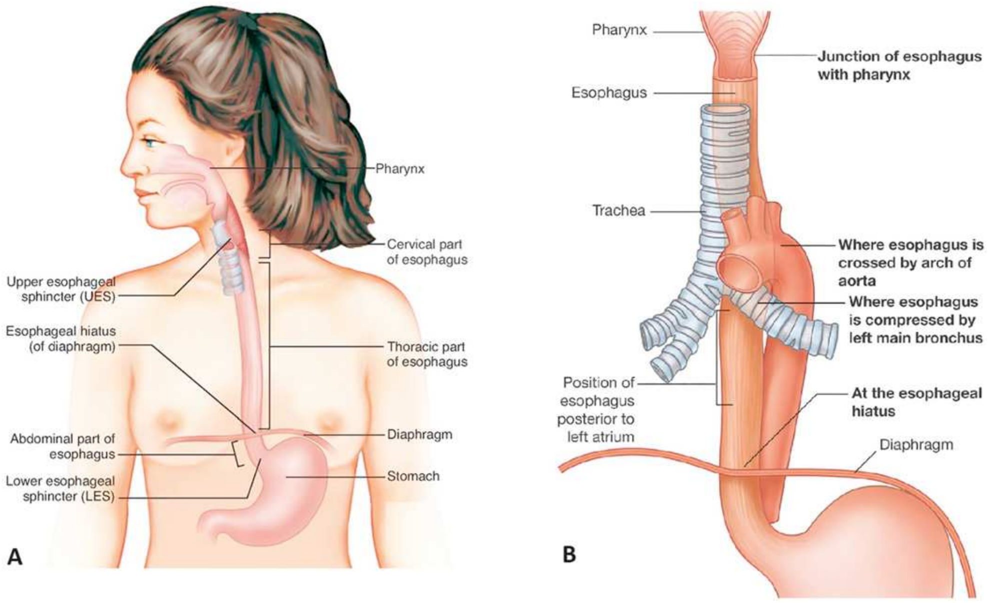


FIG. 15.12 (A) Anterior view of esophageal divisions. (B) Locations of natural constrictions of the esophagus. A, Modified from Patton K, Thibodeau G. *Anatomy and Physiology.* 8th ed. St. Louis: Mosby; 2013. B, From Drake R, Vogl W, Mitchell AWM. *Gray's Anatomy for Students.* 2nd ed. Philadelphia: Churchill Livingstone; 2010.

The anterior view of the upper torso showing the divisions of esophagus (A) and natural constrictions in esophagus (B). The cervical esophagus, pharynx, thoracic esophagus, diaphragm, stomach, L E S, U E S, abdominal part of esophagus, esophgeal hiatus of diaphragm are labeled. A close-up of the trachea and esophagus with the following locations labeled: where esophagus crosses arch of aorta, esophagus crosses left main bronchus, and esophagus crosses pharynx labeled. The position of the esophagus is posterior to the left atrium.

Stomach

The *stomach* is the dilated, sac-like portion of the digestive tract extending between the esophagus and the small intestine (Fig. 15.13). Its wall is composed of the same four layers as the esophagus.

The stomach is divided into the following four parts:

- Cardia
- Fundus
- Body
- Pyloric portion

The *cardia* of the stomach is the section immediately surrounding the esophageal opening. The *fundus* is the superior portion of the stomach that expands superiorly and fills the dome of the left hemidiaphragm. When the patient is in the upright position, the fundus is usually filled with gas; in radiography, this is referred to as the *gas bubble*. Descending from the fundus and beginning at the level of the cardiac notch is the *body* of the stomach. The inner mucosal layer of the body of the stomach contains numerous longitudinal folds called *rugae*. When the stomach is full, the rugae are smooth. The body of the stomach ends at a vertical plane passing through the *angular notch*. Distal to this plane is the *pyloric portion* of the stomach, which consists of the *pyloric antrum,* to the immediate right of the angular notch, and the narrow *pyloric canal,* which communicates with the duodenal bulb.

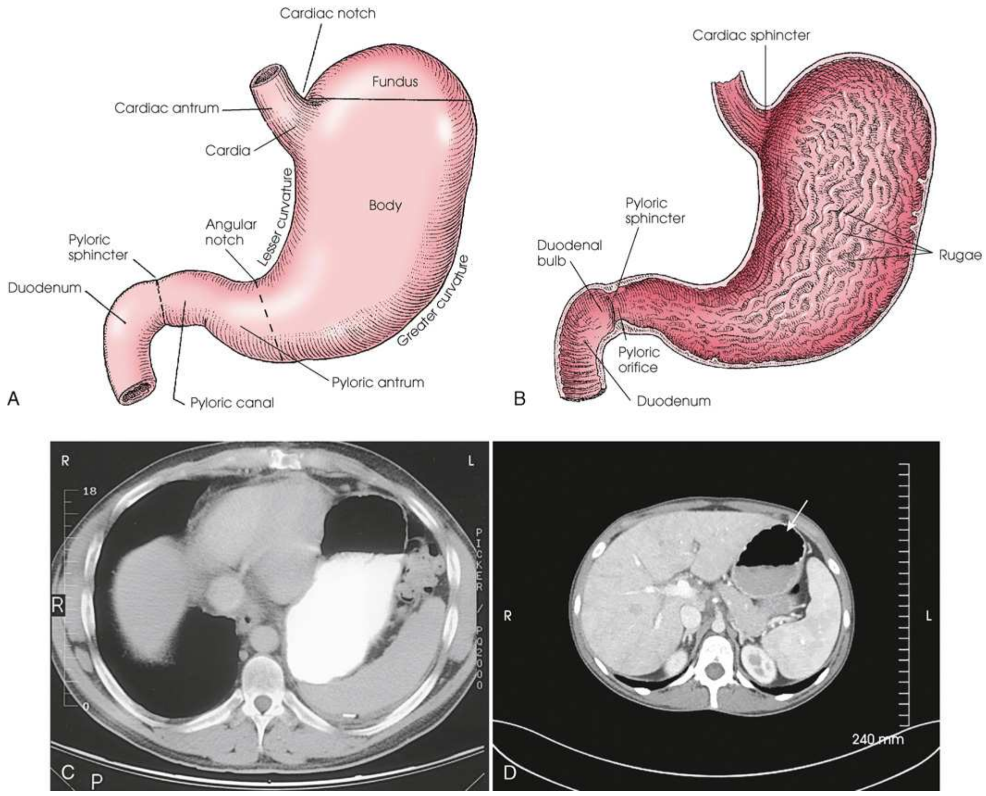


FIG. 15.13 (A) Anterior surface of stomach. (B) Interior view. (C) Axial CT image of upper abdomen showing position of stomach in relation to surrounding organs. Note contrast media *(white)* and air *(black)* in stomach. (D) Axial CT image showing stomach without contrast media. Note air *(arrow)* and empty stomach. D, Courtesy Heath Yarbrough, RT[R][MR][CT], NEA Baptist Memorial Hospital, Jonesboro, AR.

The anterior view of stomach and the inferior surface of stomach and two M R I scan images. The Cardiac antrum, Cardia Angular, Pyloric notch, sphincter, Duodenum, fundus, body, Pyloric canal, Pyloric antrum, and curvature of stomach are labeled in anterior view. The Pyloric sphincter, Duodenal bulb, Duodenum, Pyloric orifice, cardiac sphincter, Rugae are labeled in the inferior view. Two M R I scans show the axial view of the abdominal cavity with and without contrast media.

The stomach has anterior and posterior surfaces. The right border of the stomach is marked by the *lesser curvature*. The lesser curvature begins at the esophagogastric junction, is continuous with the right border of the esophagus, and is a concave curve ending at the pylorus. The left and inferior borders of the stomach are marked by the *greater curvature*. The greater curvature begins at the sharp angle at the esophagogastric junction, the *cardiac notch,* and follows the superior curvature of the fundus and then the convex curvature of the body down to the pylorus. The greater curvature is four to five times longer than the lesser curvature.

The entrance to and the exit from the stomach are controlled by muscular sphincters. The esophagus joins the stomach at the esophagogastric junction through an opening termed the *cardiac orifice*. The muscle controlling the cardiac orifice is called the *cardiac sphincter* or the *lower esophageal sphincter (LES)*. The opening between the stomach and the small intestine is the *pyloric orifice,* and the muscle controlling the pyloric orifice is called the *pyloric sphincter*.

The size, shape, and position of the stomach depend on body habitus and vary with posture and the amount of stomach contents (Fig. 15.14). In persons with a hypersthenic habitus, the stomach is almost horizontal and is high, with its most dependent portion well above the umbilicus. In persons with an asthenic habitus, the stomach is vertical and occupies a low position, with its most dependent portion extending well below the transpyloric, or interspinous, line. Between these two extremes are the intermediate types of bodily habitus with corresponding variations in shape and position of the stomach. The habitus of 85% of the population is either sthenic or hyposthenic. Radiographers should become familiar with the various positions of the stomach in the different types of body habitus so that accurate positioning of the stomach is ensured.

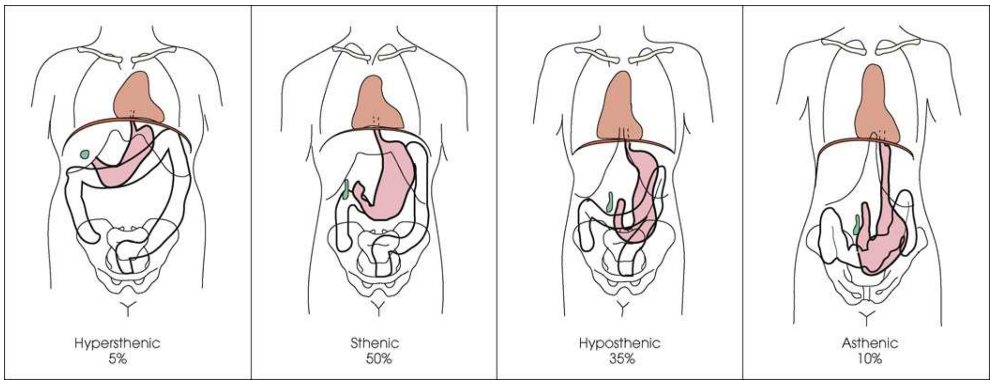


FIG. 15.14 Size, shape, and position of stomach and large intestine for the four different types of body habitus. Note extreme difference between hypersthenic and asthenic types.

Four illustrations denote the stomach and large intestine for the four different types of body habitus. The body types are Hypersthenic 5%, Sthenic 50%, Hyposthenic 35%, and Asthenic 10%. The first one has a pear-shaped body and the stomach is just below the liver. In the second one the stomach and intestines are in the mid abdomen. In the third one the stomach is stretched in the posterior end. In the fourth one it is further stretched. The posterior part of stomach, and the intestines are in the lower abdomen.

The stomach has several functions in the digestive process. The stomach serves as a storage area for food until it can be digested further. It is also where food is broken down. Acids, enzymes, and other chemicals are secreted to break food down chemically. Food is also mechanically broken down through churning and peristalsis. Food that has been mechanically and chemically altered in the stomach is transported to the duodenum as a material called *chyme*.

Small Intestine

The *small intestine* extends from the pyloric sphincter of the stomach to the ileocecal valve, where it joins the large intestine at a right angle. Digestion and absorption of food occur in this portion of the alimentary canal. The length of the adult small intestine averages about 22 ft (6.5 m), and its diameter gradually diminishes from approximately 1½ inches (3.8 cm) in the proximal part to approximately 1 inch (2.5 cm) in the distal part. The wall of the small intestine contains the same four layers as the walls of the esophagus and stomach. The mucosa of the small intestine contains a series of finger-like projections called *villi*, which assist the processes of digestion and absorption.

The small intestine is divided into the following three portions:

- Duodenum
- Jejunum
- Ileum

The *duodenum* is 8 to 10 inches (20 to 24 cm) long and is the widest portion of the small intestine (Fig. 15.15). It is retroperitoneal and is relatively fixed in position. Beginning at the pylorus, the duodenum follows a C-shaped course. Its four regions are described as the *first* (superior), *second* (descending), *third* (horizontal or inferior), and *fourth* (ascending) portions. The segment of the first portion is called the *duodenal bulb* because of its radiographic appearance when it is filled with an opaque contrast medium. The second portion is about 3 or 4 inches (7.6 to 10 cm) long. This segment passes inferiorly along the head of the pancreas and in close relation to the undersurface of the liver. The common bile duct and the pancreatic duct usually unite to form the *hepatopancreatic ampulla,* which opens on the summit of the *greater duodenal papilla* in the duodenum. The third portion passes toward the left at a slight superior inclination for a distance of about 2½ inches (6 cm) and continues as the fourth portion on the left side of the vertebrae. This portion joins the jejunum at a sharp curve called the *duodenojejunal flexure* and is supported by the *suspensory muscle of the duodenum* (ligament of Treitz). The duodenal loop, which lies in the second portion, is the most fixed part of the small intestine and normally lies in the upper part of the umbilical region of the abdomen; however, its position varies with body habitus and with the amount of gastric and intestinal contents.

The remainder of the small intestine is arbitrarily divided into two portions, with the upper two fifths referred to as the *jejunum* and the lower three fifths referred to as the *ileum*. The jejunum and the ileum are gathered into freely movable loops, or gyri, and are attached to the posterior wall of the abdomen by the mesentery. The loops lie in the central and lower part of the abdominal cavity within the arch of the large intestine.

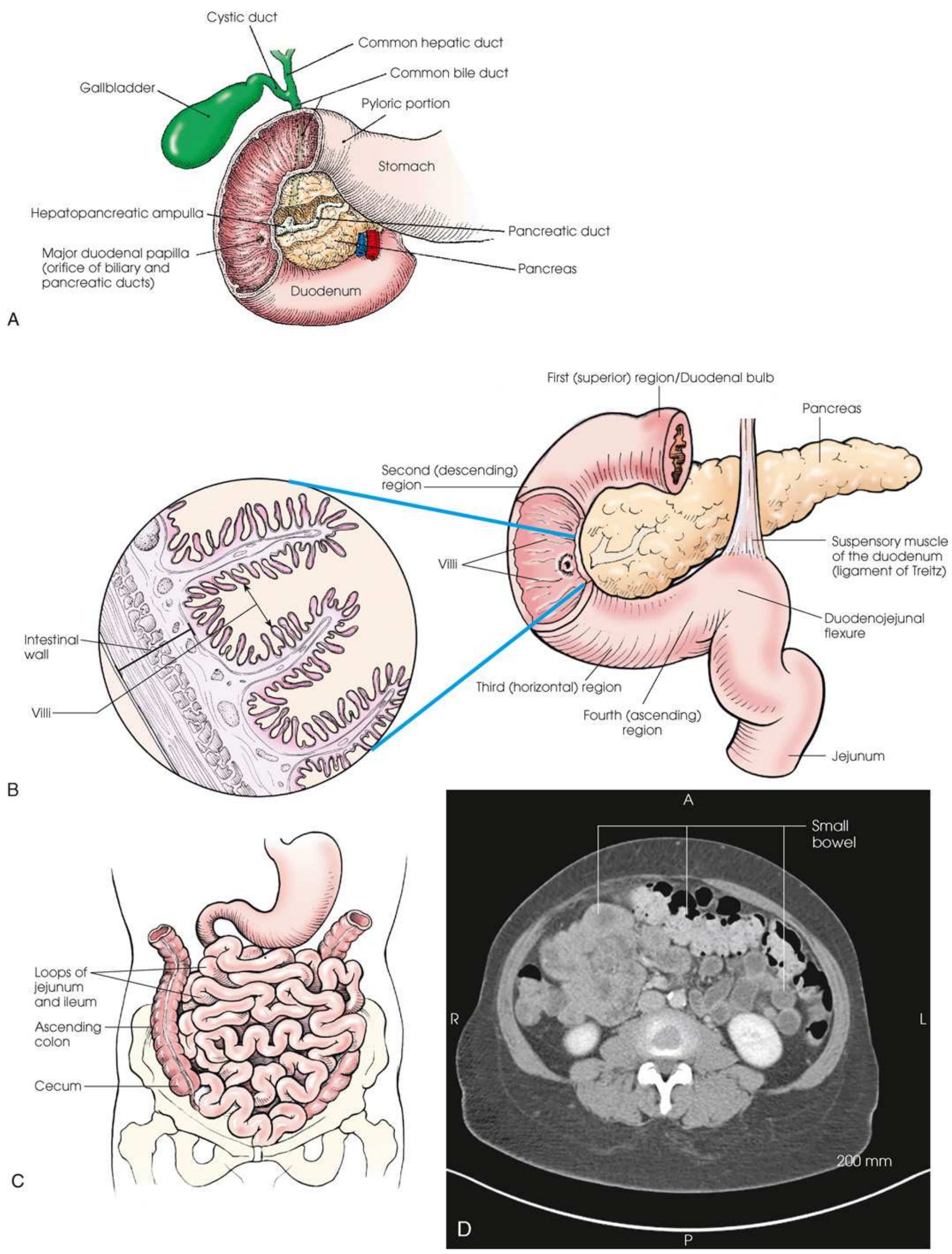


FIG. 15.15 (A) Duodenal loop in relation to biliary and pancreatic ducts. (B) Anatomic areas of duodenum. *Inset:* Cross-section of duodenum, showing villi. (C) Loops of small intestine lying in central and lower abdominal cavity. (D) CT axial image of small bowel loops with contrast media. D, Courtesy Kacey Higgins, RT[R][CT], NEA Baptist Memorial Hospital, Jonesboro, AR.

Four illustration and a scan image. A, the close-up view the duodenum with the Common hepatic duct, Common bile duct Pyloric portion, Stomach, gall bladder, cystic duct, Hepatopancreatic ampulla, Major duodenal papilla (orifice of biliary and pancreatic ducts) labeled. B, a close-up of the brush border with intestinal villi and wall. C, a cross-section of the duodenum with the First (superior) region/Duodenal bulb, Pancreas, Suspensory muscle of the duodenum, (ligament of Treitz), Duodenojejunal flexure. D, the anterior view of the abdomen with Loops of jejunum and ileum, Ascending colon, and Cecum labeled. The M R I scan of the abdominal cavity depicts the small bowel.

Large Intestine

The *large intestine* begins in the right iliac region, where it joins the ileum of the small intestine, forms an arch surrounding the loops of the small intestine, and ends at the anus (Fig. 15.16). The large intestine has four main parts, as follows:

- Cecum
- Colon
- Rectum
- Anal canal

The large intestine is about 5 ft (1.5 m) long and is greater in diameter than the small intestine. The wall of the large intestine contains the same four layers as the walls of the esophagus, stomach, and small intestine. The muscular portion of the intestinal wall contains an external band of longitudinal muscle that forms into three thickened bands called *taeniae coli*. One band is positioned anteriorly, and two are positioned posteriorly. These bands create a pulling muscle tone that forms a series of pouches called the *haustra*. The main functions of the large intestine are reabsorption of fluids and elimination of waste products.

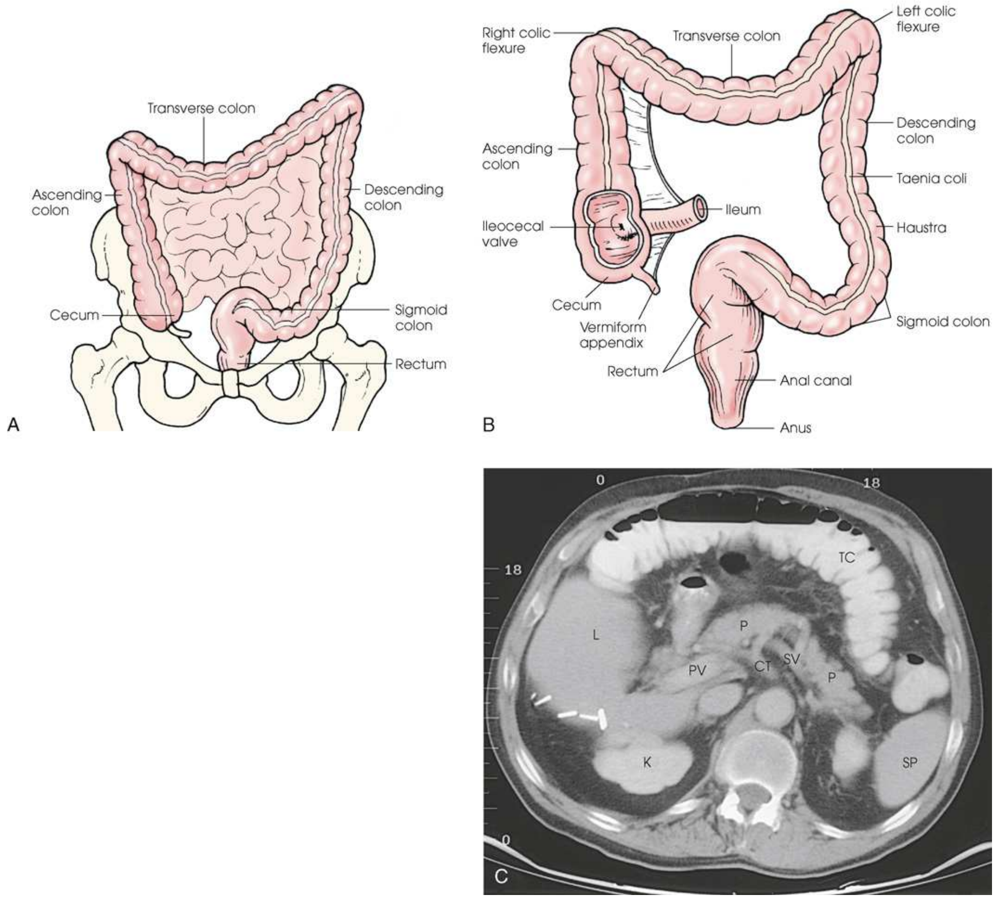


FIG. 15.16 (A) Anterior aspect of large intestine positioned in abdomen. (B) Anterior aspect of large intestine. (C) Axial CT image of upper abdomen showing actual image of transverse colon positioned in anterior abdomen.

Two illustrations and a scan image depict the anterior projection large intestine. The Ascending colon, descending colon, Transverse colon, sigmoid colon, rectum, and cecum are labeled in the first illustration. The Right colic flexure, Ascending colon, Ileocecal valve, Cecum, Vermiform appendix, Anus Anal canal, Ileum, Transverse colon, Left colic flexure, Descending colon, Taenia coli, Haustra Sigmoid colon, and Rectum are labeled in the second illustration. The scan image depicts the transverse colon positioned in the anterior abdomen.

The *cecum* is the pouch-like portion of the large intestine that is below the junction of the ileum and the colon. The cecum is approximately 2½ inches (6 cm) long and 3 inches (7.6 cm) in diameter. The *vermiform appendix* is attached to the posteromedial side of the cecum. The appendix is a narrow, worm-like tube that is about 3 inches (7.6 cm) long. The *ileocecal valve* is just below the junction of the ascending colon and the cecum. The valve projects into the lumen of the cecum and guards the opening between the ileum and the cecum.

The *colon* is subdivided into ascending, transverse, descending, and sigmoid portions. The *ascending colon* passes superiorly from its junction with the cecum to the undersurface of the liver, where it joins the transverse portion at an angle called the *right colic flexure* (formerly hepatic flexure). The *transverse colon,* which is the longest and most movable part of the colon, crosses the abdomen to the undersurface of the spleen. The transverse portion makes a sharp curve, called the *left colic flexure* (formerly splenic flexure), and ends in the descending portion. The *descending colon* passes inferiorly and medially to its junction with the *sigmoid portion* at the superior aperture of the lesser pelvis. The sigmoid colon curves to form an S-shaped loop and ends in the rectum at the level of the third sacral segment.

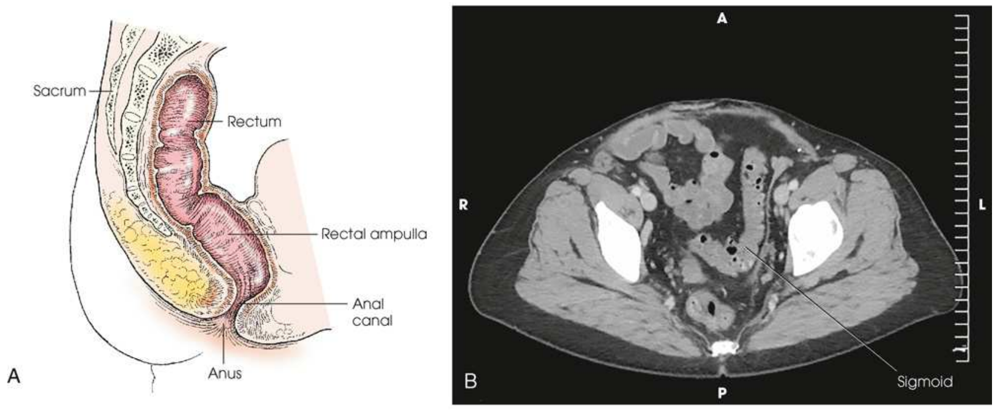


FIG. 15.17 (A) Sagittal section showing direction of anal canal and rectum. (B) Axial CT image of lower pelvis showing rectum and sigmoid colon in relation to surrounding organs. B, Courtesy Aimee Rowlett, RT[R][CT], NEA Baptist Memorial Hospital, Jonesboro, AR.

A sagittal view of the anal canal and a C T scan of the lower abdomen. The Anus, Sacrum, Anal canal, Rectum, and Rectal ampulla are labeled. The rectum and sigmoid colon are labeled in the scan image.

The *rectum* extends from the sigmoid colon to the anal canal. The *anal canal* terminates at the *anus,* which is the external aperture of the large intestine (Fig. 15.17). The rectum is approximately 6 inches (15 cm) long. The distal portion, which is about 1 inch (2.5 cm) long, is constricted to form the anal canal. Just above the anal canal is a dilatation called the *rectal ampulla*. Following the sacrococcygeal curve, the rectum passes inferiorly and posteriorly to the level of the pelvic floor and bends sharply anteriorly and inferiorly into the anal canal, which extends to the anus. The rectum and anal canal have two AP curves; this fact must be remembered when an enema tube is inserted.

The size, shape, and position of the large intestine vary greatly, depending on body habitus (see Figs. 15.14 and 15.20). In hypersthenic patients, the large intestine is positioned around the periphery of the abdomen and may require more images to show its entire length. The large intestine of asthenic patients, which is bunched together and positioned low in the abdomen, is at the other extreme.

Liver and Biliary System

The *liver,* the largest gland in the body, is an irregularly wedge-shaped gland. It is situated with its base on the right and its apex directed anteriorly and to the left (Fig. 15.18). The deepest point of the liver is the inferior aspect just above the right kidney. The diaphragmatic surface of the liver is convex and conforms to the undersurface of the diaphragm. The visceral surface is concave and is molded over the viscera on which it rests. Almost all of the right hypochondrium and a large part of the epigastrium are occupied by the liver. The right portion extends inferiorly into the right lateral region as far as the fourth lumbar vertebra, and the left extremity extends across the left hypochondrium.

At the *falciform ligament,* the liver is divided into a large *right lobe* and a much smaller *left lobe*. Two minor lobes are located on the medial side of the right lobe: the *caudate lobe* on the posterior surface and the *quadrate lobe* on the inferior surface (Fig. 15.19A). The hilum of the liver, called the *porta hepatis,* is situated transversely between the two minor lobes.

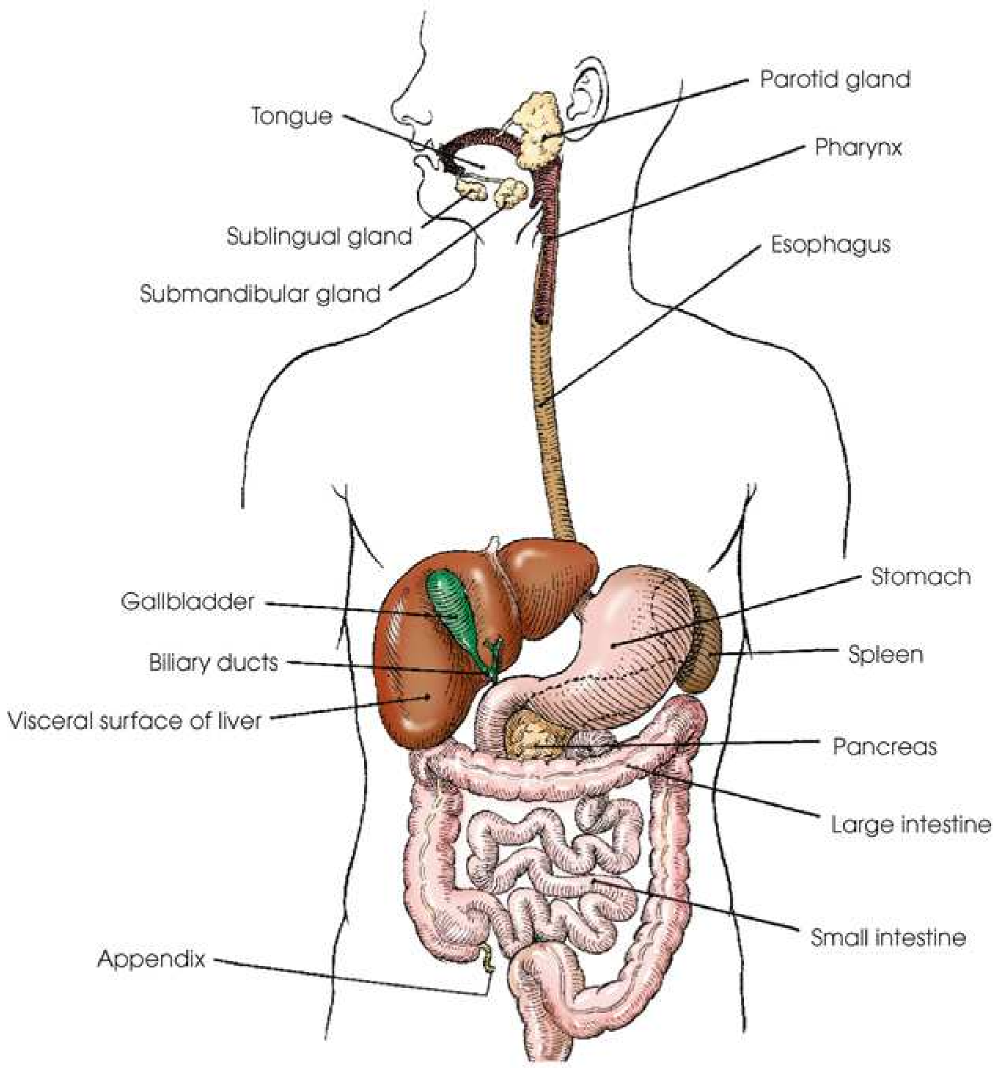


FIG. 15.18 Alimentary tract and accessory organs. To show position of gallbladder in relation to liver, the liver is shown with inferior portion pulled anteriorly and superiorly, placing the liver in an atypical position.

The alimentary canal of a human body with the organs labeled starting from top to bottom. The Tongue, Sublingual gland, Submandibular gland, Gallbladder, Biliary ducts, Duodenum, Vermiform appendix and Rectum are labeled on the left. The Parotid gland, Pharynx, Esophagus, Stomach, Spleen, Pancreas, Large intestine, and Small intestine are labeled on the right.

The *portal vein* and the *hepatic artery,* both of which convey blood to the liver, enter the porta hepatis and branch out through the liver substance (see Fig. 15.19C). The portal vein ends in the sinusoids, and the hepatic artery ends in capillaries that communicate with sinusoids. In addition to the usual arterial blood supply, the liver receives blood from the portal system.

The portal system, of which the portal vein is the main trunk, consists of the veins arising from the walls of the stomach, from the greater part of the intestinal tract and the gallbladder, and from the pancreas and the spleen. The blood circulating through these organs is rich in nutrients and is carried to the liver for modification before it is returned to the heart. The *hepatic veins* convey the blood from the liver sinusoids to the inferior vena cava.

The liver has numerous physiologic functions. The primary consideration from the radiographic standpoint is the formation of *bile*. The gland secretes bile at the rate of 1 to 3 pints (½ to 1½ L) each day. Bile, the channel of elimination for the waste products of red blood cell destruction, is an excretion and a secretion. As a secretion, it is an important aid in the emulsification and assimilation of fats. The bile is collected from the liver cells by the ducts and is carried to the gallbladder for temporary storage or is poured directly into the duodenum through the common bile duct.

The biliary, or excretory, system of the liver consists of the bile ducts and gallbladder (see Fig. 15.19). Beginning within the lobules as bile capillaries, the ducts unite to form larger and larger passages as they converge, finally forming two main ducts, one leading from each major lobe. The two main *hepatic ducts* emerge at the porta hepatis and join to form the *common hepatic duct,* which unites with the *cystic duct* to form the *common bile duct*. The hepatic and cystic ducts are each about 1½ inches (3.8 cm) long. The common bile duct passes inferiorly for a distance of approximately 3 inches (7.6 cm). The common bile duct joins the pancreatic duct, and they enter together or side by side into an enlarged chamber known as the *hepatopancreatic ampulla,* or *ampulla of Vater*. The ampulla opens into the descending portion of the duodenum. The distal end of the common bile duct is controlled by the *choledochal sphincter* as it enters the duodenum. The hepatopancreatic ampulla is controlled by a circular muscle known as the *sphincter of the hepatopancreatic ampulla,* or *sphincter of Oddi*. During interdigestive periods, the sphincter remains in a contracted state, routing most of the bile into the gallbladder for concentration and temporary storage; during digestion, it relaxes to permit the bile to flow from the liver and gallbladder into the duodenum. The hepatopancreatic ampulla opens on an elevation on the duodenal mucosa known as the *major duodenal papilla*.

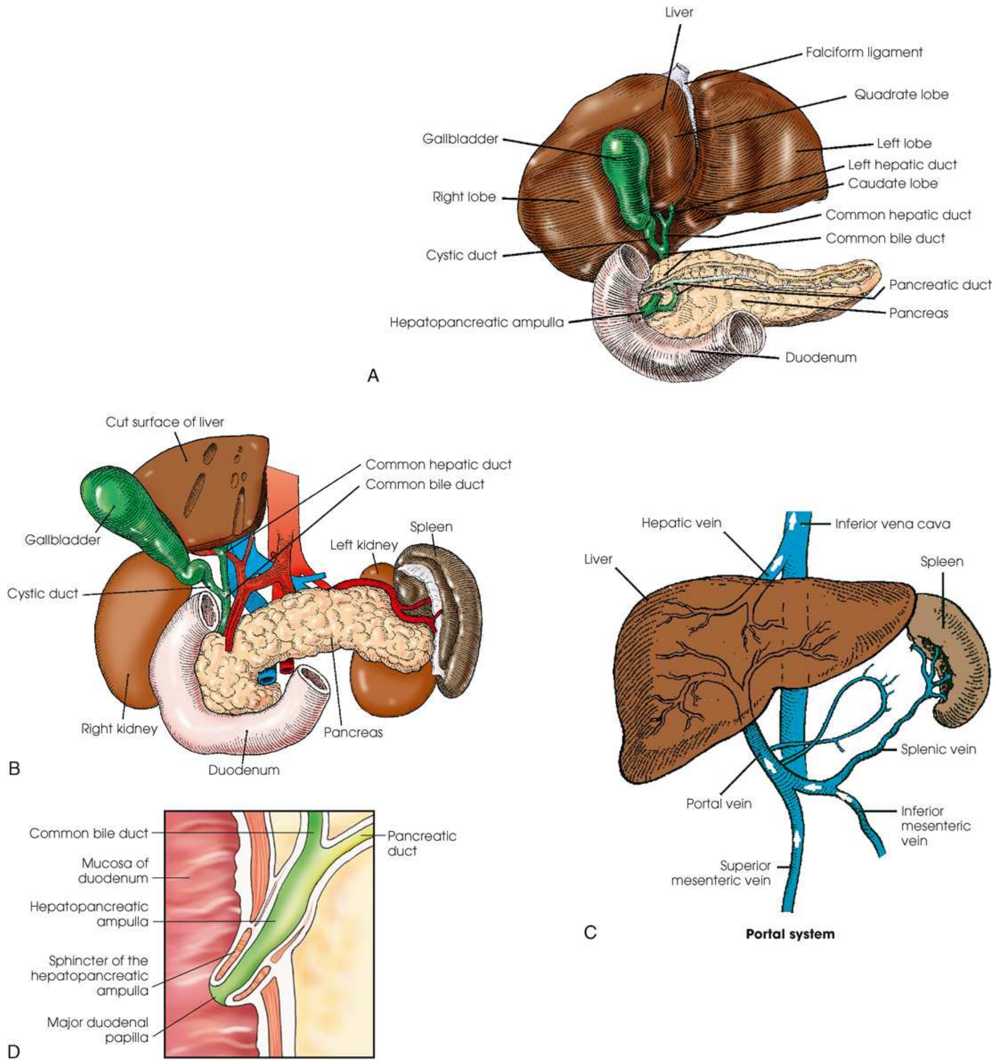


FIG. 15.19 (A) Visceral surface (inferoposterior aspect) of liver and gallbladder. (B) Visceral (inferoposterior) surface of gallbladder and bile ducts. (C) Portal system showing hepatic artery and vein and other surrounding vessels. (D) Detail of drainage system into duodenum.

Four illustrations of the liver and gall bladder. A denotes the visceral surface. The Falciform ligament, Quadrate lobe, Left lobe, Right Lobe, Left hepatic duct, Caudate lobe, Common hepatic duct, Common bile duct, Cystic duct, and Hepatopancreatic ampulla are labeled. B denotes the Common hepatic duct, Common bile duct, Pancreas, Duodenum, Cystic duct, Gallbladder, Cut surface of liver, Spleen, and Left kidney. C denotes the Inferior vena cava, Spleen, Splenic vein, Inferior mesenteric vein, Superior mesenteric vein, Portal system, Portal vein, and Liver. D denotes the drainage system into the duodenum. The Mucosa of duodenum, Hepatopancreatic ampulla, Major duodenal papilla, Pancreatic duct, and Common bile duct are labeled.

The *gallbladder* is a thin-walled, more or less pear-shaped, musculomembranous sac with a capacity of approximately 2 oz. The gallbladder concentrates bile through absorption of the water content; stores bile during interdigestive periods; and, by contraction of its musculature, evacuates the bile during digestion. The muscular contraction of the gallbladder is activated by a hormone called *cholecystokinin*. This hormone is secreted by the duodenal mucosa and is released into the blood when fatty or acid chyme passes into the intestine. The gallbladder consists of a narrow neck that is continuous with the *cystic duct*; a body or main portion; and a fundus, which is its broad lower portion. The gallbladder is usually lodged in a fossa on the visceral (inferior) surface of the right lobe of the liver, where it lies in an oblique plane inferiorly and anteriorly. Measuring about 1 inch (2.5 cm) in width at its widest part and 3 to 4 inches (7.5 to 10 cm) long, the gallbladder extends from the lower right margin of the porta hepatis to a variable distance below the anterior border of the liver. The position of the gallbladder varies with body habitus; it is high and well away from the midline in hypersthenic persons and low and near the spine in asthenic persons (Fig. 15.20). The gallbladder is sometimes embedded in the liver and frequently hangs free below the inferior margin of the liver.

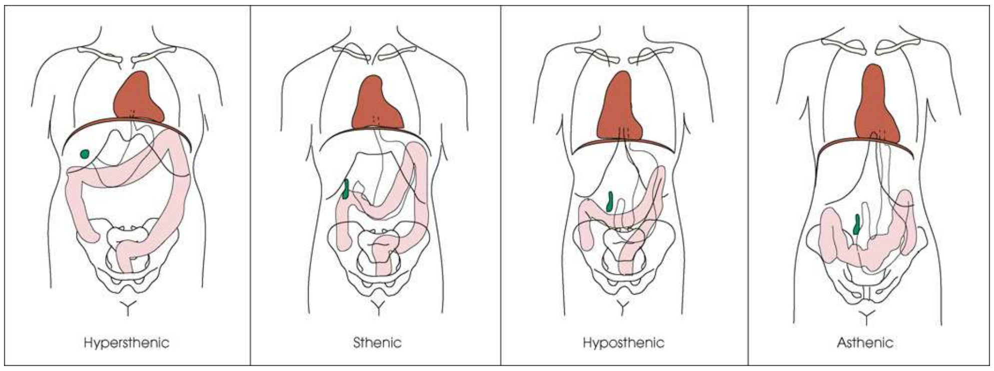


FIG. 15.20 Gallbladder *(green)* position varies with body habitus. Note extreme difference in position of gallbladder between hypersthenic and asthenic habitus. Large intestine is *pink* in these diagrams.

Four illustrations of anterior torso denote the position of gall bladder for the four different types of body habitus. The body types are Hypersthenic 5%, Sthenic 50%, Hyposthenic 35%, and Asthenic 10%. The first one has a pear-shaped body and the gall bladder is towards the top-left above the large intestine. In the second one the gall bladder is lower. In the third one the gall bladder moved to the right. In the fourth one it is placed closer to the stomach and duodenum.

Pancreas and Spleen

The *pancreas* is an elongated gland situated across the posterior abdominal wall. Extending from the duodenum to the spleen (Fig. 15.21; see Fig. 15.19), the pancreas is about 5½ inches (14 cm) long and consists of a head, neck, body, and tail. The *head,* which is the broadest portion of the organ, extends inferiorly and is enclosed within the curve of the duodenum at the level of the second or third lumbar vertebra. The *body* and *tail* of the pancreas pass transversely behind the stomach and in front of the left kidney, with the narrow tail terminating near the spleen. The pancreas cannot be seen on plain radiographic studies.

The pancreas is an *exocrine* and an *endocrine* gland. The exocrine cells of the pancreas are arranged in lobules with a highly ramified duct system. This exocrine portion of the gland produces *pancreatic juice,* which acts on proteins, fats, and carbohydrates. The endocrine portion of the gland consists of clusters of islet cells, or islets of Langerhans, which are randomly distributed throughout the pancreas. Each islet comprises clusters of cells surrounding small groups of capillaries. These cells produce the hormones *insulin* and *glucagon,* which are responsible for glucose metabolism. The islet cells do not communicate directly with the ducts but release their secretions directly into the blood through a rich capillary network.

The digestive juice secreted by the exocrine cells of the pancreas is conveyed into the *pancreatic duct* and from there into the duodenum. The pancreatic duct often unites with the common bile duct to form a single passage via the hepatopancreatic ampulla, which opens directly into the descending duodenum.

The *spleen* is included in this section only because of its location; it belongs to the lymphatic system. The spleen is a gland-like but ductless organ that produces lymphocytes and stores and removes dead or dying red blood cells. The spleen is more or less bean-shaped and measures about 5 inches (13 cm) long, 3 inches (7.6 cm) wide, and 1½ inches (3.8 cm) thick. Situated obliquely in the left upper quadrant, the spleen is just below the diaphragm and behind the stomach. It is in contact with the abdominal wall laterally, with the left suprarenal gland and left kidney medially, and with the left colic flexure of the colon inferiorly. The spleen is visualized with and without contrast media.

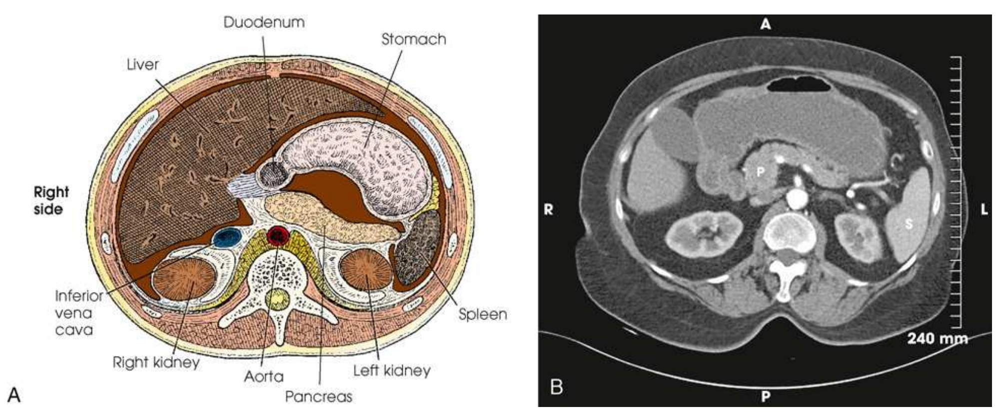


FIG. 15.21 (A) Sectional image of upper abdomen (viewed from the patient's feet upward), showing relationship of digestive system components. (B) Axial CT image of abdomen, demonstrating pancreas *(P)* and the spleen *(S)*. Courtesy NEA Baptist Memorial Hospital, Jonesboro, AR.

A cross-section of the upper abdomen (A) and a M R I scan of the axial view of the abdomen (B). The Duodenum, Stomach, Spleen, Aorta, Left kidney, Right kidney, Inferior vena cava, Liver, and Pancreas are labeled in the cross section. The pancreas and spleen are labeled in the scan image.

Abbreviations Used In Chapter 15

BE	Barium enema
CTC	CT colonography
ERCP	Endoscopic retrograde cholangiopancreatography
LES	Lower esophageal sphincter
MBSS	Modified barium swallow study
MPR	Multiplanar reconstruction
TEA	Top of ear attachment
UES	Upper esophageal sphincter
UGI	Upper gastrointestinal
VC	Virtual colonoscopy
VFSS	Videofluoroscopic swallow study

See Addendum B for a summary of all abbreviations used in Volume 2.

Sample Exposure Technique Chart Essential Projections

These techniques were accurate for the equipment used to produce each exposure. However, use caution when applying them in your department because “there is considerable variability in image receptor response owing to varying scatter sensitivity, the use of grids with different grid ratios, collimation, beam filtration, the choice of kilovoltage, source-to-image distance, and image receptor size.” [a]

These techniques were accurate for the equipment used to produce each exposure. However, use caution when applying them in your department because generator output characteristics and IR energy sensitivities vary widely. [a]

This chart was created in collaboration with Dennis Bowman, AS, RT(R), Clinical Instructor, Community Hospital of the Monterey Peninsula, Monterey, CA.

http://digitalradiographysolutions.com/

Digestive System, Alimentary Canal								
Part	**cm**	**kVp**[b]	**SID**[c]	**Collimation**	**CR**[d]		**DR**[e]	
					mAs	**Dose (mGy)**[f]	**mAs**	**Dose (mGy)**[f]
Esophagus								
AP and PA[g]	16	120	40″	10″ × 17″ (24 × 43 cm)	8[h]	1.832	4[h]	0.904
Obliques[g]	21	120	40″	10″ × 17″ (24 × 43 cm)	12[h]	3.230	6[h]	1.621
Lateral[g]	30	120	40″	10″ × 17″ (24 × 43 cm)	24[h]	8.230	12[h]	4.085
Stomach and duodenum								
PA and AP[g]	21	120	40″	10″ × 12″ (24 × 30 cm)	10[h]	2.610	5[h]	1.291
PA and AP oblique[g]	24	120	40″	10″ × 12″ (24 × 30 cm)	15[h]	4.495	7.5[h]	2.245
Lateral[g]	27	120	40″	10″ × 12″ (24 × 30 cm)	30[h]	9.770	15[h]	4.860
Small intestine								
PA and AP[g]	21	120	40″	14″ × 17″ (35 × 43 cm)	16[h]	4.320	8[h]	2.160
Large intestine								
PA and AP[g]	21	120	40″	14″ × 17″ (35 × 43 cm)	20[h]	5.420	10[h]	2.700
PA and AP[g] **axial**	24	120	40″	14″ × 17″ (35 × 43 cm)	32[h]	9.365	16[h]	4.650
PA and AP oblique[g]	24	120	40″	14″ × 17″ (35 × 43 cm)	25[h]	7.310	12.5[h]	3.635
Lower lateral (rectum)[g]	31	120	40″	10″ × 12″ (24 × 30 cm)	60[h]	22.21	30[h]	10.89
AP and PA decubitus (air contrast)[g]	24	120	40″	17″ × 14″ (43 × 35 cm)	25[h]	7.320	12.5[h]	3.640

[a] ACR-AAPM-SIMM Practice Parameters for Digital Radiography, revised 2017.

[b] kVp values are for a high-frequency generator.

[c] 40 inches *minimum*; 44 to 48 inches recommended to improve spatial resolution (mAs increase needed, but no increase in patient dose will result).

[d] AGFA CR MD 4.0 General IP, CR 75.0 reader, 400 speed class, with 6:1 (178LPI) grid when needed.

[e] GE Definium 8000, with 13:1 grid when needed.

[f] All doses are skin entrance for average adult (160 to 200 pounds male, 150 to 190 pounds female) at part thickness indicated.

[g] Bucky/Grid.

[h] Large focal spot.

Radiography

Summary of Anatomy

Digestive system

Alimentary canal

- Mouth
- Pharynx
- Esophagus
- Stomach
- Small intestine
- Large intestine (colon)
- Anus

Accessory glands

- Salivary glands
  - Parotid glands
  - Parotid ducts
  - Submandibular glands
  - Submandibular ducts
  - Sublingual glands
  - Sublingual ducts
- Liver
- Gallbladder
- Pancreas

Mouth

- Oral vestibule
- Oral cavity
- Oropharynx
- Hard palate
- Soft palate
  - Uvula
  - Anterior arches
  - Posterior arches
  - Tonsil
- Tongue
  - Apex
  - Sublingual space
  - Frenulum of the tongue
  - Sublingual fold
  - Teeth

Pharynx

- Nasopharynx
- Soft palate
- Hard palate
- Uvula
- Pharyngeal tonsil
- Oropharynx
- Hyoid bone
  - Laryngeal pharynx

Larynx

- Epiglottis
- Thyroid cartilage
- Piriform recess
- Laryngeal cavity

- Vestibular folds (false vocal cords)
- Laryngeal vestibule
- Rima glottides
- Vocal folds (true vocal cords)
    - Glottis

Esophagus

- Fibrous layer
- Muscular layer
- Submucosal layer
    - Cervical esophagus
    - Thoracic esophagus
    - Abdominal esophagus
- Esophagogastric junction
- Cardiac antrum
- Cardiac notch

Stomach

- Cardia
- Fundus
- Body
    - Rugae
- Angular notch
- Pyloric portion
    - Pyloric antrum
    - Pyloric canal
- Lesser curvature
- Cardiac notch
- Greater curvature
- Cardiac orifice
- Cardiac sphincter
- Pyloric orifice
- Pyloric sphincter
- Chyme

Small intestine

- Villi
- Duodenum (four regions)
    - First (superior)—duodenal bulb
    - Second (descending)—major duodenal papilla
    - Third (horizontal)
    - Fourth (ascending)—duodenojejunal flexure; suspensory muscle of duodenum
- Jejunum
- Ileum

Large intestine

- Taeniae coli
- Haustra
- Cecum
- Vermiform appendix
- Ileocecal valve
- Colon
    - Ascending colon
    - Right colic flexure
    - Transverse colon
    - Left colic flexure
    - Descending colon
    - Sigmoid colon
- Rectum
    - Rectal ampulla
    - Anal canal

- Anus

Liver and biliary system

- Falciform ligament
- Right lobe
- Left lobe
- Caudate lobe
- Quadrate lobe
- Porta hepatis
- Hepatic artery
- Portal vein
- Hepatic veins
- Hepatic ducts
- Common hepatic duct
- Cystic duct
- Common bile duct
- Hepatopancreatic ampulla
- Sphincter of hepatopancreatic ampulla
- Major duodenal papilla
- Gallbladder

Pancreas and spleen

- Pancreas
  - Head
  - Body
  - Tail
- Exocrine gland
  - Pancreatic juice
- Endocrine gland
  - Islet cells
- Pancreatic duct
- Spleen

Condition	Definition
Achalasia	Failure of smooth muscle of alimentary canal to relax
Appendicitis	Inflammation of the appendix
Barrett esophagus	Peptic ulcer of lower esophagus, often with stricture
Bezoar	Mass in the stomach formed by material that does not pass into the intestine
Biliary stenosis	Narrowing of bile ducts
Calculus	Abnormal concretion of mineral salts, often called a *stone*
Carcinoma	Malignant new growth composed of epithelial cells
Celiac disease or sprue	Malabsorption disease caused by mucosal defect in the jejunum
Cholecystitis	Acute or chronic inflammation of gallbladder
Choledocholithiasis	Calculus in common bile duct
Cholelithiasis	Presence of gallstones
Colitis	Inflammation of the colon
Diverticulitis	Inflammation of diverticula in the alimentary canal
Diverticulosis	Diverticula in the colon without inflammation or symptoms
Diverticulum	Pouch created by herniation of the mucous membrane through the muscular coat
Esophageal varices	Enlarged tortuous veins of lower esophagus, resulting from portal hypertension
Fistula	Abnormal connection between two internal organs or between an organ and the body surface
Foreign body	Foreign material in the airway
Gastritis	Inflammation of lining of stomach
Gastroesophageal reflux	Backward flow of stomach contents into the esophagus
Hiatal hernia	Protrusion of the stomach through the esophageal hiatus of the diaphragm
Hirschsprung disease or congenital aganglionic megacolon	Absence of parasympathetic ganglia, usually in the distal colon, resulting in the absence of peristalsis
Ileus	Failure of bowel peristalsis
Inguinal hernia	Protrusion of the bowel into the groin
Intussusception	Prolapse of a portion of the bowel into the lumen of an adjacent part
Malabsorption syndrome	Disorder in which subnormal absorption of dietary constituents occurs
Meckel diverticulum	Diverticulum of the distal ileum, similar to the appendix
Pancreatic pseudocyst	Collection of debris, fluid, pancreatic enzymes, and blood as a complication of acute pancreatitis
Pancreatitis	Acute or chronic inflammation of the pancreas
Polyp	Growth or mass protruding from a mucous membrane
Pyloric stenosis	Narrowing of pyloric canal causing obstruction
Regional enteritis or Crohn disease	Inflammatory bowel disease, most commonly involving the distal ileum
Salivary duct obstruction	Condition that prevents passage of saliva through the duct
Stenosis	Narrowing or contraction of a passage
Tumor	New tissue growth where cell proliferation is uncontrolled
Ulcer	Depressed lesion on the surface of the alimentary canal
Ulcerative colitis	Recurrent disorder causing inflammatory ulceration in the colon
Volvulus	Twisting of a bowel loop on itself
Zenker diverticulum	Diverticulum located just above the cardiac portion of the stomach

Table Continued

Eponymous (named) pathologies are listed in nonpossessive form to conform to the *AMA manual of style: a guide for authors and editors*. ed 10, Oxford: Oxford University Press; 2009.

Radiography

Sialography

Sialography is the term applied to radiologic examination of the salivary glands and ducts with the use of a contrast material, usually one of the water-soluble iodinated media. Because of improvements in computed tomography (CT) and magnetic resonance imaging (MRI) techniques, sialography is rarely performed. When the presence of a salivary stone or lesion is suspected, CT or MRI is often the modality of choice. Sialography remains a viable tool, however, when a definitive diagnosis is necessary for a problem related to one of the salivary ducts. [1]

Sialography is used to show such conditions as inflammatory lesions and tumors; to determine the extent of salivary fistulae; and to localize diverticula, strictures, and calculi. Because the glands are paired and the pairs are in such close proximity, only one gland at a time can be examined by the sialographic method (Fig. 15.22).

Sialography is performed as follows:

- Inject the radiopaque medium into the main duct. From there, the contrast material flows into the intraglandular ductules, making it possible to show the surrounding glandular parenchyma and the duct system (Fig. 15.23).
- Obtain preliminary images to detect any condition demonstrable without the use of a contrast medium and to establish the optimal exposure technique.
- About 2 or 3 minutes before the sialographic procedure, give the patient a secretory stimulant to open the duct and its orifice for easier passage of a cannula or catheter. For this purpose, have the patient suck on a wedge of fresh lemon. After the examination, have the patient suck on another lemon wedge to stimulate rapid evacuation of the contrast medium.

• Take an image about 10 minutes after the procedure to verify clearance of the contrast medium, if necessary.

Most physicians inject the contrast medium by manual pressure (i.e., with a syringe attached to the cannula or catheter). Other physicians advocate delivery of the medium by hydrostatic pressure only. The latter method requires the use of a water-soluble iodinated medium, with the contrast solution container (usually a syringe barrel with the plunger removed) attached to a drip stand set at a distance of 28 inches (70 cm) above the level of the patient's mouth. The filling procedure is often performed under fluoroscopic guidance with spot images obtained at various intervals.

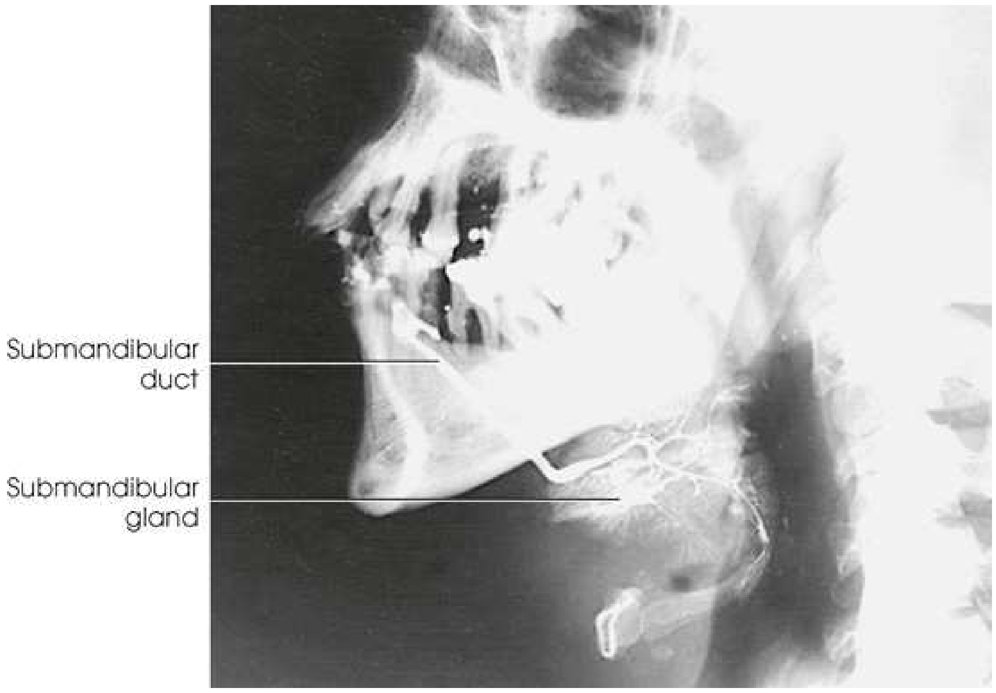


FIG. 15.22 Sialogram showing opacified submandibular gland.

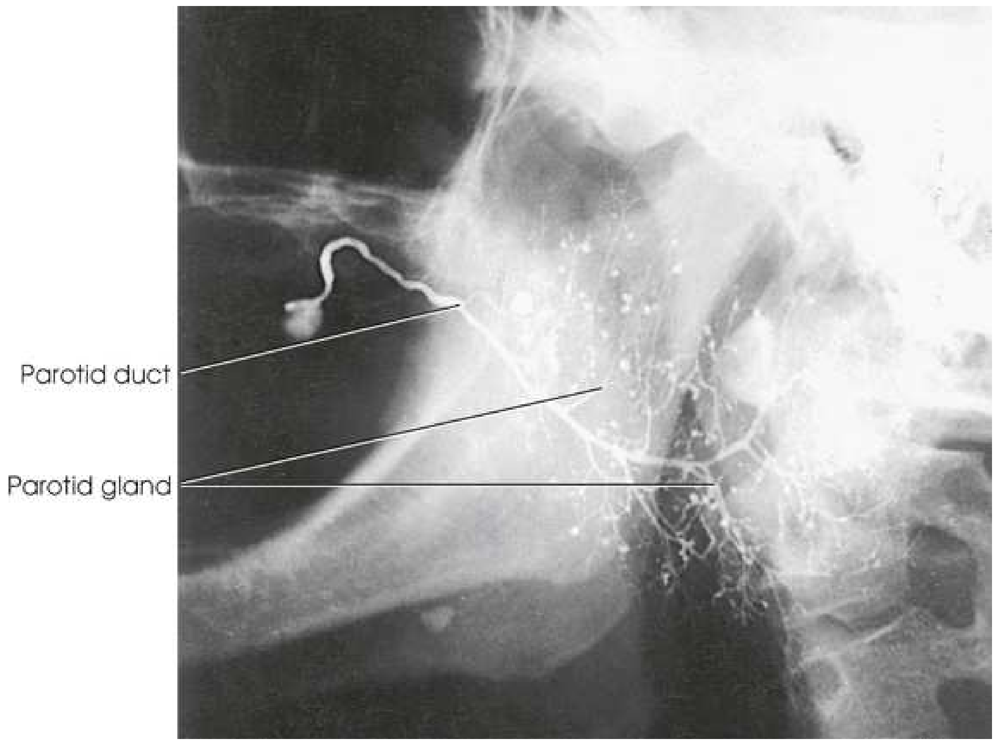


FIG. 15.23 Sialogram showing parotid gland in a patient without teeth.

Parotid Gland

Tangential Projection

Image receptor: Positioned by manufacturer or department protocol for proper anatomy display orientation; CR plate: 10 × 12 inches (24 × 30 cm) lengthwise.

Position of patient

- Place the patient in a recumbent or a seated position.
- Because the parotid gland lies midway between the anterior and posterior surfaces of the skull, obtain the tangential projection of the glandular region from the posterior or the anterior direction.

Position of part

Supine body position

- With the patient supine, rotate the head slightly toward the side being examined so that the parotid area is perpendicular to the plane of the IR.
- Center the IR to the parotid area.
- With the patient's head resting on the occiput, adjust the head so that the mandibular ramus is parallel with the longitudinal axis of the IR (Fig. 15.24).

FIG. 15.24 Tangential parotid gland, supine position.

Prone body position

- With the patient prone, rotate the head so that the parotid area being examined is perpendicular to the plane of the IR.
- Center the IR to the parotid region.
- With the patient's head resting on the chin, adjust the flexion of the head so that the mandibular ramus is parallel with the longitudinal axis of the IR (Fig. 15.25).
- When the parotid (Stensen) duct does not have to be shown, rest the patient's head on the forehead and nose.
- *Shield gonads.*
- *Respiration:* Improved radiographic quality can be obtained, particularly to show calculi, by having the patient fill the mouth with air and then puff the cheeks out as much as possible. When this cannot be done, ask the patient to suspend respiration for the exposure.

FIG. 15.25 Tangential parotid gland, prone position.

A patient lies face down on an image receptor placed on a table in a prone position. The arms of the patient rest on either side of the chest on the table. The central Ray is directed towards the back of the head.

Central ray

- Perpendicular to the plane of the IR, directed along the lateral surface of the mandibular ramus.

Collimation

- Adjust the radiation field to 1 inch (2.5 cm) beyond the skin shadow, superiorly to the top of ear attachment (TEA), and inferiorly below the mandible.

Structures shown

Contrast-filled parotid duct and gland and calcific deposits or swelling (if present) (Figs. 15.26 and 15.27).

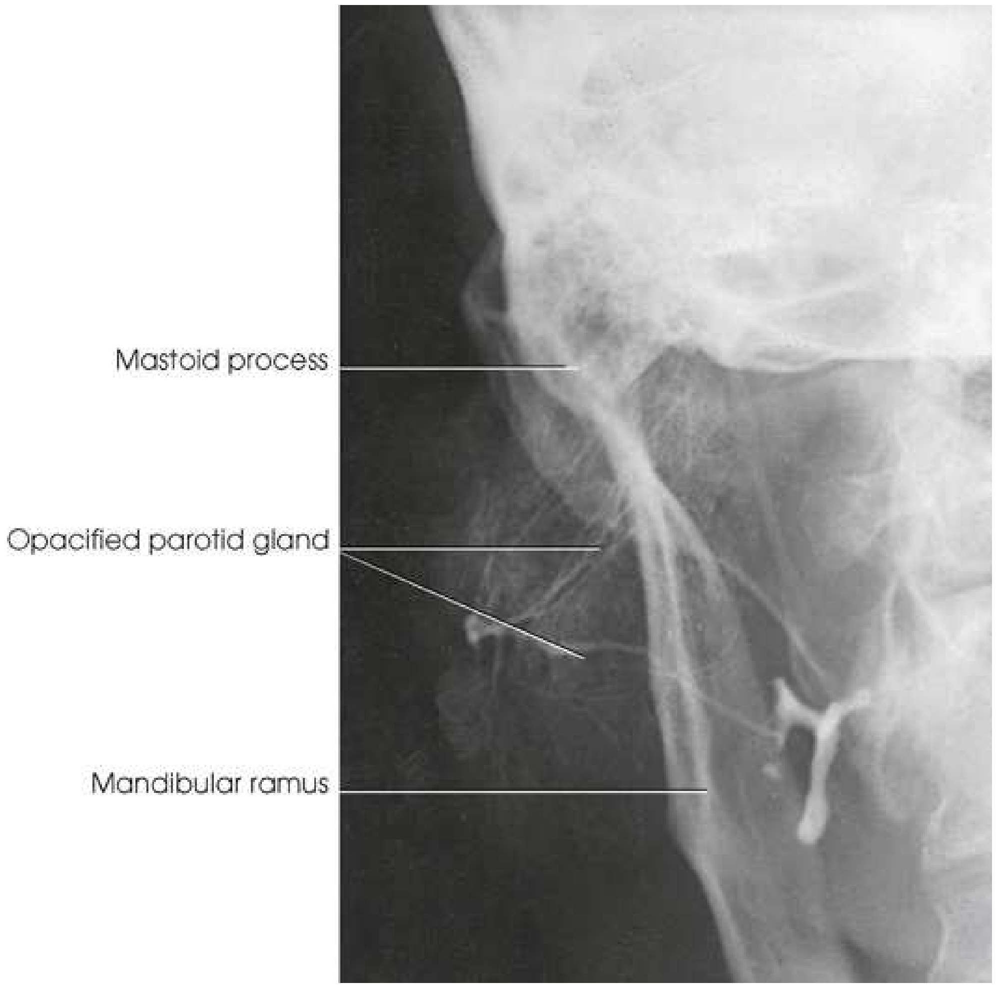


FIG. 15.26 Tangential parotid gland showing opacification.

A radiograph of the tangential parotid gland of a patient in supine position showing opacification. The opacified parotid gland is present between the mastoid process on top and the mandibular ramus below.

Evaluation Criteria

The following should be clearly seen:

- Evidence of proper collimation and presence of side marker placed clear of anatomy of interest
- Contrast medium and glandular soft tissue
- Most of the parotid gland lateral to and clear of the mandibular ramus
- Mastoid overlapping only the upper portion of the parotid gland

FIG. 15.27 Tangential parotid gland showing opacification.

A radiograph of the tangential parotid gland of a patient in supine position showing opacification. The opacified parotid gland is present between the mastoid process on top and the mandibular ramus below.

Parotid and Submandibular Glands

Lateral Projection

Right or left position

Image receptor + grid: Positioned by manufacturer or department protocol for proper anatomy display orientation; CR plate: 10 × 12 inches (24 × 30 cm) lengthwise.

Position of patient

- Place the patient in a semiprone or seated and upright position.

Position of part

Parotid gland

- With the affected side closest to the IR, extend the patient's neck so that the space between the cervical area of the spine and the mandibular rami is cleared.
- Center the IR to a point approximately 1 inch (2.5 cm) superior to the mandibular angle.
- Adjust the head so that the MSP plane is rotated approximately 15 degrees toward the IR from a true lateral position.

Submandibular gland

- Center the IR to the inferior margin of the angle of the mandible.
- Adjust the patient's head in a true lateral position (Fig. 15.28).
- An axiolateral or axiolateral oblique projection may also be performed. See Chapter 11 for positioning details.
- Iglauer [2] suggested depressing the floor of the mouth to displace the submandibular gland below the mandible. When the patient's throat is not too sensitive, accomplish this by having the patient place an index finger on the back of the tongue on the affected side.

- *Shield gonads.*
- *Respiration:* suspend.

Central ray

- Perpendicular to the center of the IR and directed (1) at a point 1 inch (2.5 cm) superior to the mandibular angle to show the parotid gland or (2) at the inferior margin of the mandibular angle to show the submandibular gland.

Collimation

- Adjust the radiation field to 1 inch (2.5 cm) beyond the anterior and inferior skin shadows and to MCP posteriorly.

FIG. 15.28 Lateral submandibular gland.

A patient lies on a table on her side with her head tilted towards the left. Her left arm is rested on the table beside her head. The image receptor is placed under her head. The central Ray is directed towards the centre of her throat.

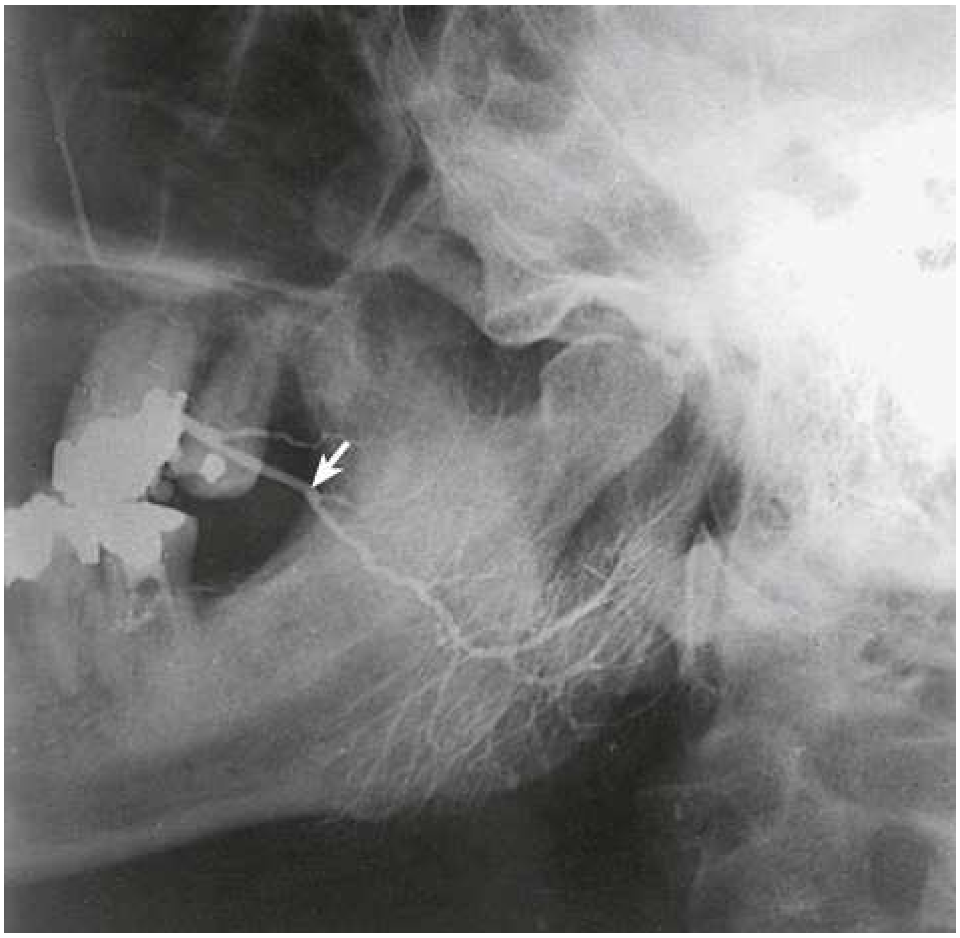


FIG. 15.29 Lateral parotid gland showing opacified gland and parotid duct *(arrow)*.

FIG. 15.30 Axiolateral submandibular gland showing opacification of submandibular duct *(arrow)*.

Structures shown

Contrast-filled parotid duct and gland (Fig. 15.29), submandibular duct and gland (Fig. 15.30), surrounding bony and soft tissues, and calcific deposits or swelling (if present).

Evaluation Criteria

The following should be clearly seen:

- Evidence of proper collimation and presence of side marker placed clear of anatomy of interest
- Mandibular rami free of overlap from the cervical vertebrae to show best the parotid gland superimposed over the ramus
- Superimposed mandibular rami and angles, if no tube angulation or head rotation is used for the submandibular gland
- Oblique position for the parotid gland
- Submandibular gland shown without superimposition of contralateral mandibular ramus, on axiolateral projections
- Contrast medium and glandular soft tissue

Soft Palate, Pharynx, Larynx, and Cervical Esophagus

Modified Barium Swallow Study

One of the most common imaging procedures of the soft palate, pharynx, and larynx is the *x-ray modified barium swallow,* which is listed in the ARRT Radiography Examination Content Specifications [3] as Swallowing Dysfunction Study. This procedure is defined by the American College of Radiology (ACR) as the "videofluoroscopic procedure performed in conjunction with a speech therapist." [4] The technical term used by the American Speech-Language-Hearing Association is *videofluoroscopic swallow study* (VFSS). Fluoroscopy is the modality of choice to demonstrate both the structure and function of the complex anatomy of deglutition and evaluate the presence of any abnormalities, especially those that allow aspiration.

FIG. 15.31 Fluoroscopy room with patient positioning chair set up for modified barium swallow study.

Deglutition

The act of swallowing is performed by the rapid and highly coordinated action of many muscles. The following points are important in radiography of the pharynx and upper esophagus:

- The middle area of the tongue becomes depressed to collect the mass, or bolus, of material to be swallowed.
- The base of the tongue forms a central groove to accommodate the bolus and then moves superiorly and inferiorly along the roof of the mouth to propel the bolus into the pharynx.
- Simultaneously with the posterior thrust of the tongue, the larynx moves anteriorly and superiorly under the root of the tongue, the sphincteric folds nearly closing the laryngeal inlet (orifice).
- The epiglottis divides the passing bolus and drains the two portions laterally into the piriform recesses as it lowers over the laryngeal entrance.

Technical considerations

Imaging and recording of deglutition must occur at 30 frames per second (fps). The fluoroscopic examination may be performed in the department using stationary equipment or in a room equipped with a mobile C-arm. A specialized patient chair is also used to facilitate consistent, safe, and comfortable upright position during imaging (Fig. 15.31). Barium sulfate is the standard contrast agent used for VFSS.

Team Members

The modified barium swallow study (MBSS) requires a coordinated team effort. The speech therapist, radiologic technologist, and radiologist have a role in providing optimum patient care while obtaining a diagnostic study. While the duties of each team member may vary slightly, the general responsibilities for each member are outlined below.

Radiologic technologist

- Prepares the room for the procedure.
- Accompanies patient into the imaging suite.
- Prepares the patient for the procedure by providing a general explanation, removing potential artifacts, provides a gown, if needed.
- Notifies the other team members of the patient's arrival to imaging.
- Assists the patient into the procedure chair or onto the footboard of the upright table.
- Shields patient appropriately.
- Obtains scout image, most commonly a lateral soft tissue neck.
- Moves the fluoroscopy tower into position, while explaining the equipment to the patient.
- In states where allowed, the technologist also operates the fluoroscopy, records the images, and marks each contrast sequence correctly.
- Transfers the recorded images to PACS to allow the speech therapist to review with the patient and the radiologist to dictate the report.
- Prepares the patient for dismissal.
- Assists with cleaning the room.

Speech therapist

- Prepares contrast media, typically a thin and a thick barium, a semi-solid barium (often labeled as "pudding"), barium on a solid, such as a cracker, and barium mixed into a carbonated beverage (Fig. 15.32).
- Administers the contrast medium, in various consistencies, quantities, and using different mechanisms, such as a spoon, cup, and straw.

FIG. 15.32 Contrast set up for MBSS. Barium sulfate in various consistencies, a carbonated beverage, and crackers for the solid food swallow test.

- Provides the patient specific swallowing instructions.
- Adjusts the patient's head position, such as the "chin tuck" position to evaluate if this position improves the effective seal of the epiglottis over the trachea.
- Consults with radiologist during procedure, particularly when aspiration is present, to adjust the protocol for an accurate assessment and diagnosis.
- Reviews the study with the patient after the procedure is concluded and provides instructions and/or further therapy.
- Assists in cleaning the room after the patient leaves.

Radiologist

- May operate fluoroscopy and perform image recording.
- Observe and comment on findings while viewing the procedure in real time from the control panel monitor.
- Dictates results of the exam for the patient's medical record.

FIG. 15.33 Patient positioned for lateral images during MBSS.

Lateral Projection

Right or left position

The lateral is often the only projection obtained during an MBSS. The AP may be added based upon information obtained during fluoroscopy of the patient in the lateral position.

Image receptor: Positioned by manufacturer or department protocol for proper anatomy display orientation; CR plate: 10 × 12 inches (24 × 30 cm) lengthwise.

Position of patient

- Seated (or standing) in a true lateral position with MCP perpendicular to the IR.
- Depress the shoulders as much as possible, and adjust them to lie in the same transverse plane.

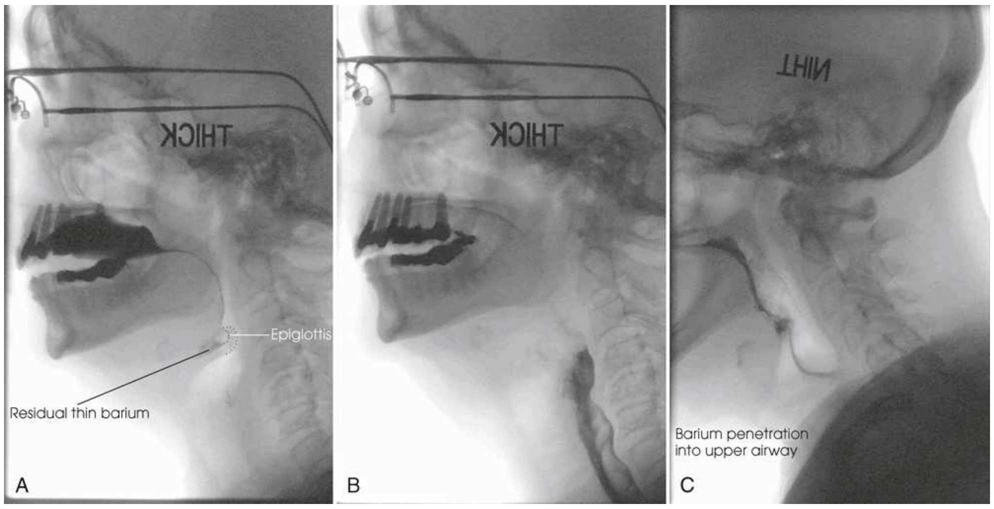


FIG. 15.34 Lateral images from modified barium swallow study. (A) Epiglottis, dotted outline. Thin barium seen on superior surface of epiglottis. (B) Same patient, later in swallowing process. All barium is inferior to epiglottis and in upper esophagus. Normal study. (C) Abnormal study. Epiglottis is curled up, and barium penetrates the upper airway. Chin tuck position performed later in this study and corrected the aspiration.

Three lateral view images of the barium swallow test of a patient. In A, a thin line of barium is visible on the epiglottis. In B, the barium is present in the esophagus of the patient. In C, one the barium is present in the upper airway and the epiglottis is curled.

Position of part

- Assist the speech therapist in adjusting the patient's head into a lateral position.
- Immobilize the head by having the patient look at an object in line with the visual axis. Speech therapist usually dictates the exact alignment of the chin (Fig. 15.33).
- *Shield gonads.*

Central ray

- Perpendicular to the IR.

Collimation

- Adjust the radiation field to the level of the EAM to the jugular notch; include all anterior oropharyngeal structures and the cervical vertebrae posteriorly. Place side marker in the collimated exposure field.

Structures shown

Profile images of the contrast-filled mouth, pharynx, and cervical esophagus in recorded videofluoroscopic images. Proper functioning of the epiglottis during deglutition is best seen in the lateral projection (Fig. 15.34).

Evaluation Criteria

The following should be clearly seen:

- Evidence of proper collimation and presence of side marker placed clear of anatomy of interest
- All soft tissue pharyngolaryngeal structures
- Area from nasopharynx to the uppermost part of the lungs in preliminary studies
- No superimposition of the trachea by the shoulders
- Closely superimposed mandibular shadows

Ap Projection

MBBS often only utilize the lateral projection. The need for the AP is often determined by specifics in the patient's history or evidence found during lateral imaging.

Position of patient

- Upright position, seated in the procedure chair or standing on the footboard of an upright table.

- If the standing position is used, have the patient distribute the weight of the body equally on the feet.

FIG. 15.35 Patient positioned for AP images during MBSS.

Position of part

- Center the MSP of the body to the midline of the vertical grid device.
- Adjust the patient's shoulders to lie in the same horizontal plane to prevent rotation of the head and neck and resultant obliquity of the throat structures.
- Center the IR at the level of or just below the laryngeal prominence.
- Assist the speech therapist in the specific head position needed to evaluate deglutition (Fig. 15.35).
- *Shield gonads.*

Central ray

- Perpendicular to the laryngeal prominence.

Collimation

- Adjust the radiation field to the level of the EAM to the jugular notch and 1 inch (2.5 cm) beyond the skin edges on the sides. Place side marker in the collimated exposure field.

Structures shown

• Contrast-filled mouth, pharynx, and cervical esophagus in recorded videofluoroscopic images. Evaluation of unilateral abnormalities are evaluated in the AP projections (Fig. 15.36).

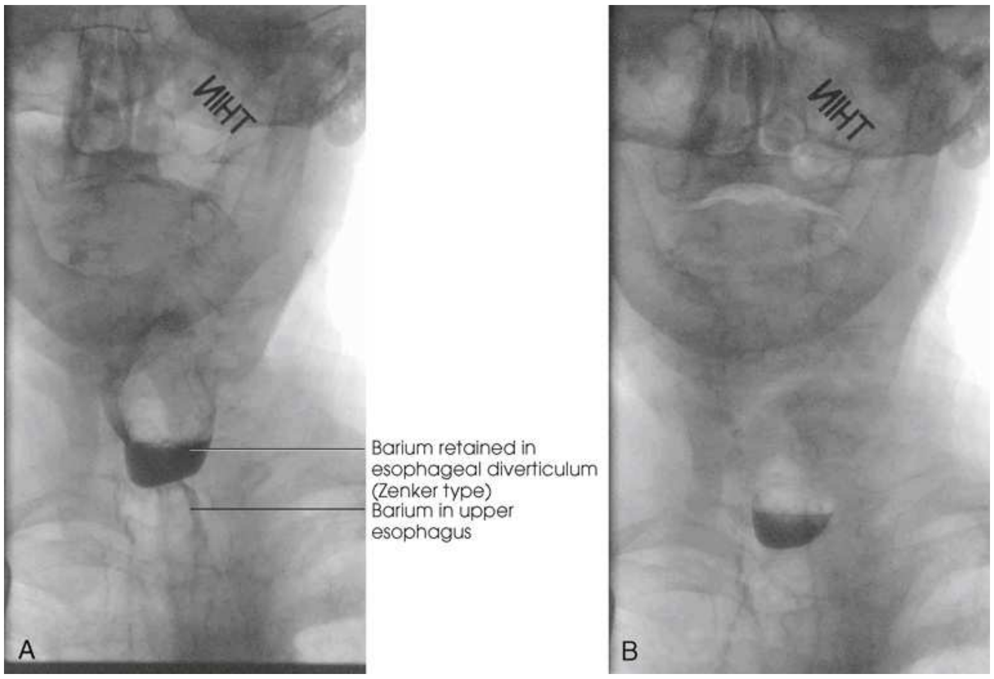


FIG. 15.36 AP images from modified barium swallow study. (A) Early swallow image shows barium retained in Zenker diverticulum and some barium flowing into esophagus. (B) Several swallows later, barium still retained in diverticulum.

Two A P images of a patient taken during barium swallow test. The first image is taken during early swallow. The Barium retained in esophageal diverticulum (Zenker type) and the Barium in upper esophagus are labeled. The second image is taken after several swallows. Barium is retained in the diverticulum.

Evaluation Criteria

The following should be clearly seen:

- Evidence of proper collimation and presence of side marker placed clear of anatomy of interest
- All soft tissue pharyngolaryngeal structures
- Area from nasopharynx to the uppermost part of the lungs without rotation

Esophagus, Stomach, Small Intestine, and Large Intestine

Technical Considerations

Gastrointestinal Transit

Peristalsis is the term applied to the contraction waves by which the digestive tube propels its contents toward the rectum. Normally three or four waves per minute occur in the filled stomach. The waves begin in the upper part of the organ and travel toward the pylorus. The average emptying time of a normal stomach is 2 to 3 hours.

Peristaltic action in the intestines is greatest in the upper part of the canal and gradually decreases toward the lower portion. In addition to peristaltic waves, localized contractions occur in the duodenum and the jejunum. These contractions usually occur at intervals of 3 to 4 seconds during digestion. The first part of a "barium meal" normally reaches the ileocecal valve in 2 to 3 hours, and the last portion reaches the ileocecal valve in 4 to 5 hours. The barium usually reaches the rectum within 24 hours.

The specialized procedures commonly used in radiologic examinations of the esophagus, stomach, and intestines are presented in this section. The esophagus connects the pharynx and the stomach and is located in the posterior part of the mediastinum; thus positioning the patient for demonstration of the contrast-filled esophagus is fairly simple, due to its consistent anatomic location. The stomach and intestines vary in size, shape, position, and muscular tonus according to the body habitus (see Fig. 15.14 and 15.20). In addition to normal structural and functional differences, various gastrointestinal abnormalities can cause further changes in location and motility. These variations make the gastrointestinal investigation of every patient an individual study, and meticulous attention must be given to each detail of the examination procedure.

Examination Procedure

The alimentary canal is typically imaged using only fluoroscopy. The radiographic projections are included in this chapter for student use as these positions are recorded during the fluoroscopic examination. The radiographer is responsible for:

• Preparing the room, equipment, and contrast media prior to the patient's arrival.

- Readying the patient for the procedure, that is, artifact removal, gowning, explanation of procedure.
- Obtaining and recording a thorough history.
- Obtaining a scout image of the anatomy of interest.
- Communicating with and assisting the patient before and after contrast administration.
- Assisting the fluoroscopist during the procedure, as needed.

If radiographic images are requested after the fluoroscopy examination, these images are also the responsibility of the radiographer. Radiographers must be proficient in recognizing the pertinent anatomy shown in each position and projection to provide proper patient assistance in fluoroscopy-only procedures and to obtain accurate radiographic images when requested.

Contrast media

Because the thin-walled alimentary canal does not have sufficient density to be shown through the surrounding structures, demonstration of it on radiographic images requires the use of an artificial contrast medium. *Barium sulfate,* which is a water-insoluble salt of the metallic element barium, is the contrast medium universally used in examinations of the alimentary canal (Fig. 15.37). The barium sulfate used for this purpose is a specially prepared, chemically pure product to which various chemical substances have been added. Barium sulfate is available as a dry powder or as a liquid. The powdered barium has different concentrations and is mixed with plain water. The concentration depends on the part to be examined and the preference of the physician.

Many special barium sulfate products are also available. Products with finely divided barium sulfate particles tend to resist precipitation and remain in suspension longer than regular barium preparations. Some barium preparations contain gums or other suspending or dispersing agents and are referred to as *suspended* or *flocculation-resistant* preparations. The speed with which the barium mixture passes through the alimentary canal depends on the suspending medium, the temperature of the medium, the consistency of the preparation, and the motile function of the alimentary canal.

In addition to barium sulfate, *water-soluble, iodinated contrast media* suitable for opacification of the alimentary canal are available (Fig. 15.38). These preparations are modifications of basic IV urographic media, such as diatrizoate sodium and diatrizoate meglumine.

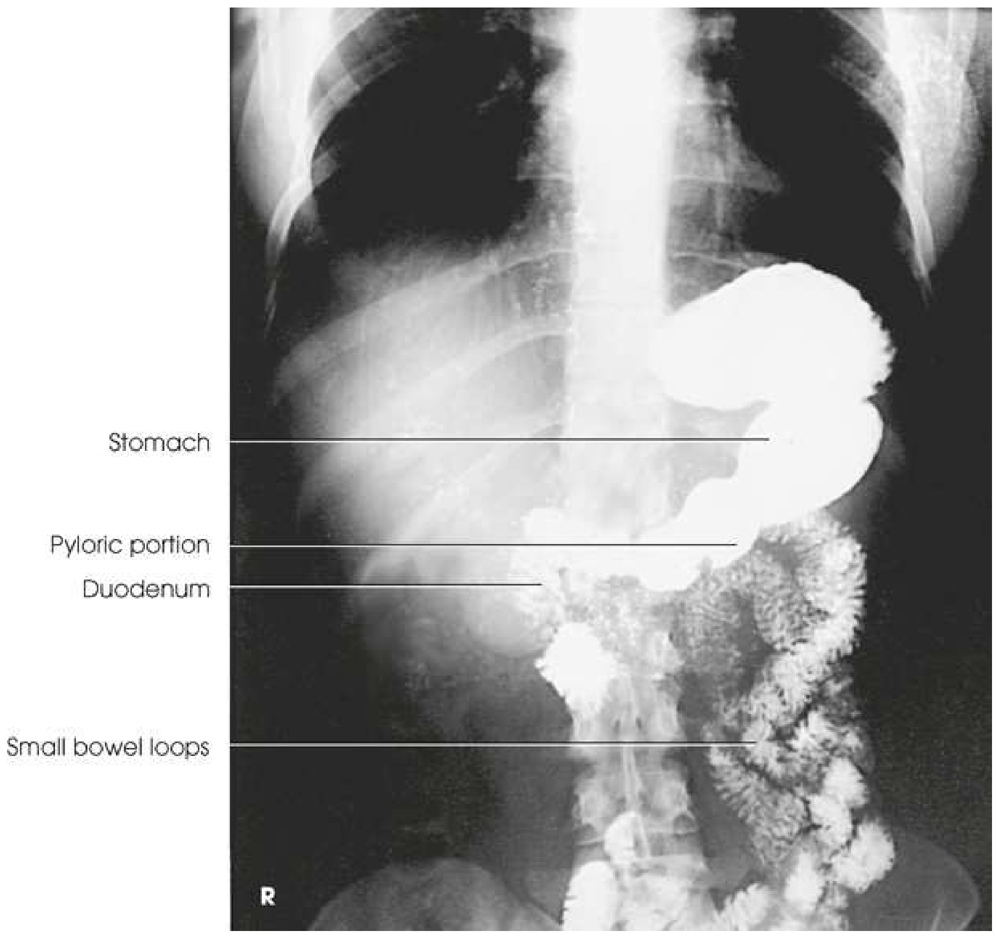


FIG. 15.37 Barium sulfate suspension in stomach, sthenic body habitus.

A radiograph of the anterior abdomen. The rib bones, spinal cord, and intestines are visible. The stomach, pyloric portion, duodenum, and small bowel loops are highlighted by the barium sulfate suspension and are labeled.

FIG. 15.38 Water-soluble, iodinated solution in stomach.

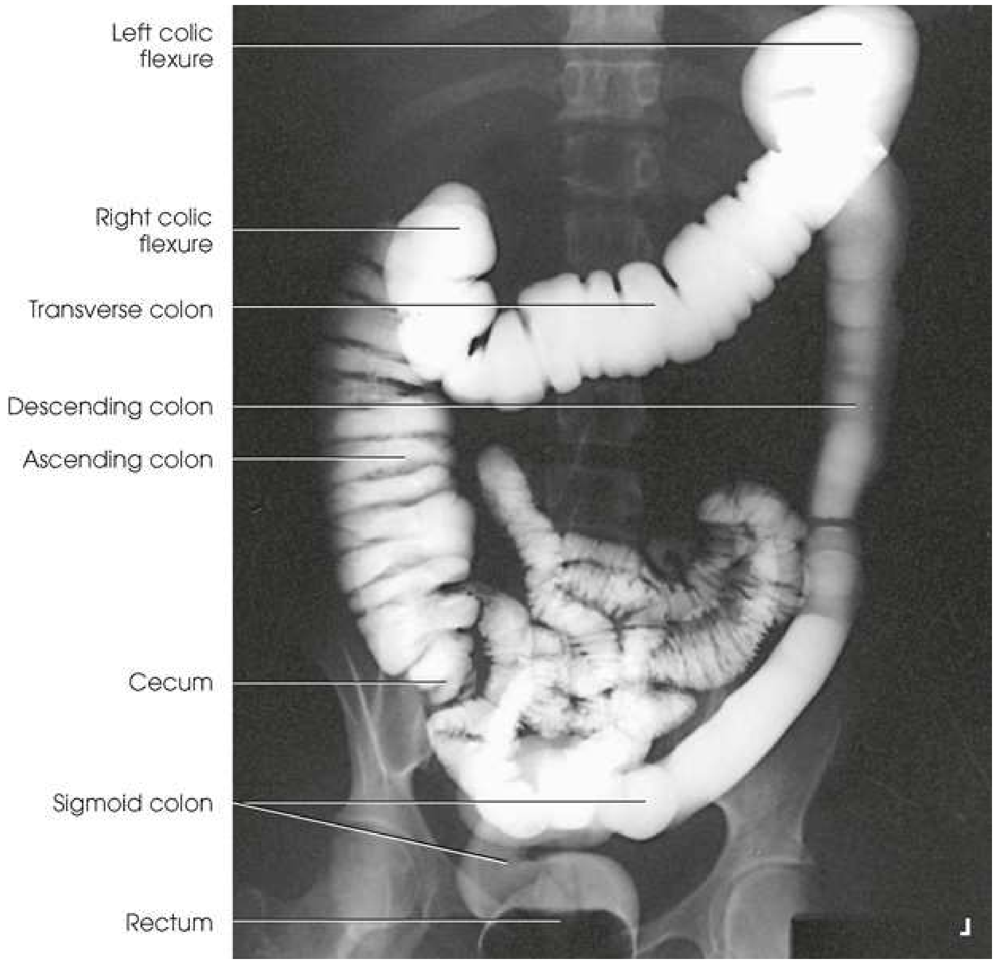


FIG. 15.39 Barium sulfate suspension administered by rectum, sthenic body habitus.

A radiograph of the anterior abdomen taken after administering barium sulfate through rectum. The rib bones, spinal cord, and intestines are visible. The right colic flexure, transverse colon, descending colon, ascending colon, cecum, sigmoid colon and rectum are highlighted and labeled.

FIG. 15.40 Water-soluble, iodinated solution administered by mouth.

A radiograph of the anterior abdomen taken after administering water soluble iodine through mouth. The rib bones, spinal cord, and intestines are visible. The stomach, intestines, colon, duodenum, and rectum are highlighted.

Iodinated solutions move through the gastrointestinal tract quicker than barium sulfate suspensions (Figs. 15.39 and 15.40). An iodinated solution normally clears the stomach in 1 to 2 hours, and the entire iodinated contrast column reaches and outlines the colon in about 4 hours. An orally administered iodinated medium differs from barium sulfate in the following ways:

1. It outlines the esophagus, but it does not adhere to the mucosa as well as a barium sulfate suspension does.
2. It affords an entirely satisfactory examination of the stomach and duodenum including mucosal delineation.
3. It permits a rapid survey of the entire small intestine but fails to provide clear anatomic detail of this portion of the alimentary canal. This failure results from dilution of the contrast medium and the resultant decrease in opacification.
4. Because of the normal rapid absorption of water through the colonic mucosa, the medium again becomes densely concentrated in the large intestine. As a result of its increased concentration and accelerated transit time, rapid investigation of the large intestine can be performed by the oral route when a patient cannot cooperate for a satisfactory enema study.

A great advantage of water-soluble media is that they are easily removed by aspiration before or during surgery. If a water-soluble, iodinated medium escapes into the peritoneum through a preexisting perforation of the stomach or intestine, no ill effects result. The medium is readily absorbed from the peritoneal cavity and excreted by the kidneys. This provides a definite advantage when perforated ulcers are being investigated.

A disadvantage of iodinated preparations is their strongly bitter taste, which can be masked only to a limited extent. Patients should be forewarned so that they can more easily tolerate ingestion of these agents. In addition, these iodinated contrast media are hyperosmolar, encouraging movement of excess fluid into the gastrointestinal tract lumen.

Radiologic apparatus

Fluoroscopic equipment provides real-time images and recording simultaneously. Remote control fluoroscopic rooms are also available and are used by the fluoroscopist in an adjacent control area (Fig. 15.41). Recorded images and video are available for immediate viewing after the procedure at appropriate workstations.

Compression and palpation of the abdomen are often performed during an examination of the alimentary canal. Many types of compression devices are available. The fluoroscopic unit shown in Fig. 15.42 shows a compression cone in contact with the patient's abdomen. This device is often used during general fluoroscopic examinations.

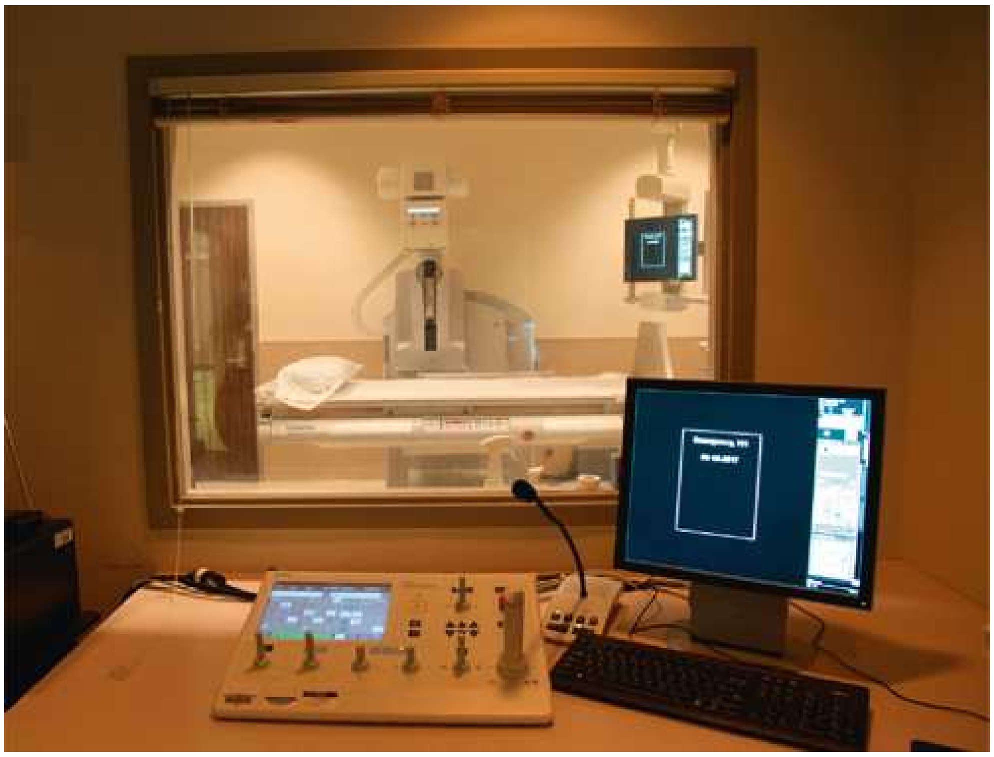


FIG. 15.41 Remote control fluoroscopic room, showing patient fluoroscopic table *(background)* and fluoroscopist's control console *(foreground)*. The fluoroscopist views the patient through the large window.

A view from a fluoroscopist's control console room. The patient fluoroscopic table is visible through a large window in the room. The patient is monitored using the equipment in the fluoroscopist's console room.

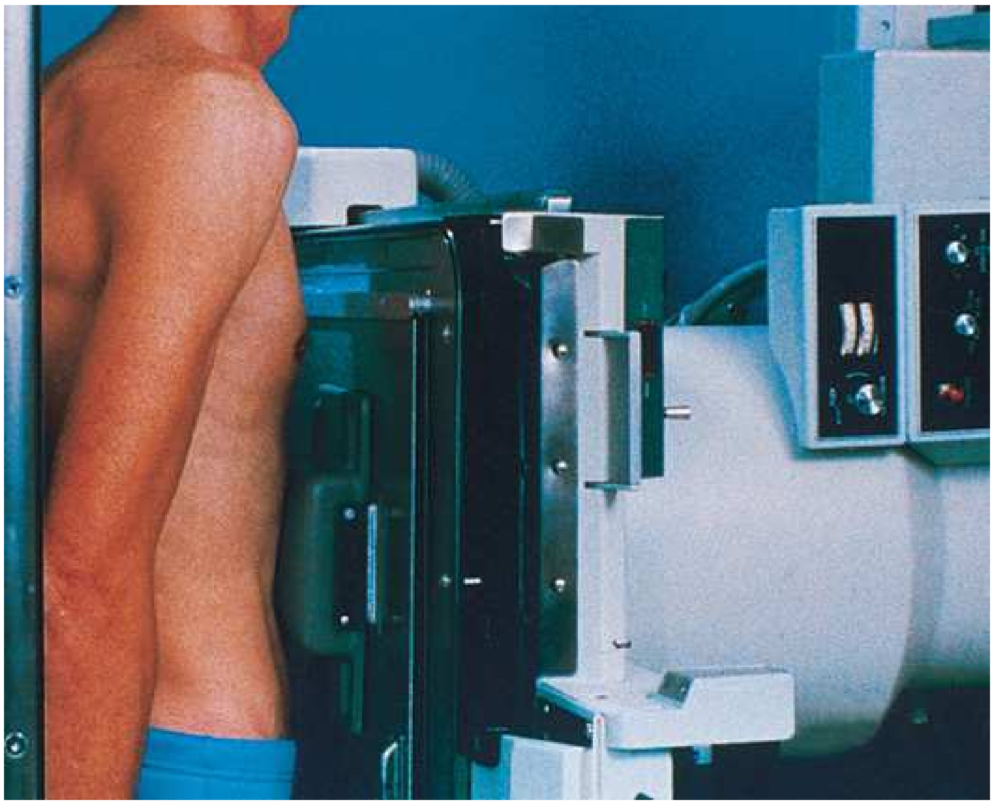


FIG. 15.42 Compression cone in contact with abdomen for fluoroscopy examination.

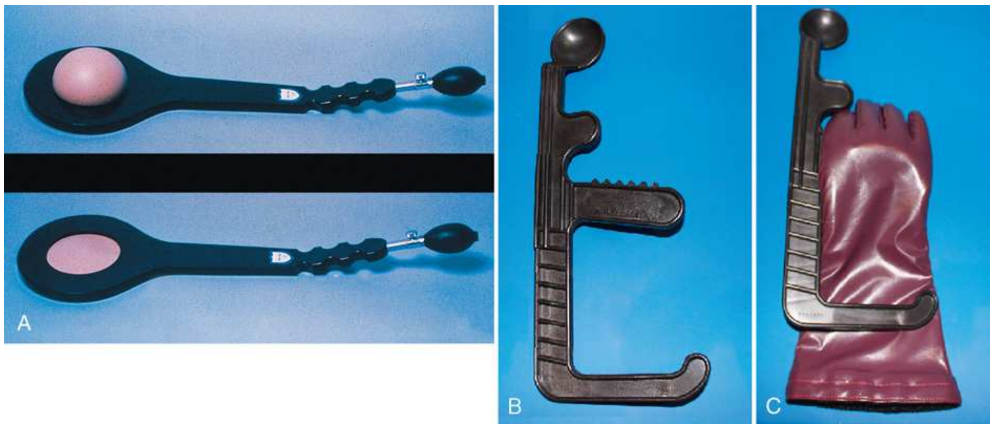


FIG. 15.43 (A) Compression paddle: inflated *(above)* and noninflated *(below)*; (B) F-spoon; (C) F-spoon with lead glove in position.

Other types of commercial compression devices include the pneumatic compression paddle and the F-spoon shown in Fig. 15.43. The compression paddle is often placed under the duodenal bulb or terminal ileum and inflated to place pressure on the abdomen. The balloon region is usually surrounded by a radiopaque ring. The F-spoon is used for the same purpose, but the compression end is completely radiolucent.

Preparation of examining room

The examining room should be completely prepared before the patient enters. In preparing the room, the radiographer should do the following:

- Adjust equipment controls to the appropriate settings.
- Have the footboard and shoulder support available.
- Check for proper operation of the imaging and recording devices.
- Prepare the required type and amount of contrast medium.
- Make appropriate image markers available.

Before beginning the examination, the radiographer must communicate with the patient in the following ways:

- Explain the type and administration route of the contrast media.
  - Use lay terminology, such as "drinking" for orally administered agents.
  - Explain the taste and texture of the contrast agent, such as "chalky and thick" for barium and "bitter" for iodinated agents.
  - For an enema examination, show the tube tip and explain insertion and the potential abdominal sensations that often accompany the flow of contrast into the colon.
- Point out that the lights are dimmed in the room during fluoroscopy, and explain the need for a darkened room during the procedure.

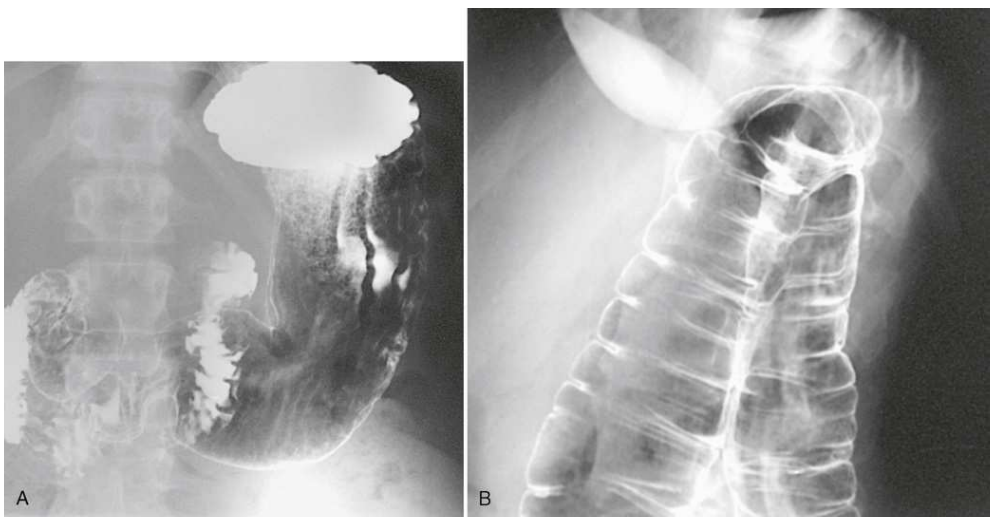


FIG. 15.44 (A) AP spot image of barium-filled fundus of stomach. (B) Spot image of air-contrast colon, showing left colic flexure.

- The fluoroscopist will instruct the patient to move into certain positions and will provide breathing instructions. Assure the patient that you will assist, as needed.
  - If radiographic images are obtained post fluoroscopy, inform the patient of the approximate number of images you will be obtaining when the fluoroscopist leaves the room.
- After you have verified that the patient understands the overall procedure, introduce the patient and the fluoroscopist to each other when the fluoroscopist enters the examining room.

Exposure time

One of the most important considerations in gastrointestinal radiography is the elimination of motion. The highest degree of motor activity is normally found in the stomach and proximal part of the small intestine. Activity gradually decreases along the intestinal tract with the slowest in the distal large bowel. Peristaltic speed also depends on the individual patient's body habitus and is influenced by pathologic changes, use of narcotic pain medication, body position, and respiration. The amount of exposure time for each region must be based on these factors.

In esophageal examinations, the radiographer should observe the following guidelines, if obtaining radiographic images post fluoroscopy:

- Use an exposure time of 0.1 second or less for upright images. The time may be slightly longer for recumbent images because the barium descends more slowly when patients are in a recumbent position.
- Barium passes through the esophagus fairly slowly if it is swallowed at the end of full inspiration. The rate of passage is increased if the barium is swallowed at the end of moderate inspiration. The barium is delayed in the lower part for several seconds, however, if it is swallowed at the end of full expiration.
- Respiration is inhibited for several seconds after the beginning of deglutition, which allows sufficient time for the exposure to be made without the need to instruct the patient to hold his or her breath after swallowing.

In examinations of the stomach and small intestine, the radiographer should observe the following guidelines:

- Use an exposure time no longer than 0.2 second for patients with normal peristaltic activity and never longer than 0.5 second; exposure time should be 0.1 second or less for patients with hypermotility.
- Make exposures of the stomach and intestines at the end of expiration in the routine procedure.

Esophagus

Radiation Protection

The patient receives radiation during fluoroscopy, while the procedure is recorded and images obtained (Fig. 15.44). When radiographic images are a required part of a partial or complete gastrointestinal examination, even more radiation is delivered to the patient. It is taken for granted that properly added filtration is in place at all times in each x-ray tube in the radiology department. It is further assumed that based on the capacity of the machines and the best available accessory equipment, exposure factors are adjusted to deliver the least possible radiation to the patient.

Protection of the patient from unnecessary radiation is a professional responsibility of the radiographer. (See Chapter 1 in Volume 1 of this atlas for specific guidelines.) In this chapter, the *Shield gonads* statement at the end of the *Position of part* section indicates that the patient is to be protected from unnecessary radiation by *restricting the radiation beam using proper collimation to include the primary anatomy of interest*. Placing lead shielding between the gonads and the radiation source when the clinical objectives of the examination are not compromised is also appropriate.

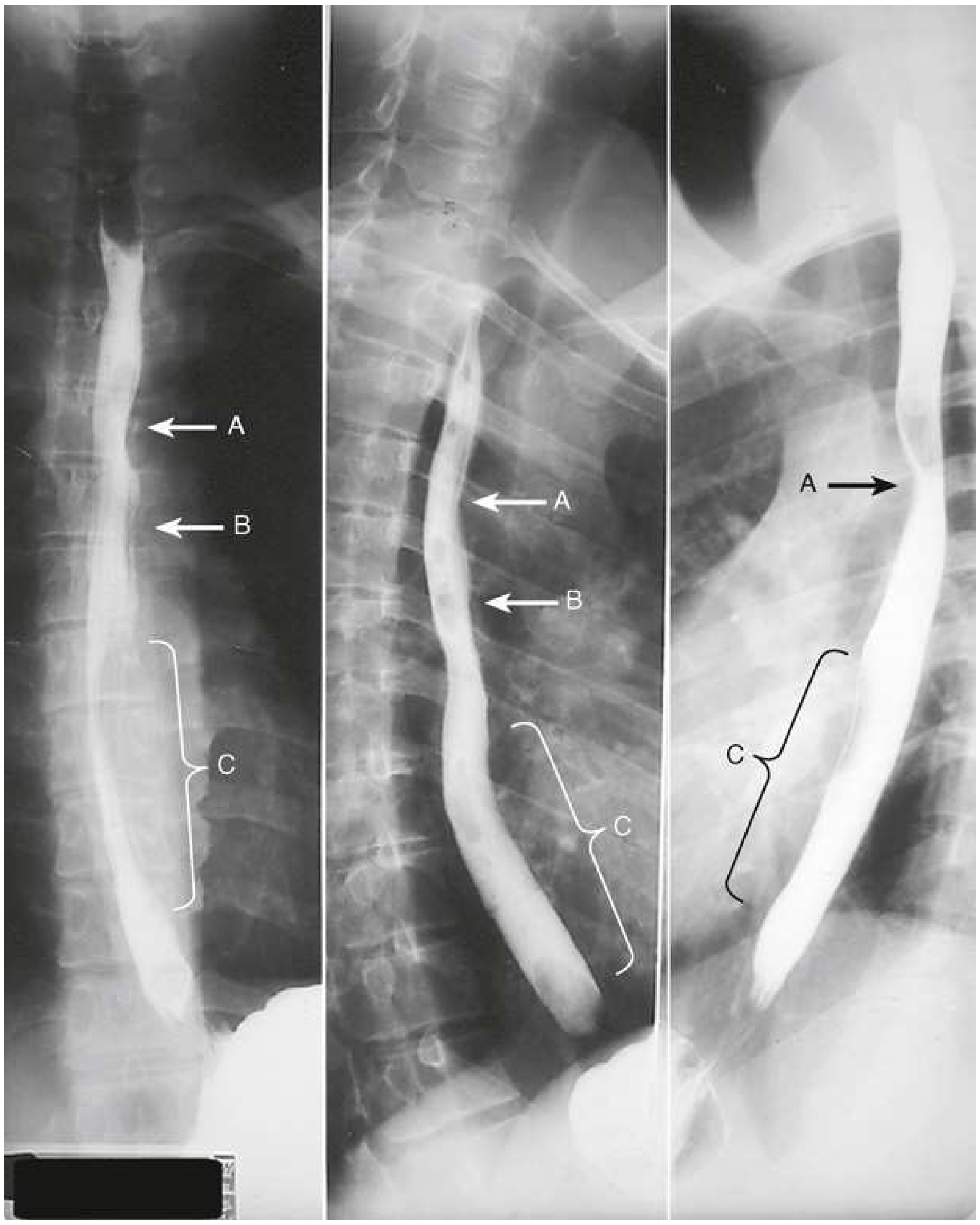


FIG. 15.45 Esophagogram images showing luminal indentations from adjacent anatomy. Normally indented structures include aortic arch *(A)*, left main stem bronchus *(B)*, and left atrium *(C)*.

Three Esophagogram images show a lateral view of the esophagus. The esophagus is visible as a long tubular structure. The upper part is the include aortic arch the middle part is the left main stem bronchus, and the posterior part is the left atrium.

Esophagus

Contrast Media Studies

The esophagus may be examined by performing a *full-column, single-contrast* study in which only barium or water-soluble, iodinated contrast agent is used to fill the esophageal lumen. A *double-contrast* procedure also may be used. For this study, high-density barium and carbon dioxide crystals (which liberate carbon dioxide when exposed to water) are the two contrast agents. No preliminary preparation of the patient is necessary. These contrast media procedures show intrinsic lesions and extrinsic pathology impressing on the esophagus. Anatomic structures normally indenting the esophagus must be appreciated to identify pathology. Normally indenting structures include the aortic arch, left main stem bronchus, and left atrium (Fig. 15.45).

Barium sulfate mixture

The ACR Practice Parameter (Resolution 29, 2013) recommends using a low-density (60% weight/volume) barium suspension for the single-contrast technique. A high-density barium (210% to 250% weight/volume) is recommended for double-contrast esophageal and gastric examinations.[5] Most barium suspensions are readily available in premixed liquid form, thus providing greater consistency than adding water to a powdered form. Whatever the weight/volume concentration of the barium, the most important criterion is that the barium flows sufficiently to coat the mucosal lining of the upper gastrointestinal (UGI) tract.

Examination procedures

For a single-contrast examination (Figs. 15.46 through 15.48), the following steps are taken:

- Start the fluoroscopic and spot-image examinations with the patient in the upright position when possible.
- Use the horizontal and Trendelenburg positions as indicated.
- After the fluoroscopic examination of the heart and lungs and when the patient is upright, instruct the patient to take the cup containing the barium suspension into the left hand and to drink it on request.

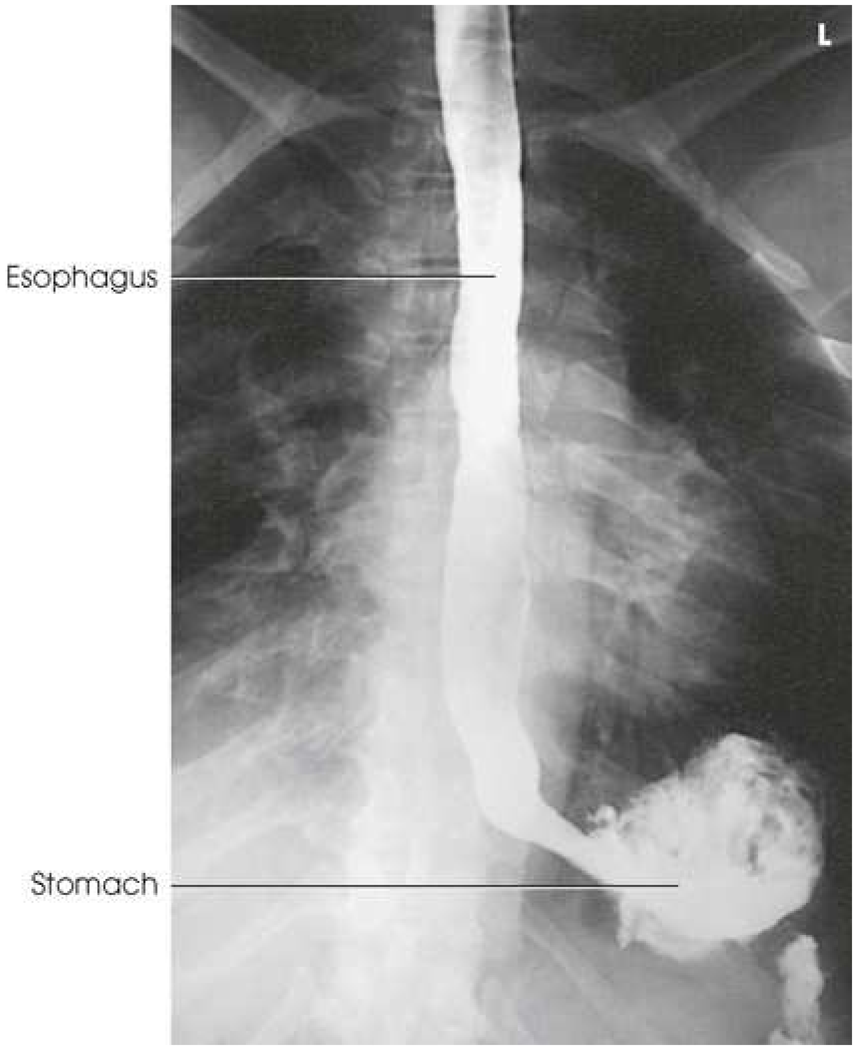


FIG. 15.46 AP esophagus, single-contrast study.

The radiologist asks the patient to swallow several mouthfuls of the barium so that the act of deglutition can be observed to determine whether any abnormality is present. The radiologist instructs the patient to perform various breathing maneuvers under fluoroscopic observation so that spot images of areas or lesions not otherwise shown can be obtained.

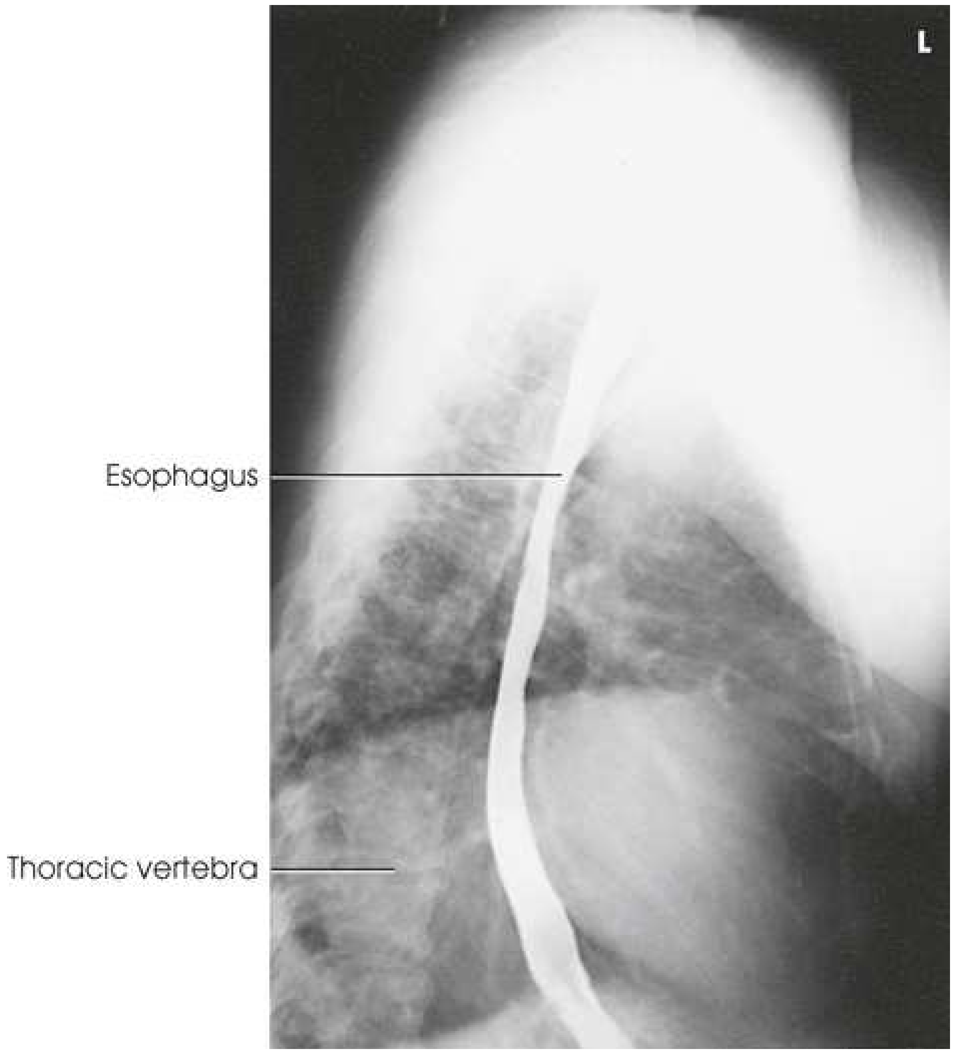


FIG. 15.47 Lateral esophagus, single-contrast study.

A radiograph of the lateral view of esophagus. The esophagus is highlighted by contrast and is visible as a long tubular structure. The thoracic vertebra beside the esophagus is highlighted and labeled.

Performance of a *double-contrast* esophageal examination (Fig. 15.49) is similar to that of a single-contrast examination. For a double-contrast examination, free-flowing, high-density barium must be used. A gas-producing substance, usually carbon dioxide crystals, can be added to the barium mixture or given by mouth immediately *before* the barium suspension is ingested. Spot images are taken during the examination, and delayed images may be obtained on request.

FIG. 15.48 PA oblique esophagus, RAO position, single-contrast study.

Opaque Foreign Bodies

Opaque foreign bodies lodged in the pharynx or in the upper part of the esophagus can usually be shown without the use of a contrast medium. A soft tissue neck or lateral projection of the retrosternal area may be taken for this purpose. A lateral neck image should be obtained at the height of swallowing for the delineation of opaque foreign bodies in the upper end of the intrathoracic esophagus. Swallowing elevates the intrathoracic esophagus a distance of two cervical segments, placing it above the level of the clavicles.

FIG. 15.49 PA oblique distal esophagus, RAO position, double-contrast spot image.

FIG. 15.50 Barium-soaked cotton ball showing nonopaque foreign body in upper esophagus *(arrow)*.

Tufts or pledgets of cotton saturated with a thin barium suspension are sometimes used to show an obstruction or to detect *nonopaque foreign bodies* in the pharynx and upper esophagus (Fig. 15.50). [6]

AP, PA, Oblique, And Lateral Projections

Image receptor + grid: Positioned by manufacturer or department protocol for proper anatomy display orientation; CR plate: 14 × 17 inches (35 × 43 cm) lengthwise.

Position of patient

- Position the patient as for chest images (AP, PA, oblique, and lateral; see Chapter 3, Volume 1). Because the RAO position of 35 to 40 degrees (Fig. 15.51) makes it possible to obtain a wider space for an unobstructed image of the esophagus between the vertebrae and the heart, it is usually used in preference to the LAO position. The LPO position has also been recommended. [7]
- Unless the upright position is specified, place the patient in the recumbent position for esophageal studies. The recumbent position is used to obtain more complete contrast filling of the esophagus (especially filling of the proximal part) by having the barium column flow against gravity. The recumbent position is routinely used to show variceal distentions of the esophageal veins because varices are best filled by having the blood flow against gravity. Variceal filling is more complete during increased venous pressure, which may be applied by full expiration or by the Valsalva maneuver.

AP or PA Projection

The following steps are taken:

- Place the patient in the supine or prone position with the arms above the head in a comfortable position.
- Center the MSP to the grid.
- Turn the head slightly, if necessary, to assist drinking of the barium mixture.
- *Shield gonads.*

Ap or Pa Oblique Projection

RAO or LPO position

The steps are as follows:

- Position the patient in the RAO or LPO position with the MSP forming an angle of 35 to 40 degrees from the grid device.
- For the RAO position, adjust the patient's side-down arm at the side and the side-up arm on the pillow by the head. For the LPO position, do the same, with the side-down arm at the side and the side-up arm on the pillow.
- Center the elevated side to the grid through a plane approximately 2 inches (5 cm) lateral to the MSP.
- *Shield gonads.*

Lateral Projection

Right or left position

The steps are as follows:

- Place the patient's arms forward, with the forearm on the pillow near the head.

FIG. 15.51 PA oblique esophagus, RAO position.

- Position the midcoronal plane to the center of the grid.
- *Shield gonads.*

Central ray

- Perpendicular to the midpoint of the IR (the central ray is at the level of T5-T6).

Collimation

- Adjust the radiation field to no larger than 12 × 17 inches (30 × 43 cm). Place side marker in the collimated exposure field.

Structures shown

Contrast-filled esophagus from the lower neck to the esophagogastric junction (Fig. 15.52).

Evaluation Criteria

The following should be clearly seen:

General

- Evidence of proper collimation and presence of side marker placed clear of anatomy of interest
- Esophagus from the lower part of the neck to its entrance into the stomach
- Esophagus filled with barium
- Penetration of the barium

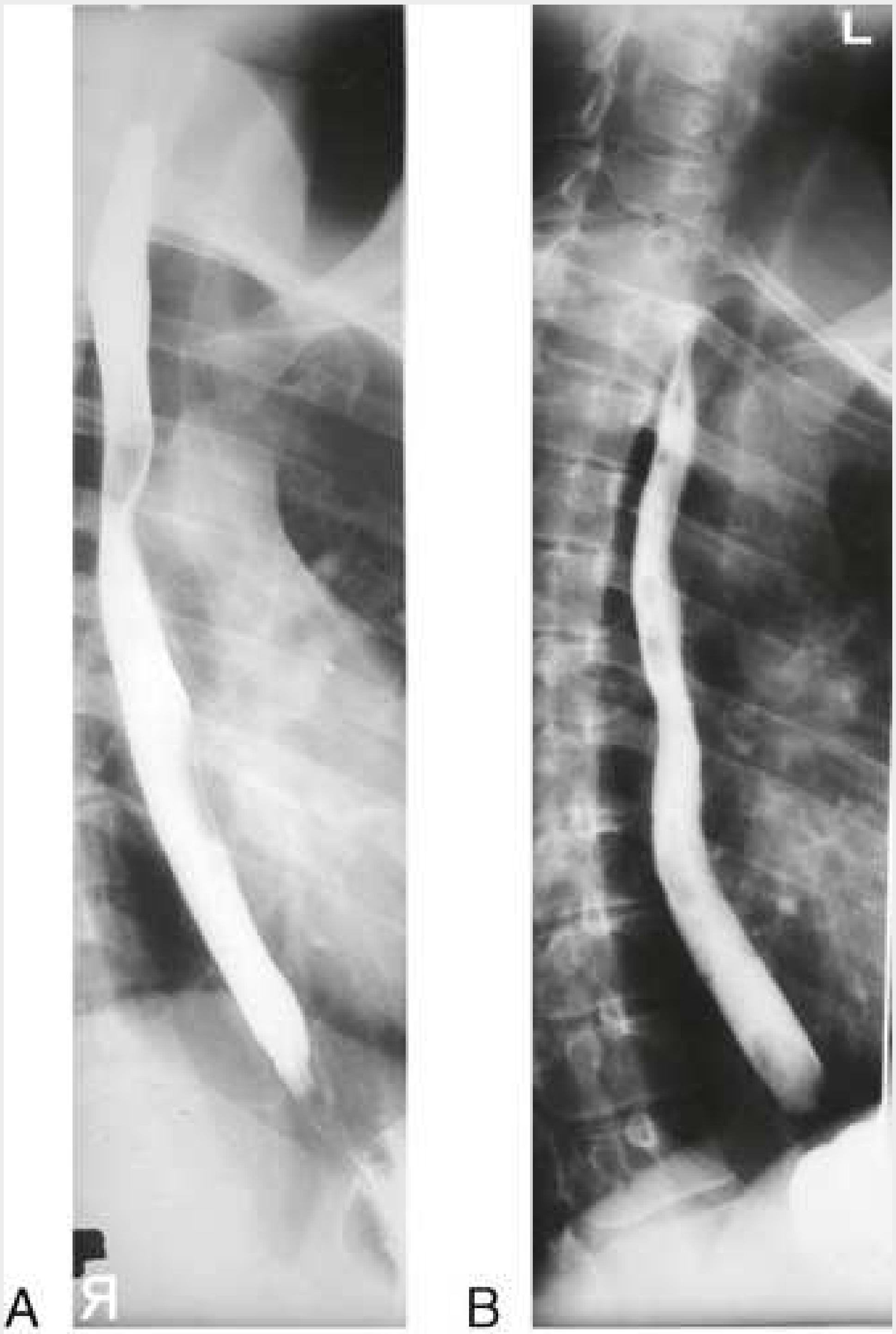


FIG. 15.52 (A) PA oblique esophagus, RAO position. (B) AP oblique esophagus, LPO position.

AP or PA projection (see Fig. 15.46)

- Esophagus through the superimposed thoracic vertebrae
- No rotation of the patient

Oblique projection (see Fig. 15.52)

- Esophagus between the vertebrae and the heart

Lateral projection (see Fig. 15.47)

- Proximal esophagus without superimposition of the patient's arm

- Ribs posterior to the vertebrae superimposed to show that the patient was not rotated

NOTE: The general criteria apply to all projections: AP or PA, oblique, and lateral.

Barium administration and respiration

- Feed the barium sulfate suspension to the patient by spoon, by cup, or through a drinking straw, depending on its consistency.
- Ask the patient to swallow several mouthfuls of barium in rapid succession and then to hold a mouthful until immediately before the exposure.
- To show esophageal varices, instruct the patient (1) to exhale fully and then swallow the barium bolus and avoid inspiration until the exposure has been made, or (2) to take a deep breath and, while holding the breath, swallow the bolus and then perform the Valsalva maneuver (Fig. 15.53A).
- For other conditions, instruct the patient simply to swallow the barium bolus, which is normally done during moderate inspiration (see Fig. 15.53B). Because respiration is inhibited for about 2 seconds after swallowing, the patient does not have to hold his or her breath for the exposure. If the contrast medium is swallowed at the end of full inspiration, make two or three exposures in rapid succession before the contrast medium passes into the stomach. To show the entire esophagus, it is sometimes necessary to make the exposure while the patient is drinking the barium suspension through a straw in rapid and continuous swallows.
- Ask the patient to swallow a barium tablet to evaluate the degree of lumen narrowing with esophageal stricture (Fig. 15.54).

FIG. 15.53 (A) Spot images showing esophageal varices. (B) Barium bolus clearly shows Schatzki ring *(arrows)*. Courtesy Michael J. Kudlas, MEd, RT[R][QM].

FIG. 15.54 AP projection showing barium pill in distal esophagus, at the site of luminal stricture.

Stomach

Gastrointestinal Series

UGI tract images are used to evaluate the distal esophagus, the stomach, and some or all of the small intestine. A UGI examination (Fig. 15.55), usually called a *gastrointestinal* or *UGI series,* may include the following:

1. A preliminary image of the abdomen to delineate the liver, spleen, kidneys, psoas muscles, and bony structures and to detect any abdominal or pelvic calcifications or tumor masses. Detection of calcifications and tumor masses requires that the survey image of the abdomen be taken after preliminary cleansing of the intestinal tract but before administration of the contrast medium.
2. Fluoroscopic recorded images only or a combination of fluoroscopic and radiographic images after contrast administration. Images will include the esophagus, stomach, and duodenum using an ingested opaque mixture, usually barium sulfate.
3. When requested, a small intestine study consisting of images obtained at frequent intervals during passage of the contrast column through the small intestine, at which time the vermiform appendix and the ileocecal region may be examined.

Nonambulatory outpatients or acutely ill patients, such as patients with a bleeding ulcer, are usually examined in the supine position using a fluoroscopic and spot-imaging procedure. Everything possible should be done to expedite the procedure. Any contrast preparation must be ready, and the examination room must be fully prepared before the patient is brought into the radiology department.

Preliminary Preparation

Preparation of patient

Because a gastrointestinal series is time-consuming, the patient should be told the approximate time required for the procedure before being assigned an appointment for an examination. The patient also needs to understand the reason for preliminary preparation so that full cooperation can be given.

The stomach must be empty for an examination of the UGI tract (the stomach and small intestine). It is also desirable to have the colon free of gas and fecal material. When the patient is constipated, a non–gas-forming laxative may be administered 1 day before the examination.

FIG. 15.55 Barium-filled AP stomach and small bowel.

A radiograph of the anterior view of the esophagus. The rib bones and vertebral bones are visible. The esophagus, stomach, and intestines are highlighted by the presence of barium. The esophagus is connected to the stomach.

An empty stomach is ensured by withholding food and water after midnight for 8 to 9 hours before the examination. When a small intestine study is to be made, food and fluid are withheld after the evening meal.

Because some research suggests that nicotine and chewing gum stimulate gastric secretion and salivation, some physicians tell patients not to smoke or chew gum after midnight on the night before the examination. This restriction is intended to prevent excessive fluid from accumulating in the stomach and diluting the barium suspension enough to interfere with its coating property. Radiographers should verify patient compliance with the preliminary preparation before obtaining the scout abdominal image, and should inform the fluoroscopist of the patient's answer when the scout image is provided for preliminary inspection.

Barium sulfate suspension

The contrast medium generally used in routine gastrointestinal examinations is barium sulfate mixed with water. The preparation must be thoroughly mixed according to the manufacturer's instructions. Specially formulated high-density barium is also available. Advances in the production of barium have all but eliminated the use of a single barium formula for most gastrointestinal examinations performed in the radiology department.

Most physicians use one of the many commercially prepared barium suspensions. These products are available in several flavors, and some are conveniently packaged in individual cups containing the dry ingredients. To these products, the radiographer merely has to add water, recap the cup, and shake it to obtain a smooth suspension. Other barium suspensions are completely mixed and ready to use.

Contrast Studies

Two general procedures are routinely used to examine the stomach: the *single-contrast* method and the *double-contrast* method. A *biphasic* examination is a combination of the single-contrast and double-contrast methods during the same procedure.

Single-Contrast Examination

In the single-contrast method (Fig. 15.56), a barium sulfate suspension is administered during the initial fluoroscopic examination. The ACR recommends a 60% weight/volume barium suspension used for this study. [8] The procedure is as follows:

- Whenever possible, begin the examination with the patient in the upright position.
- The radiologist may first examine the heart and lungs fluoroscopically and observe the abdomen to determine whether food or fluid is in the stomach.
- Give the patient a glass of barium and instruct the patient to drink it as requested by the radiologist. If the patient is in the recumbent position, administer the suspension through a drinking straw.
- The radiologist asks the patient to swallow two or three mouthfuls of barium. During this time, the radiologist examines and exposes any indicated spot images of the esophagus. By manual manipulation of the stomach through the abdominal wall, the radiologist then coats the gastric mucosa.
- Images are obtained with the spot-imaging device or another compression device to show a mucosal lesion of the stomach or duodenum.
- After studying the rugae and as the patient drinks the remainder of the barium suspension, the radiologist observes filling of the stomach and examines the duodenum further. Based on this examination, the following can be accomplished:
    1. Determine the size, shape, and position of the stomach.
    2. Examine the changing contour of the stomach during peristalsis.
    3. Observe the filling and emptying of the duodenal bulb.
    4. Detect any abnormal alteration in the function or contour of the esophagus, stomach, and duodenum.
    5. Record spot images as indicated.

The contrast medium normally begins to pass into the duodenum almost immediately. Nervous tension of the patient may delay transit of the contrast material, however.

Fluoroscopy is performed with the patient in the upright and recumbent positions while the body is rotated and the table is angled, so that all aspects of the esophagus, stomach, and duodenum are shown. Spot images are recorded as indicated. If esophageal involvement is suspected, a study is usually made with a thick barium suspension. In facilities in which subsequent radiographic images of the stomach and duodenum are required, the required projections should be obtained immediately after fluoroscopy before any considerable amount of the barium suspension passes into the jejunum.

Position of patient

The stomach and the duodenum may be examined using PA, AP, oblique, and lateral projections with the patient in the upright and recumbent positions, as indicated by the fluoroscopic findings.

One variation of the supine position is the LPO position. In another variation, the head end of the table is lowered 25 to 30 degrees to show a hiatal hernia. Finally, to show esophageal regurgitation and hiatal hernias, the head end of the table is lowered 10 to 15 degrees and the patient is rotated slightly toward the right side to place the esophagogastric (gastroesophageal) junction in profile to the right of the spine. The medical significance of diagnosing hiatal hernia is a topic that has received much attention in recent years. Some authors report little correlation between the presence of a hiatal hernia and gastrointestinal symptoms. If little correlation exists, radiographic evaluation is of little value in most hiatal hernias.

FIG. 15.56 Barium-filled PA stomach, single-contrast study.

A radiograph of the P A view of the stomach. The rib bones and vertebral bones are visible. The esophagus, stomach, and intestines are highlighted by the presence of barium. The esophagus is connected to the stomach.

Double-Contrast Examination

A second approach to examination of the gastrointestinal tract is the *double-contrast* technique (Fig. 15.57). The principal advantages of this method over the single-contrast method are that small lesions are less easily obscured and the mucosal lining of the stomach can be more clearly visualized. For successful results, the patient must be able to move with relative ease throughout the examination.

For double-contrast studies, the procedure is as follows:

- To begin the examination, place the patient on the fluoroscopic table in the upright position.
- Give the patient a gas-producing substance in the form of a powder, crystals, pills, or a carbonated beverage.
- Give the patient a small amount of commercially available, high-density barium suspension. For even coating of the stomach walls, the barium must flow freely and have low viscosity. Many high-density barium products are available; these suspensions have weight/volume ratios of up to 250%.
- Place the patient in the recumbent position, and instruct him or her to turn from side to side or to roll over a few times. This movement serves to coat the mucosal lining of the stomach as the carbon dioxide continues to expand. The patient may feel the need to belch but should refrain from doing so until the examination is finished to ensure that an optimal amount of contrast material (gas) remains for the duration of the examination.
- Just before the examination, the patient may be given glucagon or other anticholinergic medications intravenously or intramuscularly to relax the gastrointestinal tract.[9] These medications improve visualization by inducing greater distention of the stomach and intestines. Before administering these agents, the radiologist must consider numerous factors, including side effects, contraindications, availability, and cost.

Radiographic imaging procedure

The conventional images obtained after the fluoroscopic examination may be the same as images obtained for the single-contrast examination. Often the images with the greatest amount of diagnostic information are the spot images taken during fluoroscopy. In most cases, the radiologist will have already obtained most of the necessary diagnostic images. Nonfluoroscopic images may be unnecessary.

Biphasic Examination

The *biphasic* gastrointestinal examination incorporates the advantages of single-contrast and double-contrast UGI examinations, with both examinations performed during the same procedure. The patient first undergoes a double-contrast examination of the UGI tract. When this study is completed, the patient is given an approximately 15% weight/volume barium suspension, and a single-contrast examination is performed. This biphasic approach increases the accuracy of diagnosis without significantly increasing the cost of the examination.

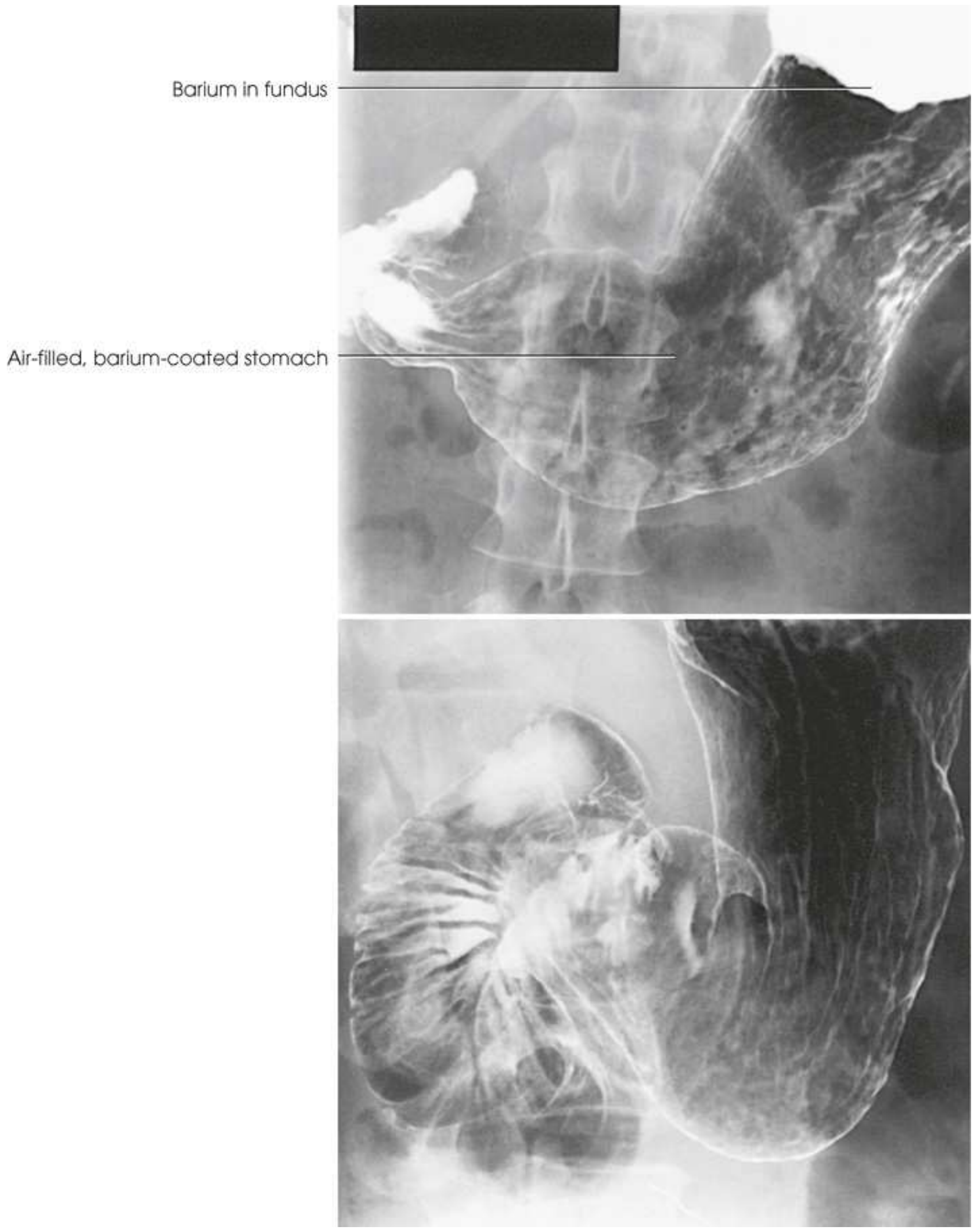


FIG. 15.57 Double-contrast stomach spot images.

Stomach and Duodenum

PA Projection

Image receptor + grid: Positioned by manufacturer or department protocol for proper anatomy display orientation; CR plate: 10 × 12 inches (24 × 30 cm) or 14 × 17 inches (35 × 43 cm) lengthwise.

Position of patient

- For radiographic studies of the stomach and duodenum, place the patient in the recumbent position. The upright position is sometimes used to show the relative position of the stomach.
- When adjusting thin patients in the prone position, support the weight of the body on pillows or other suitable pads positioned under the thorax and pelvis. This adjustment keeps the stomach or duodenum from pressing against the vertebrae, with resultant pressure-filling defects.

Position of part

• Adjust the patient's position recumbent or upright so that the midline of the grid coincides with a sagittal plane passing halfway between the vertebral column and the left lateral border of the abdomen (Fig. 15.58).
• Center the IR about 1 to 2 inches (2.5 to 5 cm) above the lower rib margin at the level of L1-L2 when the patient is prone (Figs. 15.59 and 15.60).

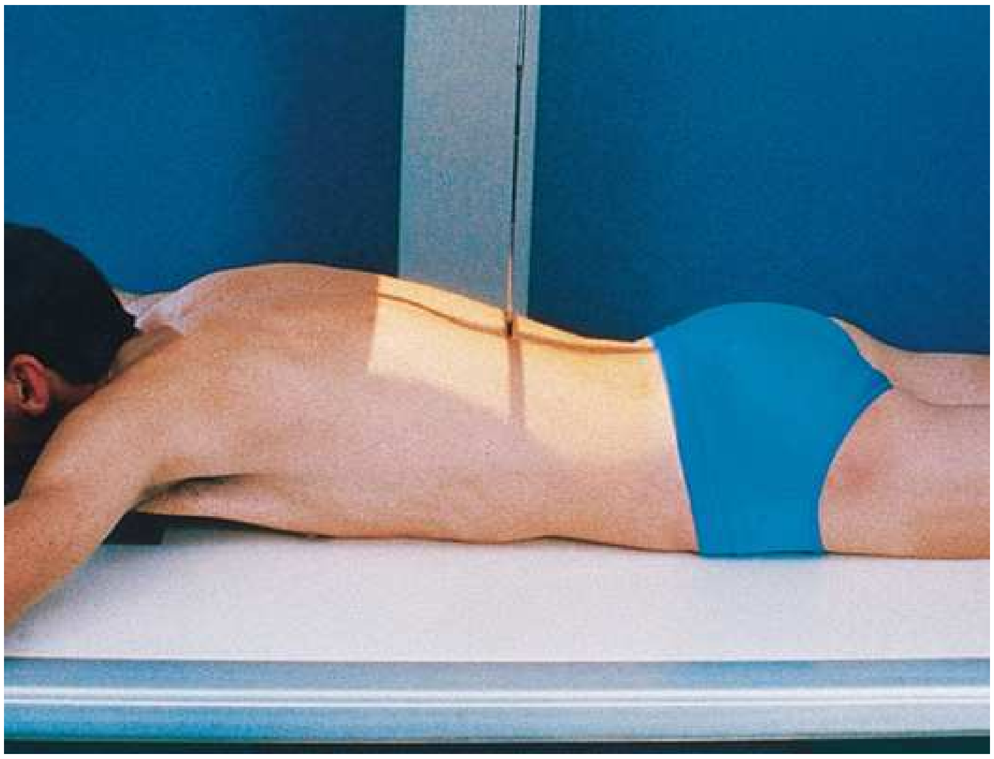


FIG. 15.58 PA stomach and duodenum.

FIG. 15.59 Single-contrast PA stomach and duodenum.

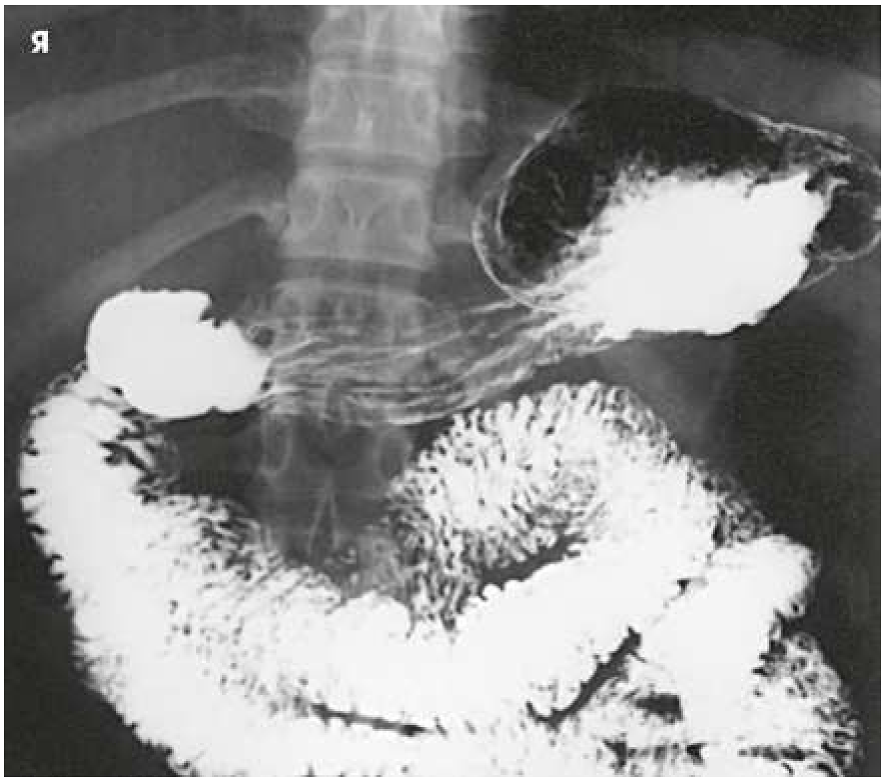


FIG. 15.60 Double-contrast PA stomach and duodenum.

A radiograph of the P A view of stomach and duodenum taken with double contrast. The stomach and duodenum are highlighted by the double contrast. The edges of the duodenum attached to the stomach are smudged.

- For upright images, center the IR 3 to 6 inches (7.6 to 15 cm) lower than L1-L2. The greatest visceral movement between prone and upright positions occurs in asthenic patients.
- *Shield gonads.*
- *Respiration:* Suspend at the end of expiration unless otherwise requested.

Central ray

- Perpendicular to the center of the IR.

Collimation

- Adjust the radiation field to no larger than 10 × 12 inches (24 × 30 cm) for smaller patients or 11 × 14 inches (28 × 35 cm) for larger patients. Place side marker in the collimated exposure field.

Structures shown

A PA projection of the contour of the barium-filled stomach and duodenal bulb is shown. The upright position shows the size, shape, and relative position of the filled stomach, but it does not adequately show the unfilled fundic portion of the organ. In the prone position, the stomach moves superiorly 1

1/2

to 4 inches (3.8 to 10 cm) according to the patient's body habitus (Figs. 15.61–15.64). At the same time, the stomach spreads horizontally, with a comparable decrease in its length. (Note that the fundus usually fills in asthenic patients.)

The pyloric canal and the duodenal bulb are well shown in patients with an asthenic or hyposthenic habitus. These structures are often partially obscured in patients with a sthenic habitus and, except in the PA axial projection, are completely obscured by the prepyloric portion of the stomach in patients with a hypersthenic habitus.

Evaluation Criteria

The following should be clearly seen:

- Evidence of proper collimation and presence of side marker placed clear of anatomy of interest
- Entire stomach and duodenal loop
- Stomach centered at the level of the pylorus

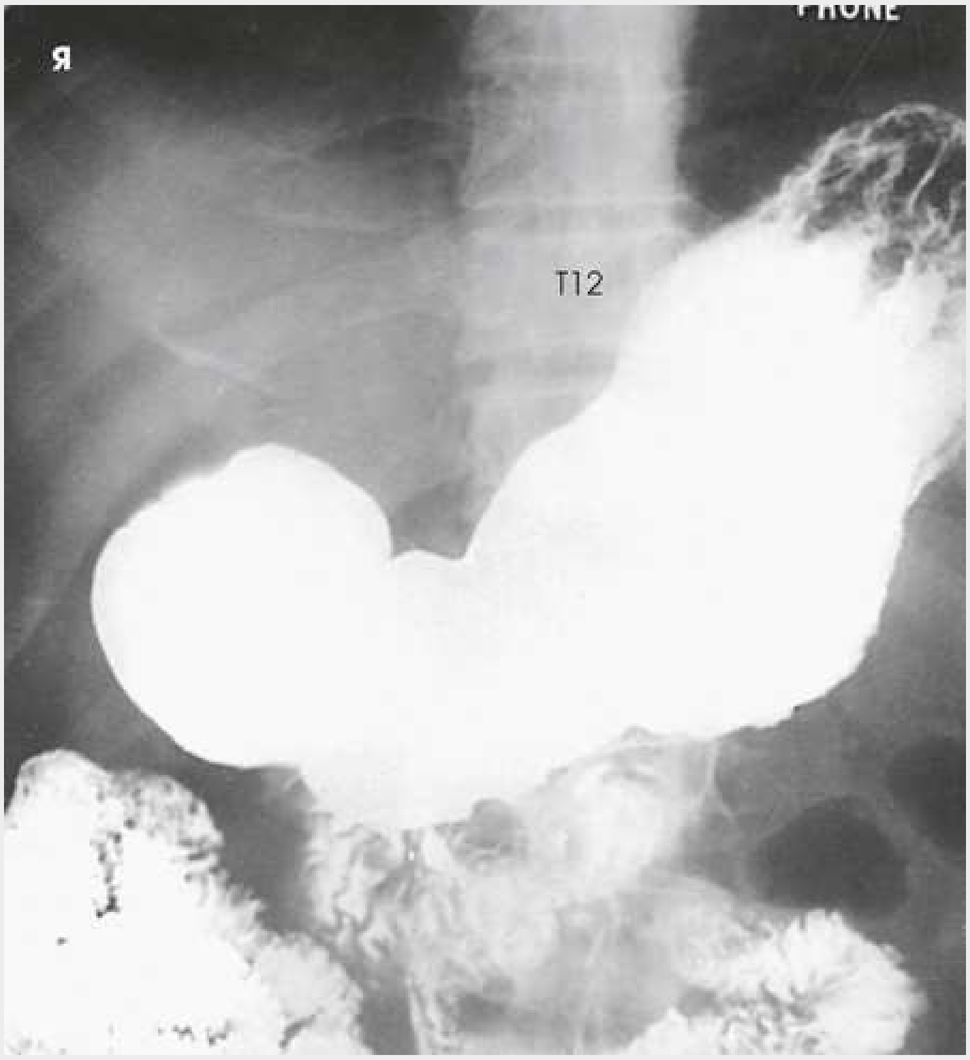


FIG. 15.61 Hypersthenic patient.

A radiograph of the P A view of stomach and duodenum of a hypersthenic patient. The stomach and duodenum are highlighted by the double contrast. The edges of the duodenum attached to the stomach are smudged.

FIG. 15.62 Sthenic patient.

A radiograph of the P A view of stomach and duodenum of a sthenic patient. The stomach and duodenum are highlighted by the double contrast. The edges of the duodenum attached to the stomach are smudged.

- No rotation of the patient
- Penetration of the contrast medium
- Surrounding anatomy

NOTE: A 14- × 17-inch (35- × 43-cm) exposure field is often used when the distal esophagus or the small bowel is to be visualized along with the stomach.

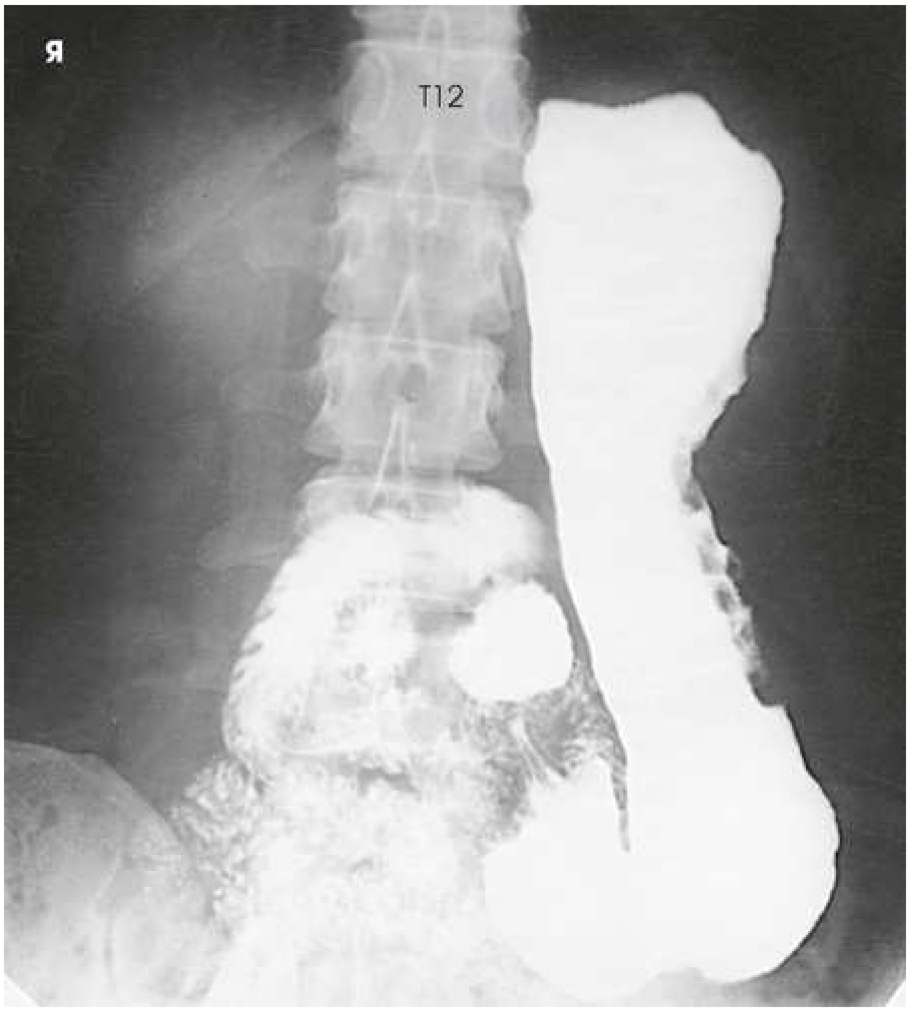


FIG. 15.63 Hyposthenic patient.

A radiograph of the P A view of stomach and duodenum of a hypersthenic patient. The stomach and duodenum are highlighted by the double contrast. The edges of the duodenum attached to the stomach are smudged.

FIG. 15.64 Asthenic patient.

A radiograph of the P A view of stomach and duodenum of an asthenic patient. The stomach and duodenum are highlighted by the double contrast. The edges of the duodenum attached to the stomach are smudged.

Pa Axial Projection

Image receptor + grid: Positioned by manufacturer or department protocol for proper anatomy display orientation; CR plate: 10 × 12 inches (24 × 30 cm) or 14 × 17 inches (35 × 43 cm) lengthwise.

Position of patient

- Place the patient in the prone position.

Position of part

- Adjust the patient's body so that the MSP is centered to the grid.
- For a sthenic patient, center the IR at the level of L2 (Fig. 15.65), at about 1 to 2 inches (2.5 to 5 cm) above the lower rib margin; center it higher for a hypersthenic patient and lower for an asthenic patient.
- *Shield gonads.*
- *Respiration:* Suspend respiration at the end of expiration unless otherwise requested.

Central ray

- Directed to the midpoint of the IR at an angle of 35 to 45 degrees cephalad. Gugliantini [10] recommended cephalic angulation of 20 to 25 degrees to show the stomach in infants.

Collimation

- Adjust the radiation field to be no larger than 14 × 17 inches (35 × 43 cm). Place side marker in the collimated exposure field.

Structures shown

Gordon [11] developed the PA axial projection to "open up" the high, horizontal (hypersthenic-type) stomach to show the greater and lesser curvatures, the antral portion of the stomach, the pyloric canal, and the duodenal bulb. The resultant image gives a hypersthenic stomach much the same configuration as the average sthenic type of stomach (Fig. 15.66).

Evaluation Criteria

The following should clearly be seen:

- Evidence of proper collimation and presence of side marker placed clear of anatomy of interest
- Entire stomach and proximal duodenum
- Stomach centered at the level of the pylorus
- Penetration of the contrast medium
- Surrounding anatomy

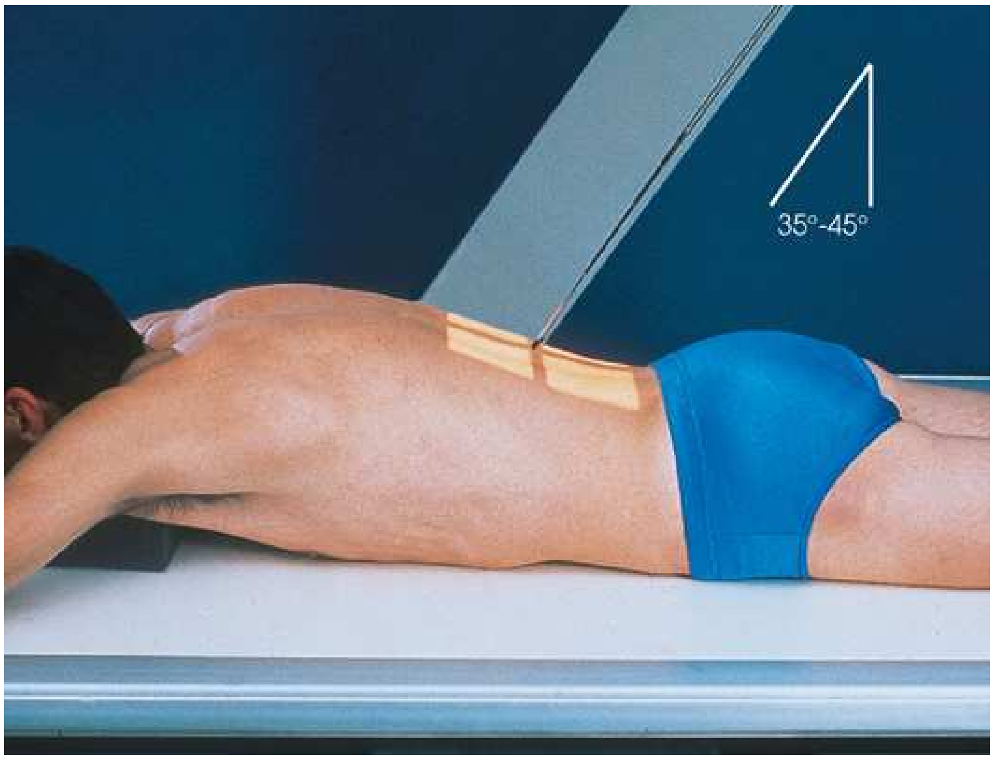


FIG. 15.65 PA axial stomach.

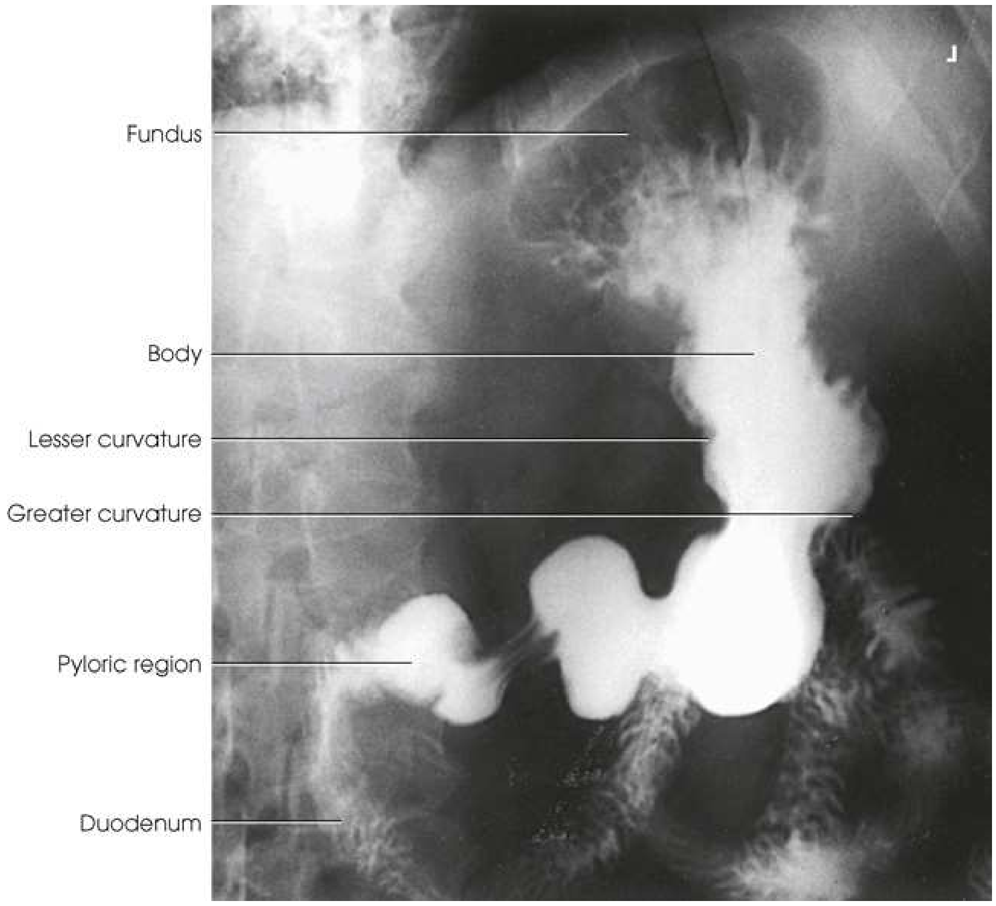


FIG. 15.66 PA axial stomach, sthenic habitus.

A radiograph of the P A view of stomach and sthenic habitus. The Duodenum, fundus, Pyloric region, Greater curvature, Lesser curvature, and Body of the stomach are highlighted and labeled. The esophagus is visible.

Pa Oblique Projection

RAO position

Image receptor + grid: Positioned by manufacturer or department protocol for proper anatomy display orientation; CR plate: 10 × 12 inches (24 × 30 cm) or 14 × 17 inches (35 × 43 cm) lengthwise.

Position of patient

- Place the patient in the recumbent position.

Position of part

- After the PA projection, instruct the patient to rest the head on the right cheek and to place the right arm along the side of the body.
- Have the patient raise his or her left side and support the body on the left forearm and flexed left knee.
- Adjust the patient's position so that a sagittal plane passing midway between the vertebrae and the lateral border of the elevated side coincides with the midline of the grid (Fig. 15.67).
- Center the IR about 1 to 2 inches (2.5 to 5 cm) above the lower rib margin, at the level of L1-L2, when the patient is prone.
- Make the final adjustment in body rotation. The approximately 40 to 70 degrees of rotation required to give the best image of the pyloric canal and duodenum depends on the size, shape, and position of the stomach. Generally, hypersthenic patients require a greater degree of rotation than sthenic and asthenic patients.
- The RAO position is used for serial studies of the pyloric canal and the duodenal bulb because gastric peristalsis is usually more active when the patient is in this position.
- *Shield gonads.*
- *Respiration:* Suspend at the end of expiration unless otherwise requested.

Central ray

- Perpendicular to the center of the IR.

Collimation

• Adjust the radiation field to no larger than 10 × 12 inches (24 × 30 cm) for smaller patients and no larger than 11 × 14 inches (28 × 35 cm) for larger patients. Place side marker in the collimated exposure field.

FIG. 15.67 PA oblique stomach and duodenum, RAO position.

Structures shown

Entire stomach and duodenal loop demonstrated. Provides the best image of the pyloric canal and duodenal bulb in sthenic patients (Figs. 15.68 and 15.69).

Because gastric peristalsis is generally more active with the patient in the RAO position, a serial study of several exposures is sometimes obtained at intervals of 30 to 40 seconds to delineate the pyloric canal and duodenal bulb.

Evaluation Criteria

The following should be clearly seen:

- Evidence of proper collimation and presence of side marker placed clear of anatomy of interest
- Entire stomach and duodenal loop
- No superimposition of the pylorus and duodenal bulb
- Duodenal bulb and loop in profile
- Stomach centered at the level of the pylorus
- Penetration of the contrast medium
- Surrounding anatomy

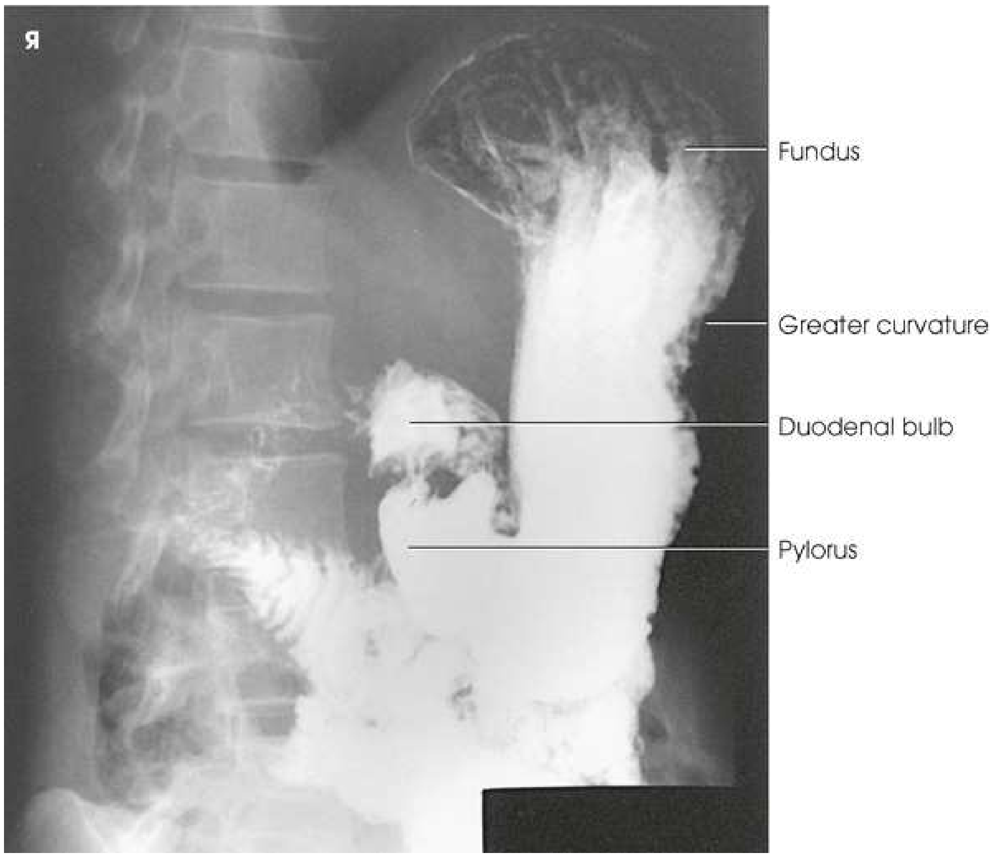


FIG. 15.68 Single-contrast PA oblique stomach and duodenum, RAO position.

A radiograph of the P A view of stomach and duodenum of a patient in R A O position. The Duodenum, fundus, Pyloric region, Greater curvature, Lesser curvature, and Body of the stomach are highlighted and labeled.

FIG. 15.69 Double-contrast PA oblique stomach and duodenum. Note esophagus entering stomach *(arrow)*.

A radiograph of the P A oblique view of stomach and duodenum of a patient. The stomach and duodenum are highlighted by the double contrast. The edges of the duodenum attached to the stomach are smudged.

Ap Oblique Projection

LPO position

Image receptor + grid: Positioned by manufacturer or department protocol for proper anatomy display orientation; CR plate: 10 × 12 inches (24 × 30 cm) or 14 × 17 inches (35 × 43 cm) lengthwise.

Position of patient

- Place the patient in the supine position.

Position of part

- Have the patient abduct the left arm and place the hand near the head, or place the extended arm alongside the body.
- Place the right arm alongside the body or across the upper chest, as preferred.
- Have the patient turn toward the left, resting on the left posterior body surface.
- Flex the patient's right knee, and rotate the knee toward the left for support.
- Place a positioning sponge against the patient's elevated back for immobilization.
- Adjust the patient's position so that a sagittal plane passing approximately midway between the vertebrae and the left lateral margin of the abdomen is centered to the IR.
- Adjust the center of the IR at the level of the body of the stomach. Centering should be adjusted at a point midway between the xiphoid process and the lower margin of the ribs (Fig. 15.70).
- The degree of rotation required to show the stomach best depends on the patient's body habitus. An average angle of 45 degrees should be sufficient for a sthenic patient, but the degree of angulation can vary from 30 to 60 degrees.
- *Shield gonads.*
- *Respiration:* Suspend at the end of expiration unless otherwise instructed.

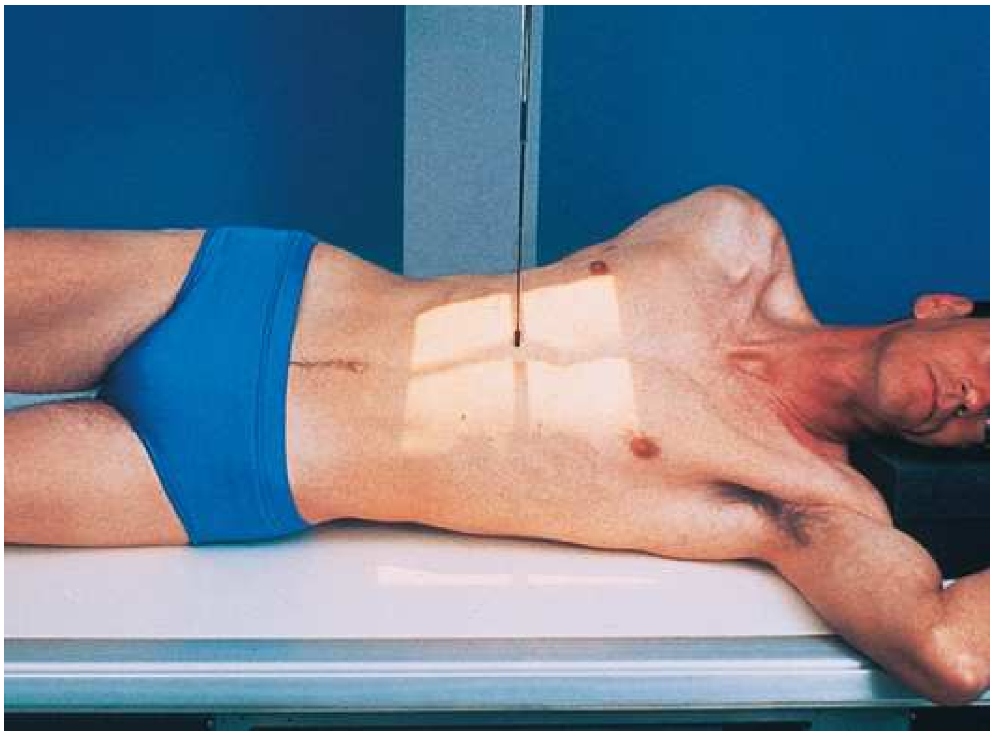


FIG. 15.70 AP oblique stomach and duodenum, LPO position.

A patient lies on his side on a table in L P O position. His head and torso are tilted towards the right and the right arm is resting behind him on the table. The central ray is directed towards the center of his abdomen.

Central ray

- Perpendicular to the center of the IR.

Collimation

- Adjust the radiation field to no larger than 10 × 12 inches (24 × 30 cm) for smaller patients and 11 × 14 inches (28 × 35 cm) for larger patients. Place side marker in the collimated exposure field.

Structures shown

The fundic portion of the stomach (Fig. 15.71). Because of the effect of gravity, the pyloric canal and the duodenal bulb are not as filled with barium as they are in the opposite and complementary position (the RAO position; see Figs. 15.67 to 15.69).

Evaluation Criteria

The following should be clearly seen:

- Evidence of proper collimation and presence of side marker placed clear of anatomy of interest
- Entire stomach and duodenal loop
- Fundic portion of stomach
- No superimposition of pylorus and duodenal bulb
- Body of the stomach centered to the image
- Penetration of the contrast medium
- Surrounding anatomy
- Body and pyloric antrum with double-contrast visualization

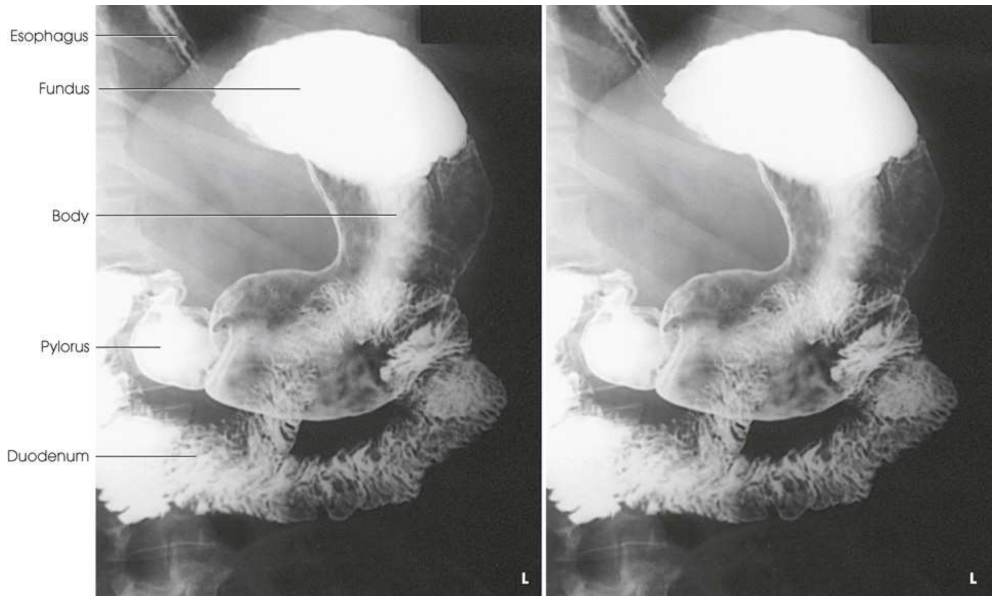


FIG. 15.71 Double-contrast AP oblique stomach and duodenum, LPO position.

Two radiographs of the A P oblique view of stomach and duodenum of a patient in L P O position. The stomach and duodenum are highlighted by the double contrast. The esophagus, Fundus, Body, Pylorus, and Duodenum are highlighted and labeled.

Lateral Projection

Right position

Image receptor + grid: Positioned by manufacturer or department protocol for proper anatomy display orientation; CR plate: 10 × 12 inches (24 × 30 cm) or 14 × 17 inches (35 × 43 cm) lengthwise.

Position of patient

- Place the patient in the *upright left lateral position* to show the left retrogastric space and in the *recumbent right lateral position* to show the right retrogastric space, duodenal loop, and duodenojejunal junction.

Position of part

- With the patient in the upright or recumbent position, adjust the body so that a plane passing midway between the midcoronal plane and the anterior surface of the abdomen coincides with the midline of the grid.
- Center the IR at the level of L1-L2 for the recumbent position (about 1 to 2 inches [2.5 to 5 cm] above the lower rib margin) and at L3 for the upright position.
- Adjust the body in a true lateral position (Fig. 15.72).
- *Shield gonads.*
- *Respiration:* Suspend at the end of expiration unless otherwise requested.

FIG. 15.72 Right lateral stomach and duodenum.

A patient lies on his side on a table in L P O position. His head and torso are on the same level and the arms are raised above chest level. The central ray is directed towards the center of his abdomen.

Central ray

- Perpendicular to the center of the IR

Collimation

- Adjust the radiation field to no larger than 10 × 12 inches (24 × 30 cm) for smaller patients and no larger than 11 × 14 inches (28 × 35 cm) for larger patients. Place side marker in the collimated exposure field.

Structures shown

The anterior and posterior aspects of the stomach, the pyloric canal, and the duodenal bulb (Figs. 15.73 and 15.74). The right lateral projection commonly affords the best image of the pyloric canal and the duodenal bulb in patients with a hypersthenic habitus.

Evaluation Criteria

The following should be clearly seen:

- Evidence of proper collimation and presence of side marker placed clear of anatomy of interest
- Entire stomach and duodenal loop
- No rotation of the patient, as shown by the vertebrae
- Stomach centered at the level of the pylorus
- Penetration of the contrast medium
- Surrounding anatomy

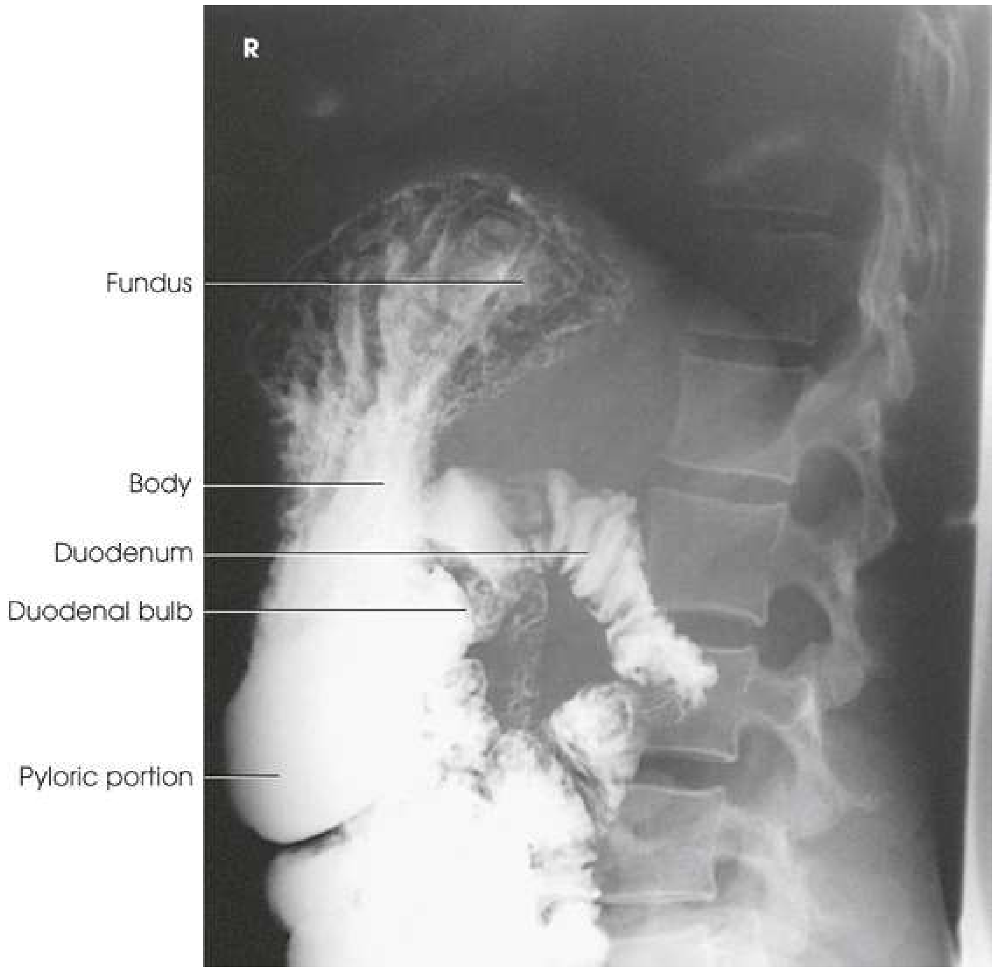


FIG. 15.73 Single-contrast right lateral stomach and duodenum.

The radiograph of the right lateral view of stomach and duodenum of a patient in single contrast. The stomach and duodenum are highlighted by the contrast. The esophagus, Fundus, Body, Pylorus, and Duodenum are highlighted and labeled.

FIG. 15.74 Double-contrast right lateral stomach and duodenum.

The radiograph of the right lateral view of stomach and duodenum of a patient in double contrast. The stomach and duodenum are highlighted by the contrast. The esophagus, Fundus, Body, Pylorus, and Duodenum are labeled.

Ap Projection

Image receptor + grid: Positioned by manufacturer or department protocol for proper anatomy display orientation; CR plate: 10 × 12 inches (24 × 30 cm) for small hiatal hernias; 14 × 17 inches (35 × 43 cm) lengthwise for large diaphragmatic herniations or for the stomach and small bowel.

Position of patient

- Place the patient in the supine position. The stomach moves superiorly and to the left in this position, and, except in thin patients, its pyloric end is elevated so that the barium flows into and fills its cardiac or fundic portions or both. Filling of the fundus displaces the gas bubble into the pyloric end of the stomach, where it allows double-contrast delineation of posterior wall lesions when a single-contrast examination is performed. If the patient is thin, the intestinal loops do not move superior enough to tilt the stomach for fundic filling. Rotating the patient's body toward the left or angling the head end of the table downward is necessary.
- Tilt the table to full or partial Trendelenburg angulation to show diaphragmatic herniations (Fig. 15.75). In the Trendelenburg position, the involved organ or organs, which may appear to be normally located in all other body positions, shift upward and protrude through the hernial orifice (most commonly through the esophageal hiatus).

NOTE: Valsalva maneuver may be used in conjunction with or as an alternative to the Trendelenburg position.

Position of part

- Adjust the position of the patient so that the midline of the grid coincides (1) with the midline of the body when a 14-
- × 17-inches (35 × 43-cm) exposure field (or CR plate) is used (see Fig. 15.75) or (2) with a sagittal plane passing midway between the midline and the left lateral margin of the abdomen when a 10- × 12-inch (24 × 30-cm) exposure field (or CR plate) is used (Fig. 15.76). Longitudinal centering of the larger exposure field depends on the extent of hernial protrusion into the thorax and is determined during fluoroscopy.

- For the stomach and duodenum, center the 10- × 12-inch (24- × 30-cm) exposure field/IR at a level midway between the xiphoid process and the lower rib margin (approximately L1-L2). For the 14- × 17-inch (35- × 43-cm) exposure field/IR, center it at the same level and adjust up or down slightly, depending on whether the diaphragm or the small bowel needs to be seen.
- *Shield gonads.*
- *Respiration*: Suspend at the end of expiration unless otherwise requested.

Central ray

- Perpendicular to the center of the IR.

Collimation

- Adjust the radiation field to no larger than 10 × 12 inches (24 × 30 cm) when the stomach alone is of interest; no larger than 14 × 17 inches (35 × 43 cm) when the small bowel is to be included. Place side marker in the collimated exposure field.

FIG. 15.75 AP stomach and duodenum with table in partial Trendelenburg position.

A patient lies facing upwards on a table in A P position. His head and torso are on the same level and the arms are resting on his sides. The central ray is directed towards the center of his abdomen.

Structures shown

Stomach

A well-filled fundic portion and usually a double-contrast delineation of the body, pyloric portion, and duodenum (Fig. 15.77). Because of the elevation and superior displacement of the stomach, this projection affords the best AP projection of the retrogastric portion of the duodenum and jejunum.

Diaphragm

An AP projection of the abdominothoracic region shows the organ or organs involved in, and the location and extent of, any gross hernial protrusion through the diaphragm (Figs. 15.78 and 15.79).

Evaluation Criteria

The following should be clearly seen:

- Evidence of proper collimation and presence of side marker placed clear of anatomy of interest
- Entire stomach and duodenal loop
- Double-contrast visualization of the gastric body, pylorus, and duodenal bulb
- Retrogastric portion of the duodenum and jejunum
- Lower lung fields on 14- × 17-inch (35- × 43-cm) images to show diaphragmatic hernias

- Stomach centered at the level of the pylorus on 10- × 12-inch (24- × 30-cm) images
- No rotation of the patient
- Penetration the contrast medium
- Surrounding soft tissues

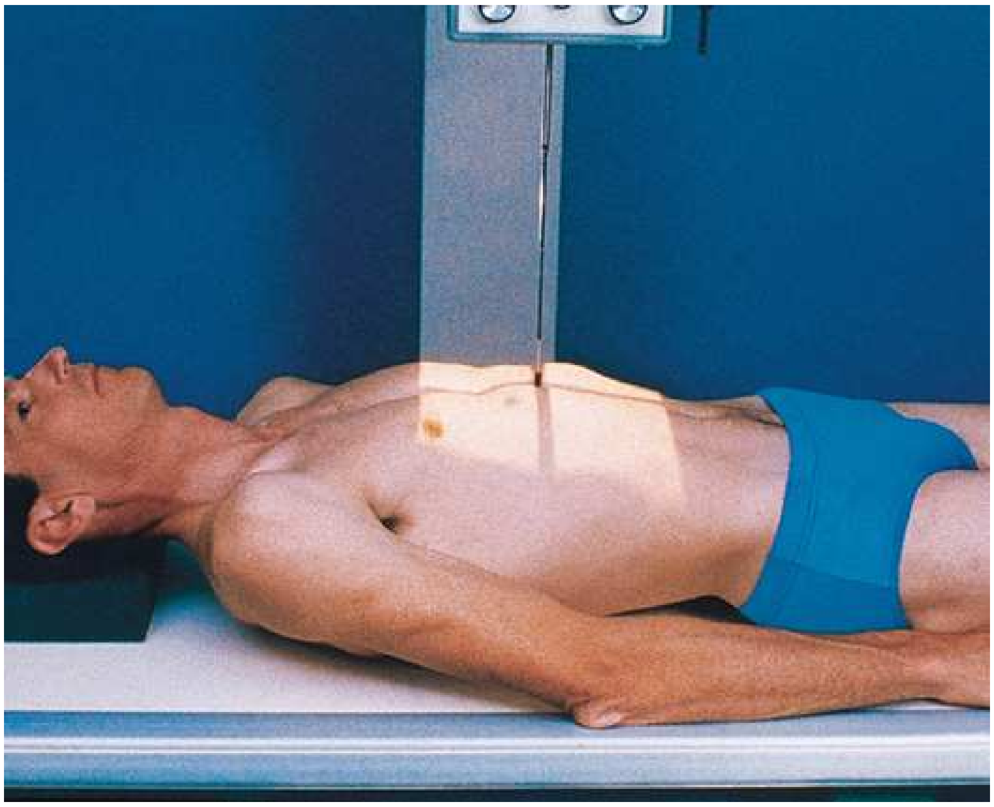


FIG. 15.76 AP stomach and duodenum.

A patient lies facing upwards on a table in A P position. His head and torso are on the same level and the arms are resting on his sides. The central ray is directed towards the center of his abdomen.

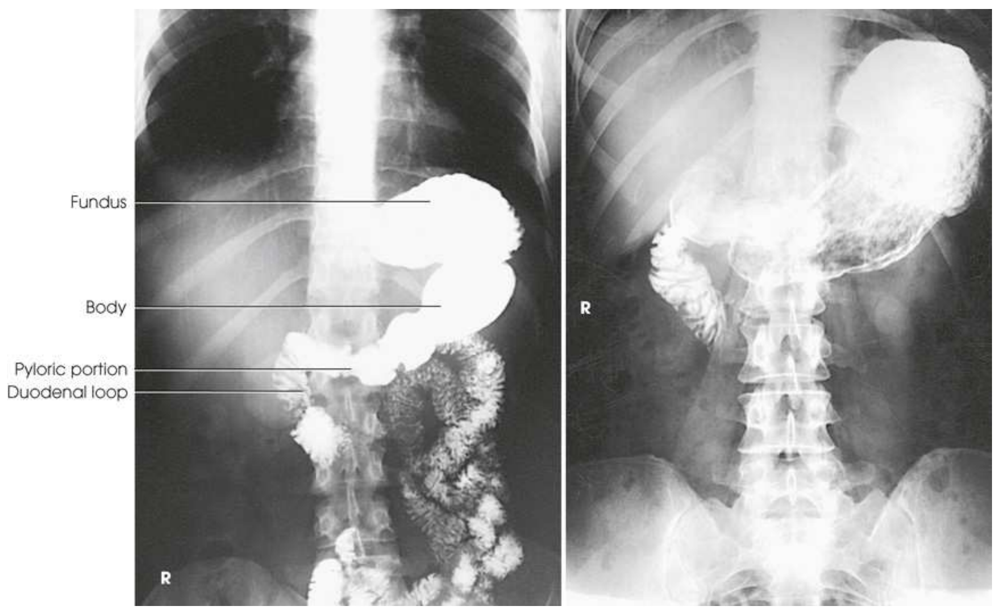


FIG. 15.77 AP stomach and duodenum, sthenic habitus.

Two radiographs of the A P view of stomach and duodenum of a patient in single habitus. The stomach and duodenum are highlighted by the contrast. The esophagus, Fundus, Body, Pylorus, and Duodenum are highlighted and labeled.

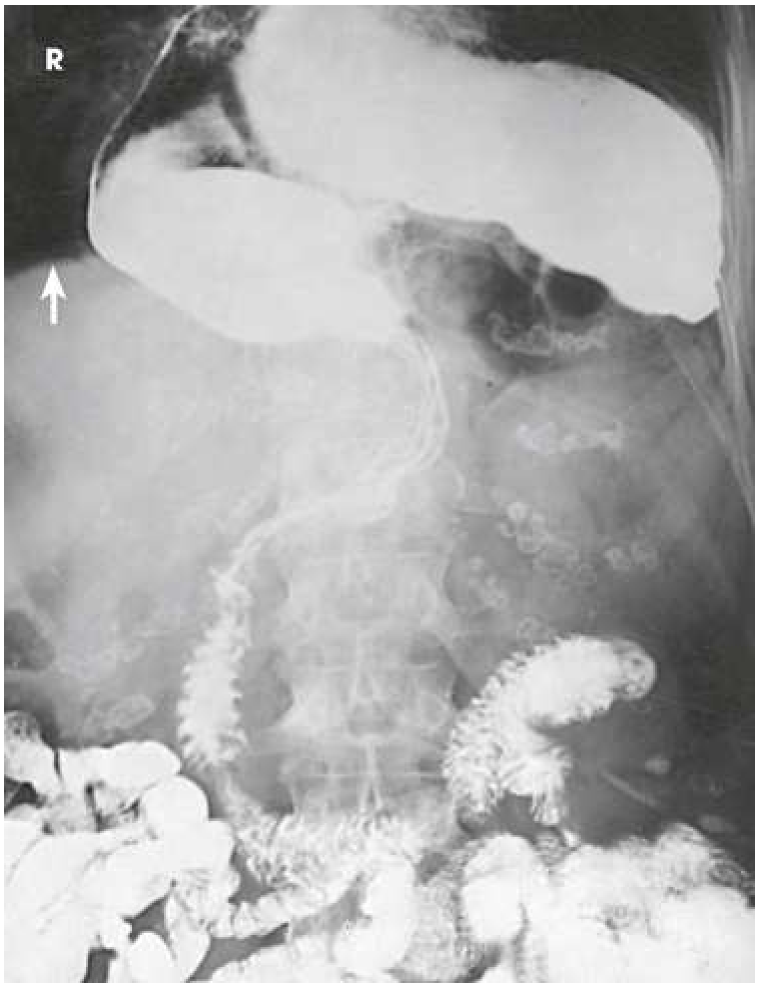


FIG. 15.78 AP stomach and duodenum, showing hiatal hernia above level of diaphragm *(arrow)*.

A radiograph of the A P view of stomach and duodenum of a patient with hiatal hernia. The stomach and duodenum are highlighted by the contrast. The rib and vertebral bones are visible. An arrow points to the hernia above the diaphragm.

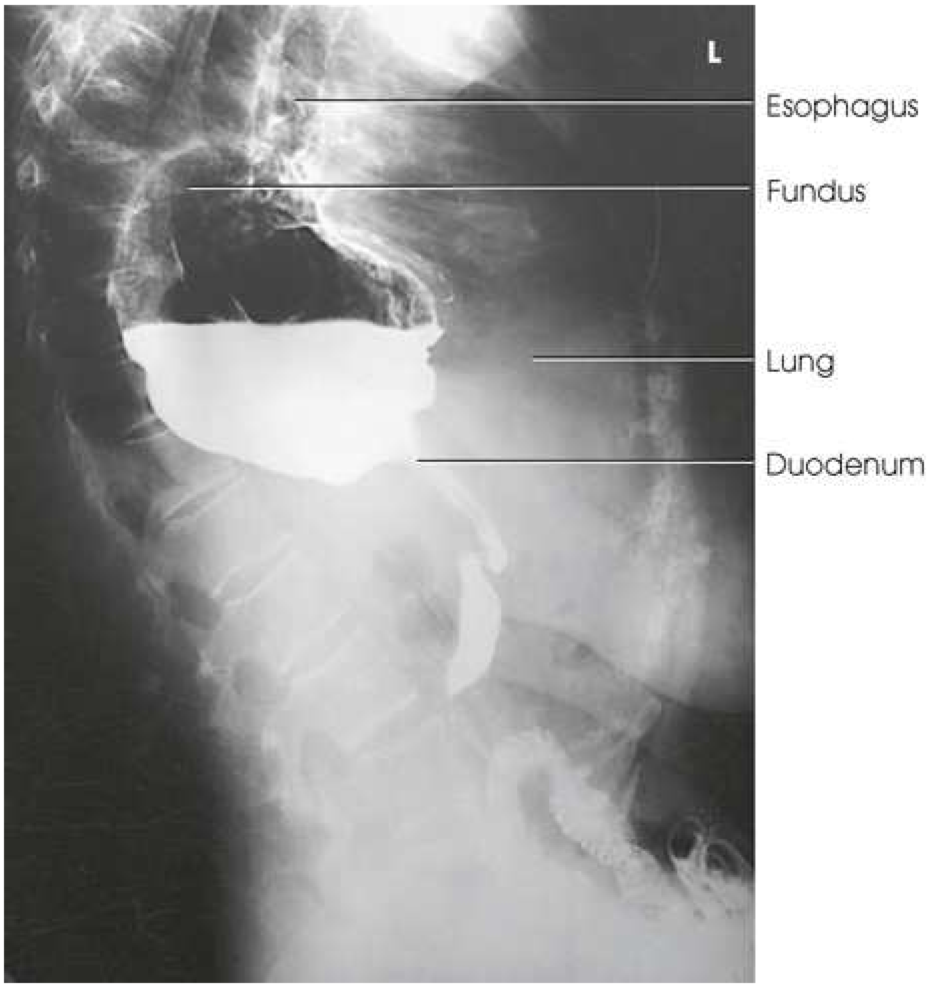


FIG. 15.79 Upright left lateral stomach showing hiatal hernia. Comparison lateral images are shown in Figs. 15.73 and 15.74.

A radiograph of the left lateral view of stomach and duodenum of a patient with hiatal hernia. The stomach and duodenum are highlighted by the contrast. The rib and vertebral bones are visible. The esophagus, Fundus, Body, Pylorus, and Duodenum are highlighted and labeled.

Superior Stomach and Distal Esophagus

Pa Oblique Projection

Wolf Method (For Hiatal Hernia)

RAO position

Image receptor + grid: Positioned by manufacturer or department protocol for proper anatomy display orientation; CR plate: 14 × 17 inches (35 × 43 cm) lengthwise.

The Wolf method [12] is a modification of the Trendelenburg position. The technique was developed for the purpose of applying greater intra-abdominal pressure than is provided by body angulation alone and ensuring more consistent results in the radiographic demonstration of small, sliding gastroesophageal herniations through the esophageal hiatus.

The Wolf method requires the use of a semicylindric radiolucent compression device measuring 22 inches (55 cm) in length, 10 inches (24 cm) in width, and 8 inches (20 cm) in height. (The compression sponge depicted in Fig. 15.80 is slightly smaller than the one described by Wolf.)

Wolf and Guglielmo [13] stated that this compression device not only provides Trendelenburg angulation of the patient's trunk, but it also increases intra-abdominal pressure enough to permit adequate contrast filling and maximal distention of the entire esophagus. A further advantage of the device is that it does not require angulation of the table; the patient can hold the barium container and ingest the barium suspension through a straw with comparative ease.

NOTE: Valsalva maneuver also increases intra-abdominal pressure and may be used instead of the Wolf method.

Position of patient

- Place the patient in the prone position on the radiographic table.

Position of part

- Instruct the patient to assume a modified knee-chest position during placement of the compression device.

• Place the compression device horizontally under the abdomen and just below the costal margin.
• Adjust the patient in a 40- to 45-degree RAO position, with the thorax centered to the midline of the grid.
• Instruct the patient to ingest the barium suspension in rapid, continuous swallows.
• To allow for complete filling of the esophagus, make the exposure during the third or fourth swallow.
• *Shield gonads.*
• *Respiration:* Suspend at the end of expiration.

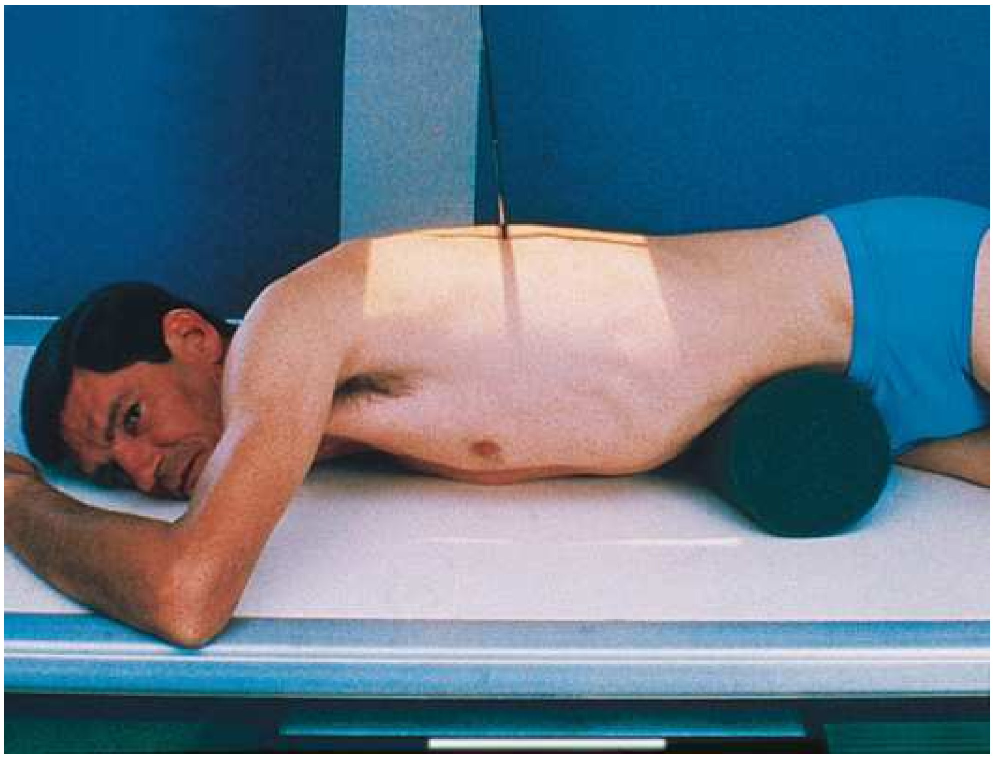


FIG. 15.80 PA oblique stomach with compression sponge, RAO position.

A patient lies on his side on a table with a cushion placed under his abdomen. His head and torso are on the same level and the arms are resting on his sides. The central ray is directed towards the center of his abdomen.

Central ray

• Perpendicular to the long axis of the patient's back and centered at the level of T6 or T7. This position usually results in 10- to 20-degree caudad angulation of the central ray.

Collimation

• Adjust the radiation field to no larger than 14 × 17 inches (35 × 43 cm). Place side marker in the collimated exposure field.

Structures shown

The relationship of the stomach to the diaphragm and is useful in diagnosing a hiatal hernia (Fig. 15.81).

Evaluation Criteria

The following should be clearly seen:

- Evidence of proper collimation and presence of side marker placed clear of anatomy of interest
- Middle or distal aspects of the esophagus and the upper aspect of the stomach
- Esophagus visible between the vertebral column and the heart
- Penetration of the contrast medium
- Surrounding anatomy

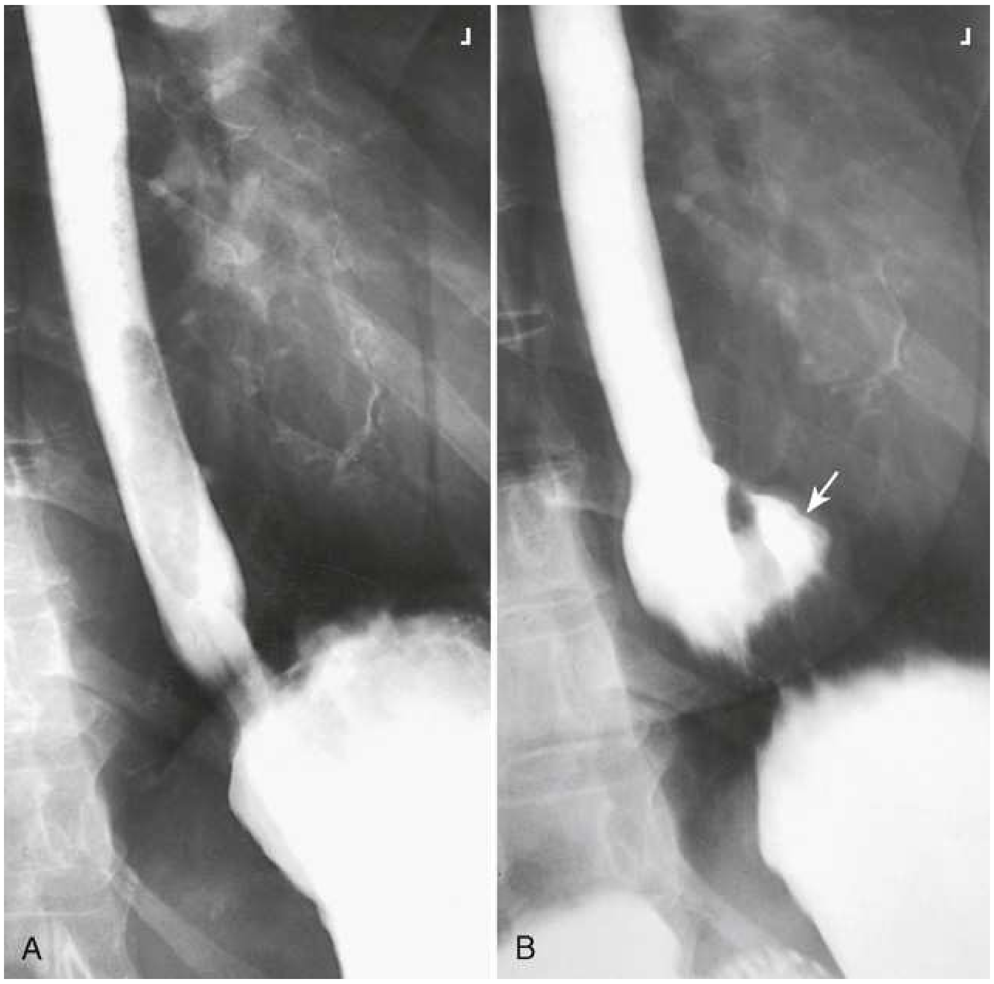


FIG. 15.81 Comparison PA axial oblique images in one patient. (A) Without abdominal compression: no evidence of hernia. (B) With abdominal compression: obvious large sliding hernia *(arrow)*.

Two radiographs of the P A axial oblique view of the stomach and duodenum of a patient with abdominal compression. The stomach and duodenum are highlighted by the contrast. An arrow points to the sliding hernia.

Small Intestine

Radiologic examinations of the small intestine are performed by administering a barium sulfate preparation (1) by *mouth*; (2) by complete *reflux filling* with a large-volume barium enema (BE); or (3) by direct injection into the bowel through an intestinal tube—a technique that is called *enteroclysis,* or small intestine enema. The latter two methods are used when the oral method fails to provide conclusive information. [14] Enteroclysis is technically difficult, so its use is usually limited to larger medical facilities.

Preparation For Examination

Preferably, the patient has a soft or low-residue diet for 2 days before the small intestine study. Because of economics, however, it often is impossible to delay the examination for 2 days. Food and fluid are usually withheld after the evening meal of the day before the examination, and breakfast is withheld on the day of the study. A cleansing enema may be administered to clear the colon; however, an enema is not always recommended for enteroclysis because enema fluid may be retained in the small intestine. The barium formula varies depending on the method of examination. The patient's bladder should be empty before and during the procedure to avoid displacing or compressing the ileum.

Oral Method of Examination

The radiographic examination of the small intestine is usually termed a *small bowel series* because several identical images are done at timed intervals. The oral examination, or ingestion of barium through the mouth, is usually preceded by a preliminary image of the abdomen. Each image of the small intestine is identified with a time marker indicating the interval between its exposure and ingestion of barium. Studies are made with the patient in the supine or the prone position. The supine position is used (1) to take advantage of the superior and lateral shift of the barium-filled stomach for visualization of retrogastric portions of the duodenum and jejunum and (2) to prevent possible compression overlapping of loops of the intestine. The prone position is used to compress the abdominal contents; this enhances radiographic image quality. For the final images in thin patients, it may be necessary to angle the table into the Trendelenburg position to "unfold" low-lying and superimposed loops of the ileum.

The first exposure of the small intestine is usually taken 15 minutes after the patient drinks the barium. The interval to the next exposure varies from 15 to 30 minutes depending on the average transit time of the barium sulfate preparation used. Regardless of the barium preparation used, the radiologist inspects the images as they are processed and varies the procedure according to requirements for the individual patient. Fluoroscopic and radiographic studies (spot or conventional) may be made of any segment of the bowel as the loops become opacified.

Some radiologists request that a glass of ice water (or another routinely used food stimulant) be given to a patient with hypomotility after 3 or 4 hours of administrating barium sulfate to accelerate peristalsis. Others give patients a water-soluble gastrointestinal contrast medium, tea, or coffee to stimulate peristalsis. Other radiologists administer peristaltic stimulants every 15 minutes through the transit time. With these methods, transit of the medium is shown fluoroscopically, spot and conventional radiographic images are exposed as indicated, and the examination is usually completed in 30 to 60 minutes.

Pa or Ap Projection

Image receptor + grid: Positioned by manufacturer or department protocol for proper anatomy display orientation; CR plate: 14 × 17 inches (35 × 43 cm) lengthwise.

Position of patient

- Place the patient in the prone or supine position.

Position of part

- Adjust the patient so that the MSP is centered to the grid.
- For a sthenic patient, center the IR at the level of L2 for images taken within 30 minutes after the contrast medium is administered (Fig. 15.82).
- For delayed images, center the IR at the level of the iliac crests.
- *Shield gonads.*
- *Respiration:* Suspend at the end of expiration unless otherwise requested.

Central ray

- Perpendicular to the midpoint of the IR (L2) for early images or at the level of the iliac crests for delayed sequence exposures.

Collimation

- Adjust the radiation field to no larger than 14 × 17 inches (35 × 43 cm). For smaller patients, collimate to within 1 inch (2.5 cm) of shadow of the abdomen flanks. Place side marker in the collimated exposure field.

Structures shown

The small intestine progressively filling until barium reaches the ileocecal valve (Figs. 15.83–15.86). When barium has reached the ileocecal region, fluoroscopy may be performed, and compression radiographic images may be obtained (Fig. 15.87). The examination is usually completed when the barium is visualized in the cecum, typically within about 2 hours for a patient with normal intestinal motility.

FIG. 15.82 AP small intestine.

Evaluation Criteria

The following should be clearly seen:

- Evidence of proper collimation and presence of side marker placed clear of anatomy of interest
- Entire small intestine on each image
- Stomach on initial images
- Time marker
- Vertebral column centered on the image
- No rotation of the patient
- Penetration of the contrast medium
- Complete examination when barium reaches the cecum

FIG. 15.83 Immediate AP small intestine.

FIG. 15.84 AP small intestine at 15 minutes.

FIG. 15.85 AP small intestine at 30 minutes, showing stomach *(st)* and small intestine *(si)*.

FIG. 15.86 AP small intestine at 1 hour, showing barium-filled cecum.

A radiograph of the A P view of the abdomen of a patient. The vertebral and rib bones are visible. The stomach and intestines are highlighted by contrast taken after 30 minutes. The cecum is filled and highlighted by barium.

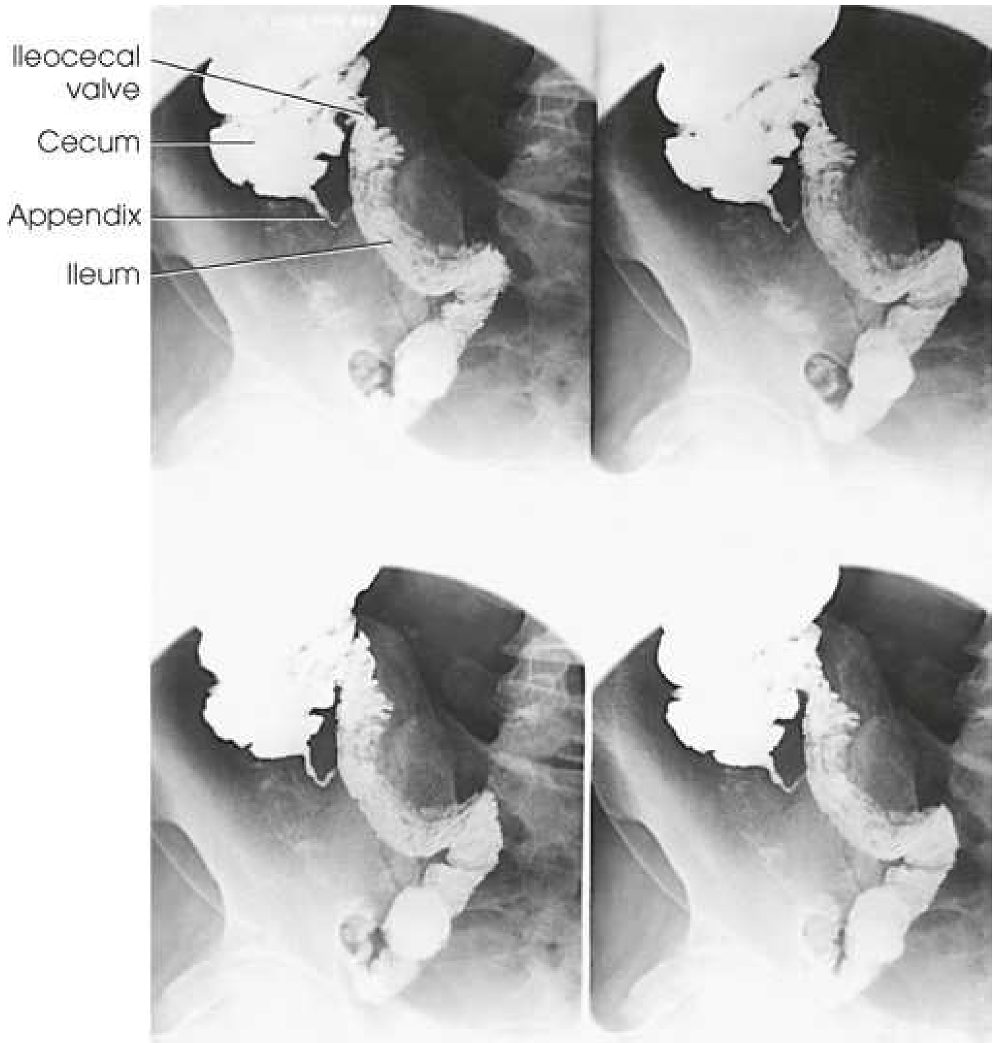


FIG. 15.87 Ileocecal studies.

Complete Reflux Examination

For a complete reflux examination of the small intestine, [15, 16] the patient's colon and small intestine are filled by a BE administered to show the colon and small bowel. Before the examination, glucagon may be administered to relax the intestine. Diazepam (Valium) may also be given to diminish patient discomfort during initial filling of the bowel. A 15% ± 5% weight/volume barium suspension is often used, and a large amount of the suspension (about 4500 mL) is required to fill the colon and small intestine.

A retention enema tip is used, and the patient is placed in the supine position for the examination. The barium suspension is allowed to flow until it is observed in the duodenal bulb. The enema bag is lowered to the floor to drain the colon before images of the small intestine are obtained (Fig. 15.88).

Enteroclysis Procedure

Enteroclysis (the injection of nutrient or medicinal liquid into the bowel) is a radiographic procedure in which contrast medium is injected into the duodenum under fluoroscopic control for examination of the small intestine. Contrast medium is injected through a specially designed enteroclysis catheter, historically a Bilbao or Sellink tube.

Before the procedure is begun, the patient's colon must be thoroughly cleansed. Enemas are not recommended as preparation for enteroclysis because some enema fluid may be retained in the small intestine. Under fluoroscopic control, the enteroclysis catheter with a stiff guidewire is advanced to the end of the duodenum at the duodenojejunal flexure, near the ligament of Treitz. The retention balloon, if present, is filled with sterile water or saline. Barium is instilled through the tube at a rate of approximately 100 mL/min (Fig. 15.89). Spot images, with and without compression, are taken as required. In some patients, air is injected after contrast fluid has reached the distal small intestine (Fig. 15.90). When CT is to be performed, an iodinated contrast medium (Figs. 15.91 and 15.92) or tap water (Figs. 15.93 and 15.94) may be used.

After fluoroscopic examination of the patient's small intestine, images of the small intestine may be requested. The projections most often requested include AP, PA, oblique, and lateral. Recumbent and upright images may be requested. (Positioning descriptions involving the abdomen are presented in Chapter 4.)

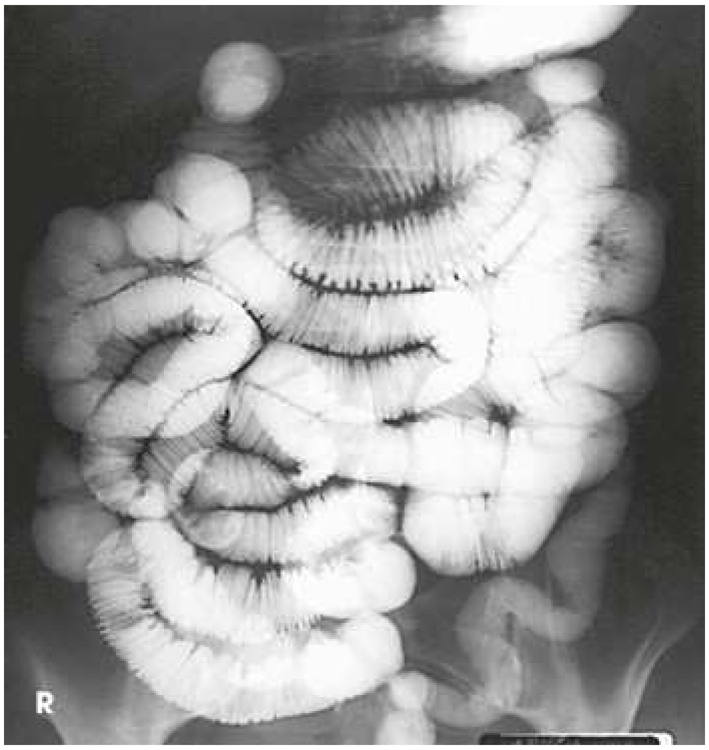


FIG. 15.88 Normal retrograde reflux examination of small intestine.

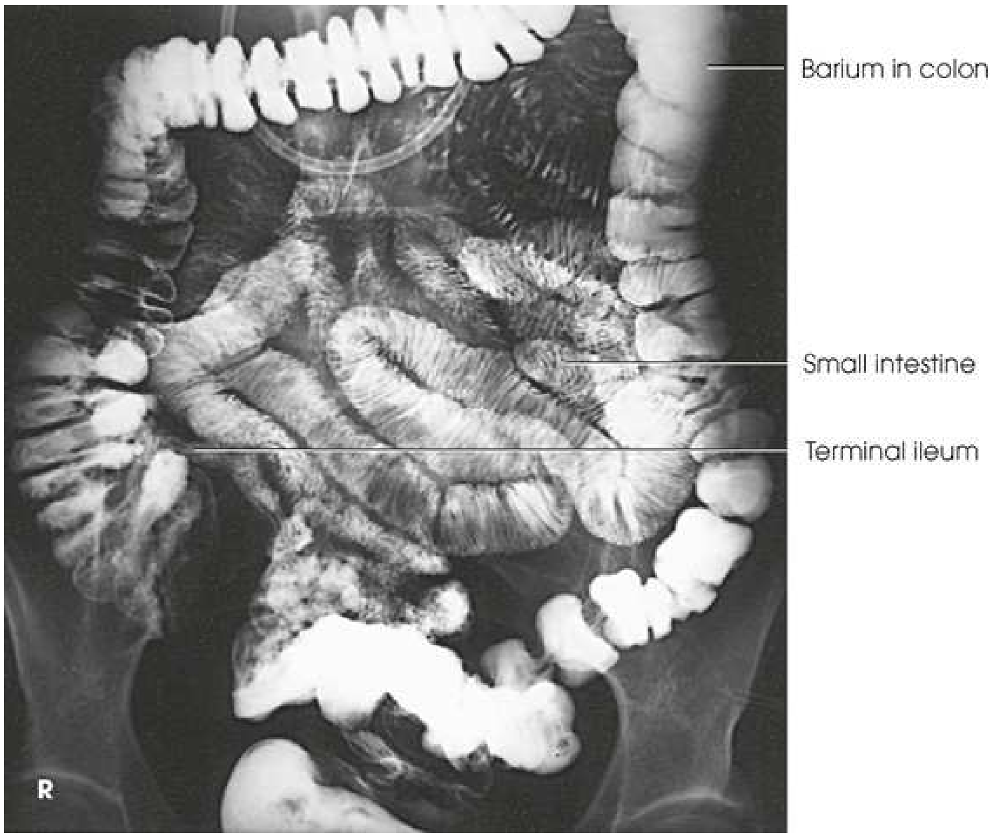


FIG. 15.89 Enteroclysis procedure with barium visualized in colon.

A radiograph of the A P view of small intestine taken in enteroclysis process. The small intestine is highly coiled and highlighted. The Barium in colon, Small intestine, and Terminal ileum are labeled.

FIG. 15.90 Air-contrast enteroclysis.

A circular radiograph of the A P view of small intestine taken in enteroclysis process. The small intestine is highly coiled and highlighted. The Enteroclysis catheter, Barium air in small intestine are labeled.

FIG. 15.91 Enteroclysis with iodinated contrast medium.Filled retention balloon is seen in duodenum *(arrow)*. Courtesy Michelle Alting, AS, RT[R].

A circular radiograph of the A P view of small intestine taken in enteroclysis process with iodine contrast medium. The small intestine is highly coiled and highlighted. An arrow points to the filled retention balloon in the duodenum.

FIG. 15.92 Axial CT enteroclysis of the patient in Fig. 15.91.

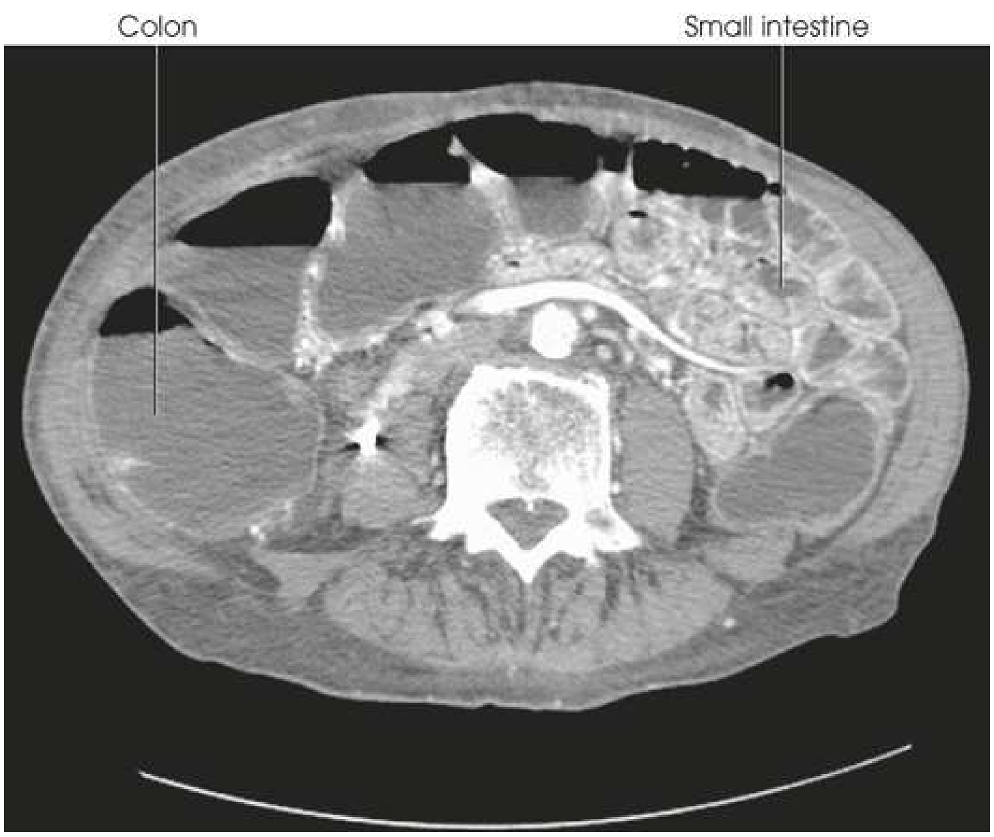


FIG. 15.93 Axial CT enteroclysis with tap water and intravenous iodinated contrast medium. Intraluminal water *(dark gray)* is clearly delineated from bowel wall *(light gray)*.

A C T scan image of the small intestine of a patient in axial view taken with iodine contrast. The abdominal cavity with large intestine, stomach, duodenum, ileum, cecum, and rest of the small intestine are visible.

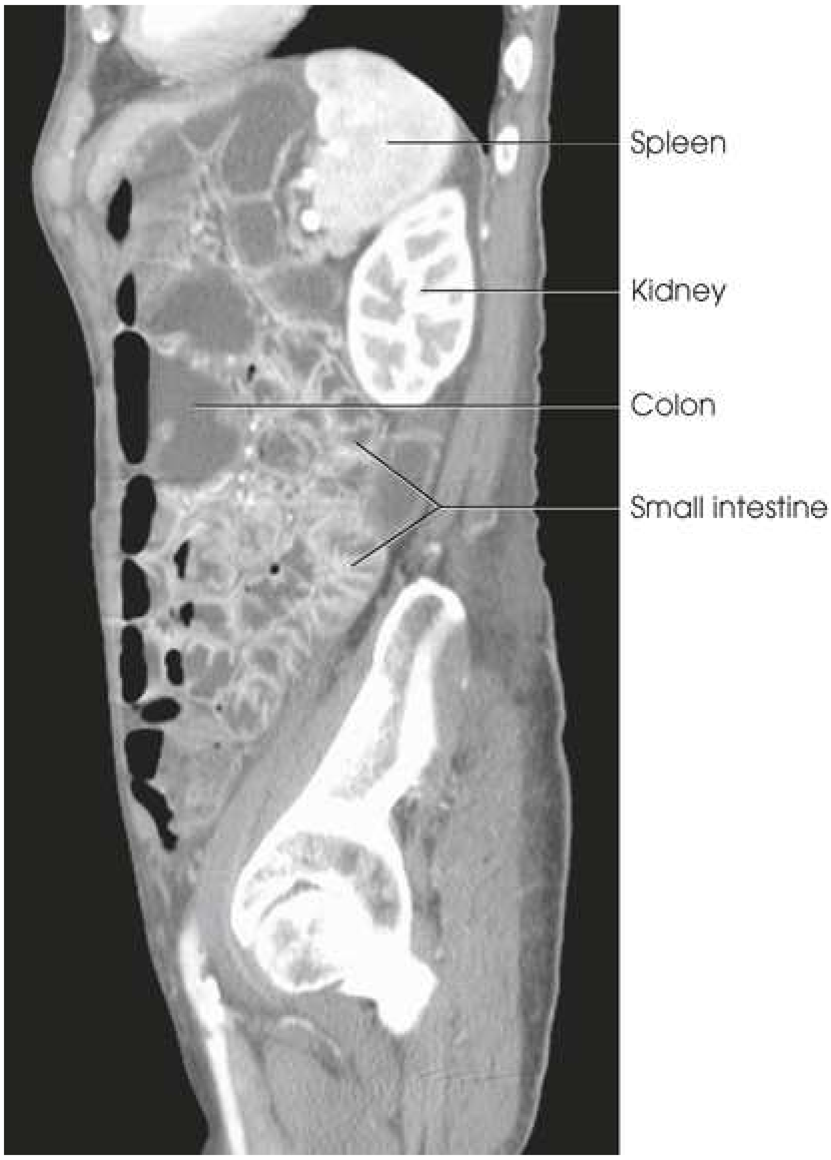


FIG. 15.94 Sagittal reconstruction of CT enteroclysis from Fig. 15.93.

Intubation Examination Procedures

Gastrointestinal intubation is a procedure in which a long, specially designed tube is inserted through the nose and passed into the stomach. From there, the tube is carried inferiorly by peristaltic action. Gastrointestinal intubation is used for therapeutic and diagnostic purposes.

When gastrointestinal intubation is used therapeutically, the tube is connected to a suction system for continuous siphoning of gas and fluid contents of the gastrointestinal tract. The purpose of the maneuver is to prevent or relieve postoperative distention or to deflate or decompress an obstructed small intestine.

Although used much less frequently than in the past, a *Miller-Abbott* double-lumen, single-balloon tube (or other similar tubing) can be used to intubate the small intestine. Just above the tip of the Miller-Abbott tube is a small, thin rubber balloon. Marks on the tube, beginning at the distal end, indicate the extent of the tube's passage and are read from the edge of the nostril. The marks are graduated in centimeters up to 85 cm and are given in feet thereafter. The lumen of the tube is asymmetrically divided into (1) a small balloon lumen that communicates with the balloon only and is used for inflation and deflation of the balloon and for injection of mercury to weight the balloon and (2) a large aspiration lumen that communicates with the gastrointestinal tract through perforations near and at the distal end of the tube. Gas and fluids are withdrawn through the aspiration lumen, and liquids are injected through it.

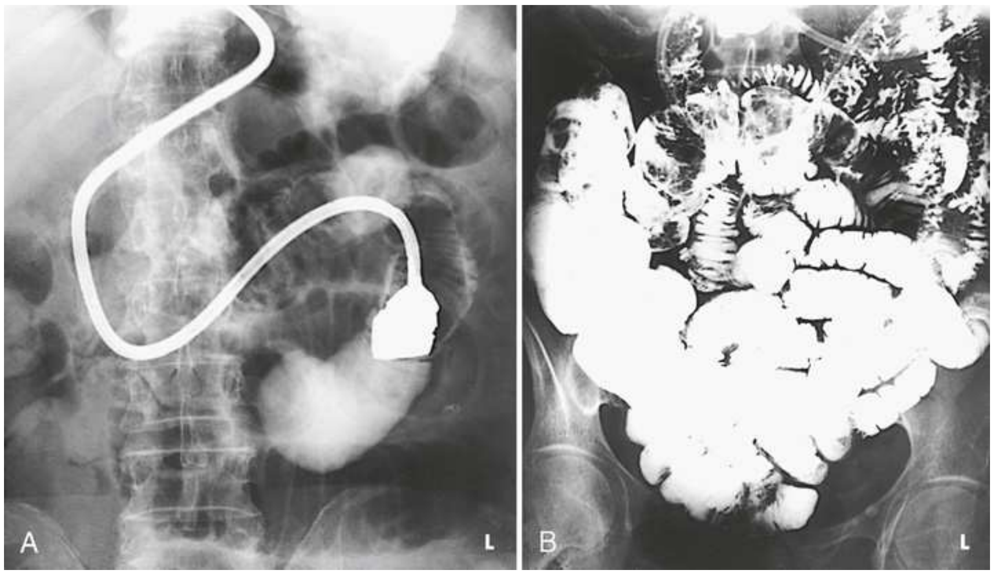


FIG. 15.95 (A) Miller-Abbott tube study with water-soluble medium. (B) Small bowel examination by Miller-Abbott tube with injection of barium sulfate.

Two radiographs for the Miller-Abbott tube study with water-soluble medium and the small bowel examination by Miller-Abbott tube with injection of barium sulfate. The tubing structure is highlighted in A. The intestine is highlighted by barium in B.

The introduction of an intestinal tube is an unpleasant experience for a patient, especially one who is acutely ill. Depending on the condition of the patient, the tube is more readily passed if the patient can sit erect and lean slightly forward, or if the patient can be elevated almost to a sitting position.

With the intestinal tube in place, the patient is turned to an RAO position, a syringe is connected to the balloon lumen, and mercury is poured into the syringe and allowed to flow into the balloon. Air is slowly withdrawn from the balloon. The tube is secured with an adhesive strip beside the nostril to prevent regurgitation or advancement of the tube. The stomach is aspirated by using a syringe or by attaching the large port of the lumen to the suction apparatus.

With the tip of the tube situated close to the pyloric sphincter and the patient in the RAO position (a position in which gastric peristalsis is usually more active), the tube should pass into the duodenum in a reasonably short time. Without intervention, this process sometimes takes many hours. Having the patient drink ice water to stimulate peristalsis is often successful. When this measure fails, the examiner guides the tube into the duodenum by manual manipulation under fluoroscopic observation. After the tube enters the duodenum, it is inflated again to provide a bolus that peristaltic waves can more readily move along the intestine.

When the tube is inserted for decompression of an intestinal obstruction and possible later radiologic investigation, the adhesive strip is removed and replaced with an adhesive loop attached to the forehead. The tube can slide through the loop without tension as it advances toward the obstructed site. The patient is then returned to the hospital room. Radiographic images of the abdomen may be taken to check the progress of the tube and the effectiveness of decompression. Simple obstructions are sometimes relieved by suction; others require surgical intervention.

If passage of the intestinal tube is arrested, suction is discontinued, and the patient is returned to the radiology department for a Miller-Abbott tube study. The contrast medium used for studies of a localized segment of the small intestine may be a water-soluble, iodinated solution (Fig. 15.95A), or a thin barium sulfate suspension. Under fluoroscopic observation, the contrast agent is injected through the large lumen of the tube with a syringe. Spot and conventional images are obtained as indicated.

When the intestinal tube is introduced for the purpose of performing a small intestine enema, the tube is advanced into the proximal loop of the jejunum and is secured at this level with an adhesive strip taped beside the nose. Medical opinion varies regarding the quantity of barium suspension required for this examination (see Fig. 15.95B). The medium is injected through the aspiration lumen of the tube in a continuous, low-pressure flow. Spot and conventional images are exposed as indicated. Except for the presence of the tube in the upper jejunum, resultant images resemble those obtained by the oral method.

Large Intestine

Contrast Media Studies

The two basic radiologic methods of examining the large intestine by means of contrast media enemas are (1) the *single-contrast* method (Fig. 15.96), in which the colon is examined with a barium sulfate suspension or water-soluble iodide only; and (2) the *double-contrast* method (Fig. 15.97), which may be performed as a two-stage or single-stage procedure. In the *two-stage, double-contrast procedure,* the colon is examined with a barium sulfate suspension and then, immediately after evacuation of the barium suspension, with an air enema or another gaseous enema. In the *single-stage, double-contrast procedure,* the fluoroscopist selectively injects the barium suspension and the gas.

Positive contrast medium shows the anatomy and tonus of the colon and most of the abnormalities to which it is subject. The addition of the air (negative) contrast distends the lumen of the bowel for optimum visualization of the barium-coated mucosal lining of the colon. Double-contrast, or air-contrast studies, allow for demonstration of small intraluminal lesions, such as polypoid tumors.

A more recent development in radiographic examination of the large intestine is *computed tomography colonography* (CTC), also called *virtual colonoscopy* (VC)—a procedure used as a primary screening tool for colorectal cancer or after a failed conventional colonoscopy. This software-driven technique combines helical CT and virtual reality software to create three-dimensional and multiplanar images of the colonic mucosa.

Examples of currently available CTC techniques include the perspective-filet or virtual dissection view, the three-dimensional topographic view, the multiplanar reformatted (MPR) view, and the colonoscopic-like endoluminal view (Figs. 15.98 through 15.100).

Contrast media

Commercially prepared barium sulfate products are generally used for routine retrograde examinations of the large intestine. Some of these products are referred to as *colloidal preparations* because they have finely divided barium particles that resist precipitation, whereas others are referred to as suspended or *flocculation-resistant preparations* because they contain some form of suspending or dispersing agent.

FIG. 15.96 Large intestine, single-contrast study.

The newest barium products available are referred to as *high-density barium sulfate*. These products absorb a greater percentage of radiation, similar to older "thick" barium products. High-density barium is particularly useful for double-contrast studies of the alimentary canal in which uniform coating of the lumen is required.

Air is the gaseous medium usually used in the double-contrast enema study. The procedure is generally called an *air-contrast study*. Carbon dioxide may also be used because it is more rapidly absorbed than the nitrogen in air when evacuation of the gaseous medium is incomplete. Use of air as a contrast medium for radiographic evaluation of the colon is not limited to the double-contrast enema procedure. Air or carbon dioxide insufflation of the colon is used to perform CTC or VC.

FIG. 15.97 Large intestine, double-contrast study.

A radiograph of the A P view of large intestine taken in double contrast. The small intestine is highly coiled and highlighted. The entire large intestine and small intestine are highlighted by contrast.

Water-soluble, iodinated contrast media enemas are performed when colon perforation or leak is suspected. These iodinated contrast agents are administered orally to selected patients when retrograde filling of the colon with barium is impossible or is contraindicated. A disadvantage of iodinated solutions is that evacuation often is insufficient for satisfactory double-contrast visualization of the mucosal pattern. When a patient is unable to cooperate for a successful enema study, orally administered iodinated medium allows satisfactory examination of the colon. With these oral agents, transit time from ingestion to colonic filling is fast, averaging 3 to 4 hours. Iodinated solutions are practically nonabsorbable from the gastrointestinal mucosa. As a result, the oral dose reaches and outlines the entire large bowel. In contrast to an ingested barium sulfate suspension, this medium is not subject to drying, flaking, and unequal distribution in the colon. It frequently delineates the intestine almost as well as the BE does.

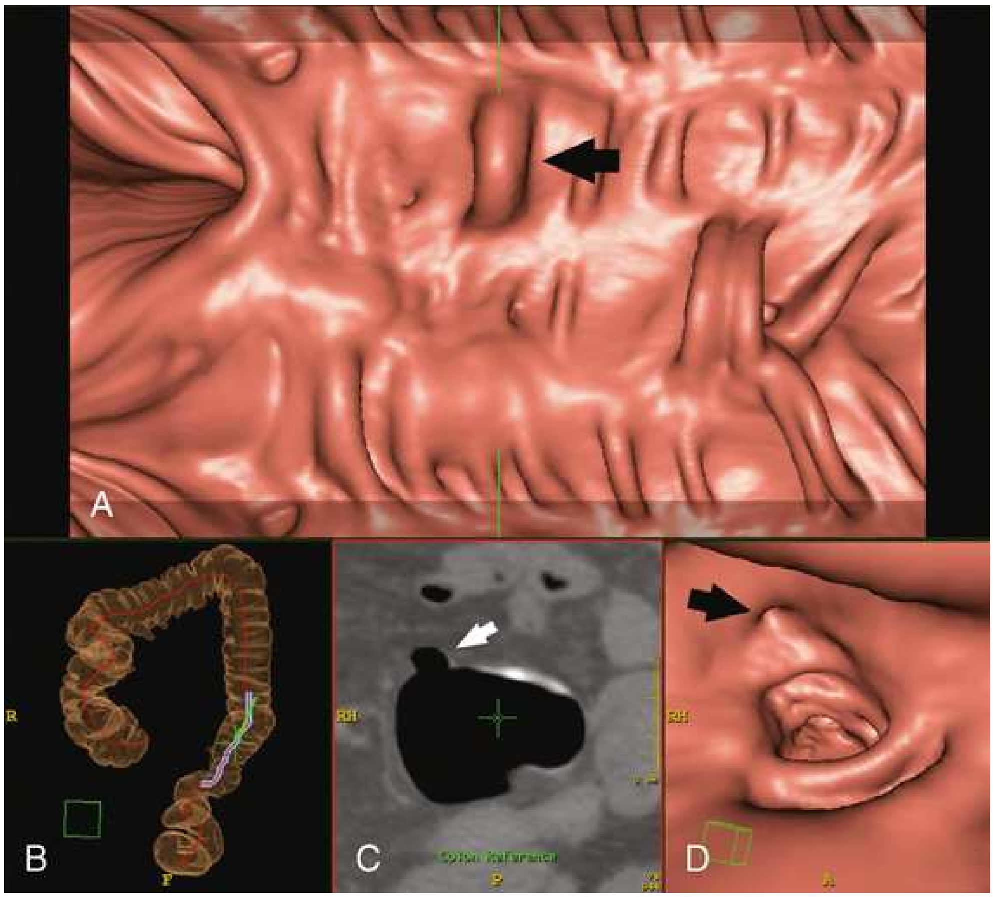


FIG. 15.98 Examples of CTC or VC. (A) Perspective-filet or virtual dissection view, showing diverticulum *(arrow)*. (B) Three-dimensional topographic view: *Purple line* in the sigmoid shows length of filet in (A). (C) Axial MPR, showing same diverticulum as in A *(arrow)*. (D) Endoluminal view showing opening *(arrow)* of diverticulum from A. D, Courtesy J. Louis Rankin, BS, RT[R][MR].

Four scan images of the diverticulum. The first one is a virtual dissection image with an arrow pointing to the diverticulum. The second one is a three dimension topographic view. A purple line denotes the length of fillet in the dissection view. The third one is an axial M P R view of the first image with an arrow pointing to the diverticulum. The last one is a endoluminal view of the opening of the diverticulum from the dissection view.

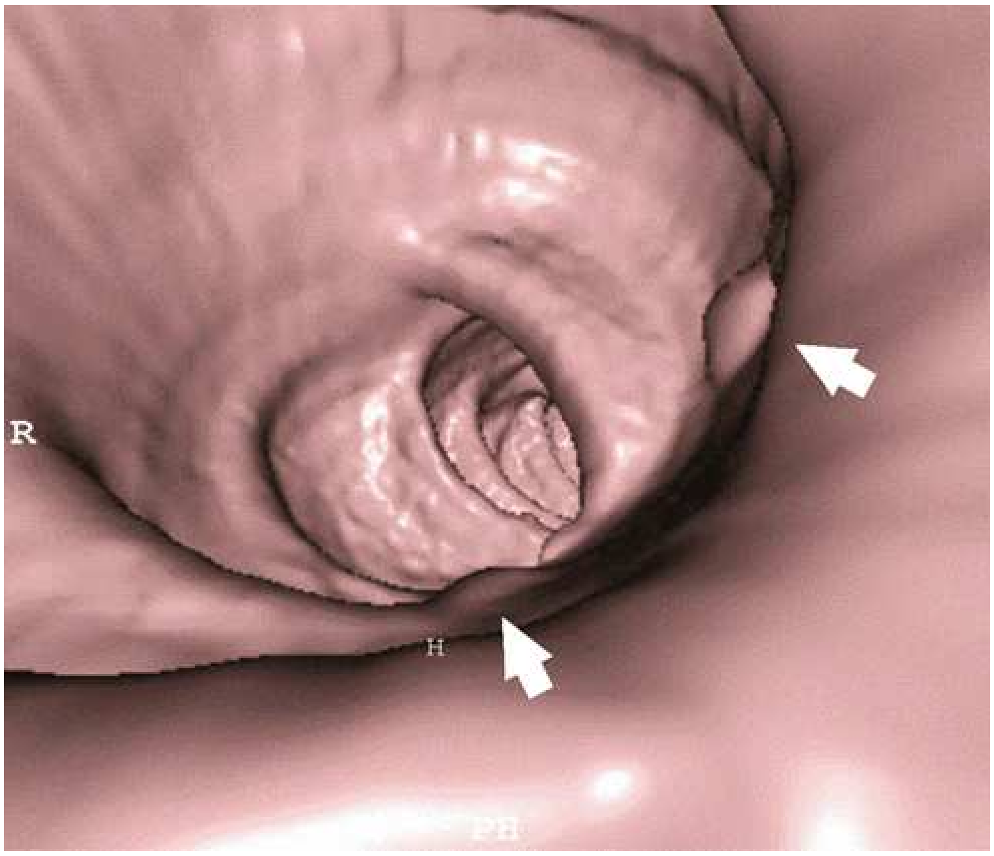


FIG. 15.99 Endoluminal CTC image, showing two tubular adenomas *(arrows)*.

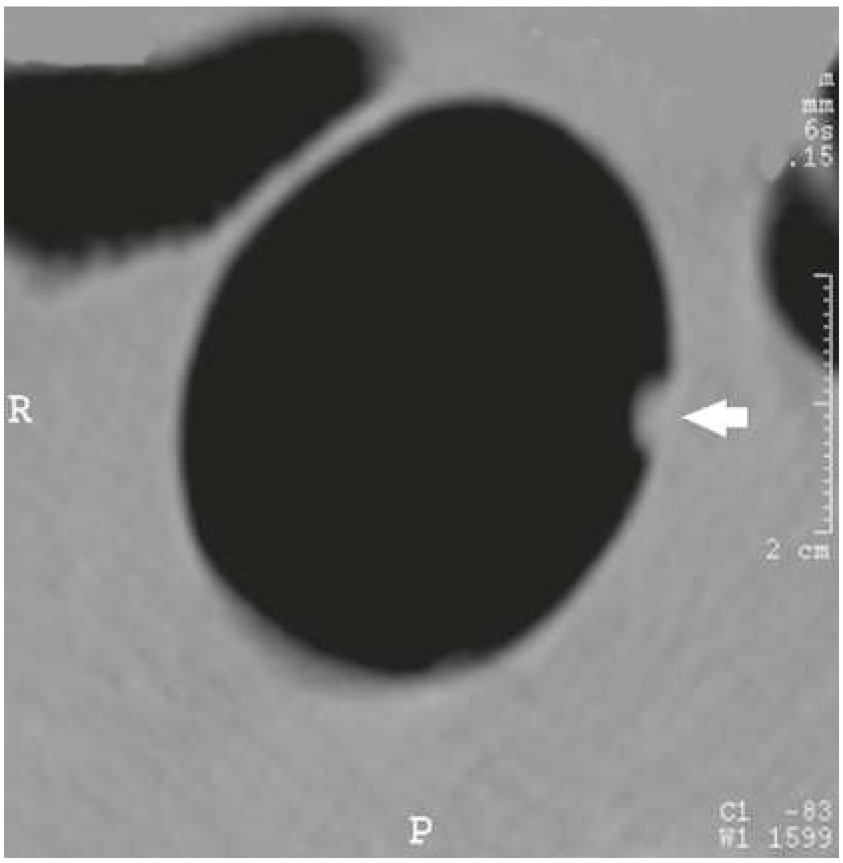


FIG. 15.100 Axial MPR image of upper tubular adenoma *(arrow)* from Fig. 15.99.

Preparation of intestinal tract

Medical opinion about preparation measures varies. Members of the medical profession usually agree, however, that the large intestine must be completely emptied of its contents to render all portions of its inner wall visible for inspection. When coated with a barium sulfate suspension, retained fecal masses are likely to simulate the appearance of polypoid or other small tumor masses (Fig. 15.101); this makes thorough cleansing of the entire colon a matter of prime importance. Preliminary preparation of the intestinal tract of patients who have a condition such as severe diarrhea, gross bleeding, or symptoms of obstruction is limited. Other patients are prepared, with modification as indicated, according to specifications established by the examining physician. The preliminary preparation usually includes dietary restrictions ("clear" liquids only) and a bowel cleansing regimen. Methods of bowel cleansing include the following:

- Complete intestinal tract cleansing kits
- Gastrointestinal lavage preparations
- Cleansing enema

Standard barium enema apparatus

Disposable soft plastic enema tips and enema bags are commercially available in different sizes. A soft rubber rectal catheter of small caliber should be used in patients who have inflamed hemorrhoids, fissures, a stricture, or other abnormalities of the anus.

Disposable rectal *retention tips* (Fig. 15.102, *inset*) have a double-lumen tube with a thin balloon at its distal end. Because of the danger of intestinal wall damage, the retention tip must be inserted with extreme care. The enema retention tip is used in a patient who has a relaxed anal sphincter or another condition that makes it difficult or impossible to retain an enema. Some radiologists routinely use retention enema tips and inflate them if necessary.

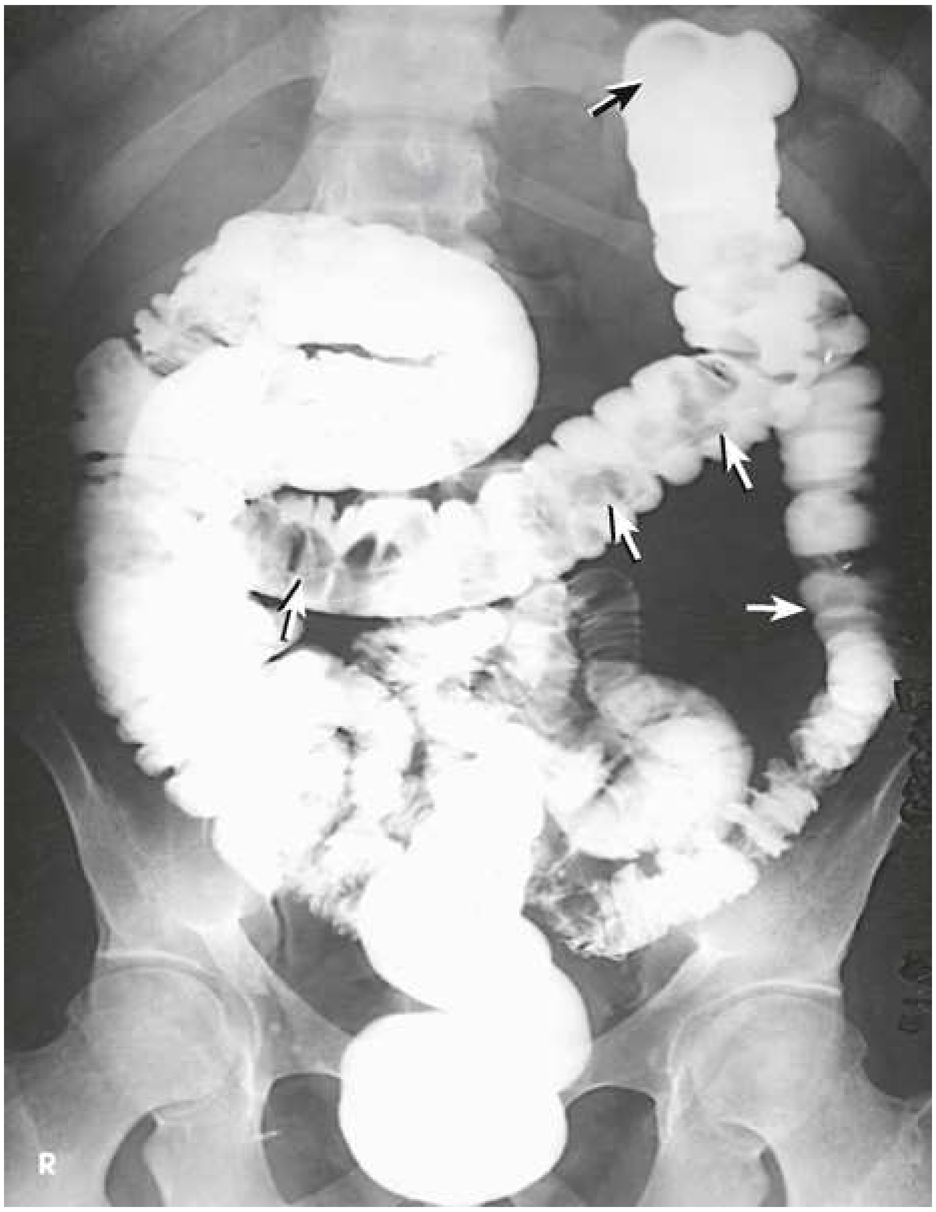


FIG. 15.101 Single-contrast, barium-filled colon, showing fecal material that simulates or masks pathologic condition *(arrows)*.

A radiograph of the A P view of large intestine taken in single contrast. The small intestine is highly coiled and highlighted. The contrast in the intestine highlights the presence of fecal materials in several placed denoted by arrows.

The disposable rectal retention tip has a balloon cuff that fits snugly against the enema nozzle before inflation and after deflation so that it can be inserted and removed with little discomfort to the patient. A reusable squeeze inflator is recommended to limit air capacity to approximately 90 mL. One complete squeeze of the inflator provides adequate distention of the retention balloon without danger of overinflation. Disposable retention tips are available for double-contrast and single-contrast enemas. For the safety of the patient, any retention balloon must be inflated with caution, using fluoroscopy, just before the examination.

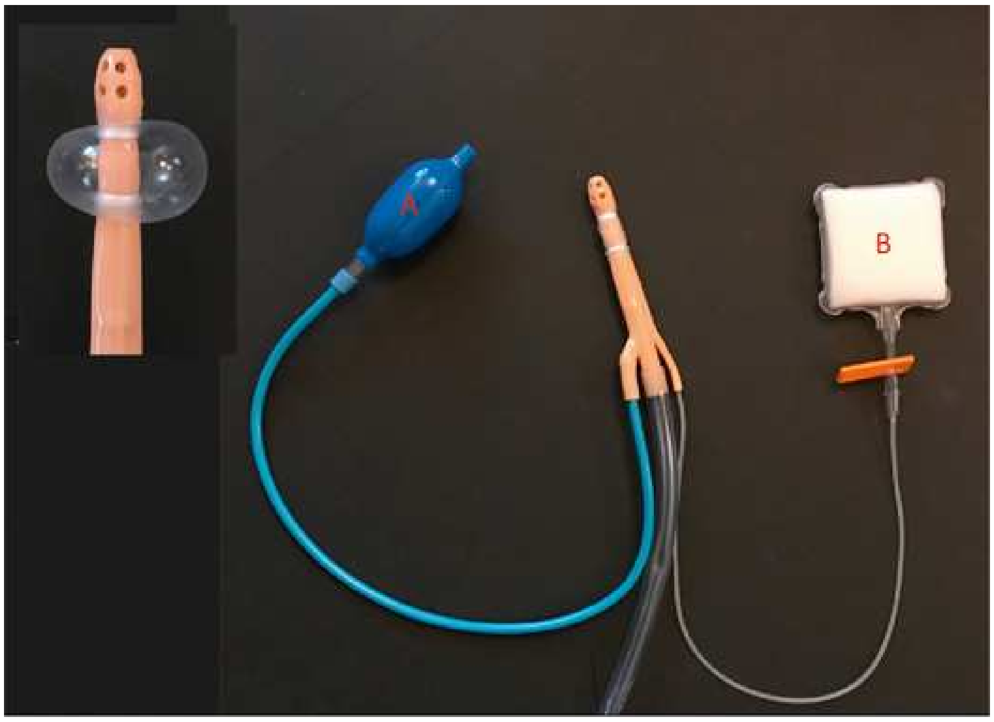


FIG. 15.102 Disposable retention enema tip. Uninflated balloon fits snugly. The bulb used to instill air into the colon is labeled *A.* The cuff used to inflate the retention balloon is labeled *B*. *(Inset)* Balloon cuff inflated with 90 mL of air (one complete squeeze of inflator).

For performance of a double-contrast BE examination, a special rectal tip is necessary to instill air in the colon (Fig. 15.103). The cuff for the inflation of the retention bulb is labeled as A, and the bulb for administering air into the colon is labeled B. The tubing to administer the air contrast during the procedure lies in the center of the lumen of the enema tip. Barium flows through the holes in the side of the tip, while air is pumped through the tubing.

FIG. 15.103 Air-contrast enema kit filled with barium. *Arrow* indicates bulb used to administer air into the colon. An asterisk *(*)* marks the retention tip inflator cuff.

Preparation of barium suspensions

Commercially prepared, premixed liquid barium preparations that can be poured into the disposable enema kit bag are recommended by the ACR. Most enema bags have a capacity of 3000 mL with graduated markings along the sides. Most BE exams require 1000 to 2000 mL of premixed liquid barium. For single-contrast exams, a low-density (15% to 20% weight/volume) barium suspension is recommended. Optimal imaging in double-contrast exams of the colon requires high-density barium (80% to 100% weight/volume). When water-soluble contrast is required, 60% to 76% density (300 to 370 mg of iodine/mL) provides adequate opacification.[17, 18] Powdered barium is also available in single-contrast disposable kit bags. Water is added, and the solution is mixed by shaking the bag. Instructions for mixing a barium preparation vary according to the manufacturer and the type of barium used. The best recommendation is to *precisely* follow the manufacturer's instructions regarding the amount and temperature of added water to attain appropriate consistency.

Preparation and care of patient

In no radiologic examination is the full cooperation of the patient more essential to success than in the retrograde examination of the colon. Few patients who are physically able to retain the enema fail to do so when they understand the procedure and realize that in large measure the success of the examination depends on them. The radiographer should observe the following guidelines in preparing a patient for retrograde examination of the colon:

- Take time to explain the procedural differences between an ordinary cleansing enema and a diagnostic enema: (1) With the diagnostic enema, the fluoroscopist examines all portions of the bowel as it is being filled with contrast medium under fluoroscopic observation; (2) this part of the examination involves palpation of the abdomen, rotation of the body as required to visualize different segments of the colon, and taking of spot images without and, when indicated, with compression; (3) a series of large radiographic images are taken before the colon can be evacuated.
- Assure the patient that retention of the diagnostic enema preparation is comparatively easy because its flow is controlled under fluoroscopic observation.
- Instruct the patient to (1) keep the anal sphincter tightly contracted against the tubing to hold it in position and prevent leakage; (2) relax the abdominal muscles to prevent intra-abdominal pressure; and (3) concentrate on deep oral breathing to reduce the incidence of colonic spasm and resultant cramps.
- Assure the patient that the flow of the enema would be stopped for the duration of any cramping.

A patient who has not had a previous colonic examination is usually fearful of being embarrassed by inadequate draping and failure to retain the enema for the required time. The radiographer can dispel or greatly relieve the patient's anxiety by taking the following steps:

- Assure the patient that he or she will be properly covered.
- Assure the patient that although there is little chance of "mishap," he or she will be well protected, and there is no need to feel embarrassed should one occur.
- Keep a bedpan in the examining room for a patient who cannot or may not be able to make the trip to the toilet.

The preliminary preparation required for a retrograde study of the colon is strenuous for the patient. The examination itself further depletes the patient's strength. Feeble patients, particularly elderly patients, are likely to become weak and faint from the exertion of the preparation, the examination, and the effort made to expel the enema. The strenuous nature of these procedures presents an increased risk for patients with a history of heart disease. An emergency call button should be available in the lavatory so that the patient can summon help if necessary. Although the patient's privacy must be respected, the radiographer or an aide should frequently inquire to ensure that the patient is all right.

Insertion of enema tip

In preparation for insertion of the enema tip, the following steps are taken:

- Instruct the patient to turn onto the left side, roll forward about 35 to 40 degrees, and rest the flexed right knee on the table, above and in front of the slightly flexed left knee (Sims position). This position relaxes the abdominal muscles, which decreases intra-abdominal pressure on the rectum and makes relaxation of the anal sphincter less difficult.
- Adjust the IV pole so that the enema contents are no higher than 24 inches (61 cm) above the level of the anus.
- Adjust the overlapping back of the gown or other draping to expose the anal region only, but keep the patient otherwise well covered. The anal orifice is commonly partially obscured by distended hemorrhoids or a fringe of undistended hemorrhoids. Sometimes there is a contraction or other abnormality of the orifice. It is necessary for the anus to be exposed and sufficiently well lighted for the orifice to be clearly visible, so that the enema tip can be inserted without injury or discomfort.
- Run a little of the barium mixture into a waste basin to free the tubing of air, and then lubricate the rectal tube well with a water-soluble lubricant.
- Advise the patient to relax and take deep breaths so that no discomfort is felt when the tube is inserted.
- Elevate the right buttock laterally to open the gluteal fold.
- As the abdominal muscles and anal sphincter are relaxed during the expiration phase of a deep breath, insert the rectal tube gently and slowly into the anal orifice. Following the angle of the anal canal, direct the tube anteriorly 1 to 1 1/2 inches (2.5 to 3.8 cm). Then, while following the curve of the rectum, direct the tube slightly superiorly.
- Insert the tube for a total distance of no more than 4 inches (10 cm). Insertion for a greater distance not only is unnecessary but also may injure the rectum.
- If the tube cannot be entered easily, ask the patient to assist if he or she is capable.
- *Never* forcibly insert a rectal tube because the patient may have distended internal hemorrhoids or another condition that makes forced insertion of the tube dangerous.
- After the enema tip is inserted, hold it in position to prevent slipping while the patient turns to the supine or prone position for fluoroscopy, according to the preference of the fluoroscopist. The retention cuff may be inflated at this time.
- Adjust the protective underpadding and relieve any pressure on the tubing, so that the enema mixture flows freely.

Single-Contrast Barium Enema

Administration of contrast medium

After preparing the patient for the examination, the radiographer observes the following steps:

- Notify the radiologist as soon as everything is ready for the examination.
- If the patient has not been introduced to the radiologist, make the introduction at this time.
- At the radiologist's request, release the control clip and ensure the enema flow.
- When occlusion of the enema tip occurs, displace soft fecal material by withdrawing the rectal tube about 1 inch (2.5 cm). Before reinserting the tip, temporarily elevate the enema bag to increase fluid pressure.

The rectal ampulla fills slowly. Unless the barium flow is stopped for a few seconds after the rectal ampulla is full, the suspension flows through the sigmoid and descending portions of the colon at a fairly rapid rate, frequently causing a severe cramp and acute stimulation of the defecation impulse. The flow of the barium suspension is usually stopped for several seconds at frequent intervals during fluoroscopically controlled filling of the colon.

During the fluoroscopic procedure, the radiologist rotates the patient to inspect all segments of the bowel. The radiologist takes spot images as indicated and determines the positions to be used for subsequent radiographic studies. On completion of the fluoroscopic examination, the enema tip is usually removed so the patient can be maneuvered more easily, and so the tip is not accidentally displaced during the imaging procedure. A retention tube is not removed until the patient is placed on a bedpan or the toilet.

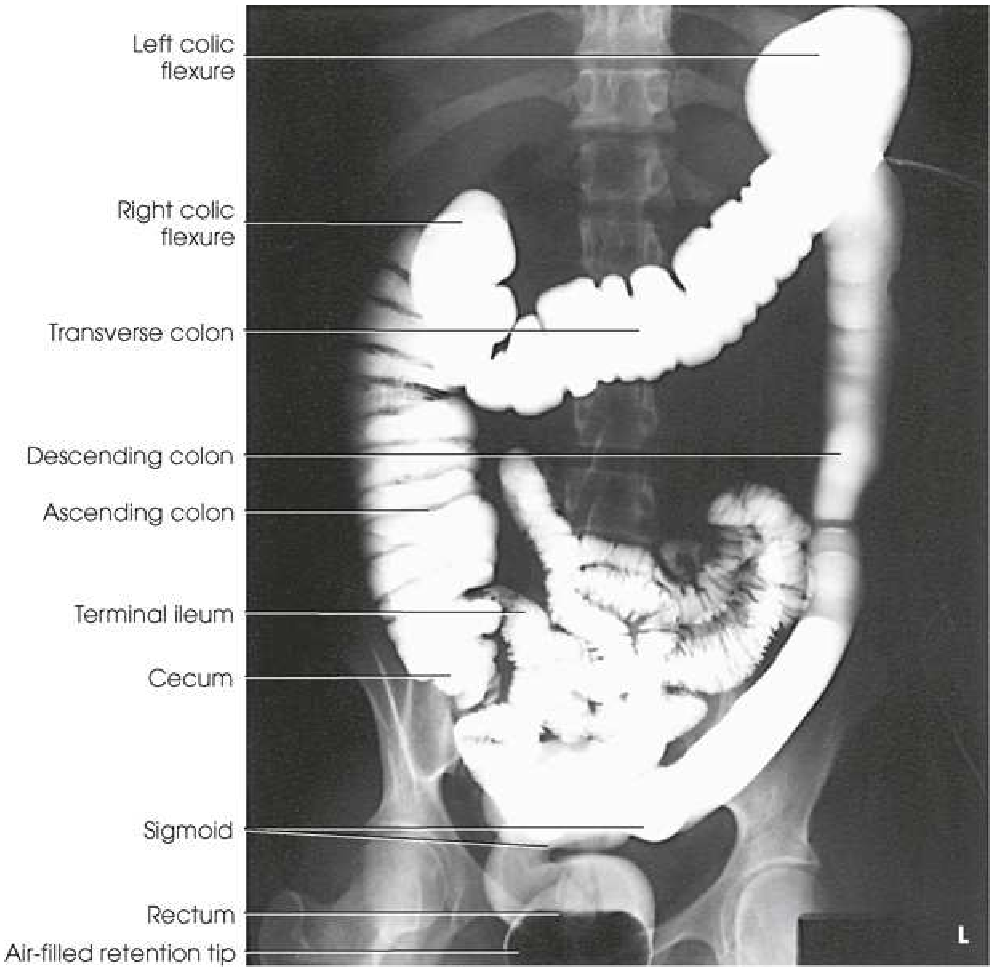


FIG. 15.104 Single-contrast BE image, sthenic habitus.

A radiograph of the A P view of the intestines taken in single contrast. The small intestine is highly coiled and highlighted. The contrast in the intestine highlights the presence of fecal materials in several placed denoted by arrows.

After the needed images have been obtained (Fig. 15.104), the patient is escorted to a toilet or placed on a bedpan and is instructed to expel as much of the barium suspension as possible. A postevacuation image is then taken (Fig. 15.105). If this image shows evacuation to be inadequate for satisfactory delineation of the mucosa, the patient may be given a hot beverage (tea or coffee) to stimulate further evacuation.

Positioning of opacified colon

The most commonly obtained projections for single-contrast BE are PA or AP and PA obliques, axial for the sigmoid, and lateral to show the rectum.

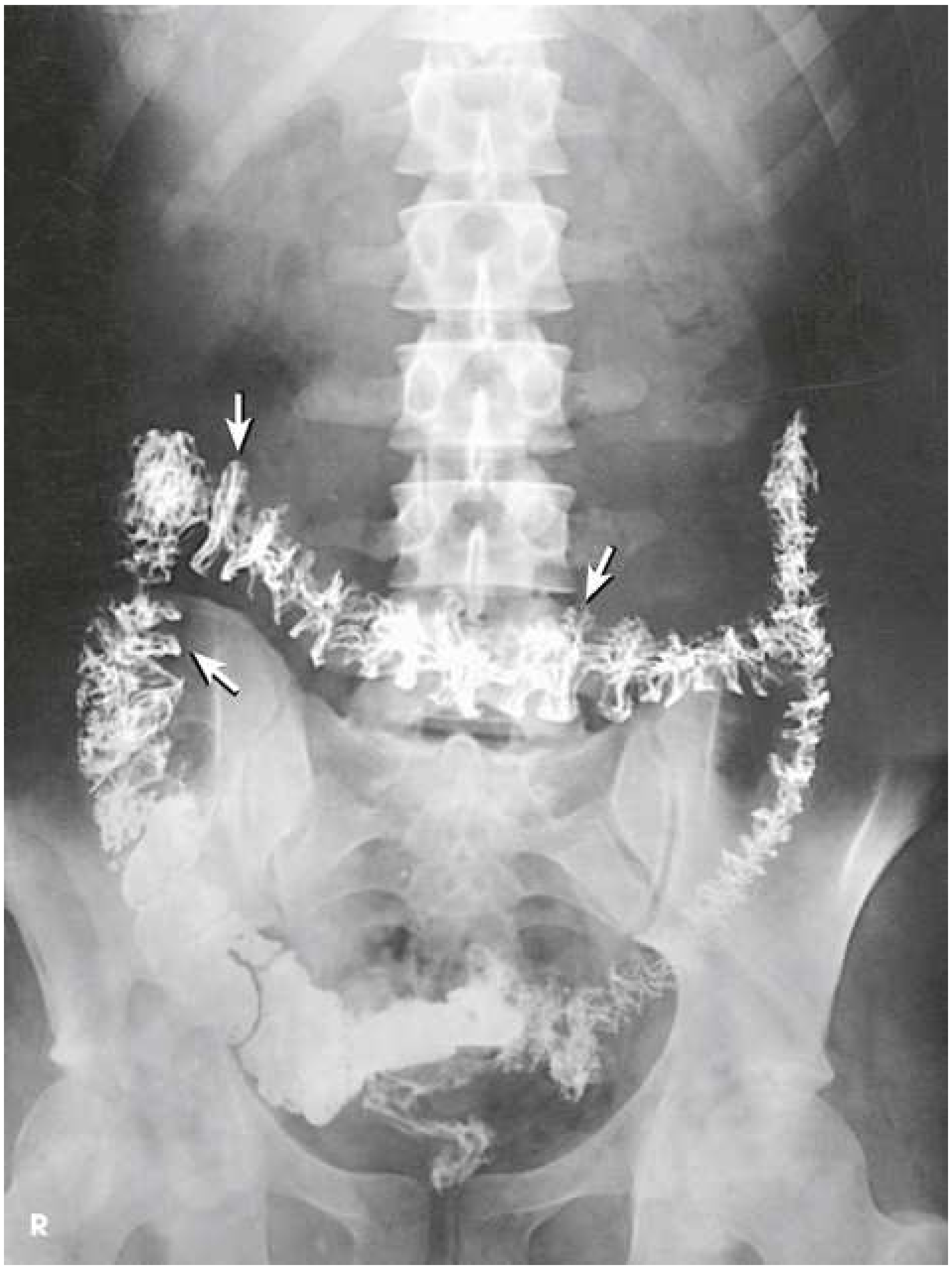


FIG. 15.105 Postevacuation image showing mucosal pattern *(arrows)*. Hyposthenic habitus.

A radiograph of the A P view of large intestine of hyposthenic habitus. The small intestine is highly coiled and highlighted. The pelvic and rib bones are visible. Arrows in the intestine point to mucosal patterns.

Double-Contrast Barium Enema

Two approaches to administering double-contrast BEs are currently in use. The first technique is a *two-stage procedure,* described by Welin, [19] which is detailed in the 13th and previous editions of *Merrill's Atlas*. The second approach is the *single-stage, double-contrast examination*. The popularity of this approach can be attributed primarily to more recent advancements in the manufacture of high-density barium sulfate.

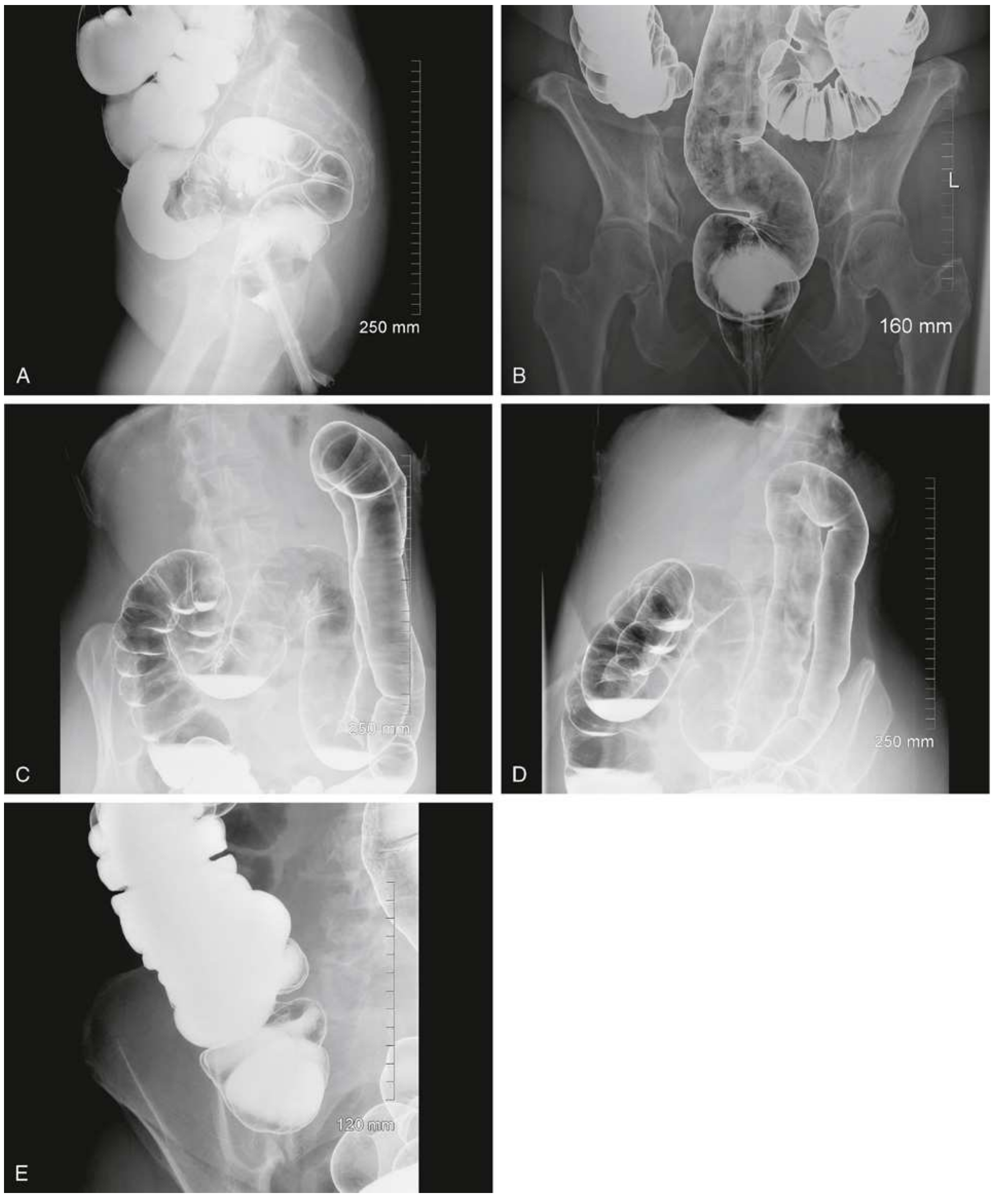


FIG. 15.106 Spot images, double-contrast BE. (A) Lateral rectum. (B) Axial sigmoid. (C) Hepatic flexure. (D) Splenic flexure. (E) Cecum. Courtesy NEA Baptist Memorial Hospital, Jonesboro, AR.

Five radiographs of the large intestine taken in double contrast. In the first one the lateral rectum is highlighted. In the second one the sigmoid axial is highlighted, in the third one the hepatic flexure is highlighted, in the fourth one the splenic flexure is highlighted, and in the last one the cecum is highlighted.

Single-stage procedure

In performing the single-stage, double-contrast enema, certain requirements must be met to ensure an adequate examination. The most important requirement is that the patient's colon must be exceptionally clean. Residual fecal material can obscure small polyps or tumor masses. A second requirement is that a suitable barium suspension must be used. A barium mixture that clumps or flakes neither clearly shows the lumen nor properly drains from the colon.

Currently available, premixed liquid barium products are generally more uniform for radiographic use than most barium suspensions mixed in the health care institution. A barium product with a density of 80% to 100% weight/volume may be used for a single-stage, double-contrast examination of the colon. The most important criterion is that the barium flows sufficiently to coat the walls of the colon.

With advances in the manufacture of high-density barium, high-quality double-contrast colon images can be consistently obtained during one filling of the colon. In the single-stage procedure, barium and air are instilled in a single procedure. Miller [20] described a *7-pump* method for performing single-stage, double-contrast examinations. This method reduces cost, saves time, and reduces radiation exposure to the patient. (A more complete description of the 7-pump method is provided in the seventh edition or earlier editions of this atlas.)

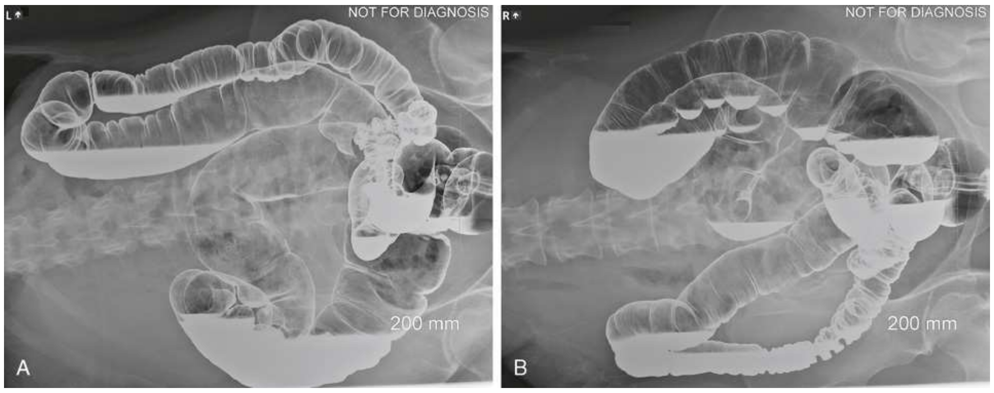


FIG. 15.107 (A) Right lateral decubitus position. (B) Left lateral decubitus position. Courtesy NEA Baptist Memorial Hospital, Jonesboro, AR.

Barium is instilled and the patient assisted in rotating to coat the mucosal lining. Air is pumped in slowly to expand the lumen. Fluoroscopy is performed to check the location of the barium, and additional air is instilled under fluoroscopic control. The entire colon is coated and expanded with air by slowly rotating the patient into various positions while imaging every portion of the colon. The ACR recommends images be obtained to attempt to demonstrate all segments of the colon in double contrast. Suggested views include the following:

- Spot images of the rectum, sigmoid colon, both flexures, and cecum in double contrast (Fig. 15.106).
- Large format images obtained with the patient supine and prone to include the entire colon.
- An axial of the sigmoid colon.
- Lateral of the rectum, either cross-table lateral or vertical beam, preferably with the enema tip removed.
- Both lateral decubitus positions of the entire colon (Fig. 15.107).
- Both flexures imaged with the patient upright or semi-upright.
- Postevacuation image.

The ACR uses the following criteria to ensure consistent quality in double-contrast BE examinations:

- Entire colon sufficiently coated with barium.
- The colon well distended with air.
- Each portion of the colon demonstrated in double-contrast on a minimum of two images taken in different positions, whenever possible.
- Demonstration of the entire colon, proven when the ileocecal valve, terminal ileum, or appendix is seen. [21]

Opacified Colon

Radiographic studies of the adult colon are made using a 14- × 17-inch (35- × 43-cm) exposure field or CR plate. Except for axial projections, these IRs may be centered at the level of the iliac crests on patients of sthenic build—higher for hypersthenic patients and lower for asthenic patients. AP and PA projections of the colon and abdomen may require two exposures, with the exposure field or CR plate crosswise: The first is centered high enough to include the diaphragm, and the second is centered low enough to include the rectum. Localized studies of the rectum and rectosigmoid junction are often exposed using a 10- × 12-inch (24- × 30-cm) exposure field or CR plate centered at or slightly above the level of the pubic symphysis. Preevacuation images of the colon include one or more images to show otherwise obscured flexed and curved areas of the large intestine.

Depending on the preference of the radiologist, the radiographic projections taken after fluoroscopy vary considerably. Any combination of the following images may be taken to complete the examination.

Pa Projection

Image receptor + grid: Positioned by manufacturer or department protocol for proper anatomy display orientation; CR plate: 14 × 17 inches (35 × 43 cm) lengthwise.

Position of patient

- Place the patient in the prone position.

Position of part

- Center the MSP to the grid.
- Adjust the center of the IR at the level of the iliac crests (Fig. 15.108).
- In addition to positioning for the PA projection, place the fluoroscopic table in a slight Trendelenburg position if necessary. This table position helps separate redundant and overlapping loops of the bowel by "spilling" them out of the pelvis.
- *Shield gonads.*
- *Respiration:* Suspend.

Central ray

- Perpendicular to the IR to enter the midline of the body at the level of the iliac crests.

Collimation

- Adjust the radiation field to no larger than 14 × 17 inches (35 × 43 cm). For smaller patients, collimate to within 1 inch (2.5 cm) of shadow of the abdomen flanks. Place side marker in the collimated exposure field.

Structures shown

The entire colon with the patient prone (Figs. 15.109–15.111).

Evaluation Criteria

The following should be clearly seen:

- Evidence of proper collimation and presence of side marker placed clear of anatomy of interest
- Entire colon including the flexures and the rectum (two images may be necessary for hypersthenic patients)
- Vertebral column centered so that ascending and descending portions of the colon are included
- Penetration of the contrast medium

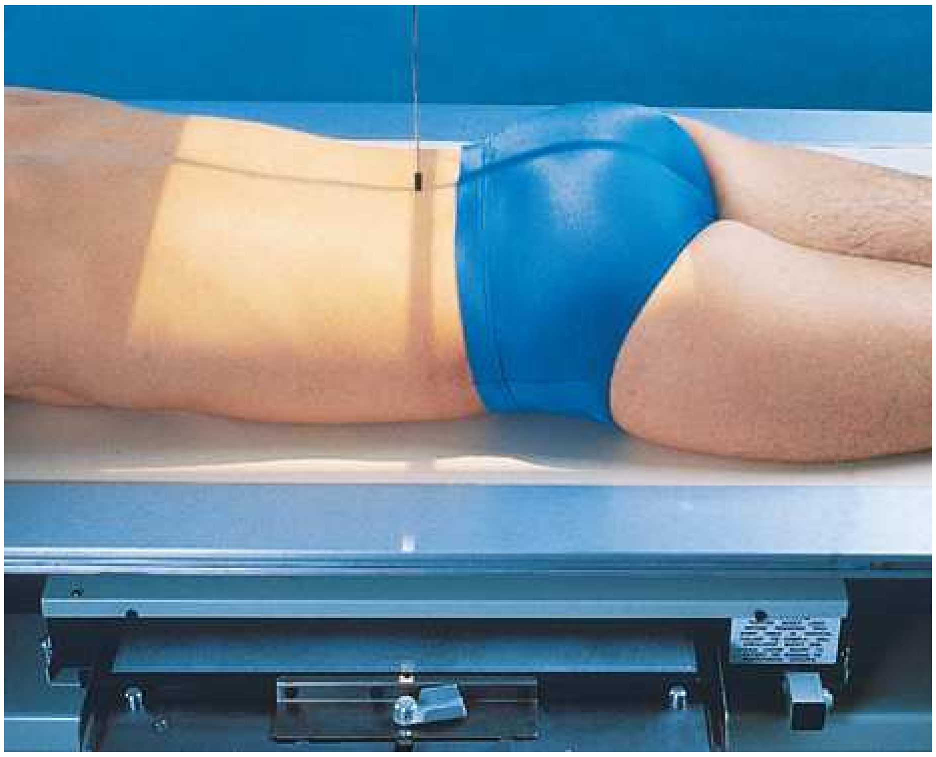


FIG. 15.108 PA large intestine.

A patient lies on his stomach, facing downwards on a table. His head and torso are on the same level and the arms are resting above his chest. The central ray is directed towards the center of his abdomen.

FIG. 15.109 Single-contrast PA large intestine.

A radiograph of the P A view of large intestine taken in single contrast. The small intestine is highly coiled and highlighted. The large intestine, stomach, duodenum, vertebral bones, and rib bones are visible.

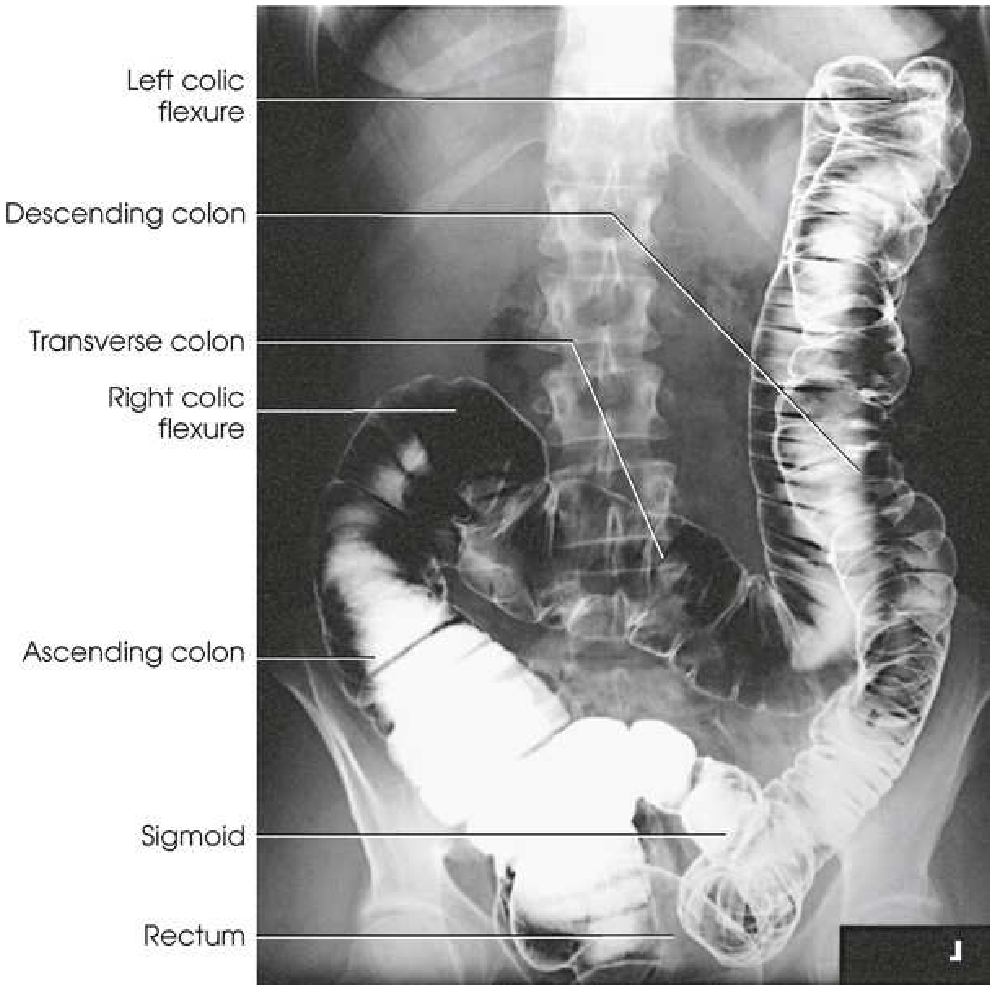


FIG. 15.110 Double-contrast PA large intestine, hyposthenic body habitus.

A radiograph of the P A view of large intestine taken in double contrast of hyposthenic body habitus. The small intestine is highly coiled and highlighted. The Left colic flexure, Right colic flexure, Transverse colon, Descending colon, Ascending colon, Terminal ileum, Cecum, Sigmoid Rectum, and Air-filled retention tip are labeled.

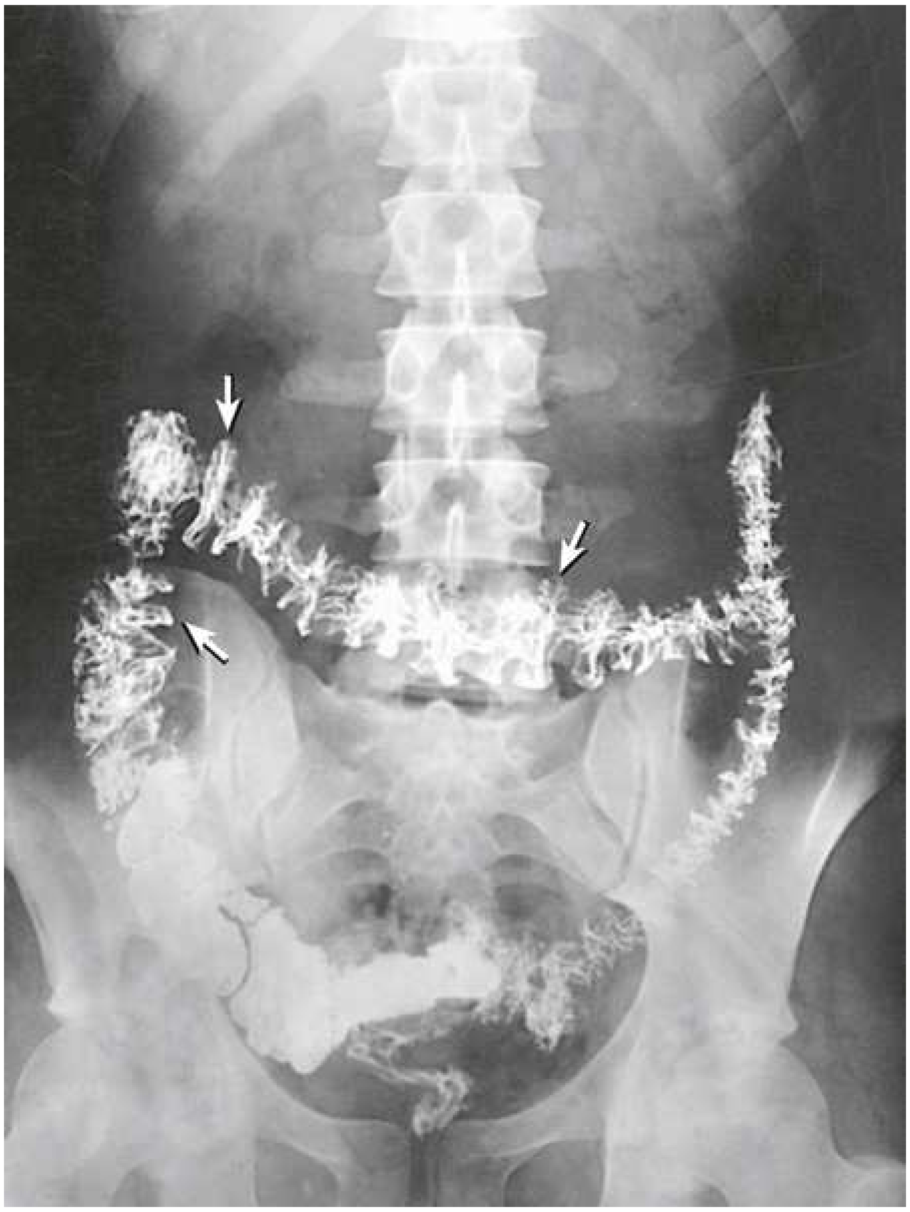


FIG. 15.111 Postevacuation PA large intestine. *Arrows* mark mucosal patterns evident in postevacuation images.

A radiograph of the P A view of large intestine of hyposthenic habitus. The small intestine is highly coiled and highlighted. The pelvic and rib bones are visible. Arrows in the intestine point to mucosal patterns.

Pa Axial Projection

Image receptor + grid: Positioned by manufacturer or department protocol for proper anatomy display orientation; CR plate: 10 × 12 inches (24 × 30 cm) or 14 × 17 inches (35 × 43 cm) lengthwise.

Position of patient

- Place the patient in the prone position.

Position of part

- Center the MSP to the grid.
- Adjust the center of the IR at the level of the iliac crests (Fig. 15.112).
- *Shield gonads.*
- *Respiration*: Suspend.

Central ray

- Directed 30 to 40 degrees caudad to enter the midline of the body at the level of the anterior superior iliac spine (ASIS).

Collimation

- Adjust the radiation field to no larger than 14 × 17 inches (35 × 43 cm) or 10 × 12 inches (24 × 30). Place side marker in the collimated exposure field.

Structures shown

The rectosigmoid area of the colon (Figs. 15.113 and 15.114).

NOTE: This axial projection is sometimes performed with the patient in the RAO position, to further reduce superimposition in the rectosigmoid area.

Evaluation Criteria

The following should be clearly seen:

- Evidence of proper collimation and presence of side marker placed clear of anatomy of interest
- Rectosigmoid area centered to image when a 10- × 12-inch (24- × 30-cm) exposure field/IR is used
- Rectosigmoid area with less superimposition than in PA projection because of angulation of the central ray
- Transverse colon and both flexures not always included
- Penetration of the contrast medium

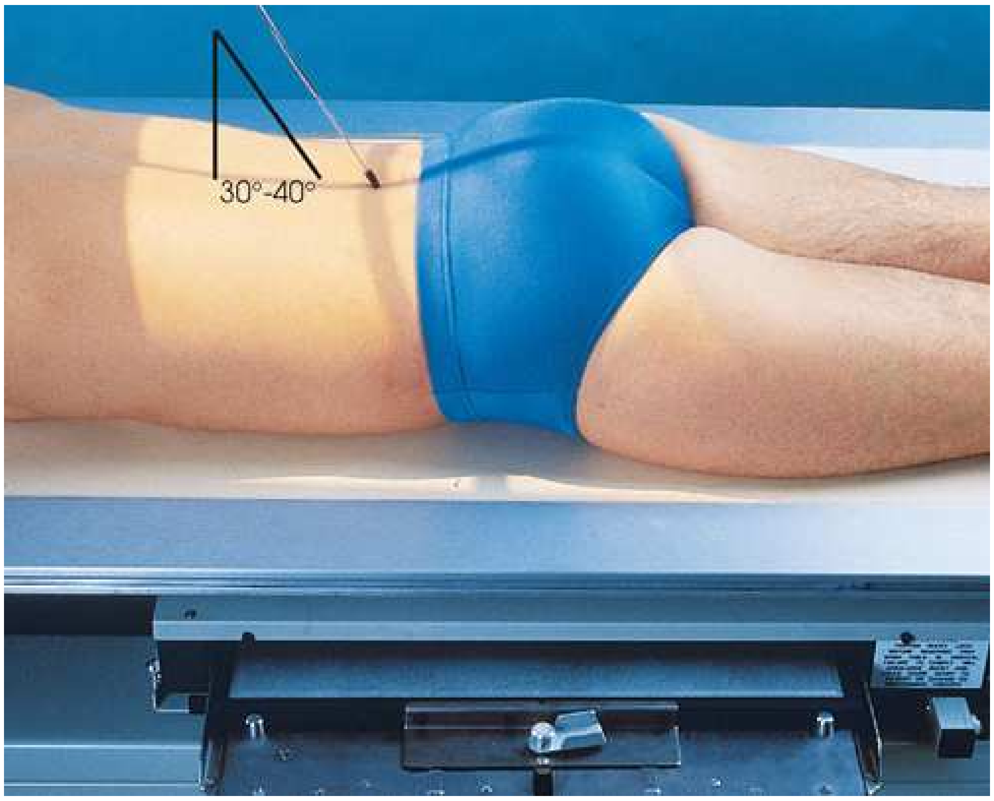


FIG. 15.112 PA axial large intestine.

A patient lies on his stomach, facing downwards on a table. His head and torso are on the same level and the arms are resting above his chest. The central ray is directed towards the center of his abdomen at an angle.

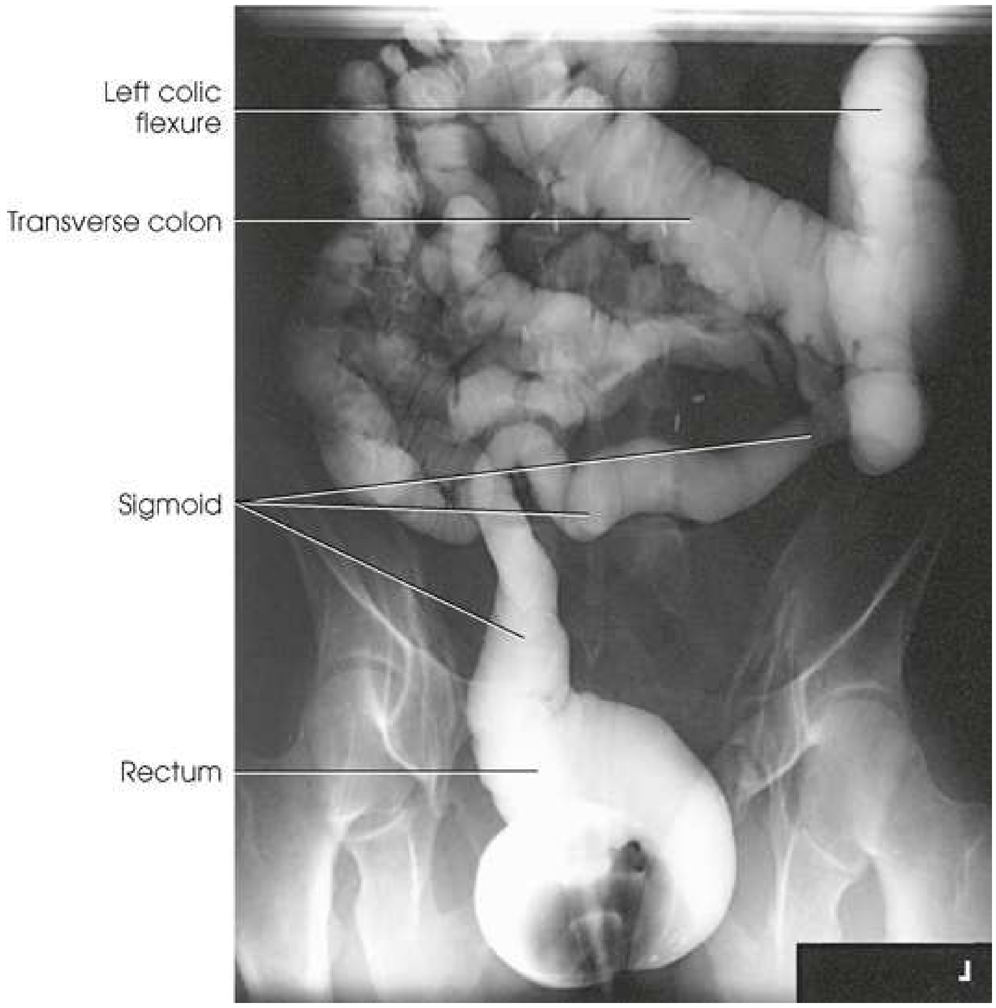


FIG. 15.113 Single-contrast PA axial (30-degree angulation) large intestine.

A radiograph of the P A view of large intestine taken in single contrast in a 30 degree angulation. The small intestine is highly coiled and highlighted. The Left colic flexure, Transverse colon, and Sigmoid Rectum are labeled.

FIG. 15.114 Double-contrast PA axial (40-degree angulation) large intestine.

Pa Oblique Projection

RAO position

Image receptor + grid: Positioned by manufacturer or department protocol for proper anatomy display orientation; CR plate: 14 × 17 inches (35 × 43 cm) lengthwise.

Position of patient

- Place the patient in the prone position.

Position of part

- With the patient's right arm by the side of the body and the left hand by the head, have the patient roll onto the right hip to obtain a 35- to 45-degree rotation from the radiographic table.
- Flex the patient's left knee to provide stability.
- Center the patient's body to the midline of the grid.
- Adjust the center of the IR at the level of the iliac crests (Fig. 15.115).
- *Shield gonads.*
- *Respiration:* suspend.

Central ray

- Perpendicular to the IR and entering approximately 1 to 2 inches (2.5 to 5 cm) lateral to the midline of the body on the elevated side at the level of the iliac crest.

Collimation

• Adjust the radiation field to no larger than 14 × 17 inches (35 × 43 cm). For smaller patients, collimate to within 1 inch (2.5 cm) of shadow of the abdomen flanks. Place side marker in the collimated exposure field.

Structures shown

The right colic flexure, the ascending portion of the colon, and the sigmoid portion of the colon (Figs. 15.116 and 15.117).

Evaluation Criteria

The following should be clearly seen:

- Evidence of proper collimation and presence of side marker placed clear of anatomy of interest
- Entire colon
- Right colic flexure less superimposed or open compared with the PA projection
- Ascending colon, cecum, and sigmoid colon
- Penetration of the contrast media

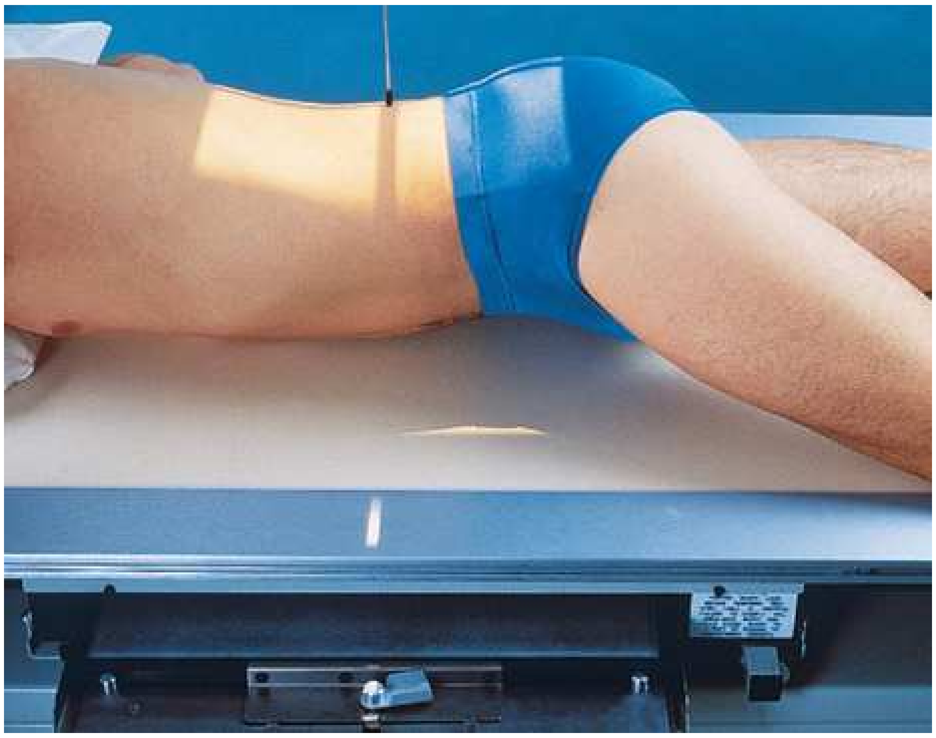


FIG. 15.115 PA oblique large intestine, RAO position.

A patient lies on his stomach, facing downwards on a table in R A O position. His left leg is raised and the left knee is slightly bent towards the table. The central ray is directed towards the center of his abdomen.

FIG. 15.116 Single-contrast PA oblique large intestine, RAO position.

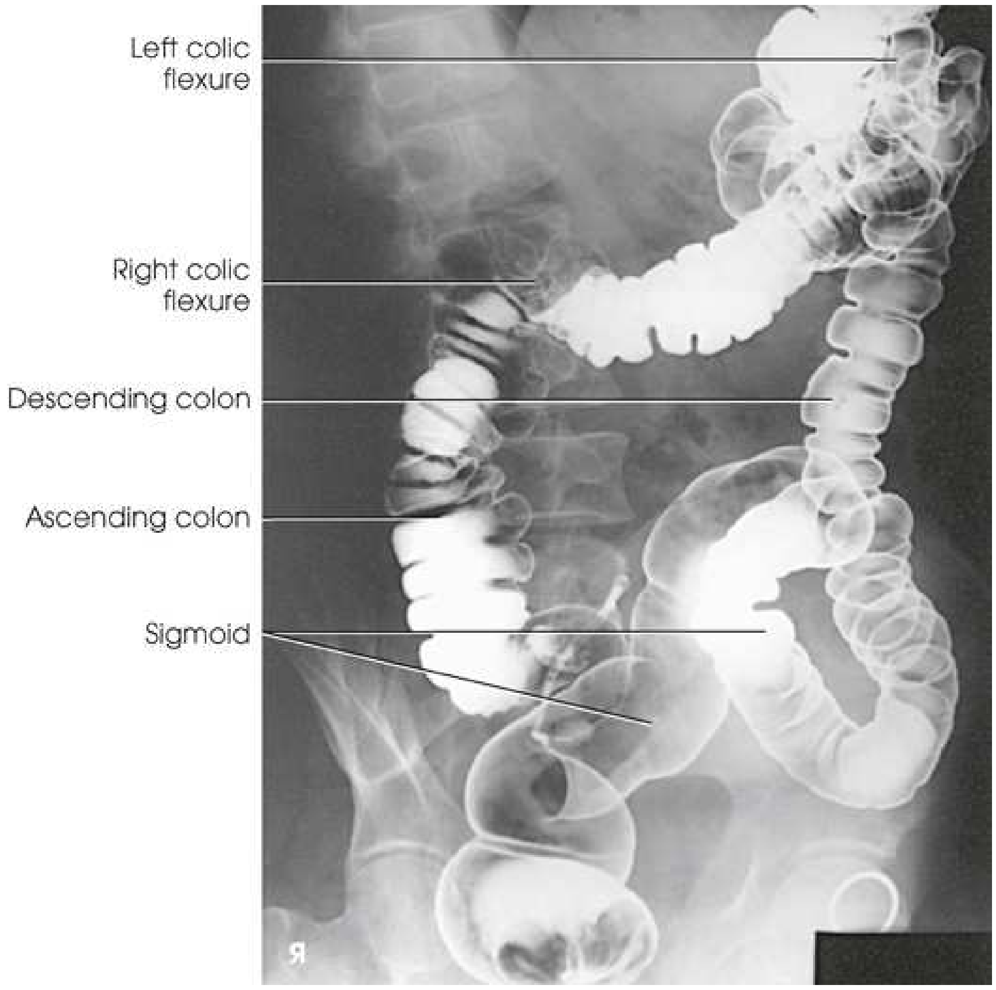


FIG. 15.117 Double-contrast PA oblique large intestine, RAO position.

A radiograph of the P A view of large intestine taken in single contrast in a 30 degree angulation. The small intestine is highly coiled and highlighted. The Left colic flexure, Transverse colon, and Sigmoid Rectum are labeled.

Pa Oblique Projection

LAO position

Image receptor + grid: Positioned by manufacturer or department protocol for proper anatomy display orientation; CR plate: 14 × 17 inches (35 × 43 cm) lengthwise.

Position of patient

- Place the patient in the prone position.

Position of part

- With the patient's left arm by the side of the body and the right hand by the head, have the patient roll onto the left hip to obtain a 35- to 45-degree rotation from the radiographic table.
- Flex the patient's right knee to provide stability.
- Center the patient's body to the midline of the grid.
- Adjust the center of the IR at the level of the iliac crest (Fig. 15.118).
- *Shield gonads.*
- *Respiration*: Suspend.

Central ray

- Perpendicular to the IR and entering approximately 1 to 2 inches (2.5 to 5 cm) lateral to the midline of the body on the elevated side at the level of the iliac crest.

Collimation

- Adjust the radiation field to no larger than 14 × 17 inches (35 × 43 cm). For smaller patients, collimate to within 1 inch (2.5 cm) of shadow of the abdomen flanks. Place side marker in the collimated exposure field.

Structures shown

The left colic flexure and the descending portion of the colon (Figs. 15.119 and 15.120).

Evaluation Criteria

The following should be clearly seen:

- Evidence of proper collimation and presence of side marker placed clear of anatomy of interest
- Entire colon
- Left colic flexure less superimposed or open compared with the PA projection
- Descending colon
- Penetration of the contrast medium

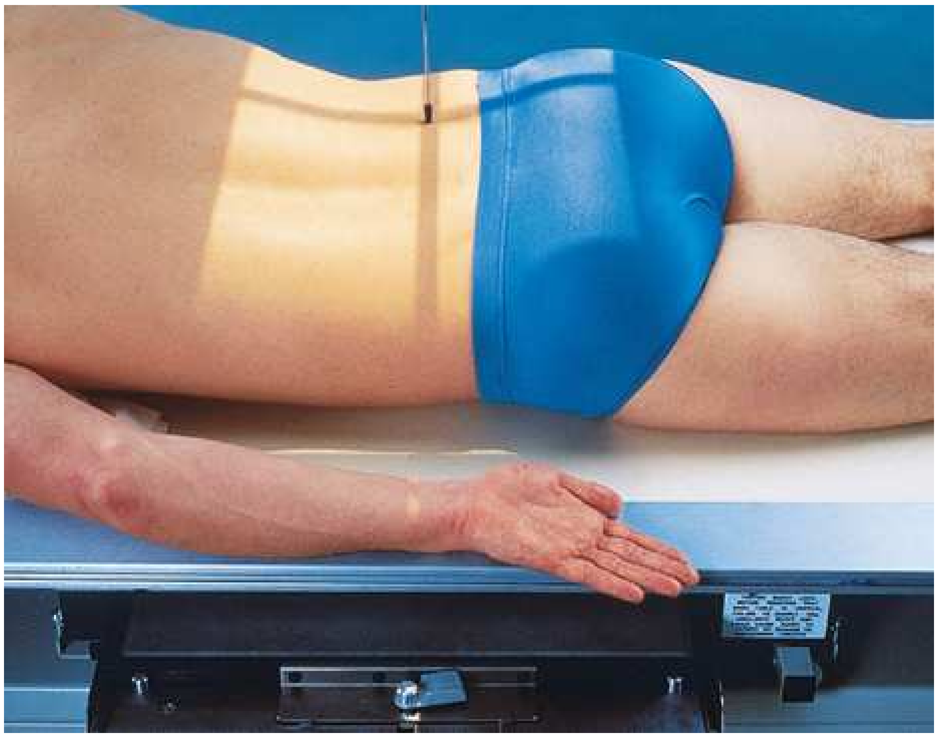


FIG. 15.118 PA oblique large intestine, LAO position.

A patient lies on his stomach, facing downwards on a table. His head and torso are on the same level and the arms are resting on either side of the torso. The central ray is directed towards the center of his abdomen at an angle.

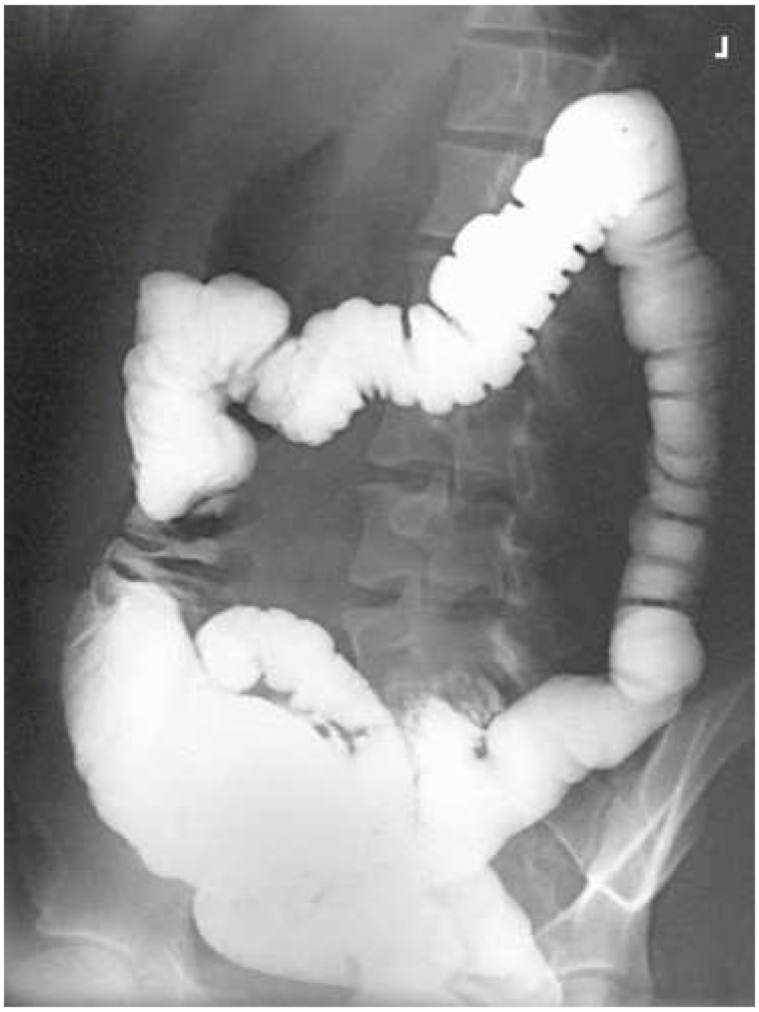


FIG. 15.119 Single-contrast PA oblique large intestine, LAO position.

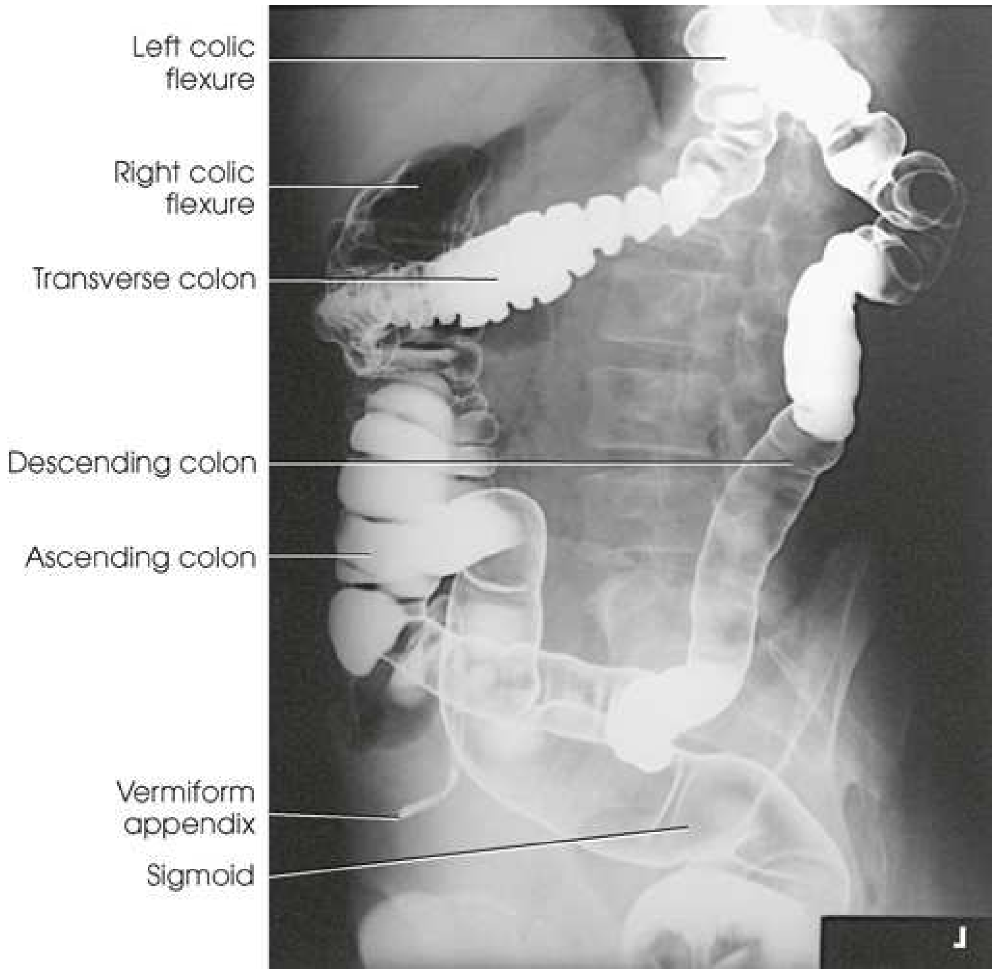


FIG. 15.120 Double-contrast PA oblique large intestine, LAO position.

A radiograph of the P A view of large intestine taken in double contrast in a 30 degree angulation. The small intestine is highly coiled and highlighted. The Left colic flexure, Transverse colon, and Sigmoid Rectum are labeled.

Lateral Projection

Right or left position

Image receptor + grid: Positioned by manufacturer or department protocol for proper anatomy display orientation; CR plate: 10 × 12 inches (24 × 30 cm) lengthwise.

Position of patient

- Place the patient in the lateral recumbent position on the left or the right side.

Position of part

- Center the midcoronal plane to the center of the grid.
- Flex the patient's knees slightly for stability, and place a support between the knees to keep the pelvis lateral.
- Adjust the patient's shoulders and hips to be perpendicular (Fig. 15.121).
- Adjust the center of the IR to the ASIS.
- *Shield gonads.*
- *Respiration*: Suspend.

Central ray

- Perpendicular to the IR to enter the midcoronal plane at the level of the ASIS.

Collimation

- Adjust the radiation field to no larger than 10 × 12 inches (24 × 30 cm). Place side marker in the collimated exposure field.

Structures shown

The rectum and the distal sigmoid portion of the colon (Figs. 15.122 and 15.123).

Evaluation Criteria

The following should be clearly seen:

- Evidence of proper collimation and presence of side marker placed clear of anatomy of interest
- Rectosigmoid area in the center of the image
- No rotation of the patient
- Superimposed hips and femora
- Superior portion of colon not included when the rectosigmoid region is the area of interest
- Penetration of the contrast medium

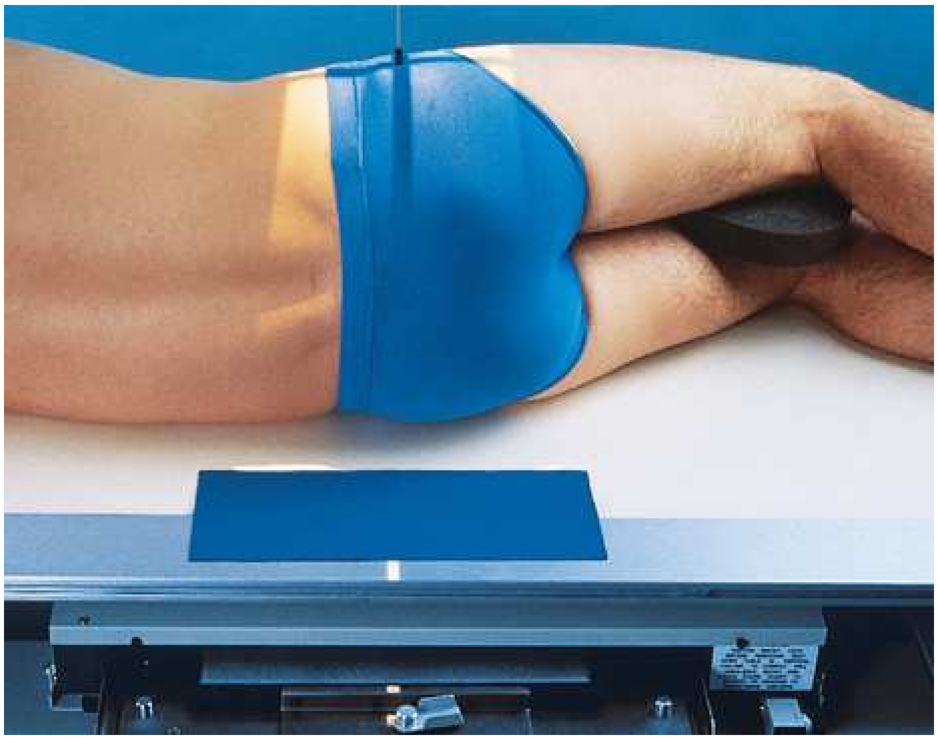


FIG. 15.121 Left lateral rectum.

A patient lies on his side, facing towards his left on a table. His posterior body is visible. The arms are resting on above the chest. His knees are bent in a crouching position. The central ray is directed towards the center of his abdomen at an angle.

FIG. 15.122 Single-contrast left lateral rectum.

FIG. 15.123 Double-contrast left lateral rectum.

A radiograph of the left lateral view of the rectum in double contrast. The edges of the rectum and the surrounding soft tissues are highlighted. The Sigmoid, Sacrum, Rectum, and Pubic symphysis are visible.

Ap Projection

Image receptor + grid: Positioned by manufacturer or department protocol or proper anatomy display orientation; CR plate: 14 × 17 inches (35 × 43 cm) lengthwise.

Position of patient

- Place the patient in the supine position.

Position of part

- Center the MSP to the grid.
- Adjust the center of the IR at the level of the iliac crests (Fig. 15.124).
- *Shield gonads.*
- *Respiration*: suspend.

Central ray

- Perpendicular to the IR to enter the midline of the body at the level of the iliac crests.

Collimation

- Adjust the radiation field to no larger than 14 × 17 inches (35 × 43 cm). For smaller patients, collimate to within 1 inch (2.5 cm) of shadow of the abdomen flanks. Place side marker in the collimated exposure field.

Structures shown

The entire colon with the patient supine (Figs. 15.125 and 15.126).

Evaluation Criteria

The following should be clearly seen:

- Evidence of proper collimation and presence of side marker placed clear of anatomy of interest
- Entire colon including the splenic flexure and the rectum (two images may be necessary for hypersthenic patients)
- Vertebral column centered so that the ascending colon and the descending colon are completely included
- Penetration of the contrast medium

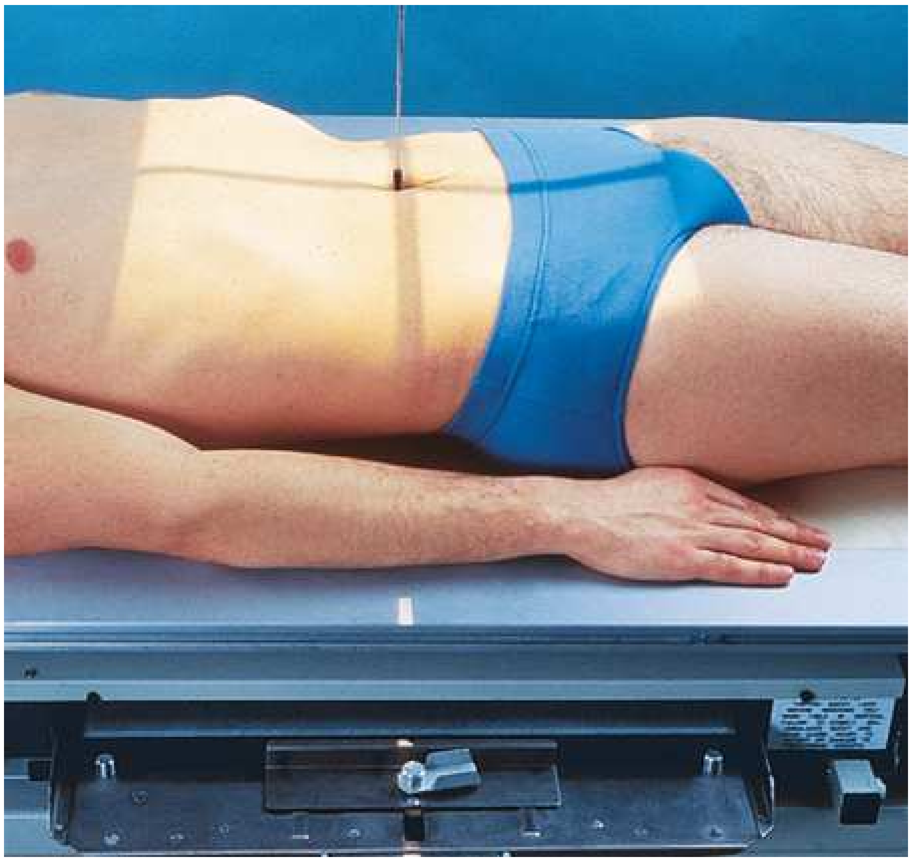


FIG. 15.124 AP large intestine.

FIG. 15.125 Single-contrast AP large intestine, sthenic habitus.

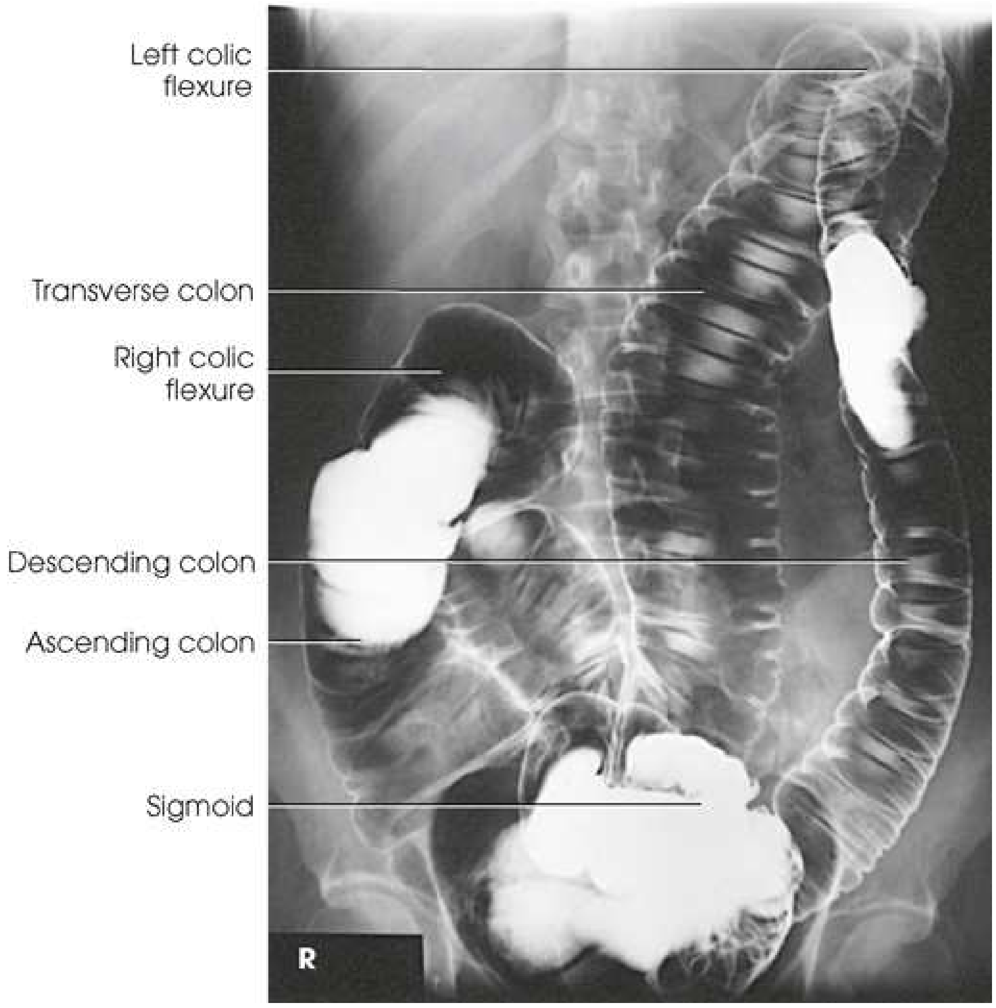


FIG. 15.126 Double-contrast AP large intestine, asthenic habitus.

A radiograph of the A P oblique view of the large intestine taken in double contrast in a asthenic habitus. The Left colic flexure, Transverse colon, Right colic flexure, Descending colon, Ascending colon, and Sigmoid are labeled.

Ap Axial Projection

Image receptor + grid: Positioned by manufacturer or department protocol for proper anatomy display orientation; CR plate: 10 × 12 inches (24 × 30 cm) or 14 × 17 inches (35 × 43 cm) lengthwise.

Position of patient

- Place the patient in the supine position.

Position of part

- Center the MSP to the grid.
- Adjust the center of the IR at a level approximately 2 inches (5 cm) above the level of the iliac crests (Fig. 15.127).
- *Shield gonads.*
- *Respiration*: Suspend.

Central ray

- Directed 30 to 40 degrees cephalad to enter the midline of the body approximately 2 inches (5 cm) below the level of the ASIS.
- Directed to enter the inferior margin of the pubic symphysis when a collimated image is desired to show the rectosigmoid region.

Collimation

- Adjust the radiation field to no larger than 14 × 17 inches (35 × 43 cm) or 10 × 12 inches (24 × 30 cm). Place side marker in the collimated exposure field.

Structures shown

The rectosigmoid area of the colon (Figs. 15.128 and 15.129). A similar image is obtained when the patient is prone (see Figs. 15.113 and 15.114).

NOTE: This axial projection is sometimes performed with the patient in the LPO position, to further reduce superimposition in the rectosigmoid area.

Evaluation Criteria

The following should be clearly seen:

- Evidence of proper collimation and presence of side marker placed clear of anatomy of interest
- Rectosigmoid area centered when a 10- × 12-inch (24- × 30-cm) IR is used
- Rectosigmoid area with less superimposition than in the AP projection because of the angulation of the central ray
- Transverse colon and flexures not included
- Penetration of the contrast medium

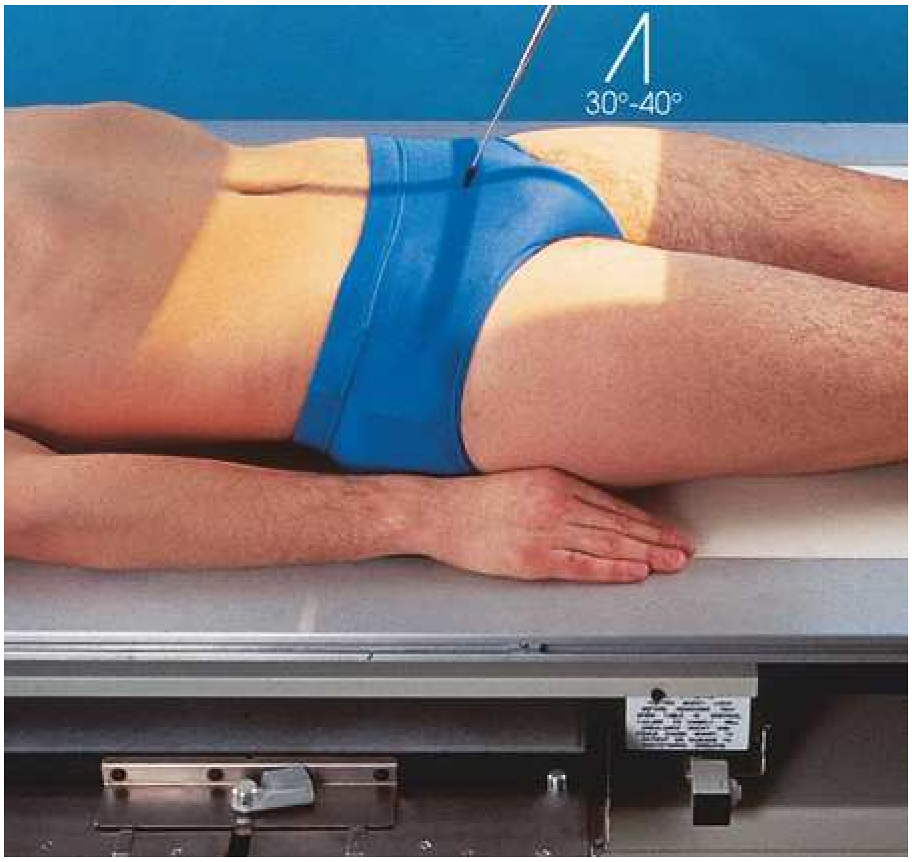


FIG. 15.127 AP axial large intestine.

A patient lies on a table facing upwards. His head and torso are on the same level and the arms are resting on either side of the torso. The central ray is directed towards the center of his pelvis at an angle.

FIG. 15.128 Single-contrast AP axial large intestine.

A radiograph of the A P axial view of the large intestine taken in single contrast. The Left colic flexure, Transverse colon, Right colic flexure, Descending colon, Ascending colon, and Sigmoid are highlighted.

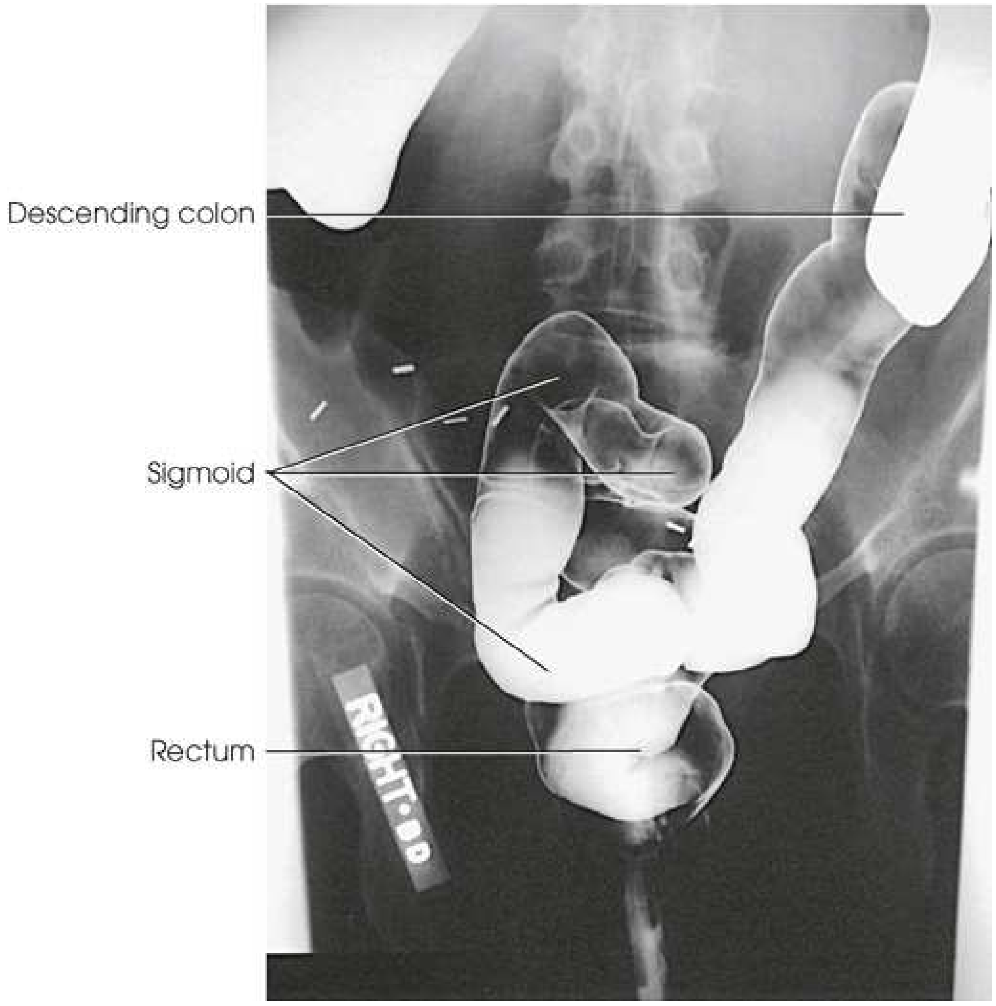


FIG. 15.129 Double-contrast AP axial large intestine.

A radiograph of the A P axial view of the large intestine taken in double contrast. The Left colic flexure, Transverse colon, Right colic flexure, Descending colon, Ascending colon, and Sigmoid are highlighted.

Ap Oblique Projection

LPO position

Image receptor + grid: Positioned by manufacturer or department protocol for proper anatomy display orientation; CR plate: 14 × 17 inches (35 × 43 cm) lengthwise.

Position of patient

- Place the patient in the supine position.

Position of part

- With the patient's left arm by the side of the body and the right arm across the superior chest, have the patient roll onto the left hip to obtain a 35- to 45-degree rotation from the table.
- Use a positioning sponge and flex the patient's right knee for stability, if necessary.
- Center the patient's body to the midline of the grid.
- Adjust the center of the IR at the level of the iliac crests (Fig. 15.130).
- *Shield gonads.*
- *Respiration*: Suspend.

Central ray

- Perpendicular to the IR to enter approximately 1 to 2 inches (2.5 to 5 cm) lateral to the midline of the body on the elevated side at the level of the iliac crest.

Collimation

• Adjust the radiation field to no larger than 14 × 17 inches (35 × 43 cm). For smaller patients, collimate to within 1 inch (2.5 cm) of shadow of the abdomen flanks. Place side marker in the collimated exposure field.

Structures shown

The right colic flexure and the ascending and sigmoid portions of the colon (Figs. 15.131 and 15.132).

Evaluation Criteria

The following should be clearly seen:

- Evidence of proper collimation and presence of side marker placed clear of anatomy of interest
- Entire colon
- Right colic flexure less superimposed or open compared with the AP projection
- Ascending colon, cecum, and sigmoid colon
- Penetration of the contrast medium

FIG. 15.130 AP oblique large intestine, LPO position.

A patient lies on his side, facing towards the left on a table in L P O position. His posterior body is visible. His right leg is raised and the right knee is slightly bent towards the left. The central ray is directed towards the pelvis.

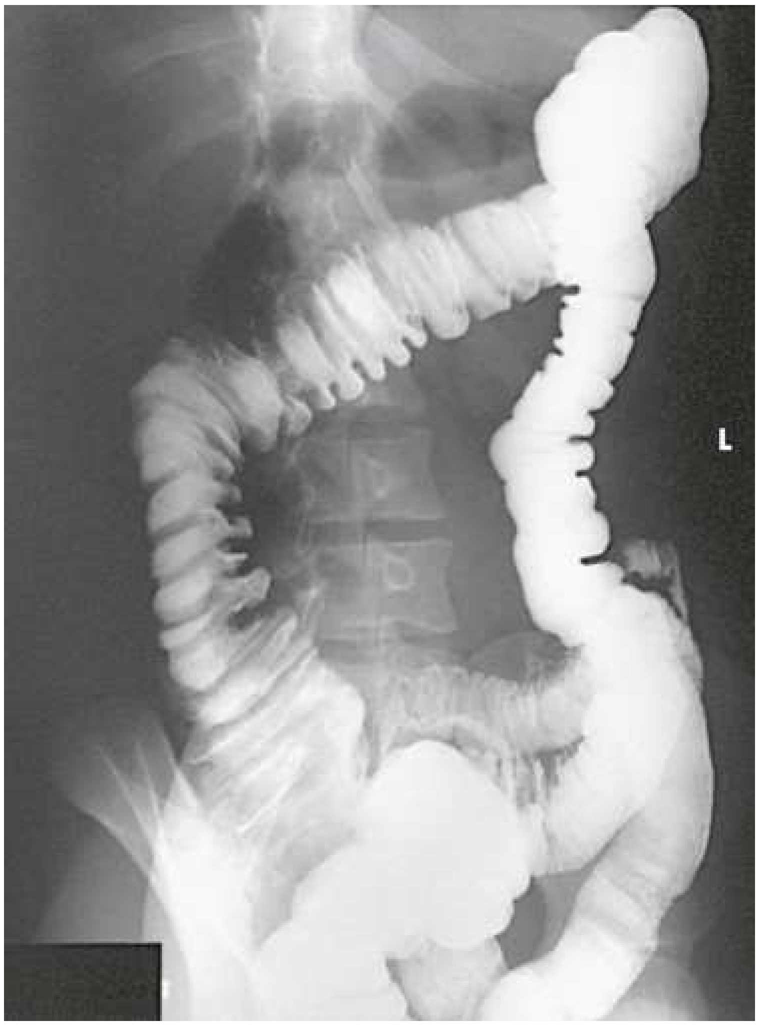


FIG. 15.131 Single-contrast AP oblique large intestine, LPO position.

A radiograph of the A P oblique view of the large intestine taken in single contrast in L P O position. The Left colic flexure, Transverse colon, Right colic flexure, Descending colon, Ascending colon, and Sigmoid are highlighted.

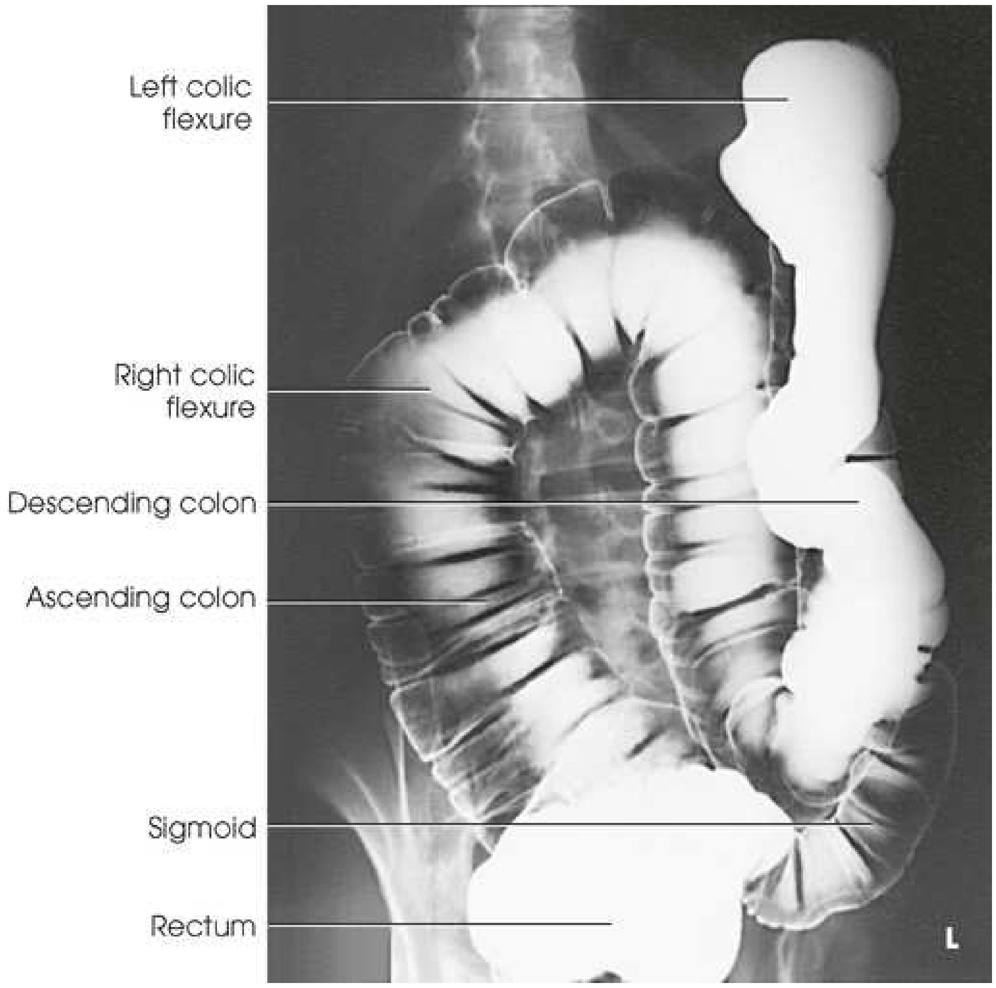


FIG. 15.132 Double-contrast AP oblique large intestine, LPO position.

A radiograph of the A P oblique view of the large intestine taken in double contrast in L P O position. The Left colic flexure, Transverse colon, Right colic flexure, Descending colon, Ascending colon, and Sigmoid are labeled.

Ap Oblique Projection

RPO position

Image receptor + grid: Positioned by manufacturer or department protocol for proper anatomy display orientation; CR plate: 14 × 17 inches (35 × 43 cm) lengthwise.

Position of patient

- Place the patient in the supine position.

Position of part

- With the patient's right arm by the side of the body and the left arm across the superior chest, have the patient roll onto the right hip to obtain a 35- to 45-degree rotation from the radiographic table.
- Use a positioning sponge and flex the patient's right knee for stability, if needed.
- Center the patient's body to the midline of the grid.
- Adjust the center of the IR at the level of the iliac crests (Fig. 15.133).
- *Shield gonads.*
- *Respiration:* suspend.

Central ray

- Perpendicular to the IR to enter approximately 1 to 2 inches (2.5 to 5 cm) lateral to the midline of the body on the elevated side at the level of the iliac crest.

Collimation

- Adjust the radiation field to no larger than 14 × 17 inches (35 × 43 cm). For smaller patients, collimate to within 1 inch (2.5 cm) of shadow of the abdomen flanks. Place side marker in the collimated exposure field.

Structures shown

The left colic flexure and the descending colon (Figs. 15.134 and 15.135).

FIG. 15.134 Single-contrast AP oblique large intestine, RPO position.

A radiograph of the A P oblique view of the large intestine taken in double contrast in R P O position. The Left colic flexure, Transverse colon, Right colic flexure, Descending colon, Ascending colon, and Sigmoid are highlighted.

Evaluation Criteria

The following should be clearly seen:

- Evidence of proper collimation and presence of side marker placed clear of anatomy of interest
- Entire colon
- Left colic flexure and descending colon
- Penetration of the contrast medium

FIG. 15.133 AP oblique large intestine, RPO position.

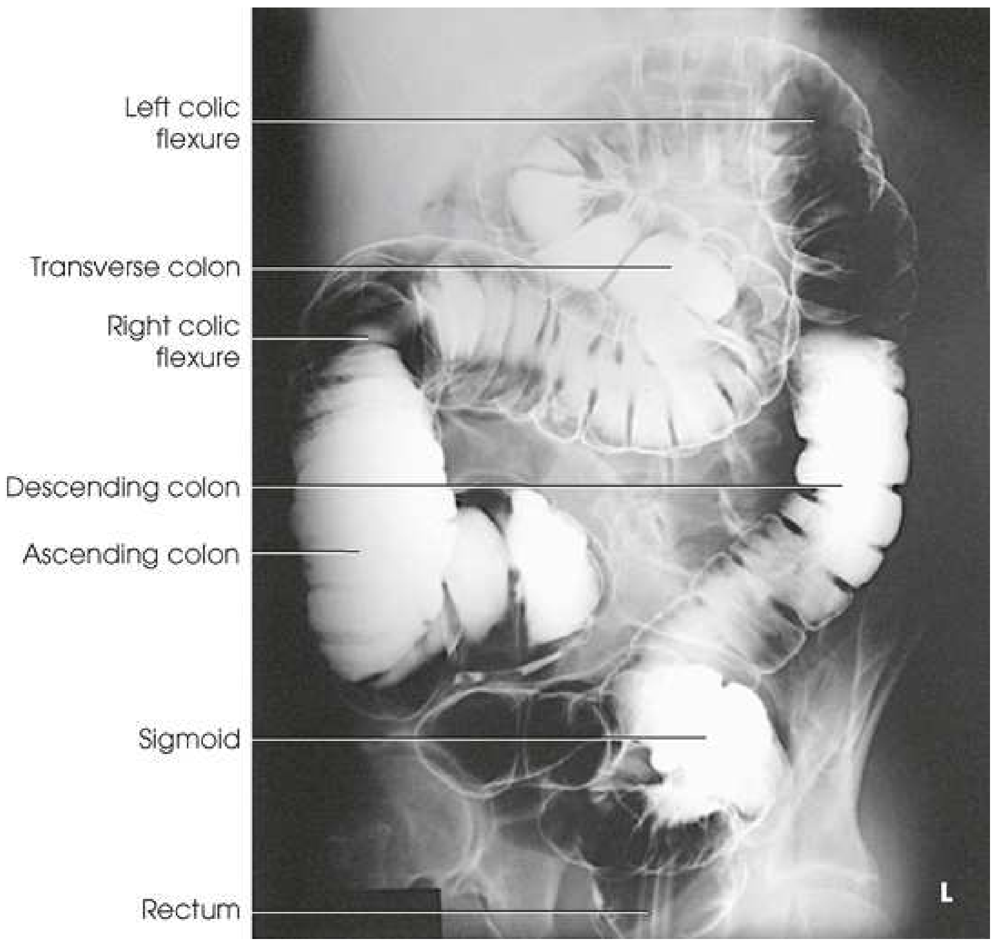


FIG. 15.135 Double-contrast AP oblique large intestine, RPO position.

A radiograph of the A P oblique view of the large intestine taken in double contrast in R P O position. The Left colic flexure, Transverse colon, Right colic flexure, Descending colon, Ascending colon, and Sigmoid are highlighted.

Decubitus Positions

When a patient is being prepared for an examination in a decubitus position, the following general guidelines are observed:

- Take all decubitus images (1) with the patient lying on the fluoroscopic table and a grid IR firmly supported behind the patient's body; (2) with the patient lying on a patient cart with the body against an upright table or chest device; or (3) with the patient lying on a table or cart and a specially designed vertical grid device behind the patient.
- To ensure that the side on which the patient is lying is shown, elevate the patient on a suitable radiolucent support. If this is not done, the image records artifacts from the mattress or from the table edge and superimposes these images over the portion of the patient's colon on the "down" side.
- For all decubitus procedures, *exercise extreme caution* to ensure that the *wheels of the cart are securely locked* so that the patient will not fall.
- For lateral decubitus images, have the patient put the back or abdomen against the vertical grid device. Most patients find it more comfortable to have their back against the vertical grid device than to have their abdomen against the same device.
- If both lateral decubitus images are requested (which is often the case with air-contrast examinations), take one image with the patient's anterior body surface against the vertical grid device and the second image with the posterior body surface against the vertical grid device.

Ap or Pa Projection

Right lateral decubitus position

Image receptor + grid: Positioned by manufacturer or department protocol for proper anatomy display orientation; CR plate: 14 × 17 inches (35 × 43 cm) lengthwise.

Position of patient

- Place the patient on the right side with the back or abdomen in contact with the vertical grid device.
- *Exercise care* to ensure that the patient does not fall from the cart or table; if a cart is used, *lock all wheels* securely.

FIG. 15.136 AP large intestine, right lateral decubitus position.

A patient lies on his side, facing towards the right on a table in decubitus position. His anterior body is visible. His arms are bent at the elbows and rested behind the head. The knees are bent in decubitus position.

Position of part

- With the patient lying on an elevated radiolucent support, center the MSP to the grid.
- Adjust the center of the IR to the level of the iliac crests (Fig. 15.136).
- *Shield gonads.*
- *Respiration*: Suspend.

Central ray

- *Horizontal* and perpendicular to the IR to enter the midline of the body at the level of the iliac crests.

Collimation

- Adjust the radiation field to no larger than 14 × 17 inches (35 × 43 cm). For smaller patients, collimate to within 1 inch (2.5 cm) of shadow of the abdomen flanks. Place side marker in the collimated exposure field.

Structures shown

The right lateral decubitus position shows an AP or PA projection of the contrast-filled colon. This position best shows the "up" medial side of the ascending colon and the lateral side of the descending colon when the colon is inflated with air (Figs. 15.137 and 15.138).

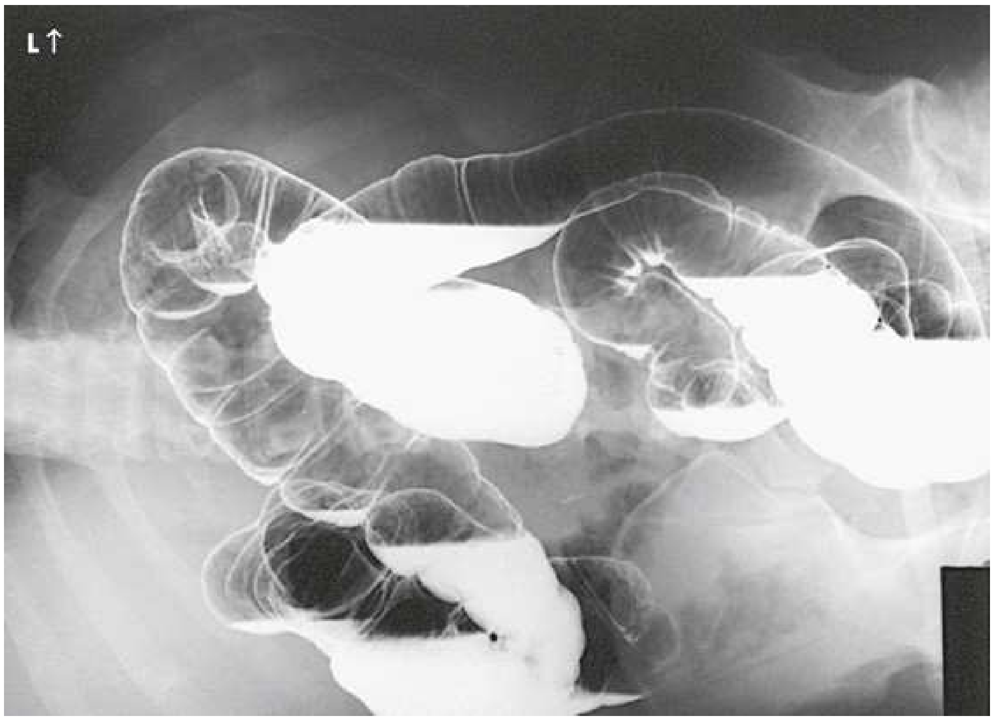


FIG. 15.137 Double-contrast AP large intestine, right lateral decubitus position.

A radiograph of the A P oblique view of the large intestine taken in double contrast in Right lateral decubitus position. The Left colic flexure, Sigmoid, Transverse colon, Right colic flexure are visible.

FIG. 15.138 Double-contrast AP large intestine, right lateral decubitus position.

A radiograph of the A P oblique view of the large intestine taken in double contrast in Right lateral decubitus position. The Left colic flexure, Sigmoid, Transverse colon, Right colic flexure are labeled.

Evaluation Criteria

The following should be clearly seen:

- Evidence of proper collimation and presence of side marker placed clear of anatomy of interest
- Area from the left colic flexure to the rectum
- No rotation of the patient, as demonstrated by symmetry of the ribs and pelvis
- For single-contrast examinations, adequate penetration of the barium; for double-contrast examinations, the air-inflated portion of the colon is of primary importance and should not be overpenetrated

Compensating Filter

Image quality can be improved on larger patients with the use of a special decubitus filter.

Pa or Ap Projection

Left lateral decubitus position

Image receptor + grid: Positioned by manufacturer or department protocol for proper anatomy display orientation; CR plate: 14 × 17 inches (35 × 43 cm) lengthwise.

Position of patient

- Place the patient on the left side with the abdomen or back in contact with the vertical grid device.
- *Exercise care* to ensure that the patient does not fall from the cart or table; if a cart is used, *lock all wheels* securely in position.

FIG. 15.139 PA large intestine, left lateral decubitus position.

A patient lies on his side, facing towards the left on a table in decubitus position. His posterior body is visible. His arms are bent at the elbows and rested behind the head. The knees are bent in decubitus position.

Position of part

- With the patient lying on an elevated radiolucent support, center the MSP to the grid.
- Adjust the center of the IR at the level of the iliac crests (Fig. 15.139).
- *Shield gonads.*
- *Respiration*: Suspend.

Central ray

- *Horizontal* and perpendicular to the IR to enter the midline of the body at the level of the iliac crests.

Collimation

- Adjust the radiation field to no larger than 14 × 17 inches (35 × 43 cm). For smaller patients, collimate to within 1 inch (2.5 cm) of shadow of the abdomen flanks. Place side marker in the collimated exposure field.

Structures shown

The left lateral decubitus position shows a PA or AP projection of the contrast-filled colon. This position best shows the "up" lateral side of the ascending colon and the medial side of the descending colon when the colon is inflated with air (Figs. 15.140 and 15.141).

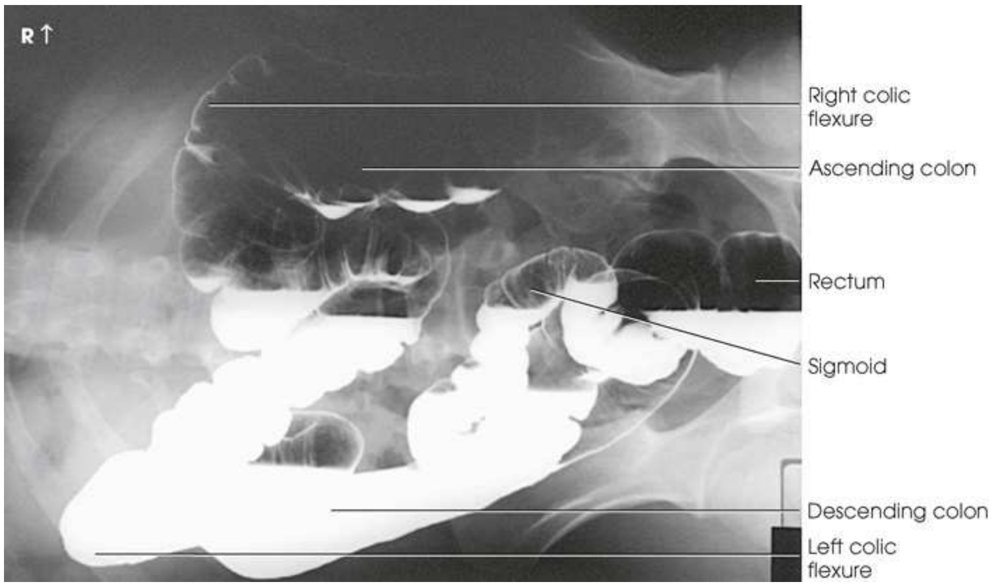


FIG. 15.140 Double-contrast PA large intestine, left lateral decubitus position.

A radiograph of the P A oblique view of the large intestine taken in double contrast in left lateral decubitus position. The left colic flexure, sigmoid, transverse colon, right colic flexure are labeled.

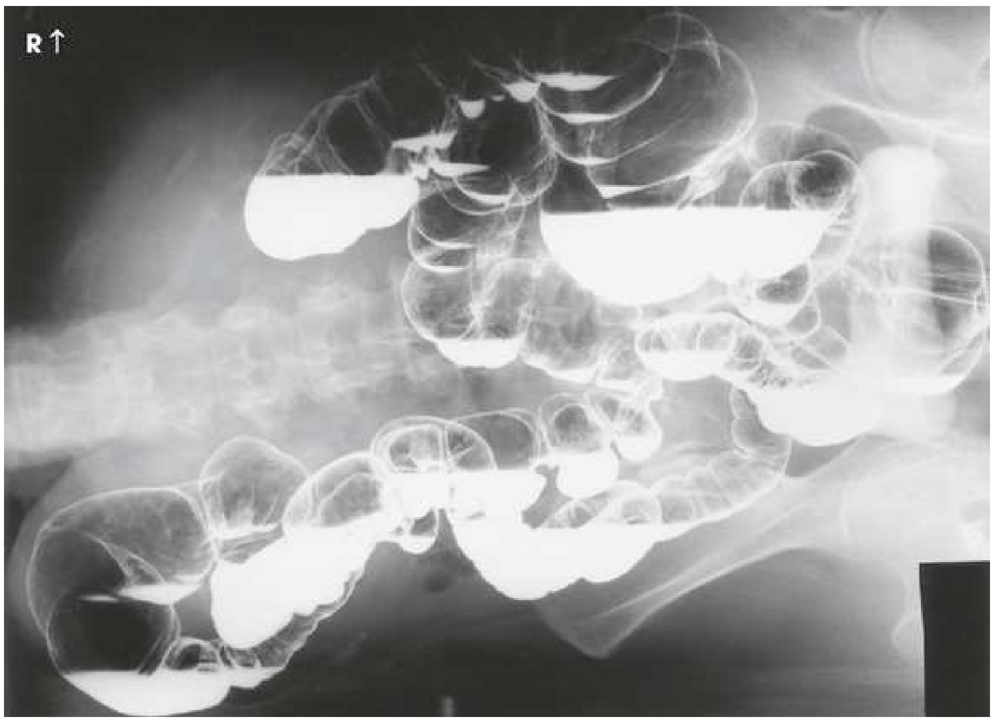


FIG. 15.141 Double-contrast PA large intestine, left lateral decubitus position.

A radiograph of the P A oblique view of the large intestine taken in double contrast in left lateral decubitus position. The left colic flexure, sigmoid, transverse colon, right colic flexure are visible.

Evaluation Criteria

The following should be clearly seen:

- Evidence of proper collimation and presence of side marker placed clear of anatomy of interest
- Area from the left colic flexure to the rectum
- No rotation of the patient, as demonstrated by symmetry of the ribs and pelvis

- For single-contrast examinations, adequate penetration of the barium; for double-contrast examinations, the air-inflated portion of the colon is of primary importance and should not be overpenetrated

Large Intestine

Lateral Projection

Right or left ventral decubitus position

Image receptor + grid: Positioned by manufacturer or department protocol for proper anatomy display orientation; CR plate: 14 × 17 inches (35 × 43 cm) lengthwise.

Position of patient

- Place the patient in the prone position with the right side or the left side against the vertical grid device.

Position of part

- Elevate the patient on a radiolucent support, and center the midcoronal plane to the grid.
- Adjust the center of the IR at the level of the iliac crests (Fig. 15.142A).
- *Shield gonads.*
- *Respiration*: Suspend.

Central ray

- *Horizontal* and perpendicular to the IR to enter the midcoronal plane of the body at the level of the iliac crests.

Collimation

- Adjust the radiation field to no larger than 14 × 17 inches (35 × 43 cm). For smaller patients, collimate to within 1 inch (2.5 cm) of shadow of the skin. Place side marker in the collimated exposure field.

Structures shown

The ventral decubitus position shows a lateral projection of the contrast-filled colon. This position best shows the "up" posterior portions of the colon and is most valuable in double-contrast examinations (see Fig. 15.142B).

Evaluation Criteria

The following should be clearly seen:

- Evidence of proper collimation and presence of side marker placed clear of anatomy of interest
- Area from the flexures to the rectum
- No rotation of the patient
- For single-contrast examinations, adequate penetration of the barium; for double-contrast examinations, the air-inflated portion of the colon is of primary importance and should not be overpenetrated
- Enema tip removed for an unobstructed image of the rectum (see Fig. 15.142C)

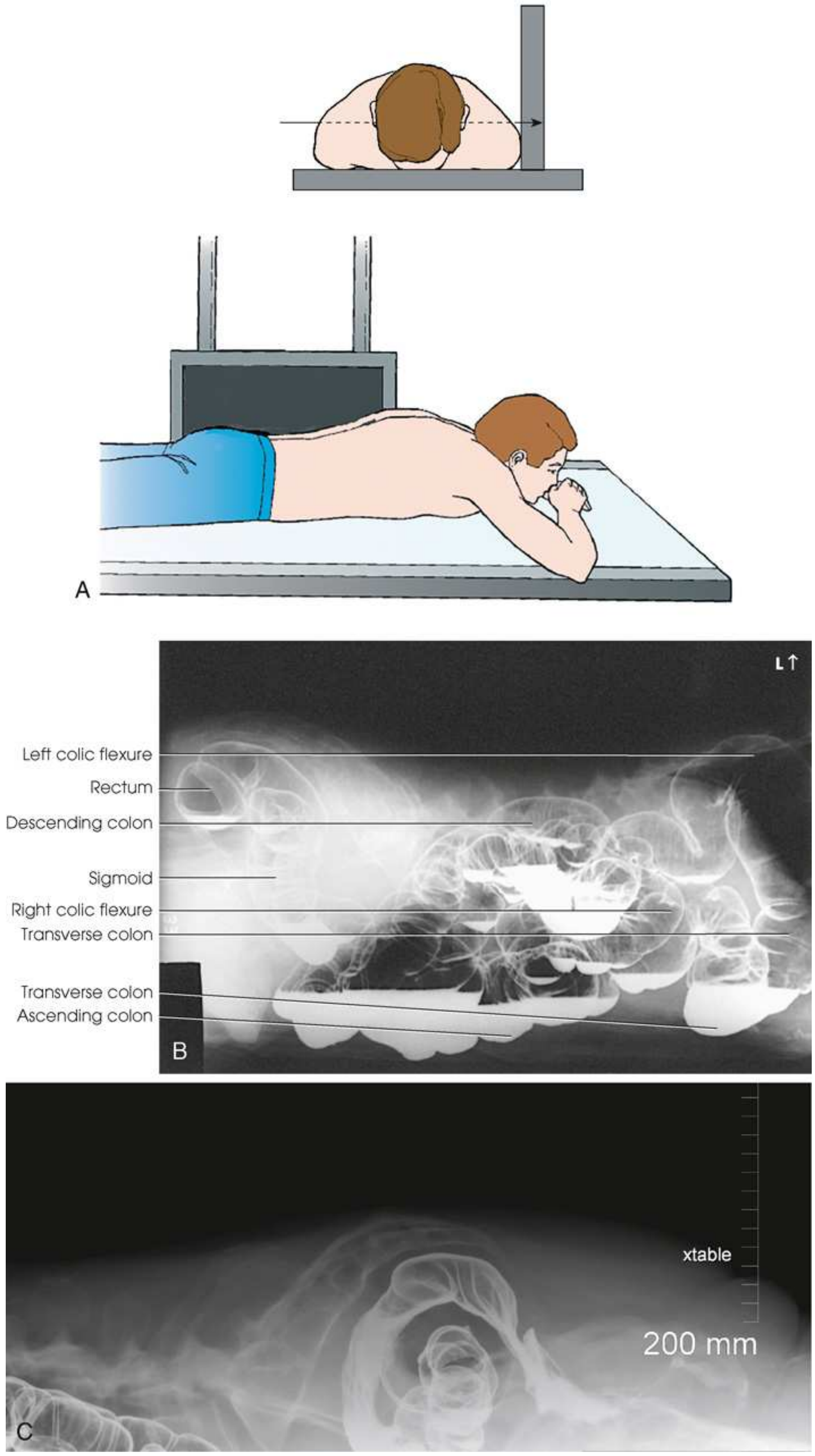


FIG. 15.142 (A) Patient in position for lateral projection, ventral decubitus position. (B) Left lateral large intestine, ventral decubitus position. (C) Lateral rectum, ventral decubitus position (enema tip removed).

An illustration of a patient lying in lateral projection position and then in ventral decubitus position. In the first position he lies face down on the table. In the second position he lies face down with the arms folded at the elbows and palms resting under the chin. The left lateral large intestine radiograph has left colic flexure, Transverse colon, Ascending colon, Transverse colon, Right colic flexure, Sigmoid, and Descending colon Rectum labeled. In the second radiograph the lateral rectum is visible in ventral decubitus position.

Ap, Pa, Oblique, And Lateral Projections

Upright position

Upright AP, PA, oblique, and lateral projections may be taken as requested. The positioning and evaluation criteria for upright images are identical to criteria required for the recumbent positions. The IR is placed at a lower level, however, to compensate for the drop of the bowel caused by the effect of gravity (Figs. 15.143 through 15.145).

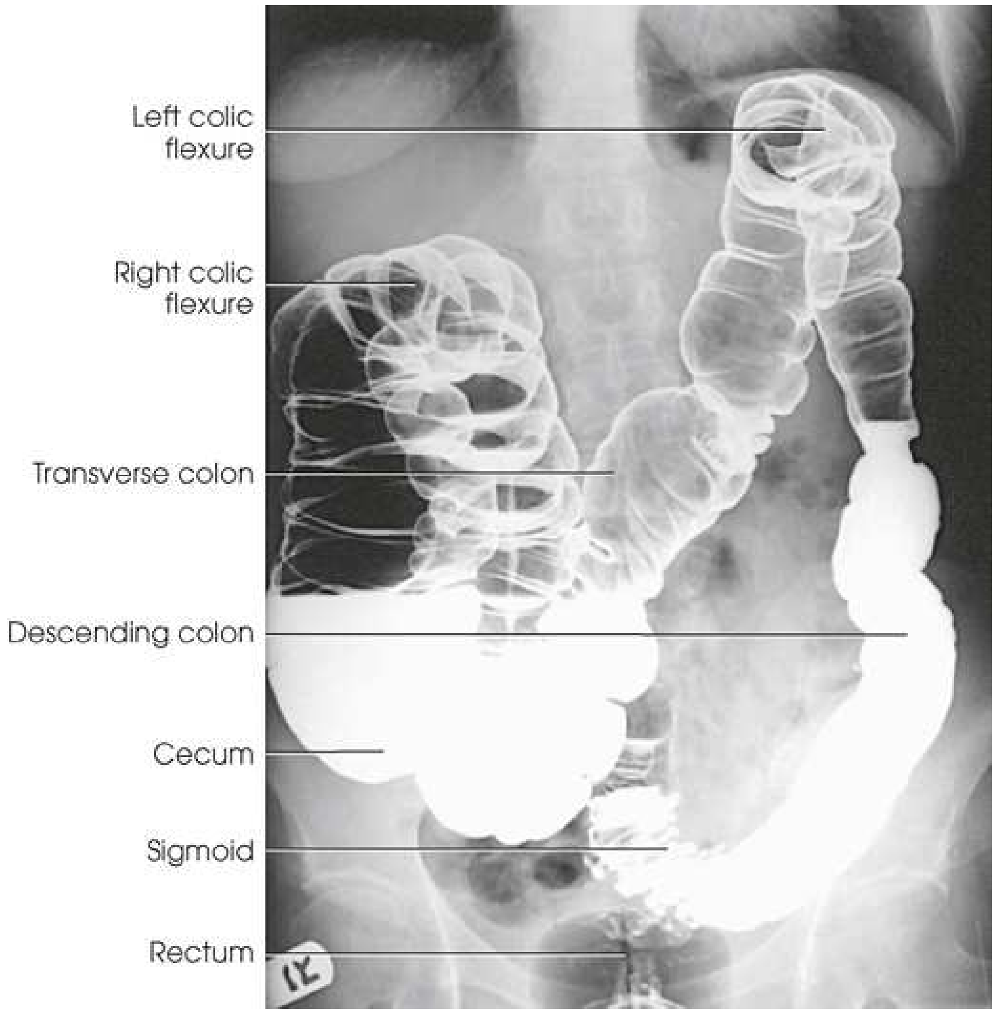


FIG. 15.143 Upright double-contrast AP large intestine.

FIG. 15.144 Upright double-contrast PA large intestine.

FIG. 15.145 Upright double-contrast AP oblique large intestine, RPO position.

A radiograph of the A P upright view of the large intestine taken in double contrast in R P O position. The Left colic flexure, Sigmoid, cecum, rectum, Transverse colon, and Right colic flexure are visible.

Colostomy Studies

Enterostomy (Greek *enteron,* "intestine" + *stoma,* "opening") is the general term applied to the surgical procedure of forming an artificial opening to the intestine, usually through the abdominal wall, for fecal passage. The regional terms are *colostomy, cecostomy, ileostomy,* and *jejunostomy*.

The colon is the most common site of disease in the large intestine, and surgical procedures are often performed on this structure. Loop colostomy is sometimes performed to divert the fecal column, temporarily or permanently, from areas of diverticulitis or ulcerative colitis. Most colostomies are performed because of malignancies of the lower bowel and rectum. When a tumor is present, the lower carcinomatous part of the bowel is resected, and the end of the remaining part of the bowel is brought to the surface through the abdominal wall. This passage, or *stoma,* has no sphincter.

Preparation of intestinal tract

Postoperative contrast enema studies are performed at suitable intervals to allow the clinician to determine the efficacy of treatment in a patient with diverticulitis or ulcerative colitis and to detect new or recurrent lesions in a patient who has had a tumor. Adequate cleansing of the bowel, which is as important in the presence of a colostomy as otherwise, is crucial to show polyps and other intraluminal lesions. In a patient with a colostomy, the usual preparation is irrigation of the stoma the night before the study and again on the morning of the examination.

Colostomy enema equipment

Although equipment must be scrupulously clean, and nondisposable items must be sterilized after each use, sterile technique is not required because the stoma is part of the intestinal tract. Except for a suitable device to prevent stomal leakage of contrast material, the equipment used in a patient with a colostomy is the same as that used in routine contrast enema studies. The same barium sulfate formula is used, and gas studies are made. Opaque and double-contrast studies can be performed in a single-stage examination with use of a disposable enema kit.

A device must be used to prevent spillage of contrast enema material in a patient with a colostomy. Otherwise, because of the absence of sphincter control, the contrast enema may escape through the colostomy almost as rapidly as it is injected. If this happens, bowel filling is unsatisfactory, and shadows cast by barium soilage of the abdominal wall and the examining table obscure areas of interest. Abdominal stomas must be effectively occluded for studies made by retrograde injection, and leakage around the stomal catheter must be prevented for studies made by injection into an abdominal or a perineal colostomy. Numerous devices are available for this purpose.

Diagnostic Enema

Diagnostic enemas may be given through a colostomy stoma with the use of tips and adhesive disks designed for the patient's use in irrigating the colostomy (Fig. 15.146). These tips are available in four sizes to accommodate the usual sizes of colostomy stomas. The tips usually have a flange to prevent them from slipping through the colostomy opening. An adhesive disk is placed over the flange to minimize reflux soilage. The enema tubing is attached directly to the tip, which the patient holds in position to prevent the weight of the tubing from displacing the tip to an angled position. In addition to keeping a set of Laird tips on hand, it is recommended that the patient be asked to bring an irrigation device.

Retention catheters or Foley catheters are also used in colostomy studies. Some radiologists use them alone, and others insert them through a device to prevent slipping and to collect leakage. Colostomy stomas are fragile and are subject to perforation by any undue pressure or trauma. Perforations have occurred during insertion of an inflated bulb into a blind pouch and as the result of overdistention of the stoma.

FIG. 15.146 Colostomy irrigation system with tip and stoma adhesive disk.

Preparation of patient

If the patient uses a special dressing, colostomy pouch, or stomal seal, he or she should be advised to bring a change for use after the examination. When fecal emission is such that a pouch is required, the patient should be given a suitable dressing to place over the stoma after the device has been removed.

The radiographer observes the following steps:

- Clothe the patient in a kimono type of gown that opens in front or back, depending on the location of the colostomy.

FIG. 15.147 Opaque colon via perineal colostomy.

- Place the patient on the examining table in the supine position if he or she has an abdominal colostomy and in the prone position if he or she has a perineal colostomy.
- Before taking the preliminary image and while wearing disposable gloves, remove and discard any dressing.
- Cleanse the skin around the stoma appropriately.
- Place a gauze dressing over the stoma to absorb any seepage until the physician is ready to start the examination.
- Lubricate the stomal catheter or tube well (but not excessively) with a water-soluble lubricant. The catheter should be inserted by the physician or the patient. If a catheter is forced through a stoma, the colon may be perforated.

Spot images are taken during the examination. Postfluoroscopy images are taken as needed. The projections requested depend on the location of the stoma and the anatomy to be shown (Figs. 15.147 through 15.150).

FIG. 15.148 Opaque colon via abdominal colostomy.

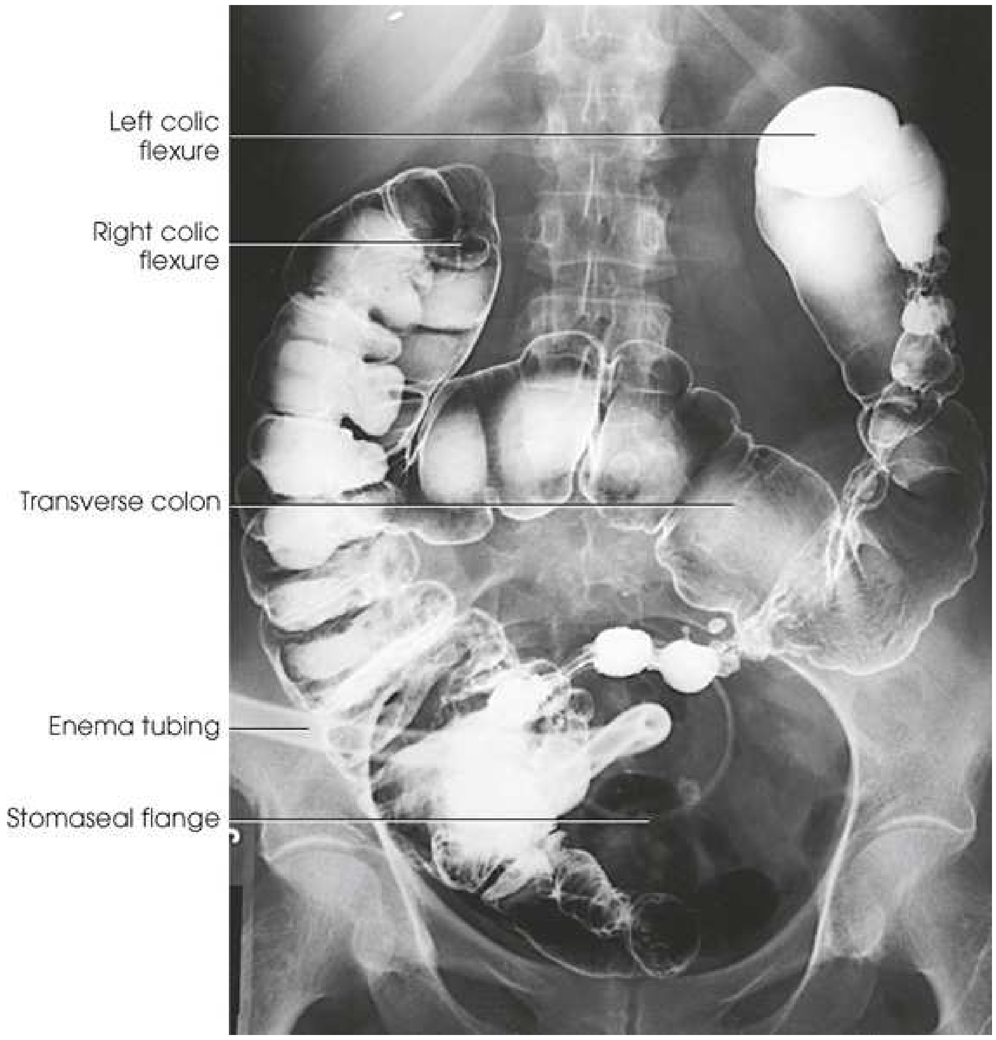


FIG. 15.149 Double-contrast colon in a patient with abdominal colostomy.

A radiograph of the colon in a patient with abdominal colostomy taken with double contrast. The Left colic flexure, Right colic flexure, Transverse colon, Enema tubing, and Stomaseal flange are labeled.

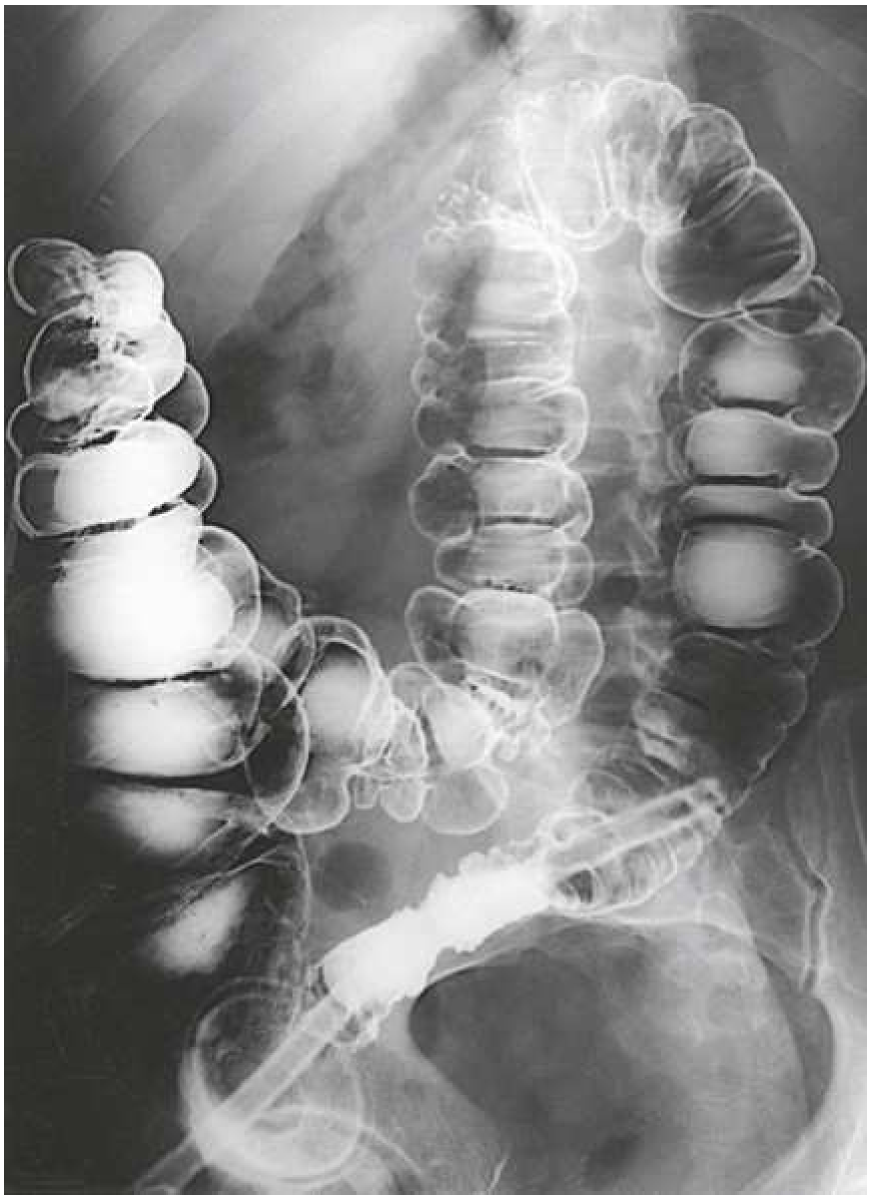


FIG. 15.150 Double-contrast AP oblique colon via abdominal colostomy.

A radiograph of A P view of the colon in a patient with abdominal colostomy taken with double contrast. The Left colic flexure, Right colic flexure, Transverse colon, Enema tubing, and Stomaseal flange are labeled.

Defecography

Defecography, evacuation proctography, or *dynamic rectal examination* is a radiologic procedure performed on patients with defecation dysfunction. No preparation of the patient is necessary, and cleansing enemas are not recommended because water remaining in the rectum dilutes the contrast medium.

Early investigators [22] mixed a diluted suspension of barium sulfate, heated it, and added potato starch to form a smooth barium paste that was semisolid and malleable. [23, 24] Barium manufacturers now package prepared barium products (100% weight/volume barium sulfate paste) with a special injector mechanism to instill barium directly into the rectum. In addition, viscous barium may be introduced into the vagina and the bladder filled with aqueous iodinated contrast media.

After the contrast medium is instilled, the patient is usually seated in the lateral position on a commercially available radiolucent commode in front of a fluoroscopic unit. A special commode chair is recommended so that the anorectal junction and the zone of interest on the image are not overexposed. Lateral projections are obtained during defecation by spot imaging at the approximate rate of 1 to 2 frames per second. Video recording of the defecation process may be used, but the special equipment necessary to interpret the images is not always available, and a hard copy of the images is unavailable. [25] The resulting images are then evaluated (Fig. 15.151). This evaluation includes measurements of the anorectal angle and the angle between the long axes of the anal canal and rectum. These measurements are compared with normal values. In addition, changes in proximity of the rectum to the vagina and bladder during defecation are assessed when these structures have been filled with contrast media (Fig. 15.152).

FIG. 15.151 Defecography. Lateral anus and rectum spot image showing long axis of anal canal *(line A-B)* and long axis of rectal canal *(line B-C)* in a patient with anorectal angle of 114 degrees. Anterior rectocele *(arrow)* also is shown.

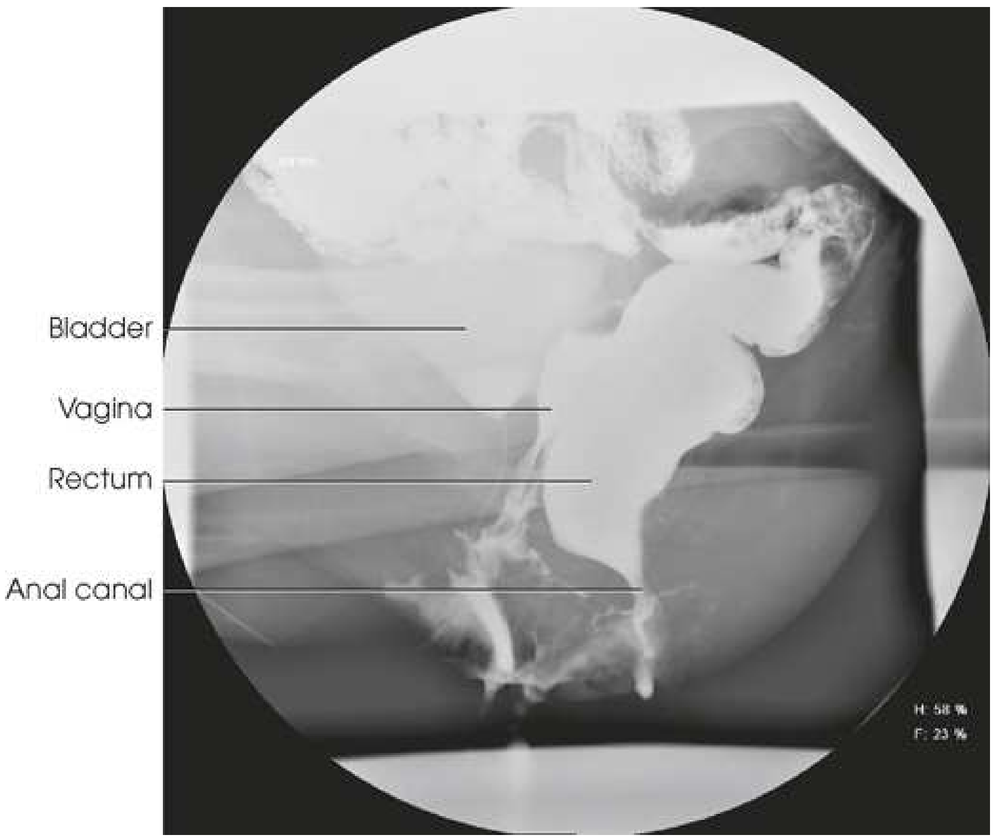


FIG. 15.152 Defecography. Lateral anal canal and rectum, vagina, and urinary bladder shown during patient straining. Courtesy Michelle Alting, AS, RT[R].

Biliary Tract and Gallbladder

Several techniques can be used to examine the gallbladder and the biliary ductal system. In many institutions, sonography is the modality of choice. This section of the atlas discusses the radiographic techniques currently available.

Table 15.1 lists some of the prefixes associated with the biliary system. *Cholegraphy* is the general term for a radiographic study of the biliary system. More specific terms can be used to describe the portion of the biliary system under investigation. *Cholecystography* is the radiographic investigation of the gallbladder, and *cholangiography* is the radiographic study of the biliary ducts.

TABLE 15.1

Biliary system combining forms

Root forms	Meaning
Chole-	Relationship with bile
Cysto-	Bag or sac
Choledocho-	Common bile duct
Cholangio-	Bile ducts
Cholecyst-	Gallbladder

Advances in sonography, CT, MRI, and nuclear medicine have reduced the radiographic examination of the biliary tract primarily to direct injection procedures including percutaneous transhepatic cholangiography (PTC), postoperative (T-tube) cholangiography, and endoscopic retrograde cholangiopancreatography (ERCP). The contrast agent selected for use in direct-injection techniques may be any one of the water-soluble iodinated compounds employed for intravenous urography.

FIG. 15.153 PTC with Chiba needle *(arrow)* in position, showing dilated biliary ducts.

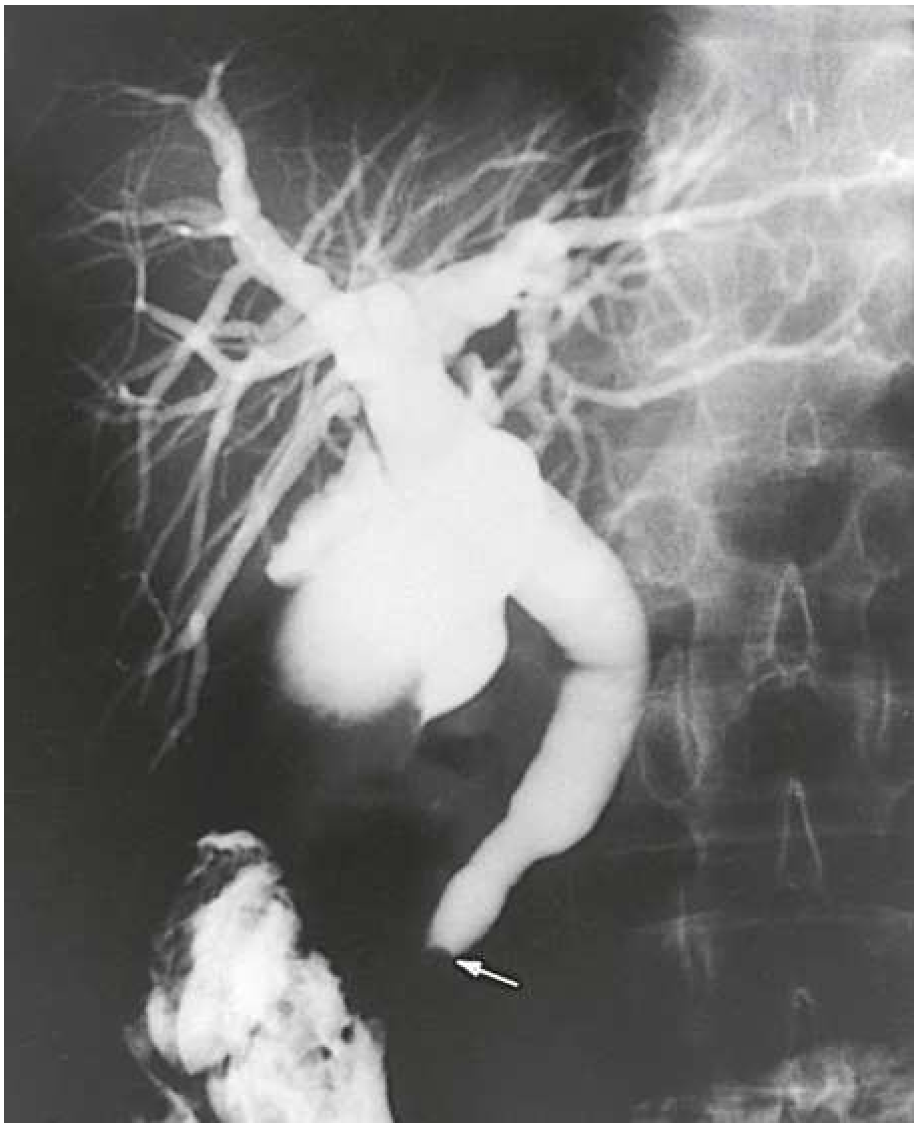


FIG. 15.154 PTC showing obstruction stone at ampulla *(arrow)*.

Percutaneous Transhepatic Cholangiography

PTC [26] is another technique employed for preoperative radiologic examination of the biliary tract. This technique is used for patients with jaundice when the ductal system has been shown to be dilated by CT or sonography, but the cause of the obstruction is unclear. Performance of this examination has greatly increased because of the availability of the Chiba ("skinny") needle. In addition, PTC is often used to place a drainage catheter for treatment of obstructive jaundice. When a drainage catheter is used, diagnostic and drainage techniques are performed at the same time.

FIG. 15.155 PTC showing stenosis *(arrow)* of common hepatic duct caused by trauma.

PTC is performed by placing the patient on the radiographic table in the supine position. The patient's right side is surgically prepared and appropriately draped. After a local anesthetic is administered, the Chiba needle is held parallel to the floor and inserted through the right lateral intercostal space and advanced toward the liver hilum. The stylet of the needle is withdrawn, and a syringe filled with contrast medium is attached to the needle. Under fluoroscopic control, the needle is slowly withdrawn until contrast medium is seen to fill the biliary ducts. In most instances, the biliary tree is readily located because the ducts are generally dilated. After the biliary ducts are filled, the needle is completely withdrawn, and serial or spot AP projections of the biliary area are taken (Figs. 15.153 through 15.155).

Biliary Drainage Procedure And Stone Extraction

If dilated biliary ducts are identified by CT, PTC, or sonography, the radiologist, after consultation with the referring physician, may elect to place a drainage catheter in the biliary duct.[27, 28] A needle larger than the Chiba needle used in the PTC procedure is inserted through the lateral abdominal wall and into the biliary duct. A guidewire is passed through the lumen of the needle, and the needle is removed. After the catheter is passed over the guidewire, the wire is removed, leaving the catheter in place.

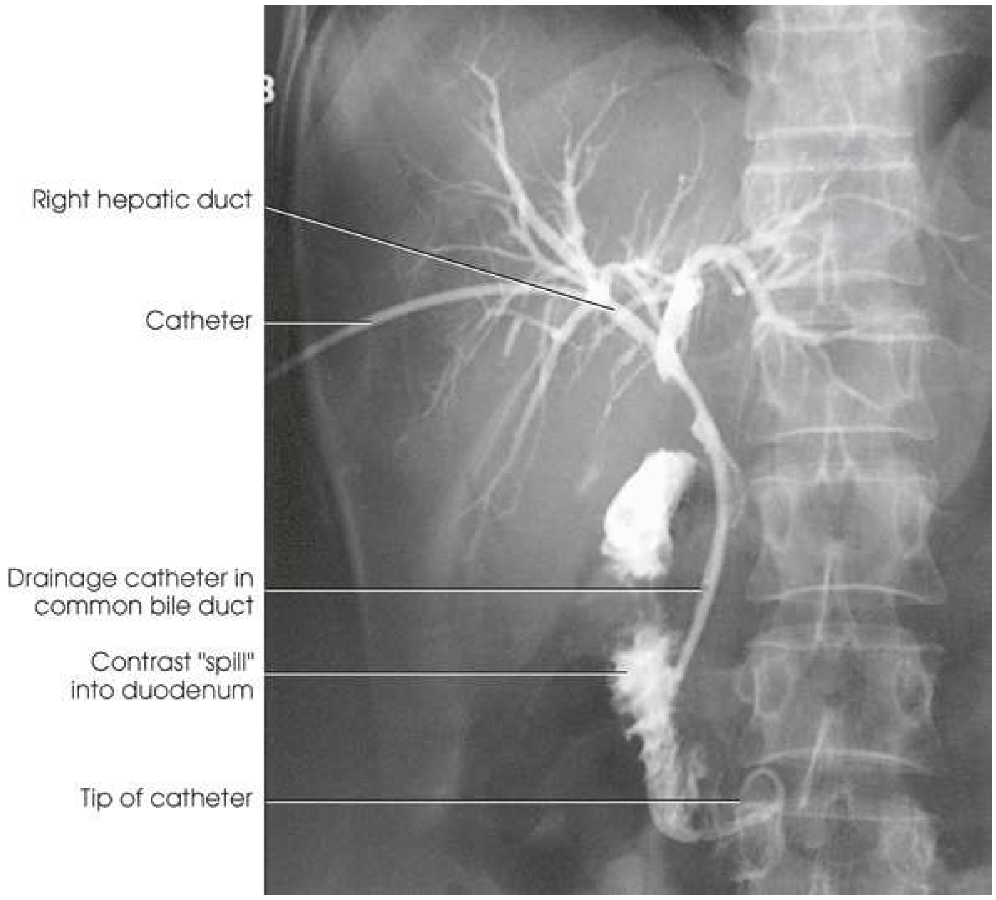


FIG. 15.156 PTC with drainage catheter in place.

FIG. 15.157 Post-PTC image showing wire basket *(arrow)* around retained stone.

A post P T C image of a patient with drainage catheter. Right hepatic duct, Catheter, Drainage catheter in common bile duct, Contrast "spill" into duodenum, the tip of catheter are visible, an arrow points to a wire basket.

The catheter can be left in place for prolonged drainage, or it can be used for attempts to extract retained stones if they are identified. Retained stones are extracted using a wire basket and a small balloon catheter under fluoroscopic control. This extraction procedure is usually attempted after the catheter has been in place for some time (Figs. 15.156 and 15.157).

Postoperative (T-Tube) Cholangiography

Postoperative, delayed, and *T-tube cholangiography* are radiologic terms applied to the biliary tract examination that is performed via a T-shaped or pigtail-shaped catheter left in the common hepatic and common bile ducts for postoperative drainage (Fig. 15.158). A pigtail catheter is required for laparoscopic biliary procedures because it can be placed percutaneously. The T-tube catheter can be placed only during an open surgical procedure. This examination is performed to show the caliber and patency of the ducts, the status of the sphincter of the hepatopancreatic ampulla, and the presence of residual or previously undetected stones or other pathologic conditions.

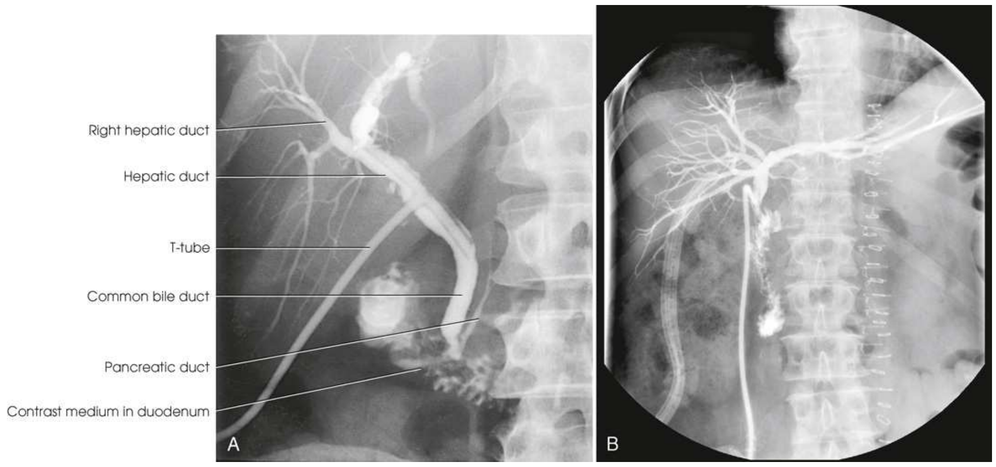


FIG. 15.158 (A) Postoperative cholangiogram with T-tube catheter. (B) Postoperative cholangiogram with pigtail catheter.

Two images denote a Postoperative cholangiogram with T-tube catheter and a Postoperative cholangiogram with pigtail catheter. The right hepatic duct, Pancreatic duct, Contrast medium in duodenum, Common bile duct, and T-tube are labeled in the first image.

Postoperative cholangiography is performed in the radiology department. Preliminary preparation usually consists of the following:

1. The drainage tube is clamped the day before the examination to let the tube fill with bile as a preventive measure against air bubbles entering the ducts, where they would simulate cholesterol stones.
2. The preceding meal is withheld.
3. When indicated, a cleansing enema is administered about 1 hour before the examination. Premedication is not required.

The contrast agent used is one of the water-soluble iodinated contrast media. The density of the contrast medium used in postoperative cholangiograms is recommended to be no greater than 25% to 30% because small stones may be obscured with a higher concentration.

After a preliminary image of the abdomen has been obtained, the patient is adjusted in the RPO position (AP oblique projection) with the RUQ of the abdomen centered to the midline of the grid (Fig. 15.159).

With universal precautions employed, the contrast medium is injected under fluoroscopic control, and spot and conventional images are made as indicated. Otherwise, 10- × 12-inch (24- × 30-cm) exposure field or CR plates are exposed serially after each of several fractional injections of the medium and then at specified intervals until most of the contrast solution has entered the duodenum.

Stern et al. [29] stressed the importance of obtaining a lateral projection to show anatomic branching of the hepatic ducts in this plane and to detect any abnormality not otherwise shown (Fig. 15.160). The clamp generally is not removed from the T-tube before the examination is completed. The patient may be turned onto the right side for this study.

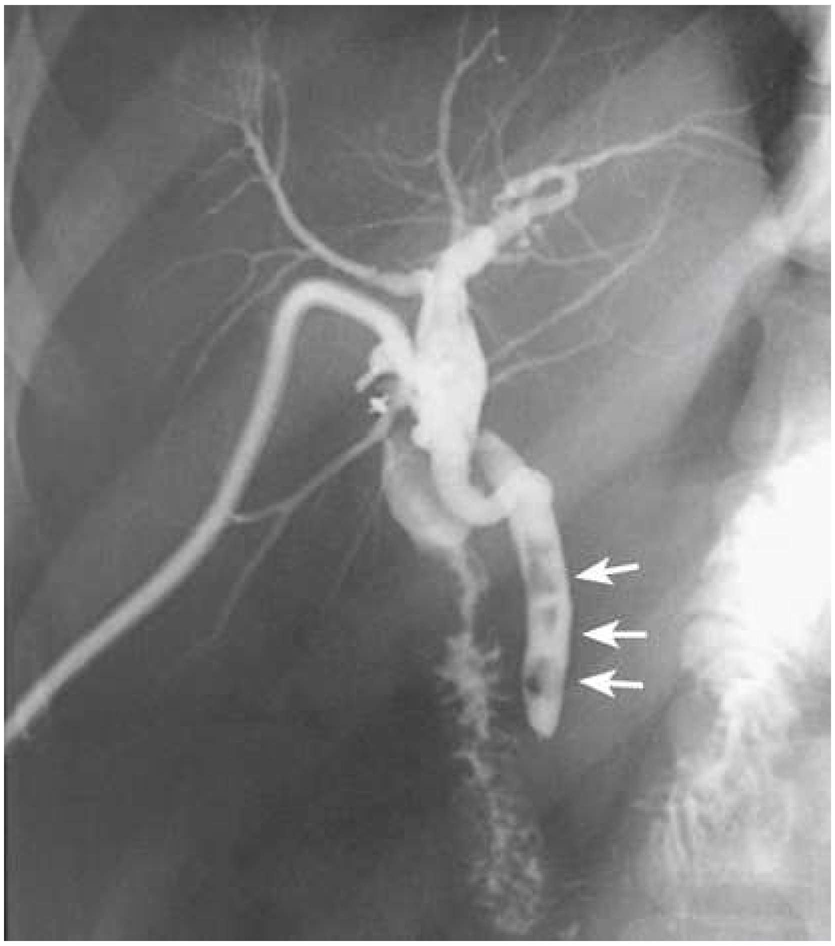


FIG. 15.159 AP oblique postoperative cholangiogram, RPO position, showing multiple stones in common bile duct *(arrows)*.

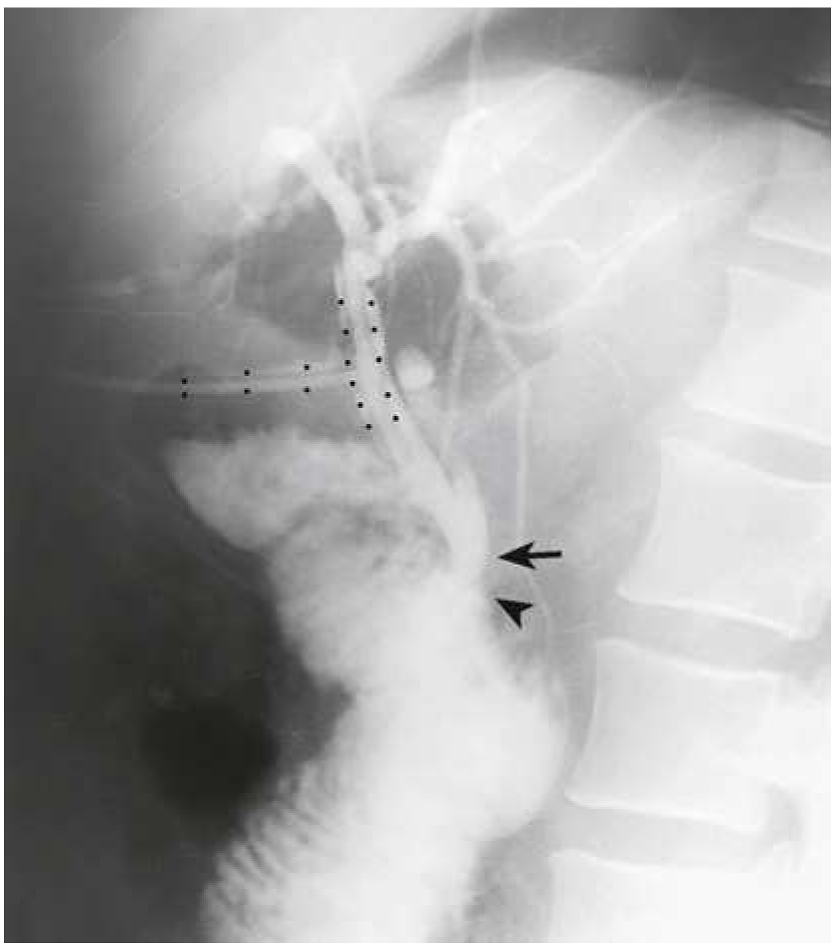


FIG. 15.160 Right lateral cholangiogram showing AP location of T-tube *(dots)*, common bile duct *(arrow)*, and hepatopancreatic ampulla (duct of Vater) *(arrowhead)*.

Biliary Tract and Pancreatic Duct

Endoscopic Retrograde Cholangiopancreatography

ERCP is a procedure used to diagnose biliary and pancreatic pathologic conditions. ERCP is a useful diagnostic method when the biliary ducts are not dilated and when no obstruction exists at the ampulla.

ERCP is performed by passing a fiberoptic endoscope through the mouth into the duodenum under fluoroscopic control. To ease passage of the endoscope, the patient's throat is sprayed with a local anesthetic. Because this causes temporary pharyngeal paresis, food and drink are usually prohibited for at least 1 hour after the examination. Food may be withheld for 10 hours after the procedure to minimize irritation to the stomach and small bowel.

After the endoscopist locates the hepatopancreatic ampulla (ampulla of Vater), a small cannula is passed through the endoscope and directed into the ampulla (Fig. 15.161). When the cannula is properly placed, a water-soluble, iodinated contrast medium is injected into the common bile duct. The patient may then be moved, fluoroscopy performed, and spot images taken (Figs. 15.162 and 15.163). Oblique spot images may be taken to prevent overlap of the common bile duct and the pancreatic duct. Because the injected contrast material should drain from normal ducts within approximately 5 minutes, images must be exposed immediately.

The contrast medium that is used depends on the preference of the radiologist or gastroenterologist. Dense contrast agents opacify small ducts well, but they may obscure small stones. If small stones are suspected, use of a more dilute contrast medium is suggested.[30] A history of patient sensitivity to an iodinated contrast medium in another examination (e.g., intravenous urography) does not contraindicate its use for ERCP. The patient must be watched carefully, however, for a reaction to the contrast medium during ERCP.

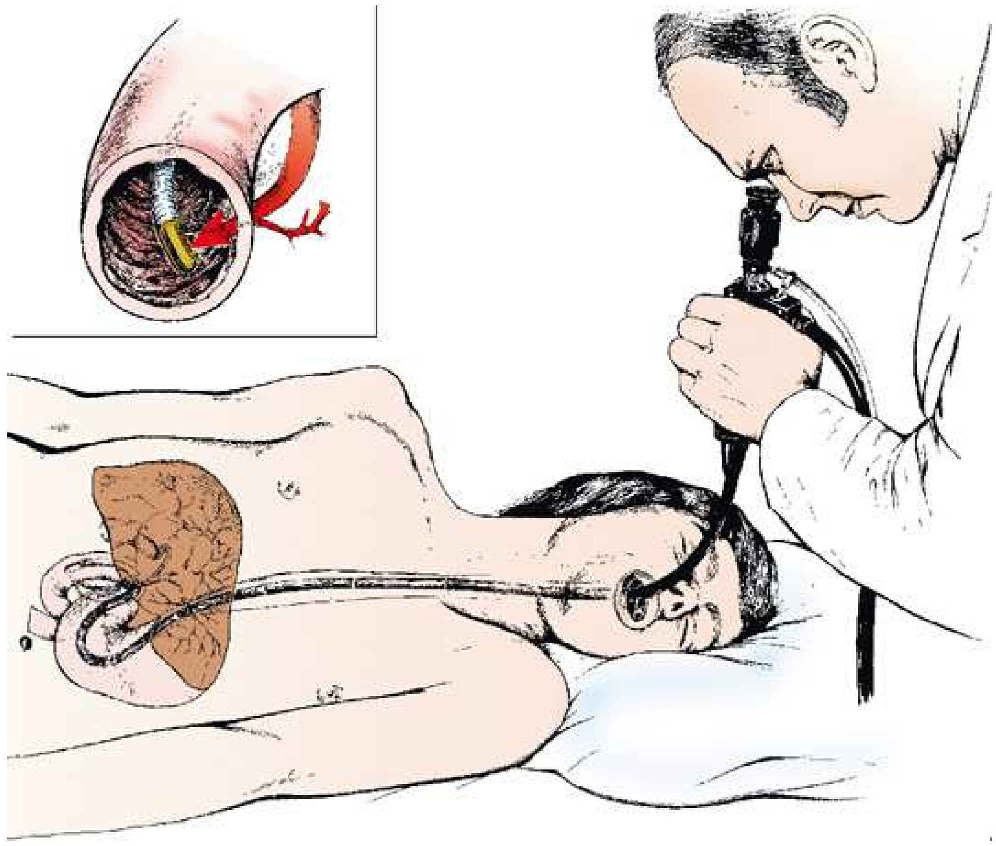


FIG. 15.161 Cannulation procedure. Procedure is begun with the patient in left lateral position. This schematic diagram gives an overview of location of the examiner and position of scope and its relationship to various internal organs. *Inset:* Magnified view of tip of scope with cannula in papilla. From Stewart ET, Vennes JA, Geenen JE. *Atlas of endoscopic retrograde cholangiopancreatography.* St Louis: Mosby; 1977.

An illustration of the cannulation procedure. A medical practitioner inserts his scope into the mouth of a patient who is in left lateral position on a bed and looks into the other end of the scope. A magnified view of the tip of the scope shows the cannula in papilla.

ERCP is often indicated when clinical and radiographic findings indicate abnormalities in the biliary system or pancreas. Sonography of the upper part of the abdomen before endoscopy is often recommended to assure the physician that no pancreatic pseudocysts are present. This step is important because contrast medium injected into pseudocysts may lead to inflammation or rupture.

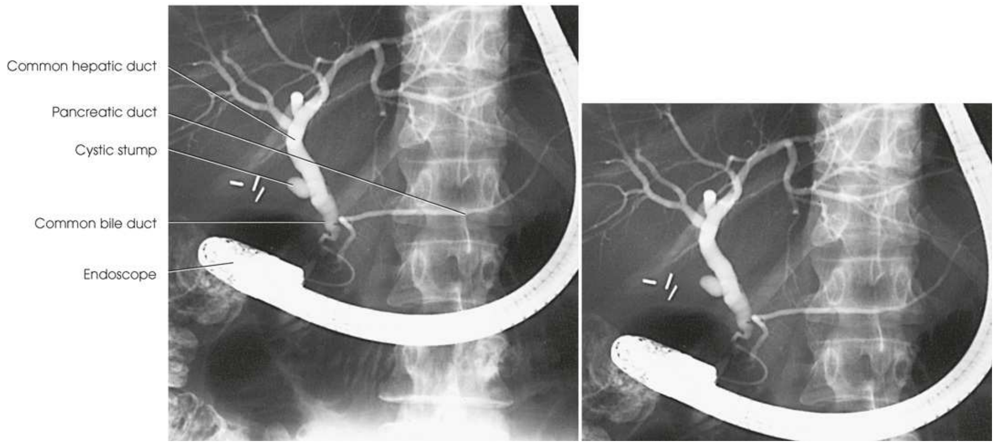


FIG. 15.162 ERCP spot image, PA projection.

FIG. 15.163 ERCP spot image, PA projection.

Abdominal Fistulae and Sinuses

To show radiographically the origin and extent of fistulae (abnormal passages, usually between two internal organs) and sinuses (abnormal channels leading to abscesses), the following steps are taken:

- Fill the tract with a radiopaque contrast medium, usually under fluoroscopic control.
- Obtain right-angle projections. Oblique projections are occasionally required to show the full extent of a sinus tract.
- To explore fistulae and sinuses in the abdominal region, have the intestinal tract as free of gas and fecal material as possible.
- Unless the injection is made under fluoroscopic control, take a scout image of the abdomen to check the condition of the intestinal tract before beginning the examination.
- When more than one sinus opening is present, occlude each accessory opening with sterile gauze packing to prevent reflux of the contrast substance and to identify every opening with a specific lead marker placed over the dressing (Figs. 15.164 through 15.166).
- Dress and identify the primary sinus opening in a similar manner if the catheter is removed after the injection.

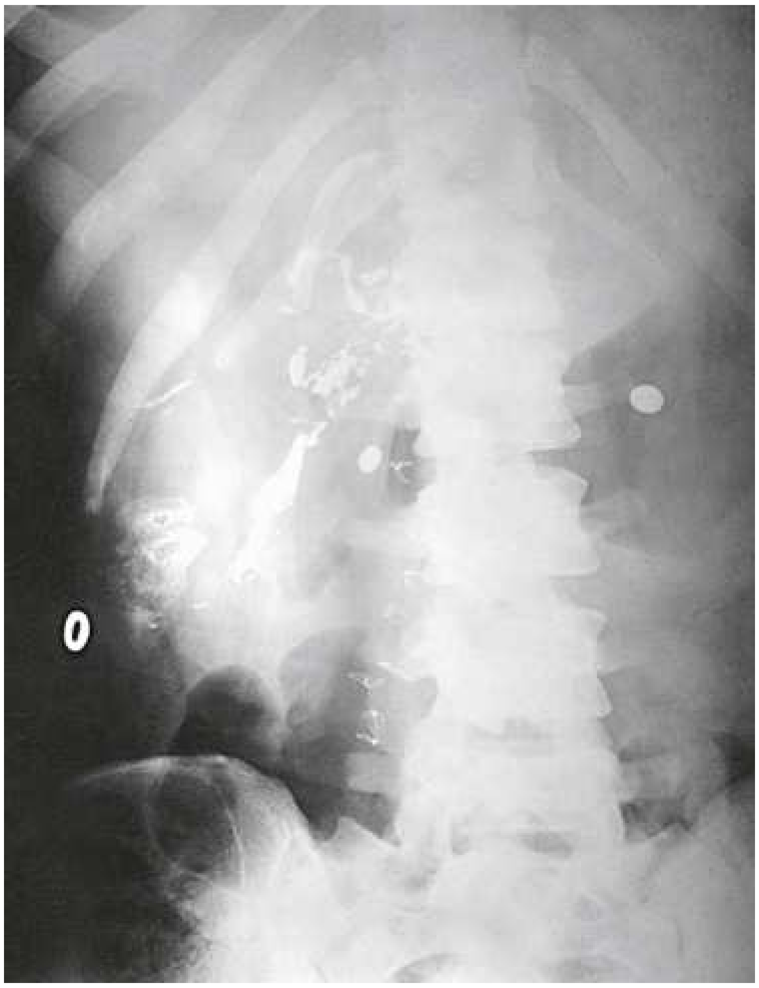


FIG. 15.164 AP abdomen showing contrast media–filled sinus tract with lead circular ring on body surface.

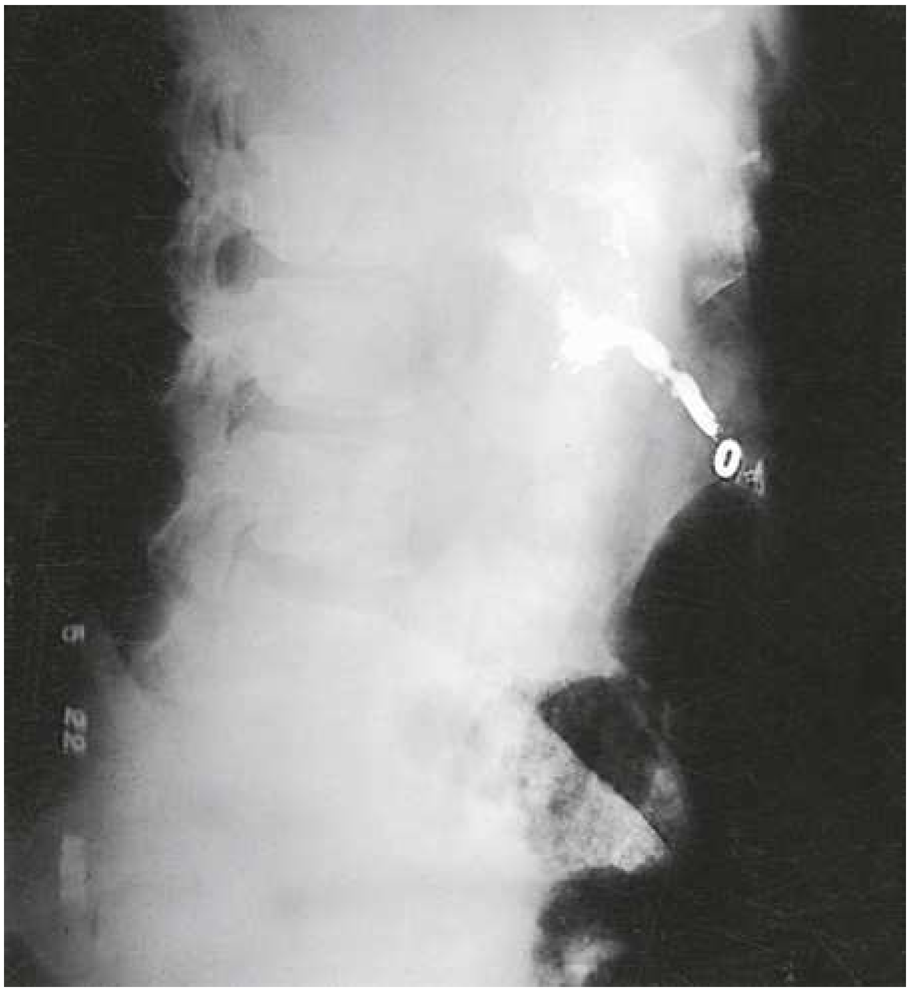


FIG. 15.165 Lateral abdomen showing sinus tract with lead circular ring on body surface.

- When reflux of contrast medium occurs, cleanse the skin thoroughly before making an exposure.
- When fluoroscopy is not employed, place the patient in position for the first projection before the injection to prevent drainage of the opaque substance by unnecessary movement. An initial image is taken and evaluated before the examination is started or the patient's position is changed.

To show a fistula involving the colon, barium is instilled by enema. If a fistula involving the small bowel is suspected, the patient ingests a thin barium suspension, which is followed by fluoroscopy or radiography until it reaches the suspected region. The bladder is filled with iodinated contrast media when involvement of this structure is evaluated. Cutaneous fistulae and sinus tracts are opacified by introduction of an iodinated contrast medium through a small-diameter catheter. The procedures are performed using fluoroscopic observation, with images taken as indicated.

FIG. 15.166 Oblique abdomen, LPO position, showing fistula *(arrow)*.

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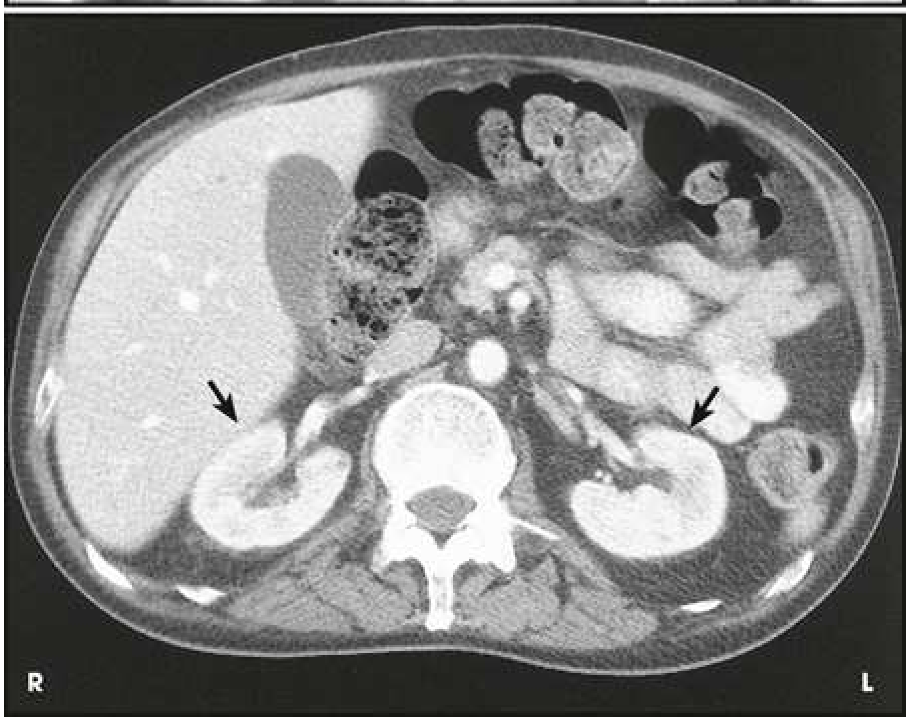
16: Urinary System and Venipuncture



OUTLINE

Summary of Projections

Projections, Positions, and Methods					
Page	Essential	Anatomy	Projection	Position	Method
304		Urinary system	AP		
306		Urinary system	AP oblique	RPO and LPO	
307		Urinary system	Lateral	R or L	
308		Urinary system	Lateral	Dorsal decubitus	
309		Renal parenchyma	AP		
312		Pelvicaliceal system and ureters: *Retrograde urography*	AP		
316		Urinary bladder	AP axial or PA axial		
318		Urinary bladder	AP oblique	RPO or LPO	
320		Urinary bladder	Lateral	R or L	
321		Male cystourethrography	AP oblique	RPO or LPO	
322		Female cystourethrography	AP		INJECTION

Icons in the Essential column indicate projections frequently performed in the United States and Canada. Students should be competent in these projections.

AP, Anteroposterior; *L,* left; *LPO,* left posterior oblique; *PA,* posteroanterior; *R,* right; *RPO,* right posterior oblique.

Urinary System Anatomy

Urinary System

The *urinary system* includes two *kidneys*, two *ureters*, one *urinary bladder*, and one *urethra* (Figs. 16.1 and 16.2). The functions of the kidneys include removing waste products from the blood, maintaining fluid and electrolyte balance, and secreting substances that affect blood pressure and other important body functions. The kidneys normally excrete 1 to 2 L of urine per day. Urine is expelled from the body via the *excretory system*, as the urinary system is often called. The excretory system consists of the following:

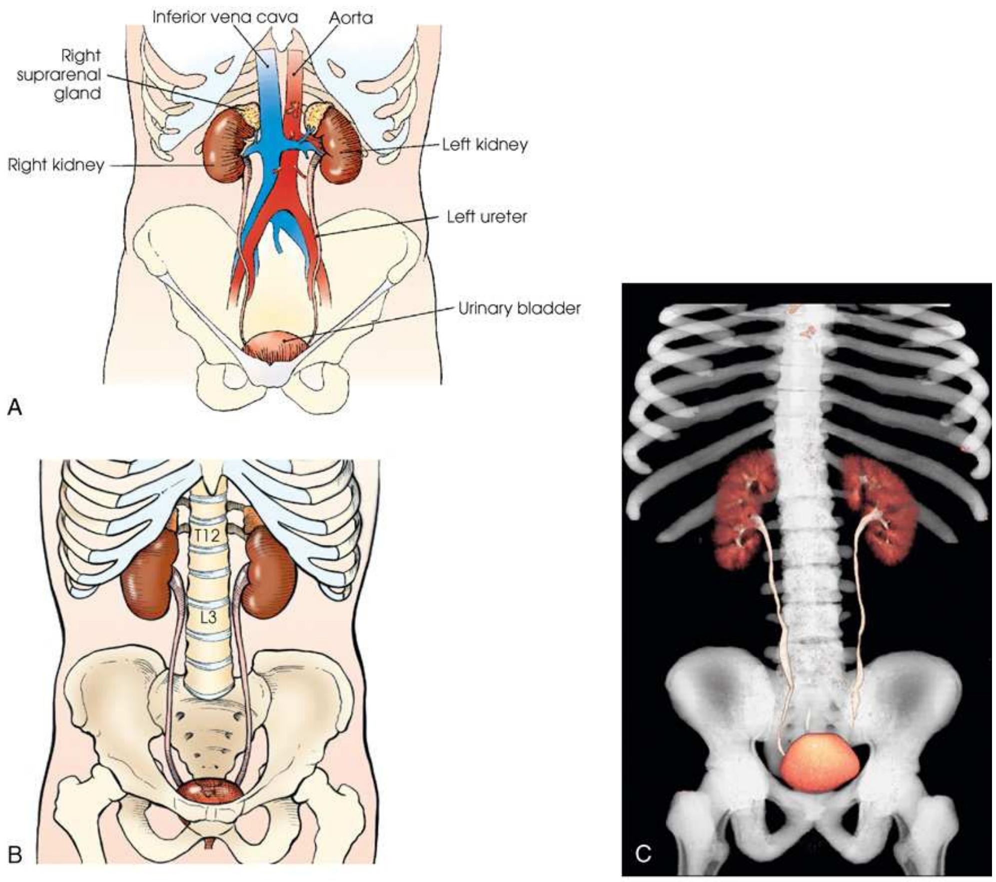


FIG. 16.1 Anterior aspect of urinary system in relation to surrounding structures. (A) Abdominal structures. (B) Bony structures. (C) Three-dimensional CT image of urinary system in relation to bony structures.

Two illustrations and a scan image depict the anterior projection of the urinary system. A is an illustration of the organs of the abdomen. The inferior vena cava, Aorta, Left kidney, right kidney, Left ureter, Right suprarenal gland, and Urinary bladder are labeled. B is an illustration of the posterior rib bones, lumbar vertebrae, and pelvic bones. C is a C T scan of the abdomen. The pelvic bones, vertebral column, kidneys, ureters, bladder, and urethra are visible.

- A variable number of urine-draining branches in the kidney called the *calyces* and an expanded portion called the *renal pelvis*, which together are known as the *pelvicaliceal system*
- Two long tubes called *ureters*, with one ureter extending from the pelvis of each kidney
- A saclike portion, the *urinary bladder*, which receives the distal portion of the ureters and serves as a reservoir
- A third and smaller tubular portion, the *urethra*, which conveys the urine to the exterior of the body

Suprarenal Glands

Closely associated with the urinary system are the two *suprarenal*, or *adrenal*, *glands*. These ductless endocrine glands have no functional relationship with the urinary system but are included in this chapter because of their anatomic relationship with the kidneys. Each suprarenal gland consists of a small, flattened body composed of an internal *medullary portion* and an outer *cortical portion*. Each gland is enclosed in a fibrous sheath and is situated in the retroperitoneal tissue in close contact with the fatty capsule overlying the medial and superior aspects of the upper pole of the kidney. The suprarenal glands furnish two important substances: (1) epinephrine, which is secreted by the medulla; and (2) cortical hormones, which are secreted by the cortex. These glands are subject to malfunction and numerous diseases. They are not usually shown on preliminary images but are delineated when computed tomography (CT) is used. The suprarenal circulation may be shown by selective catheterization of a suprarenal artery or vein in angiographic procedures.

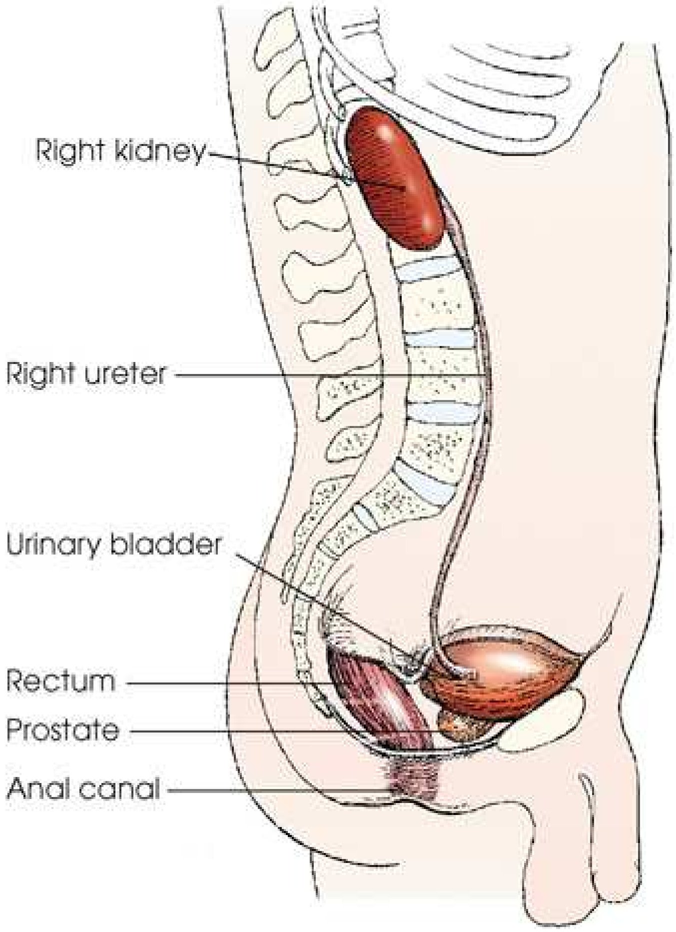


FIG. 16.2 Lateral aspect of male urinary system in relation to surrounding structures.

A lateral view of the male urinary system. The right kidney, right ureter from the kidney, urinary bladder, rectum, prostate and Anal Canal are labeled. The bony structures like the vertebral column, pelvic girdle, and part of the lower rib are visible.

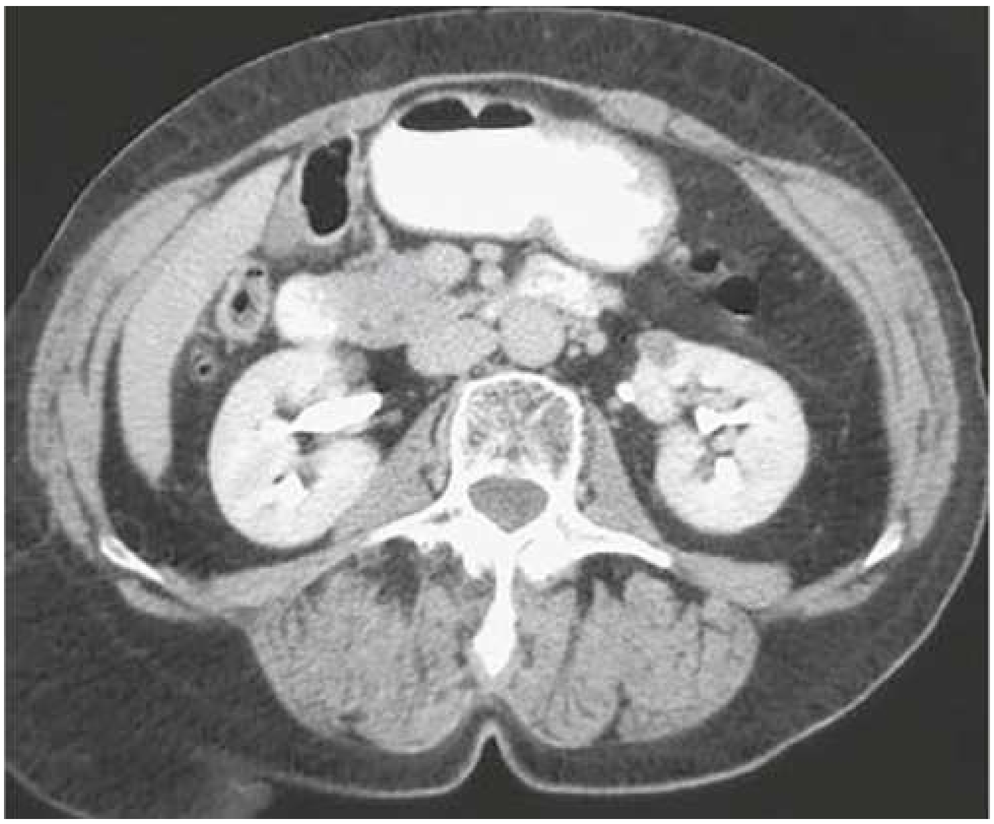


FIG. 16.3 CT of kidneys with contrast, excretory phase, illustrates 30-degree anterior angulation of kidneys. Note carcinoma in left kidney, upper pole. From Haaga J, Boll D. *CT and MRI of the Whole Body.* 6th ed. Philadelphia: Elsevier; 2017.

Kidneys

The *kidneys* are bean-shaped bodies. The lateral border of each kidney is convex, and the medial border is concave. They have slightly convex anterior and posterior surfaces, and they are arbitrarily divided into upper and lower poles. The kidneys are approximately 4½ inches (11.5 cm) long, 2 to 3 inches (5 to 7.6 cm) wide, and about 1¼ inches (3 cm) thick. The left kidney usually is slightly longer and narrower than the right kidney.

The kidneys are situated behind the peritoneum (retroperitoneal) and are in contact with the posterior wall of the abdominal cavity, one kidney lying on each side of and in the same coronal plane with L3. The superior aspect of the kidney lies more posterior than the inferior aspect (see Fig. 16.2). Each kidney lies in an oblique plane and is rotated about 30 degrees anteriorly toward the aorta, which lies on top of the vertebral body (Fig. 16.3). This natural anatomic position is the basis for the 30-degree rotation of the AP oblique projections (RPO and LPO positions). In AP oblique projections, the elevated kidney is demonstrated without distortion, as the 30-degree rotation orients the upper kidney parallel to the IR plane. The dependent kidney is positioned almost perpendicular to the IR plane, so the lower kidney is oriented to demonstrate the anterior and posterior surfaces in the oblique positions.

The kidneys normally extend from the level of the superior border of T12 to the level of the transverse processes of L3 in sthenic individuals; they are higher in individuals with a hypersthenic habitus and lower in persons with an asthenic habitus. Because of the large space occupied by the liver, the right kidney is slightly lower than, or caudal to, the left kidney.

The outer covering of the kidney is called the *renal capsule*. The capsule is a semitransparent membrane that is continuous with the outer coat of the ureter. Each kidney is embedded in a mass of fatty tissue called the *adipose capsule*. The capsule and kidney are enveloped in a sheath of superficial fascia, the *renal fascia*, which is attached to the diaphragm, lumbar vertebrae, peritoneum, and other adjacent structures. The kidneys are supported in a fairly fixed position, partially through the fascial attachments and partially by the surrounding organs. They have respiratory movement of approximately 1 inch (2.5 cm) and normally drop no more than 2 inches (5 cm) in the change from the supine to the upright position.

The concave medial border of each kidney has a longitudinal slit, or *hilum*, for transmission of the blood and lymphatic vessels, nerves, and ureter (Fig. 16.4). The hilum expands into the body of the kidney to form a central cavity called the *renal sinus*. The renal sinus is a fat-filled space surrounding the renal pelvis and vessels.

Each kidney has an outer renal cortex and an inner *renal medulla*. The renal medulla, composed mainly of the collecting tubules that give it a striated appearance, consists of 8 to 15 cone-shaped segments called the *renal pyramids*. The apices of the segments converge toward the renal sinus to drain into the pelvicaliceal system. The more compact renal cortex lies between the periphery of the organ and the bases of the medullary segments and extends medially between the pyramids to the renal sinus. These extensions of the cortex are called *renal columns*.

The essential microscopic components of the parenchyma of the kidney are called *nephrons* (Fig. 16.5). Each kidney contains approximately 1 million of these tubular structures. The individual nephron is composed of a *renal corpuscle* and a *renal tubule*. The renal corpuscle consists of a double-walled membranous cup called the *glomerular capsule* (Bowman capsule) and a cluster of blood capillaries called the *glomerulus*. The glomerulus is formed by a minute branch of the renal artery entering the capsule and dividing into capillaries. The capillaries turn back and, as they ascend, unite to form a single vessel leaving the capsule.

The vessel entering the capsule is called the *afferent arteriole*, and the one leaving the capsule is termed the *efferent arteriole*. After exiting the glomerular capsules, the efferent arterioles form the capillary network surrounding the straight and convoluted tubules, and these capillaries reunite and continue on to communicate with the renal veins.

The thin inner wall of the capsule closely adheres to the capillary coils and is separated by a comparatively wide space from the outer layer, which is continuous with the beginning of a renal tubule. The glomerulus serves as a filter for the blood, permitting water and finely dissolved substances to pass through the walls of the capillaries into the capsule. The change from filtrate to urine is caused in part by the water and the usable dissolved substances being absorbed through the epithelial lining of the tubules into the surrounding capillary network.

Each renal *tubule* continues from a glomerular capsule in the cortex of the kidney and then travels a circuitous path through the cortical and medullary substances, becoming the *proximal convoluted tubule*, the *nephron loop* (loop of Henle), and the *distal convoluted tubule*. The distal convoluted tubule opens into the collecting ducts that begin in the cortex. The *collecting ducts* converge toward the renal pelvis and unite along their course so that each group within the pyramid forms a central tubule that opens at a *renal papilla* and drains its tributaries into the minor calyx.

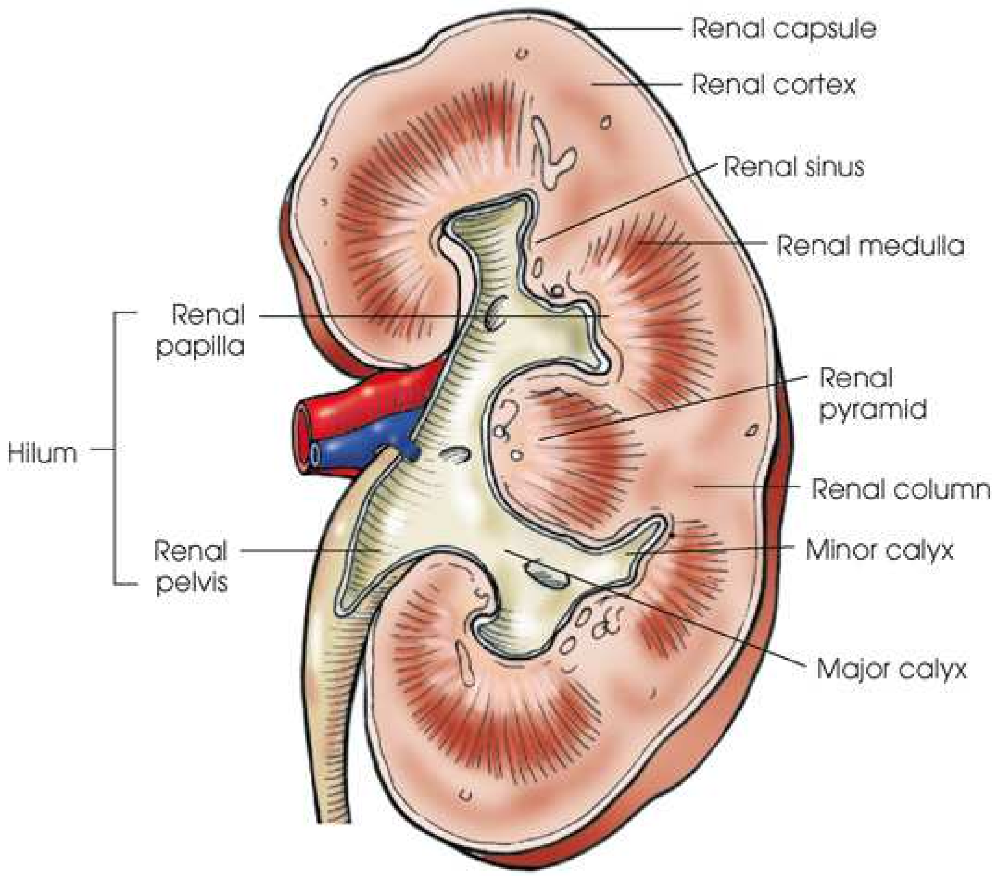


FIG. 16.4 Midcoronal section of kidney.

The lateral view of midcoronal section of kidney. The bean-shaped kidney is covered by a renal capsule. The Renal cortex, Renal column, Renal medulla, Renal pyramid, Minor calyx, Major calyx, Hilum which has the Renal papilla and Renal pelvis, and Renal sinus are labeled.

The *calyces* are cup-shaped stems arising at the sides of the papilla of each renal pyramid. Each calyx encloses one or more papillae so that there are usually fewer calyces than pyramids. The beginning branches are called the *minor calyces* (numbering from 4 to 13), and they unite to form two or three larger tubes called the *major calyces*. The major calyces unite to form the expanded, funnel-shaped renal pelvis. The wide upper portion of the *renal pelvis* lies within the hilum, and its tapering lower part passes through the hilum to become continuous with the ureter. This area where the renal pelvis transitions to the ureter is called the *ureteropelvic junction* (UPJ).

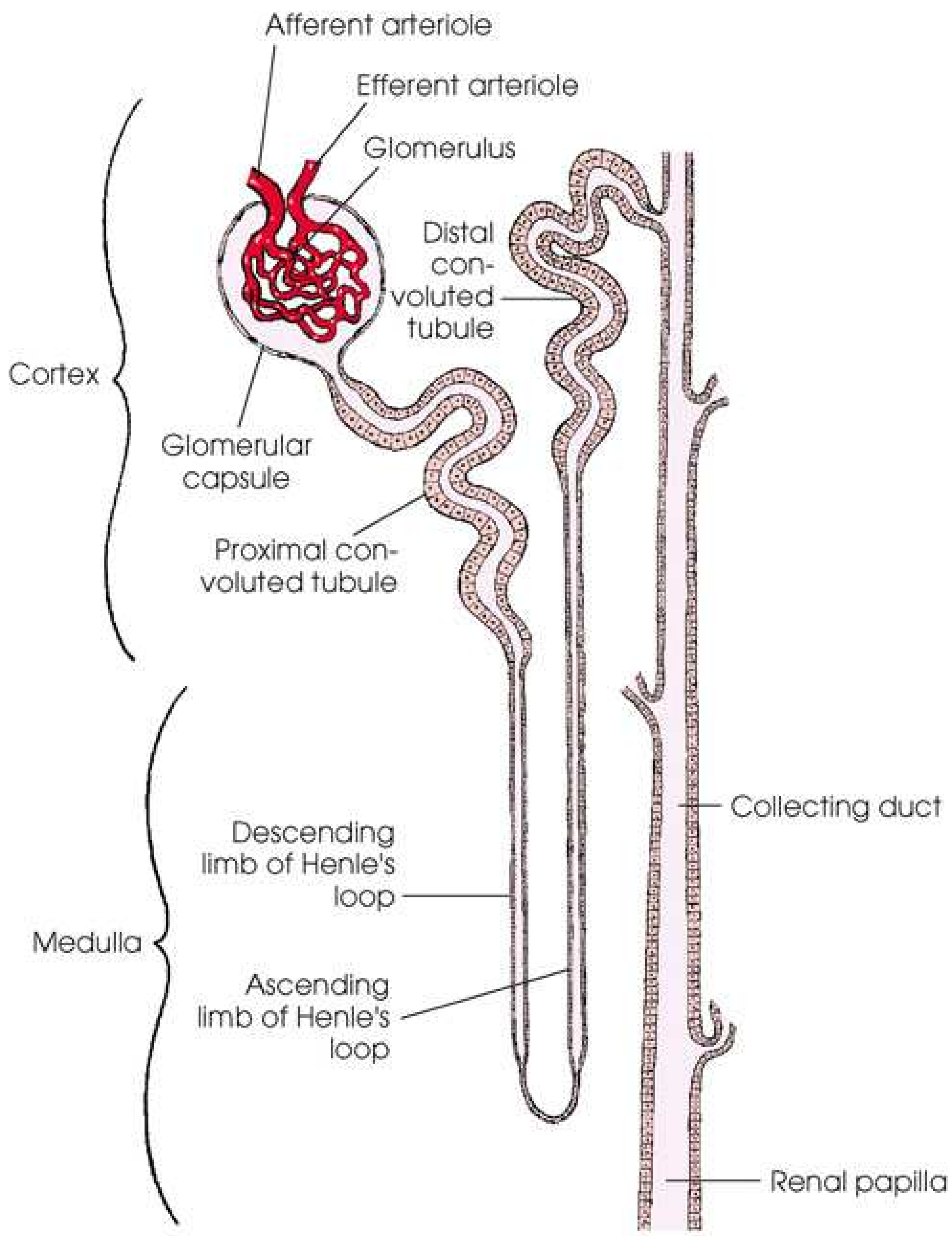


FIG. 16.5 Diagram of nephron and collecting duct.

The anterior view of the nephron and the collecting ducts. The upper part is the cortex and the lower part is the medulla. The cortex consists of the Afferent arteriole, Efferent arteriole, Glomerulus, Glomerular capsule, Proximal and Distal convoluted tubules. The medulla consists of Collecting duct, Renal papilla, Descending limb of Henle's loop and Ascending limb of Henle's loop.

Ureters

Each *ureter* is 10 to 12 inches (25 to 30 cm) long. The ureters descend behind the peritoneum and in front of the psoas muscle and the transverse processes of the lumbar vertebrae, pass inferiorly and posteriorly in front of the sacral wing, and then curve anteriorly and medially to enter the posterolateral surface of the urinary bladder at approximately the level of the ischial spine. The ureters convey the urine from the renal pelves to the bladder by slow, rhythmic peristaltic contractions.

Urinary Bladder

The *urinary bladder* is a musculomembranous sac that serves as a reservoir for urine. The bladder is situated immediately posterior and superior to the pubic symphysis and is directly anterior to the rectum in the male and anterior to the vaginal canal in the female. The *apex* of the bladder is at the anterosuperior aspect and is adjacent to the superior aspect of the pubic symphysis. The most fixed part of the bladder is the neck, which rests on the prostate in the male and on the pelvic diaphragm in the female.

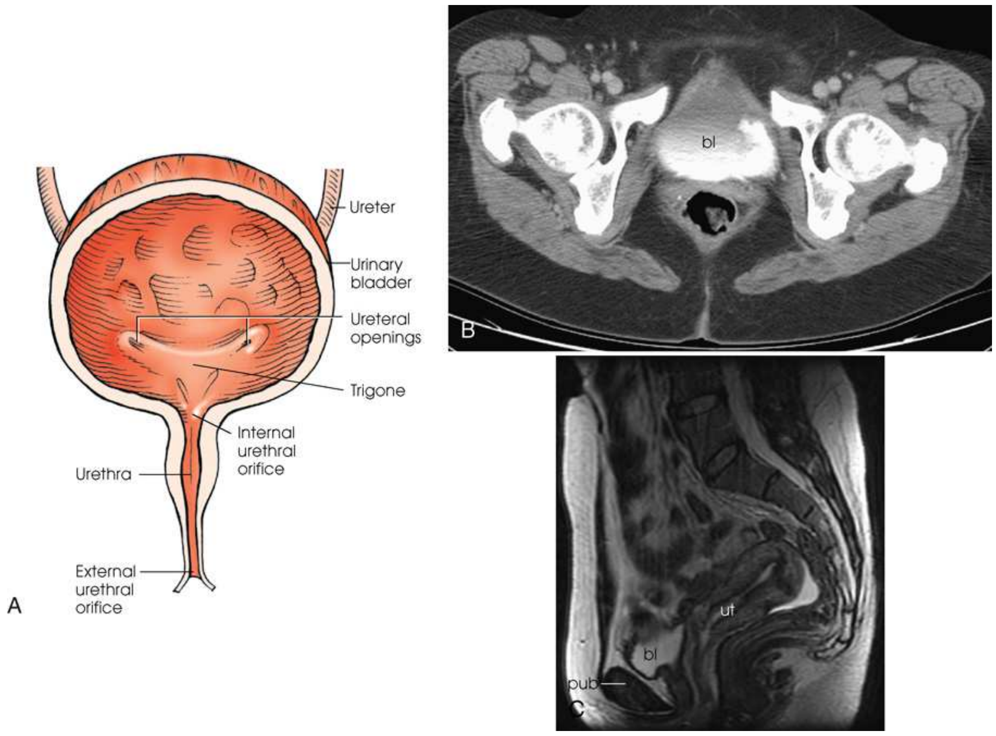


FIG. 16.6 (A) Anterior view of urinary bladder. (B) Axial CT image of pelvis showing contrast medium–filled bladder *(bl)*. (C) Sagittal MRI of female pelvis showing contrast medium–filled bladder *(bl)* and relationship to uterus *(ut)* and pubis *(pub)*.

The anterior view of the urinary bladder with two C T scan images. The bladder has a pair of Ureteral openings above the trigone which drain into the internal urethral orifice. It leads to the urethra which ends in external urethral orifice. The first scan image depicts a pelvis with a filled bladder highlighted by contrast. The second one is a sagittal view of a female pelvis with the contrast filled bladder, pubis, and uterus labeled.

The bladder varies in size, shape, and position according to its content. It is freely movable and is held in position by folds of the peritoneum. When empty, the bladder is located in the pelvic cavity. As the bladder fills, it gradually assumes an oval shape while expanding superiorly and anteriorly into the abdominal cavity. The adult bladder can hold approximately 500 mL of fluid when completely full. The urge for *micturition* (urination) occurs when about 250 mL of urine is in the bladder.

The ureters enter the posterior wall of the bladder at the lateral margins of the superior part of its *base* and pass obliquely through the wall to their respective internal orifices (Fig. 16.6). This portion of each ureter, where it joins the bladder, is called the *ureterovesical junction* (UVJ). These two openings are about 1 inch (2.5 cm) apart when the bladder is empty and about 2 inches (5 cm) apart when the bladder is distended. The openings are equidistant from the internal urethral orifice, which is situated at the neck (lowest part) of the bladder. The triangular area between the three orifices is called the *trigone*. The mucosa over the trigone is always smooth, whereas the remainder of the lining contains folds, called *rugae*, when the bladder is empty.

Urethra

The *urethra*, which conveys the urine out of the body, is a narrow, musculomembranous tube with a sphincter type of muscle at the neck of the bladder. The urethra arises at the internal urethral orifice in the urinary bladder and extends about 1½ inches (3.8 cm) in the female and 7 to 8 inches (17.8 to 20 cm) in the male.

The female urethra passes along the thick anterior wall of the vagina to the external urethral orifice, which is located in the vestibule about 1 inch (2.5 cm) anterior to the vaginal opening (see Fig. 16.6). The male urethra extends from the bladder to the end of the penis and is divided into *prostatic*, *membranous*, and *spongy* portions (Fig. 16.7). The prostatic portion is about 1 inch (2.5 cm) long, reaches from the bladder to the floor of the pelvis, and is completely surrounded by the prostate. The membranous portion of the canal passes through the urogenital diaphragm; it is slightly constricted and about ½ inch (1.3 cm) long. The spongy portion passes through the shaft of the penis, extending from the floor of the pelvis to the external urethral orifice. The distal prostatic, membranous, and spongy parts of the male urethra also serve as the excretory canal of the reproductive system.

Prostate

The *prostate*, a small glandular body surrounding the proximal part of the male urethra, is situated just posterior to the inferior portion of the pubic symphysis. The prostate is considered part of the male reproductive system, but because of its close proximity to the bladder, it is commonly described with the urinary system. The conical base of the prostate is attached to the inferior surface of the urinary bladder, and its apex is in contact with the pelvic diaphragm. The prostate measures about 1½ inches (3.8 cm) transversely and ¾ inch (1.9 cm) anteroposteriorly at its base; vertically, the prostate is approximately 1 inch (2.5 cm) long. The prostate gland secretes a milky fluid that combines with semen from the seminal vesicles and vas deferens. These secretions enter the urethra via ducts in the prostatic urethra.

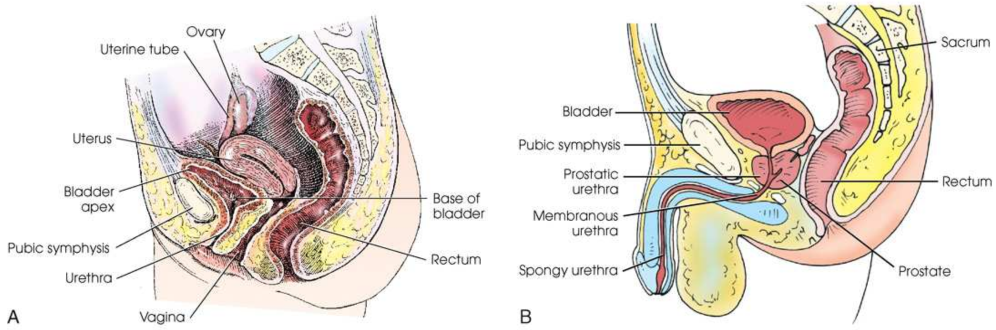


FIG. 16.7 (A) Midsagittal section through female pelvis. (B) Male pelvis.

The Midsagittal sections through the female pelvis and male pelvis. In the female pelvis the Ovary, Uterine tube, Uterus, Bladder apex, Pubic symphysis, Urethra, Vagina, Base of bladder, and Rectum are labeled. In the male pelvis the Bladder, Pubic symphysis, Prostatic urethra, Membranous urethra, Spongy urethra, Sacrum, Rectum, and Prostate are labeled.

Summary of Anatomy

Urinary system (excretory system)

Kidneys (R and L)

- Ureters (R and L)
- Urinary bladder
- Urethra

Suprarenal glands (adrenal glands)

Medullary portion

- Cortical portion

Kidneys

Adipose capsule

- Renal fascia
- Hilum
- Renal capsule
- Renal sinus
- Renal cortex
- Renal columns
- Renal medulla
- Renal pyramids
- Nephrons
- Renal corpuscle
- Glomerular capsule (Bowman capsule)
- Glomerulus
- Afferent arteriole
- Efferent arteriole
- Renal tubule
- Proximal convoluted tubule
- Nephron loop (loop of Henle)
- Distal convoluted tubule
- Collecting ducts
- Renal papilla
- Calyces
- Minor calyces
- Major calyces
- Renal pelvis

Urinary bladder

Apex

Base

Neck

Trigone

Rugae

Urethra

Male urethra

Prostatic

Membranous

Spongy

Prostate

Summary of Pathology

Condition	Definition
Benign prostatic hyperplasia (BPH)	Enlargement of prostate
Calculus	Abnormal concretion of mineral salts, often called a stone
Carcinoma	Malignant new growth composed of epithelial cells
Bladder	Carcinoma located in the bladder
Renal cell	Carcinoma located in the kidney
Congenital anomaly	Abnormality present at birth
Duplicate collecting system	Two renal pelves or ureters from the same kidney
Horseshoe kidney	Fusion of the kidneys, usually at the lower poles
Pelvic kidney	Kidney that fails to ascend and remains in the pelvis
Cystitis	Inflammation of the bladder
Fistula	Abnormal connection between two internal organs or between an organ and the body surface
Glomerulonephritis	Inflammation of the capillary loops in the glomeruli of the kidney
Hydronephrosis	Distention of renal pelvis and calyces with urine
Nephroptosis	Excessive inferior displacement of the kidneys or kidney prolapse
Phleboliths	Pelvic vein calcifications
Polycystic kidney	Massive enlargement of the kidney with the formation of many cysts
Pyelonephritis	Inflammation of the kidney and renal pelvis
Renal hypertension	Increased blood pressure to the kidneys
Renal obstruction	Condition preventing normal flow of urine through the urinary system
Stenosis	Narrowing or contraction of a passage
Tumor	New tissue growth where cell proliferation is uncontrolled
Wilms	Most common pediatric abdominal neoplasm affecting the kidney
Ureterocele	Ballooning of the lower end of the ureter into the bladder
Vesicoureteral reflux	Backward flow of urine from the bladder into the ureters

Eponymous (named) pathologies are listed in nonpossessive form to conform to the *AMA Manual of Style: A Guide for Authors and Editors*. 10th ed. Oxford: Oxford University Press; 2009.

Sample Exposure Technique Chart Essential Projections

These techniques were accurate for the equipment used to produce each exposure. However, use caution when applying them in your department because "there is considerable variability in image receptor response owing to varying scatter sensitivity, the use of grids with different grid ratios, collimation, beam filtration, the choice of kilovoltage, source-to-image distance, and image receptor size."[1]

This chart was created in collaboration with Dennis Bowman, AS, RT(R), Clinical Instructor, Community Hospital of the Monterey Peninsula, Monterey, CA. http://digitalradiographysolutions.com/.

Urinary System

Part	cm	kVp[a]	SID[b]	Collimation	CR[c]		DR[d]	
					mAs	Dose (mGy)[e]	mAs	Dose (mGy)[e]
Urinary system (urography)								
AP[f]	21	80	40″	14″ × 17″ (35 × 43 cm)	40[g]	5.480	16[g]	2.168
AP oblique[f]	24	80	40″	14″ × 17″ (35 × 43 cm)	56[g]	8.250	25[g]	3.660
Lateral[f]	27	80	40″	12″ × 17″ (30 × 43 cm)	100[g]	15.89	40[g]	6.320
Urinary bladder								
AP and PA axial[f]	16	80	40″	9″ × 9″ (23 × 23 cm)	56[g]	6.790	22[g]	2.670
AP oblique[f]	21	80	40″	9″ × 9″ (23 × 23 cm)	65[g]	8.510	28[g]	3.660
Lateral[f]	31	85	40″	8″ × 9″ (20 × 23 cm)	110[g]	20.41	45[g]	8.300

[1] ACR-AAPM-SIMM Practice Parameter for Digital Radiography, revised 2017.

[a] kVp values are for a high-frequency generator.

[b] 40 inches minimum; 44–48 inches recommended to improve spatial resolution (mAs increase needed, but no increase in patient dose will result).

[c] AGFA CR MD 4.0 General IP, CR 75.0 reader, 400 speed class, with 6:1 (178LPI) grid when needed.

[d] GE Definium 8000, with 13:1 grid when needed.

[e] All doses are skin entrance for an average adult (160–200 pound male, 150–190 pound female) at part thickness indicated.

[f] Bucky/Grid.

[g] Large focal spot.

Abbreviations Used in Chapter 16

ACR	American College of Radiology
ASRT	American Society of Radiologic Technologists
BPH	Benign prostatic hyperplasia
BUN	Blood urea nitrogen
CDC	US Centers for Disease Control and Prevention
EU	Excretory urogram
GFR	Glomerular filtration rate
IV	Intravenous
IVP	Intravenous pyelogram
IVU	Intravenous urogram
UPJ	Ureteropelvic junction
VCUG	Voiding cystourethrogram

See Addendum B for a summary of all abbreviations used in Volume 2.

Urinary System Radiography

Overview

Radiographic examination of the urinary system involves the use of a water-soluble iodinated contrast medium to allow visualization of the pertinent anatomy and, frequently, to evaluate physiologic function. The role of radiography in the evaluation of the urinary system has changed because of the increased use of multiplanar imaging modalities such as CT, magnetic resonance imaging (MRI), and ultrasonography (US). Multidetector CT, with three-dimensional reconstruction capabilities, has improved the visualization of small pathologies that were difficult or impossible to see on radiographic images. Despite the decreased use of contrast urography, the American College of Radiology (ACR) specifies that excretory urography is particularly useful in demonstrating the collecting system and ureters and in evaluating ureteral obstruction, compression, and displacement. In addition, contrast urography can be tailored to provide diagnostic information at a lower radiation dose than can be provided by helical multidetector CT.[1]

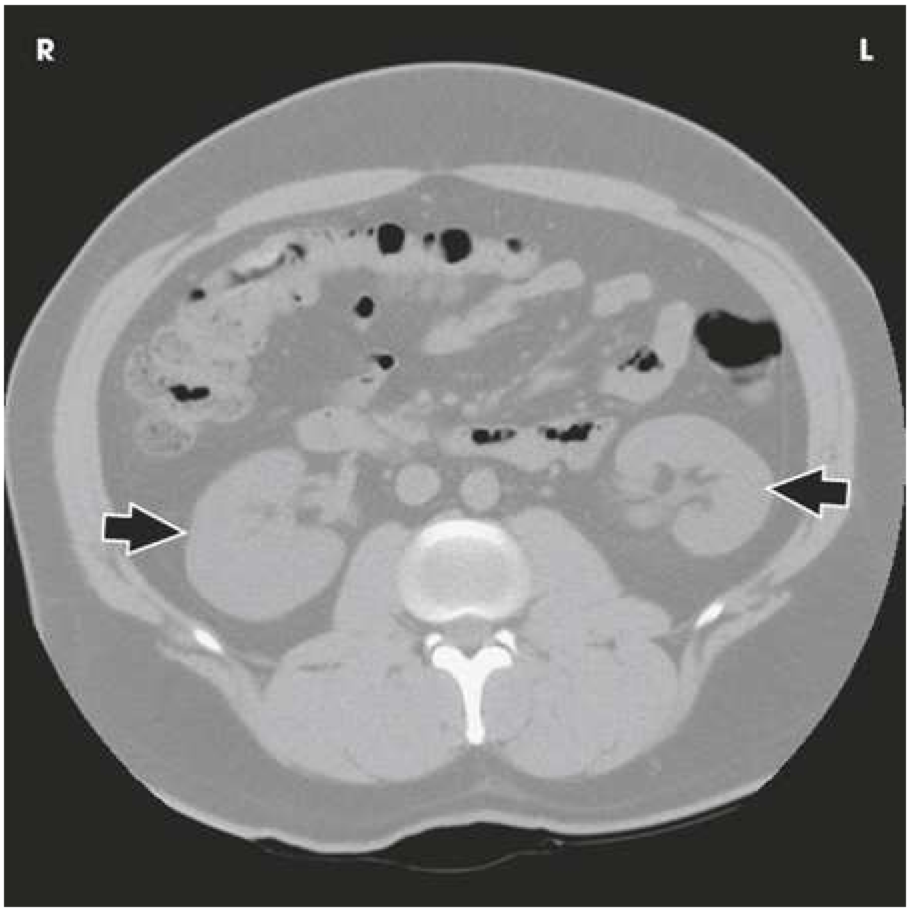


FIG. 16.8 CT of abdomen without contrast media showing parenchyma and renal pelvis of both kidneys *(arrows)*. Courtesy Karl Mockler, RT[R].

A C T scan image of the superior abdomen cavity. The parenchyma is visible. The kidneys appear as bean-shaped structures on either sides of the pelvic girdle. Two arrows point to the renal pelvis of the left and right kidneys.

FIG. 16.9 CT "stone protocol" without contrast media showing renal calculus in left distal ureter *(arrow)*. Courtesy Karl Mockler, RT[R].

The specialized radiography procedures are preceded by a plain, or scout, image of the abdominopelvic areas for detection of abnormalities that can be shown on plain radiography. The preliminary examination may consist of only a KUB. Oblique or lateral projections, or both, may be obtained to localize calcifications, such as urinary calculi or phleboliths, and tumor masses. An upright position may be used to show the mobility of the kidneys to demonstrate nephroptosis and for the detection of low-grade obstruction. [2]

Preliminary radiography can usually show the position and mobility of the kidneys and usually their size and shape because of the contrast furnished by the radiolucent fatty capsule surrounding the kidneys. In addition, properly selected CT soft tissue windows can show the renal parenchyma without contrast media (Fig. 16.8). Visualization of the thin-walled drainage, or collecting, system (calyces and pelves, ureters, urinary bladder, and urethra) requires that the canals be filled with a contrast medium. The urinary bladder is outlined when it is filled with urine, but it is not adequately shown. The ureters and the urethra cannot be distinguished on preliminary images. A CT "stone protocol" without a contrast medium can clearly show calcified renal stones (Fig. 16.9).

Imaging of the Kidneys

Cysts and tumor masses situated within the kidney are usually imaged using contrast-enhanced CT (Fig. 16.10) or US (Fig. 16.11). Angiographic procedures are used to investigate the blood vessels of the kidneys and the suprarenal glands (see Chapter 27, Volume 3). An example of the direct injection of contrast medium into the renal artery is shown in Fig. 16.12.

Radiologic investigations of the renal drainage, or collecting, system are performed by various procedures classified under the general term *urography*. This term embraces two regularly used techniques for filling the urinary canals with a contrast medium. Imaging of cutaneous urinary diversions has been described by Long. [3]

Antegrade filling

Antegrade filling techniques allow the contrast medium to enter the kidney in the normal direction of blood flow. In selective patients, this is done by introducing the contrast material directly into the kidney through a percutaneous puncture of the renal pelvis—a technique called *percutaneous antegrade urography*. Much more commonly used is the physiologic technique, in which the contrast agent is generally administered intravenously. This technique is called *excretory* or *intravenous urography* (EU or IVU) and is shown in Fig. 16.13.

IVU is used in examinations of the upper urinary tract in infants and children and is generally considered to be the preferred technique in adults unless the use of the retrograde technique is definitely indicated. Because the contrast medium is administered intravenously and all parts of the urinary system are normally shown, the excretory technique is correctly referred to as IVU. The term *pyelography* refers to the radiographic demonstration of the renal pelves and calyces. This examination has been erroneously called an intravenous pyelogram (IVP).

FIG. 16.10 CT image of abdomen with contrast media showing early filling of both kidneys *(arrows)*.

FIG. 16.12 Selective right renal arteriogram.

After the opaque contrast medium enters the bloodstream, it is conveyed to the renal glomeruli and is discharged into the capsules with the glomerular filtrate, which is excreted as urine. With the reabsorption of water, the contrast material becomes sufficiently concentrated to render the urinary canals radiopaque. The urinary bladder is well outlined by this technique, and satisfactory voiding urethrograms may be obtained.

FIG. 16.11 US image of normal right kidney in the sagittal plane.

FIG. 16.13 Excretory urogram.

FIG. 16.14 Retrograde urogram.

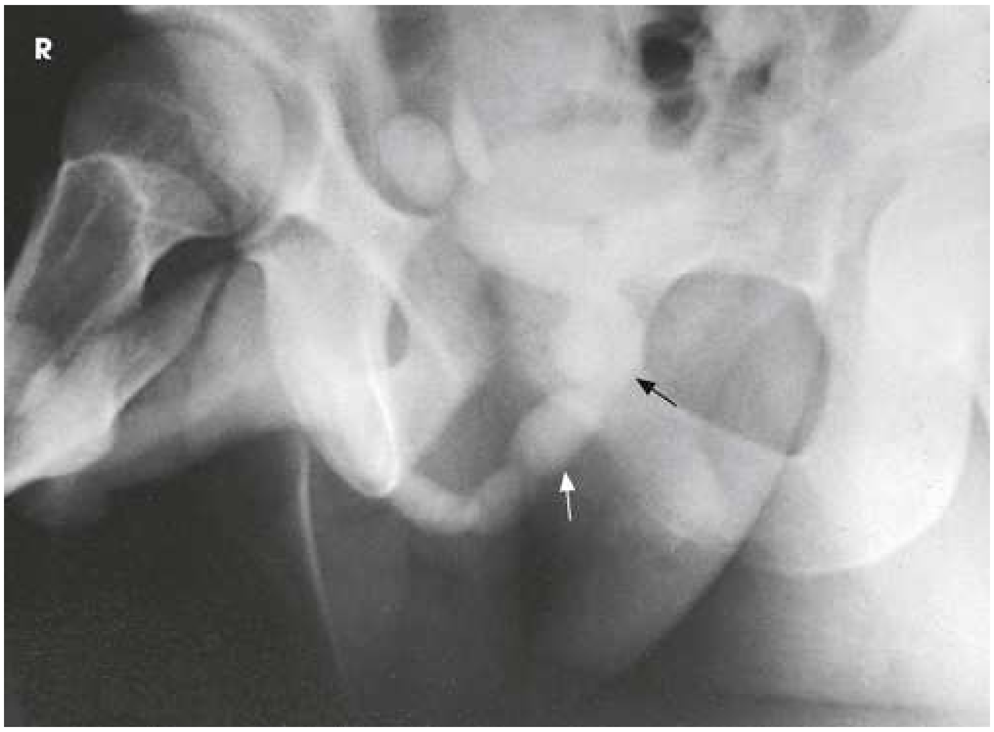


FIG. 16.15 Voiding study after routine injection intravenous urogram (IVU). Dilation of proximal urethra *(arrows)* is the result of urethral stricture.

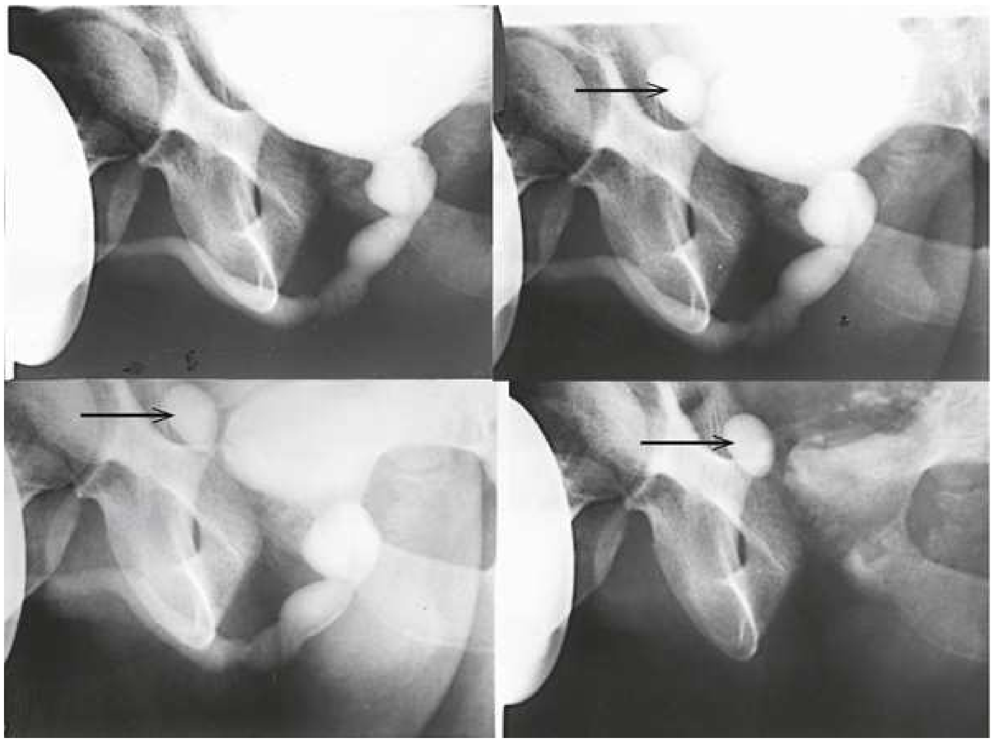


FIG. 16.16 Voiding studies of same patient as in Fig. 16.15 after infusion nephrourography. Note increase in opacification of contrast medium–filled cavities by this method and bladder diverticulum *(arrows)*.

Four serial nephrogram images of a patient in lateral projection from top-left to bottom-left. An arrow points to the bladder diverticulum in the images which is varying in opacification. The opacification of contrast medium–filled cavities is increasing from the first image to the last image.

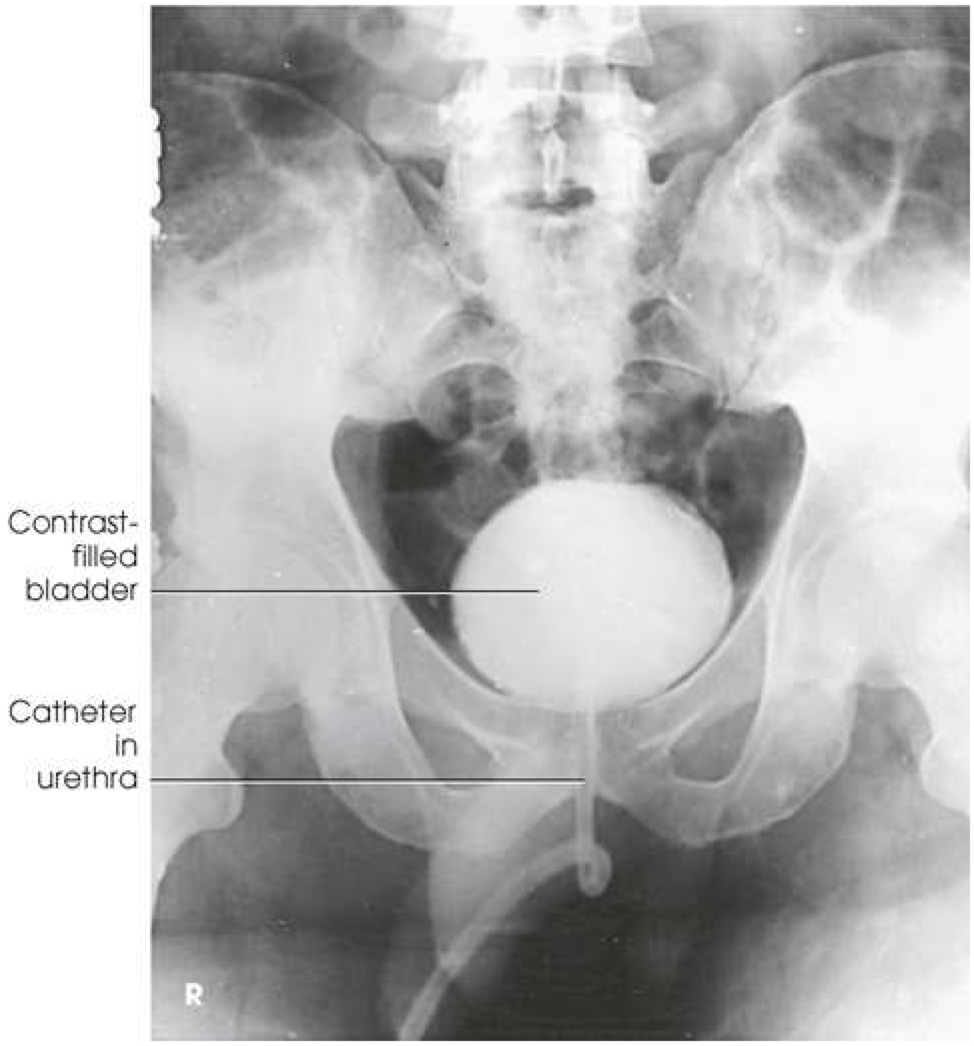


FIG. 16.17 Cystogram.

A cystogram of a patient taken in a anterior projection. The urinary bladder at the center is filled and has a tube-like catheter inserted into the urethra. The bladder is highlighted by a contrast medium. The pelvic bones and lumbar vertebrae are visible.

Retrograde filling

In some procedures involving the urinary system, the contrast material is introduced against the normal flow. This is called *retrograde urography* (Fig. 16.14). The contrast medium is injected directly into the canals via ureteral catheterization for contrast filling of the upper urinary tract and via urethral catheterization for contrast filling of the lower part of the urinary tract. Cystoscopy is required to localize the vesicoureteral orifices for the passage of ureteral catheters.

Retrograde urographic examination of the proximal urinary tract is primarily a urologic procedure. Catheterization and contrast filling of the urinary canals are performed by the attending urologist in conjunction with a physical or endoscopic examination. This technique enables the urologist to obtain catheterized specimens of urine directly from each renal pelvis. Because the canals can be fully distended by direct injection of the contrast agent, the retrograde urographic examination sometimes provides more information about the anatomy of the different parts of the collecting system than can be obtained by the excretory technique. For the retrograde procedure, an evaluation of kidney function depends on an intravenously administered dye substance to stain the color of the urine that subsequently trickles through the respective ureteral catheters. The antegrade and retrograde techniques of examination are occasionally required for a complete urologic study.

FIG. 16.18 Cystoureterogram: AP bladder showing distal ureters.

Investigations of the lower urinary tract—bladder, lower ureters, and urethra—are usually done by the retrograde technique, which requires no instrumentation beyond the passage of a urethral catheter. Investigations may also be done by the physiologic technique (Figs. 16.15 and 16.16). Bladder examinations are usually denoted by the general term *cystography* (Fig. 16.17). A procedure that includes inspection of the lower ureters is *cystoureterography* (Fig. 16.18), and a procedure that includes inspection of the urethra is *cystourethrography* (Fig. 16.19).

FIG. 16.19 Injection cystourethrogram showing urethra in a male patient.

Contrast media

Retrograde urography (Figs. 16.20 and 16.21) was first performed in 1904 with the introduction of air into the urinary bladder. In 1906, retrograde urography and cystography were performed with the first opaque medium, a colloidal silver preparation that is no longer used. Silver iodide, which is a nontoxic inorganic compound, was introduced in 1911. Sodium iodide and sodium bromide, also inorganic compounds, were first used for retrograde urography in 1918. The bromides and iodides are no longer widely used for examinations of the renal pelves and ureters because they irritate the mucosa and commonly cause considerable patient discomfort.

Because a large quantity of solution is required to fill the urinary bladder, iodinated salts in concentrations of 30% or less are used in cystography. A large selection of commercially available contrast media may be used for all types of radiographic examinations of the urinary system. It is important to review the product insert packaged with every contrast agent.

Excretory urography (Figs. 16.22 and 16.23) was first reported by Rowntree et al. in 1923. [4] These investigators used a 10% solution of chemically pure sodium iodide as the contrast medium. This agent was excreted too slowly, however, to show the renal pelves and ureters satisfactorily, and it proved too toxic for functional distribution. Early in 1929, Roseno and Jepkins [5] introduced a compound containing sodium iodide and urea. The latter constituent, which is one of the nitrogenous substances removed from the blood and eliminated by the kidneys, served to accelerate excretion and to fill the renal pelves with opacified urine quickly. Although satisfactory renal images were obtained with this compound, patients experienced considerable distress as a result of its toxicity.

In 1929, Swick developed the organic compound Uroselectan, which had an iodine content of 42%. Present-day ionic contrast media for excretory urography are the result of extensive research by many investigators. These media are available under various trade names in concentrations ranging from approximately 50% to 70%. Sterile solutions of the media are supplied in dose-size ampules or vials.

In the early 1970s, research was initiated to develop nonionic contrast media. Development progressed, and several nonionic contrast agents are currently available for urographic, vascular, and intrathecal injection. Although nonionic contrast media are less likely to cause a reaction in the patient, they are more expensive than ionic agents. Despite this cost, nonionics are most commonly used because of the increase in patient safety and comfort.

FIG. 16.20 Retrograde urogram with contrast medium–filled right renal pelvis and catheter in left renal pelvis.

A retrograde urogram of a patient. The left and right kidneys, ureters, lumbar vertebrae, pelvis, are visible. The contrast medium highlights the renal pelvis of right kidney and a catheter in left renal pelvis.

FIG. 16.21 Retrograde urogram.

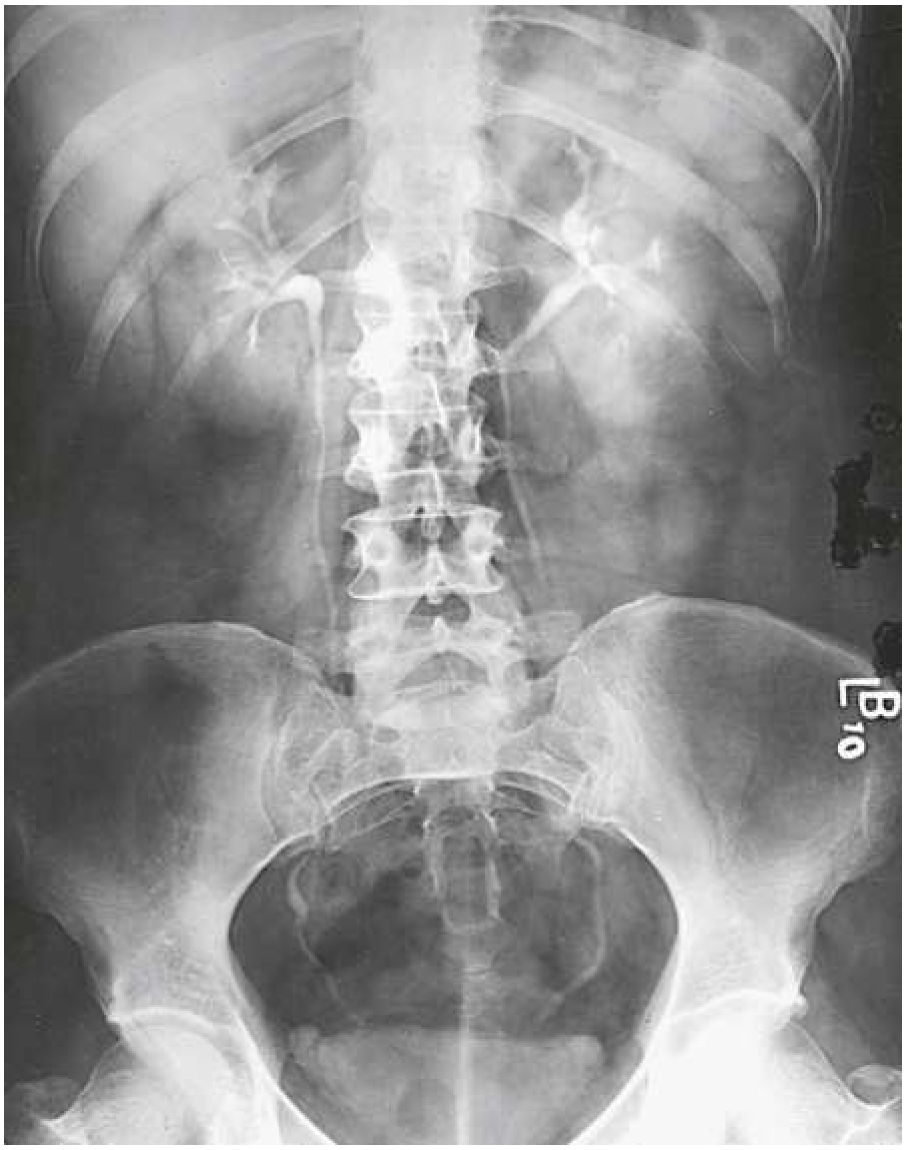


FIG. 16.22 Excretory urogram, 10 minutes after injection of contrast medium.

The urogram of a patient taken after 10 minutes of injecting a contrast medium. The left and right kidneys, ureters, lumbar vertebrae, and pelvis, are visible. The contrast medium highlights the bladder and parts of the rib bones and soft tissues.

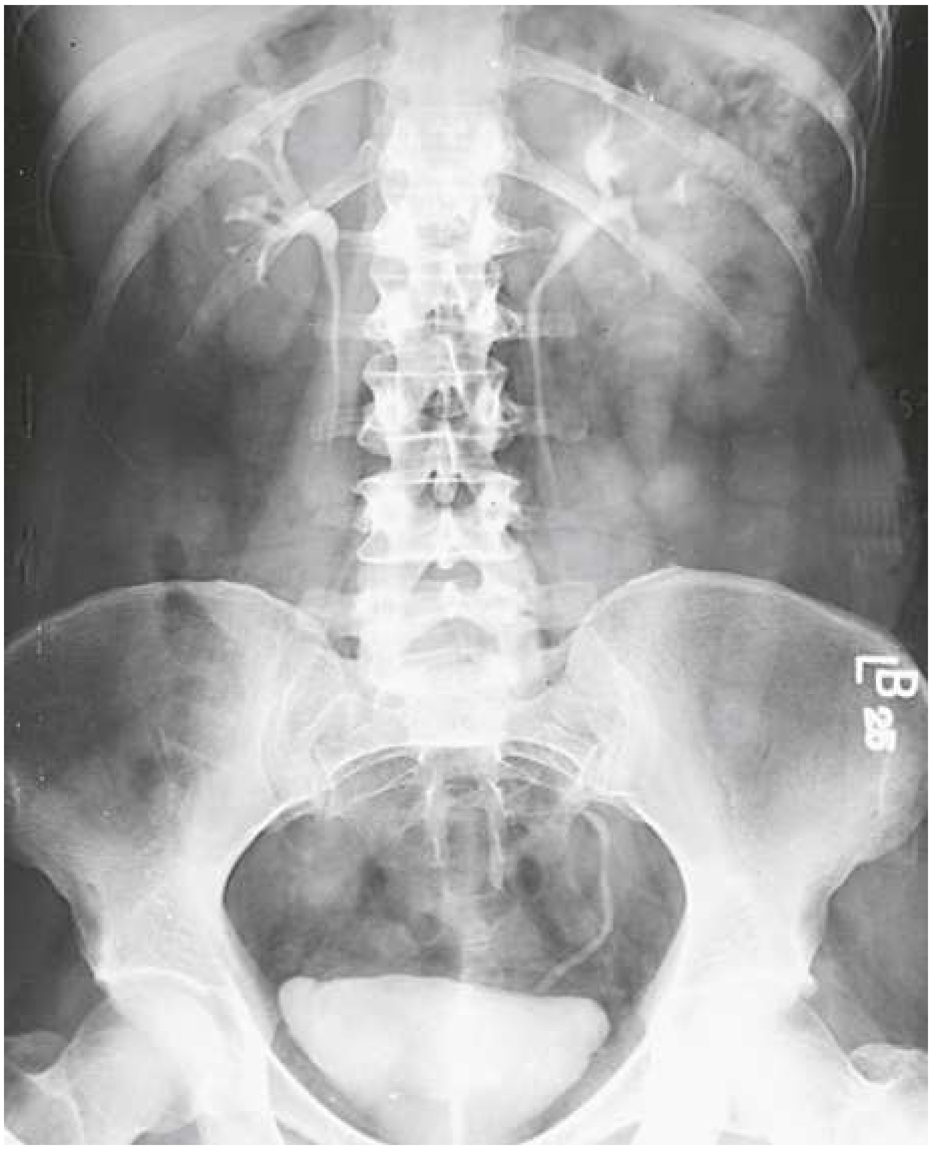


FIG. 16.23 Excretory urogram on same patient as in Fig. 16.22, 25 minutes after contrast medium injection.

The urogram of a patient taken after 25 minutes of injecting a contrast medium. The left and right kidneys, ureters, lumbar vertebrae, and pelvis, are visible. The contrast medium highlights the bladder and parts of the rib bones and soft tissues.

Adverse reactions to iodinated media

The iodinated organic preparations that are compounded for urologic examinations are of low toxicity. Consequently, adverse reactions are usually mild and of short duration. Common reactions include a feeling of warmth and flushing. Occasionally nausea, vomiting, a few hives, and edema of the respiratory mucous membrane result. Severe and serious reactions occur only rarely but are always a possibility. The clinical history of each patient must be carefully checked, and the patient must be kept under careful observation for any sign of systemic reactions. According to the 2017 version of the ACR Manual on Contrast Media, "nearly all life-threatening contrast reactions occur within the first 20 minutes after contrast medium injection." The patient should not be left unattended during this time period. Emergency equipment and medication (diphenhydramine, epinephrine) to treat adverse reactions must be readily available. The ACR additionally states that the radiologist, or his or her qualified designee, who is on-site during the procedure must be prepared and able to treat these reactions.

Preparation of intestinal tract

Although unobstructed visualization of the urinary tracts requires that the intestinal tract be free of gas and solid fecal material (Fig. 16.24), bowel preparation is not attempted in infants and children. The use of cleansing measures in adults depends on the condition of the patient. Gas (particularly swallowed air, which is quickly dispersed through the small bowel) rather than fecal material usually interferes with the examination.

FIG. 16.24 Preliminary AP abdomen for urogram.

Hope and Campoy [6] recommended that infants and children be given a carbonated soft drink to distend the stomach with gas. By this maneuver, the gas-containing intestinal loops are usually pushed inferiorly, and the upper urinary tracts, particularly on the left side of the body, are clearly visualized through the outline of the gas-filled stomach. Hope and Campoy stated that the aerated drink should be given in an amount adequate to inflate the stomach fully: at least 2 oz. is required for a newborn infant, and 12 oz. is required for a 7-year-old child. In conjunction with the carbonated drink, Hope and Campoy recommended using a highly concentrated contrast medium. A gas-distended stomach is shown in Fig. 16.25.

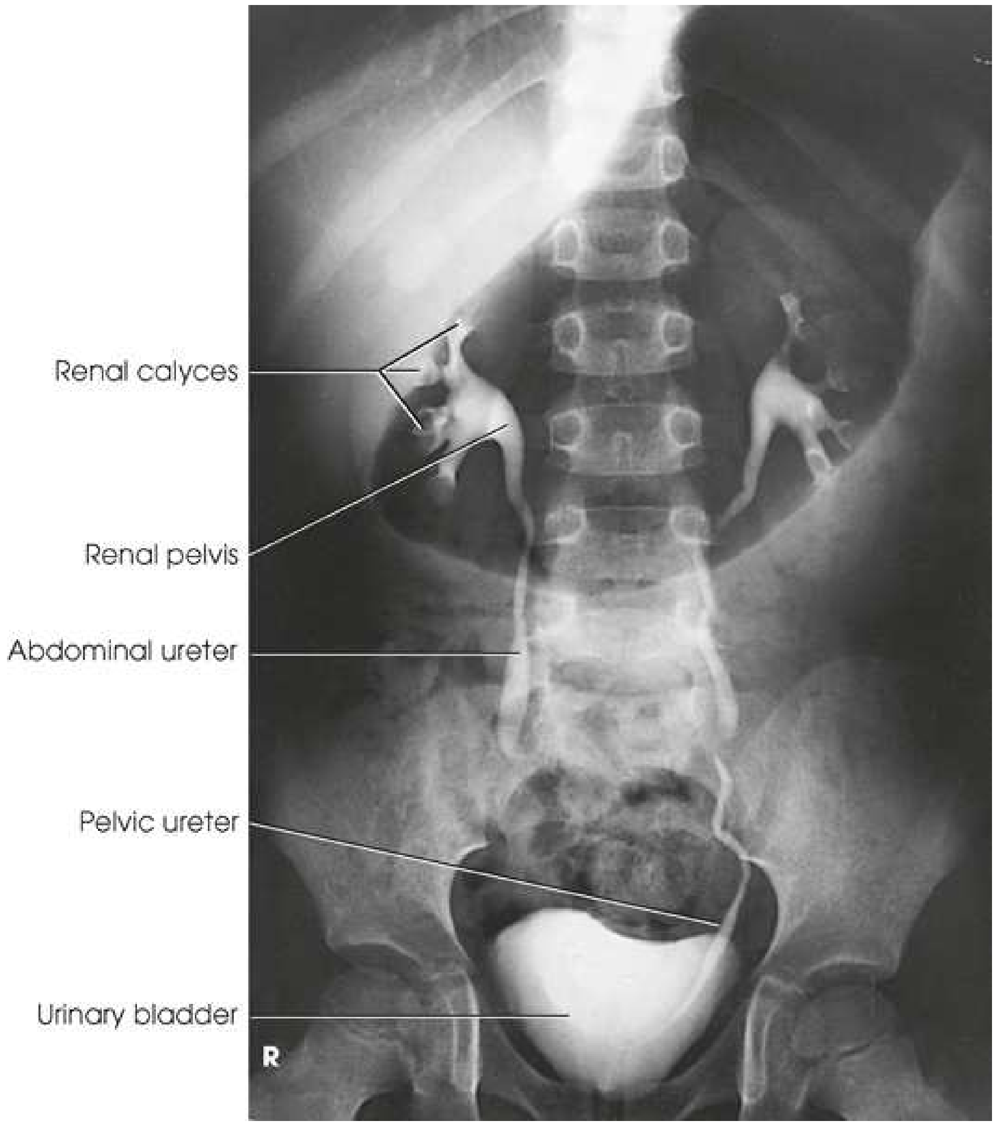


FIG. 16.25 Supine urogram at 15-minute interval with gas-filled stomach.

The urogram of the gas-filled stomach of a patient in supine position taken at an interval of 15 minutes. The left and right kidneys, ureters, lumbar vertebrae, pelvic bones, rib bones, urinary bladder, and urethra are visible

Berdon et al. [7] stated that the prone position resolves the problem of obscuring gas in most patients (Figs. 16.26 and 16.27). It is unnecessary to inflate the stomach with air alone or with air as part of an aerated drink. By exerting pressure on the abdomen, the prone position moves the gas laterally away from the pelvicaliceal structures. Gas in the antral portion of the stomach is displaced into its fundic portion, gas in the transverse colon shifts into the ascending and descending segments, and gas in the sigmoid colon shifts into the descending colon and rectum. These investigators noted, however, that the prone position occasionally fails to produce the desired result in small infants when the small intestine is dilated. Gastric inflation also fails in these patients because the dilated small intestine merely elevates the gas-filled stomach and does not improve visualization. They recommended examination of such infants *after* the intestinal gas has passed.

Preparation of patient

Medical opinion concerning patient preparation varies widely. With modifications as required, the following procedure seems to be in general use:

- When time permits, have the patient follow a low-residue diet for 1 to 2 days to prevent gas formation caused by excessive fermentation of the intestinal contents.
- Have the patient eat a light evening meal on the day before the examination.
- When indicated by costive bowel action, administer a non-gas-forming laxative the evening before the examination.
- Have the patient take nothing by mouth after midnight on the day of the examination. The patient should not be dehydrated, however. Patients with multiple myeloma, high uric acid levels, or diabetes must be well hydrated before IVU is performed; these patients are at increased risk for contrast medium-induced renal failure if they are dehydrated.

FIG. 16.26 Urogram: supine position. Intestinal gas obscuring left kidney.

- In preparation for *retrograde urography*, have the patient drink a large amount of water (4 or 5 cups) several hours before the examination to ensure the excretion of urine in an amount sufficient for bilateral catheterized specimens and renal function tests.
- No patient preparation is usually necessary for the examination of the lower urinary tract.

Outpatients should be given explicit directions regarding any order from the physician pertaining to diet, fluid intake, and laxatives or other medication. The patient should also be given a suitable explanation for each preparative measure to ensure cooperation.

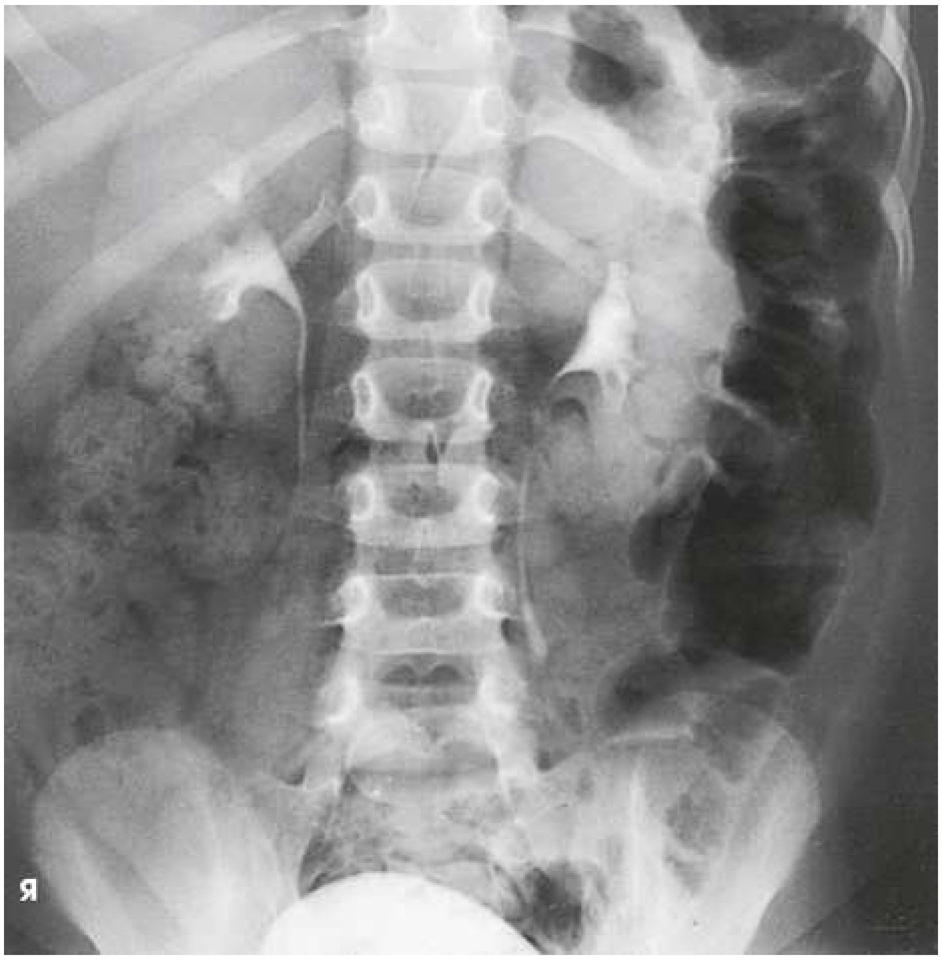


FIG. 16.27 Urogram: prone position, in the same patient as in Fig. 16.26. Visualization of left kidney and ureter is markedly improved.

Equipment

Any standard radiographic table is suitable to perform preliminary excretory urography and most retrograde studies of the bladder and urethra. A combination cystoscopic-radiographic unit facilitates retrograde urographic procedures requiring cystoscopy. The cystoscopic unit is also used for IVU and retrograde bladder and urethra studies; however, for the patient's comfort, the table should have an extensible leg rest.

Infusion nephrourography requires a table equipped with tomographic apparatus. Tomography should be performed when intestinal gas obscures some of the underlying structures, or when hypersthenic patients are being examined (Fig. 16.28).

For the patient's comfort and to prevent delays during the examination, all preparations for the examination should be completed before the patient is placed on the table. In addition to an identification and side marker, excretory urographic studies require a time interval marker for each postinjection study. Body position markers (supine, prone, upright or semi-upright, Trendelenburg, decubitus) should also be used.

Some institutions perform excretory urograms (proximal urinary tract studies) using a 10 × 12-inch (24 × 30-cm) crosswise radiation field or CR plate, but these studies can also be made using a 14 × 17-inch (35 × 43-cm) lengthwise exposure field or CR plate (Figs. 16.29 and 16.30). The upright study is made using a lengthwise 14 × 17-inch (35 × 43-cm) radiation field or CR plate because it is taken to show the mobility of the kidneys, to demonstrate nephroptosis, and to outline the lower ureters and bladder. Studies of the bladder before and after voiding are usually taken using a crosswise 10 × 12-inch (24 × 30-cm) radiation field or CR plate.

FIG. 16.28 Urogram: AP projection using tomography.

The following guidelines are observed in preparing additional equipment for the examination:

- Have an emergency cart fully equipped and conveniently placed.
- Arrange the instruments for injection of the contrast agent on a small, movable table or on a tray.
- Have frequently used sterile items readily available. Disposable syringes and needles are available in standard sizes and are widely used in this procedure.
- Have required nonsterile items available: a tourniquet, a small waste basin, an emesis basin, general disposable wipes, one or two bottles of contrast medium, and a small prepared dressing for application to the puncture site.
- Have iodine or alcohol wipes available.
- Provide a folded towel or a small pillow that can be placed under the patient's elbow to relieve pressure during the injection.

FIG. 16.29 Urogram: AP projection of kidneys and proximal ureters, 10 × 12-inch (24 × 30-cm) radiation field. Courtesy St. Bernard's Medical Center, Jonesboro, AR.

Procedure

Image quality and exposure technique

Urograms should have the same contrast as abdominal images and are exposed with kVp sufficient to penetrate the iodinated contrast medium. The images must show a sharply defined outline of the kidneys, lower border of the liver, and lateral margin of the psoas muscles. The amount of bone detail visible in these studies varies according to the thickness of the abdomen (Fig. 16.31).

Motion control

The elimination of motion in urographic examinations depends on exposure time and on securing the full cooperation of the patient.

The examination procedure should be explained so that the adult patient is prepared for any transitory distress caused by an injection of contrast solution or by the cystoscopic procedure. The patient should be assured that everything possible will be done for the patient's comfort. The success of the examination depends in large part on the ability of the radiographer to gain the confidence of the patient.

FIG. 16.30 Urogram: AP projection using 14 × 17-inch (35- × 43-cm) radiation field. Courtesy St. Bernard's Medical Center, Jonesboro, AR.

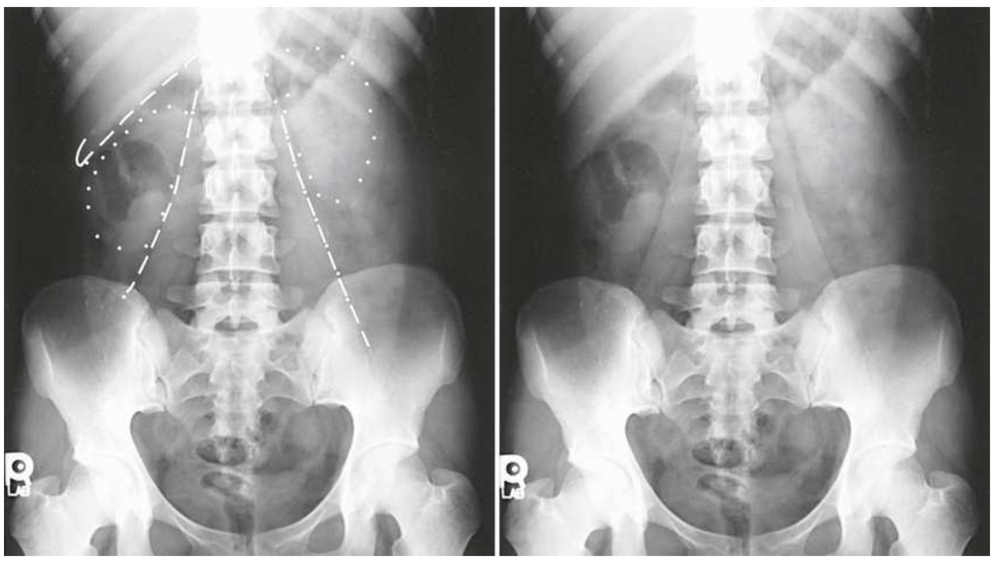


FIG. 16.31 AP abdomen showing margins of kidney *(dots)*, liver *(dashes)*, and psoas muscles *(dot-dash lines)*.

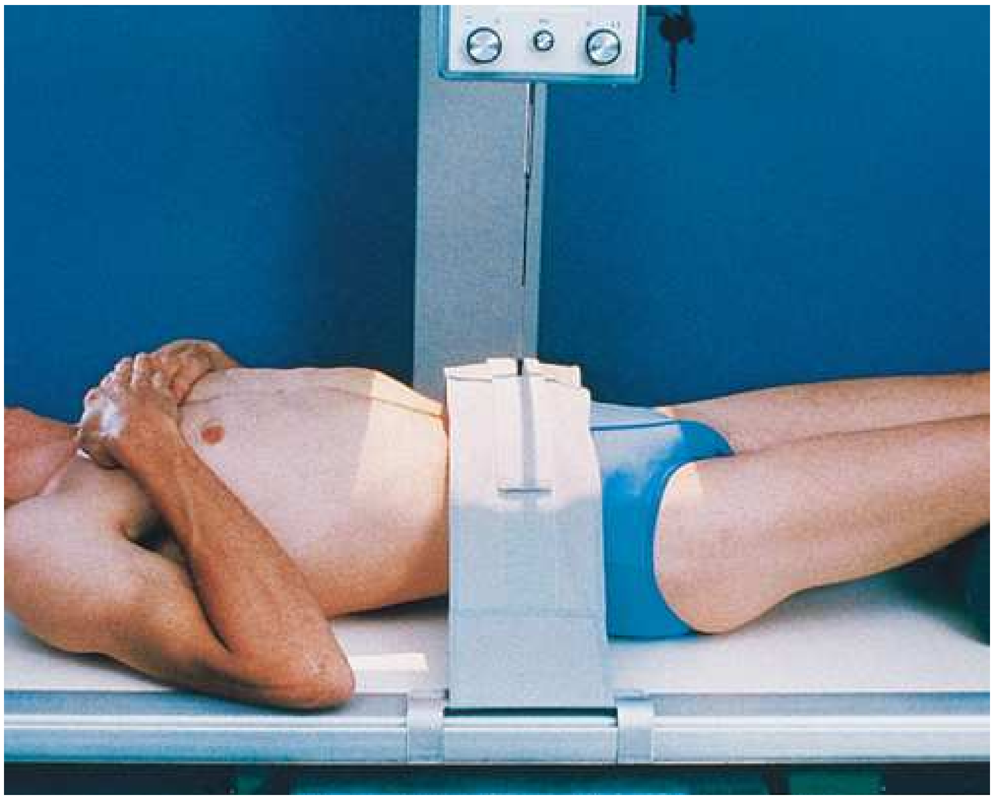


FIG. 16.32 Ureteral compression device in place for urogram.

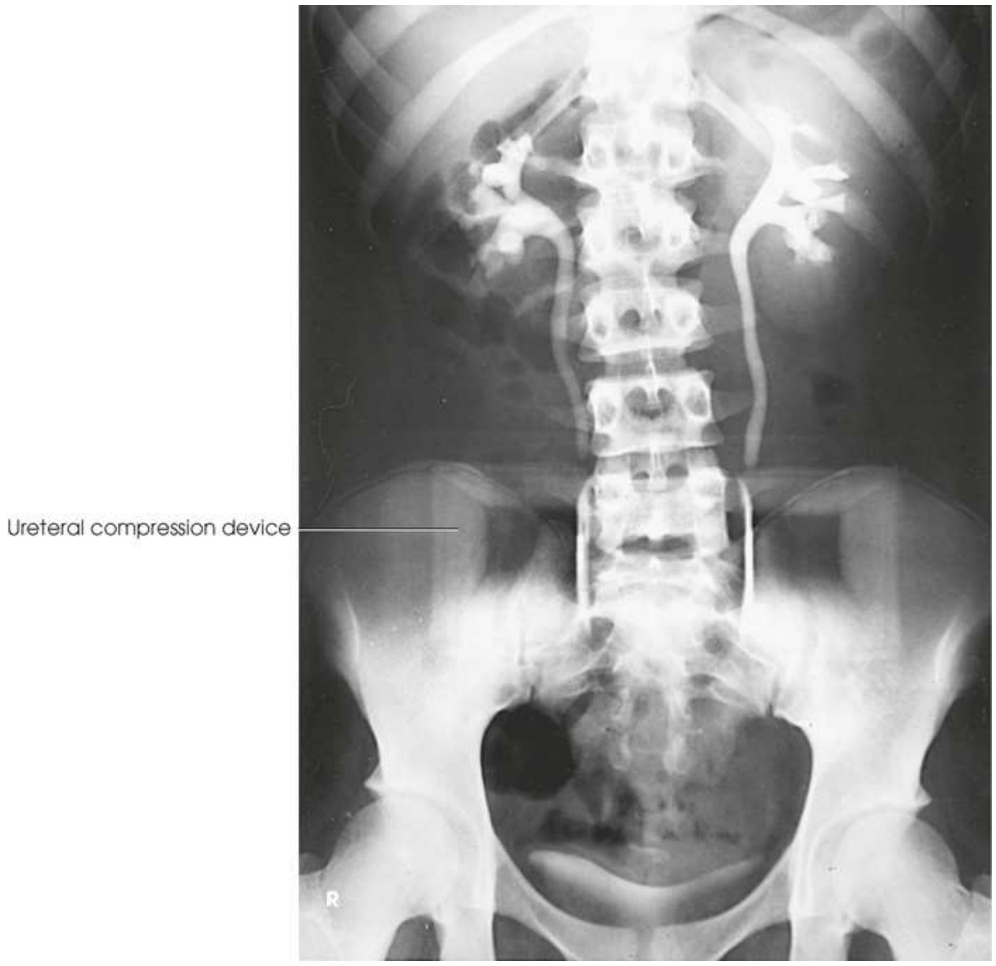


FIG. 16.33 Urogram showing ureteral compression device in proper position over distal ureters.

Ureteral compression

In excretory urography, compression is sometimes applied over the distal ends of the ureters. This compression is applied to retard the flow of the opacified urine into the bladder and to ensure adequate filling of the renal pelves and calyces. If compression is used, it must be placed so that the pressure over the distal ends of the ureters is centered at the level of the anterior superior iliac spine (ASIS). As much pressure as the patient can comfortably tolerate is applied with the immobilization band (Figs. 16.32 and 16.33). This pressure should be released slowly when the compression device is removed to reduce pain caused by rapid changes in intra-abdominal pressure. Compression is generally contraindicated if a patient has urinary stones, an abdominal mass or aneurysm, a colostomy, a suprapubic catheter, traumatic injury, or recent abdominal surgery.

As a result of improvements in contrast agents, ureteral compression is not routinely used in most health care facilities. With the increased doses of contrast medium now employed, most of the ureteral area is usually shown over a series of images. In addition, a prone image is an adequate substitute for ureteral compression for filling the pyelocaliceal system and mid-ureters.

Respiration

For purposes of comparison, all exposures are made at the end of the same phase of breathing—at the *end of expiration* unless otherwise requested. Because the normal respiratory excursion of the kidneys varies from ½ to 1½ inches (1.3 to 3.8 cm), it is occasionally possible to differentiate renal shadows from other shadows by making an exposure at a different phase of arrested respiration. When an exposure is made at a respiratory phase different from what is usually used, the image should be so marked.

Preliminary Examination

A preliminary examination of the abdomen is made before a specialized investigation of the urinary tract is conducted. This examination sometimes reveals extrarenal lesions that are responsible for the symptoms attributed to the urinary tract and renders the urographic procedure unnecessary. An upright AP projection may also be required to show the mobility of the kidneys. An oblique or lateral projection, or both, in the dorsal decubitus position may be required to localize a tumor mass or to differentiate renal stones from gallstones or calcified mesenteric nodes.

The scout image—an AP projection with the patient recumbent—shows the contour of the kidneys; their location in the supine position; and the presence of renal calculi or calcifications outside the renal collecting system, such as phleboliths, which are small calcifications in the wall of pelvic veins (see Fig. 16.31). This image also serves to check the preparation of the gastrointestinal tract and to enable the radiographer to make any necessary alterations to exposure factors.

Radiation Protection

As with all radiographic procedures, it is the responsibility of the radiographer to minimize radiation exposure to the patient by

- Applying a gonadal shield if it does not overlap the area under investigation. For most projections in this chapter, females generally cannot be shielded without obscuring a portion of the urinary system.
- Restricting radiation to the area of interest by close collimation.
- Working carefully so that repeat exposures are unnecessary.

Intravenous Urography

IVU shows the function and structure of the urinary system. *Function* is shown by the ability of the kidneys to filter contrast medium from the blood and concentrate it with the urine. Anatomic *structures* are usually visualized as the contrast material follows the excretion route of the urine. The primary application of IVU is to evaluate the suspected or continued presence of ureteral obstruction.

The *ACR Practice Guideline for the Performance of Excretory Urography* (2014) emphasizes that an evaluation of the merits and availability of cross-sectional imaging modalities should be performed before IVU is performed. Indications for IVU include, but are not limited to, the following:

- Evaluation of known or suspected ureteral obstruction
- Recurrent urolithiasis—follow-up with limited images for recurrent calculi or stones of the kidneys or urinary tract to decrease patient's total radiation exposure compared to CT studies
- Assessment of suspected congenital abnormalities
- Evaluation of upper urinary tract to investigate abnormalities that increase infection risks
- Assessment of upper urinary tract lesions that may explain hematuria
- Assessment of the effects of trauma and therapeutic interventions

The most common contraindications for IVU relate to (1) the ability of the kidneys to filter contrast medium from the blood and (2) the patient's allergic history. Some contraindications can be overcome by the use of nonionic contrast agents. Patients with conditions in which the kidneys are unable to filter waste or excrete urine (renal failure, anuria) should have the kidneys evaluated by some technique other than excretory urography. Older patients and patients with any of the following risk factors are strong candidates to receive a nonionic contrast medium or should be examined using another modality: asthma, previous contrast media reaction, circulatory or cardiovascular disease, elevated creatinine level, sickle cell disease, diabetes mellitus, or multiple myeloma.

Radiographic Procedure

Before the procedure begins, the patient should be instructed to empty the bladder and change into an appropriate radiolucent gown. Emptying the bladder prevents dilution of the contrast medium with urine. The patient's clinical history, allergic history, and blood creatinine levels should be reviewed. The normal creatinine level is 0.5 to 1.2 mg/100 mL. The glomerular filtration rate (GFR), a calculation that uses the creatinine level (plus age, race, gender, and body size), is the best overall index of kidney function. The National Kidney Foundation considers a normal GFR range to be 90 to 120 mL/min/1.73 m^2 and a value of 90 mL/min or less as an indicator of renal dysfunction; however, this is an age-related value, as GFR decreases with age. A below-normal GFR should be reviewed by the radiologist or the physician before the contrast media procedure is continued. The radiographer then takes the following steps:

- Place the patient on the table in the supine position, and adjust the patient to center the MSP of the body to the midline of the grid.
- Place a support under the patient's knees to reduce the lordotic curvature of the lumbar spine and to provide greater comfort for the patient (Fig. 16.34).
- Attach the footboard in preparation for a possible upright or semiupright position.

- If the head of the table is to be lowered farther to enhance pelvicaliceal filling, attach the shoulder support and adjust it to the patient's height.
- When ureteric compression is to be used, place the compression device so that it is ready for immediate application at the specified time.
- Obtain a preliminary, or scout, image of the abdomen. Then, prepare for the first postinjection exposure before the contrast medium is injected.
- Place CR plates in the Bucky tray, and for DR equipment, ensure the grid is engaged; position identification, side, and time interval markers; and make any change in centering or exposure technique as indicated by the scout image.
- Have ready a folded towel or other suitable support and the tourniquet for placement under the selected elbow.
- Prepare the contrast medium for injection using an aseptic technique.
- According to the preference of the examining physician, administer 30 to 100 mL of the contrast medium to an adult patient of average size. The dose administered to infants and children is regulated according to age and weight.

FIG. 16.34 Patient in supine position for urogram, AP projection. Note support under knees.

A patient in supine position lies on his back with the knees slightly bent. The knees are supported by a cushion. His hands are folded over the chest. The ureteral compression device is placed above his abdomen.

- Produce images at specified intervals from the time of *completion of the injection* of contrast medium. (This may depend on the protocol of the department.) These time intervals must be included on each image. Depending on the patient's hydration status and the speed of the injection, the contrast agent normally begins to appear in the pelvicaliceal system within 2 to 8 minutes.

Uptake of contrast medium is seen in the nephrons of the kidney if an image is exposed as the kidneys start to filter the contrast medium from the blood. The initial contrast "blush" of the kidney is termed the *nephrogram phase*. Nephrotomography, if a component of the routine IVU procedure, is usually performed during the nephrogram phase. As the kidneys continue to filter and concentrate the contrast medium, it is directed to the pelvicaliceal system. The greatest concentration of contrast medium in the kidneys normally occurs 15 to 20 minutes after injection. Typically, each image is reviewed immediately to determine, according to the kidney function of the individual patient, the time intervals at which the most intense kidney image can be obtained.

FIG. 16.35 Urogram at 3 minutes.

The most commonly recommended radiographic images for IVU are AP projections at time intervals ranging from 3 to 20 minutes (Figs. 16.35–16.37). Some physicians prefer bolus injection of the contrast medium followed by a 30-second image to obtain a nephrogram. AP oblique projections (30-degree) may be taken at 5- to 10-minute intervals. In some patients, supplemental images are required to show better all parts of the urinary system and to differentiate normal anatomy from pathologic conditions. These may include an AP projection with the patient in the Trendelenburg or upright position, oblique or lateral projections, or a lateral projection with the patient in the dorsal or ventral decubitus position.

Unless further study of the bladder is indicated or voiding urethrograms are to be made, the patient is sent to the lavatory to void. A postvoid image of the bladder (Figs. 16.38 and 16.39) may be taken to detect, by the presence of residual urine, conditions such as small tumor masses or enlargement of the prostate gland in men. When all necessary images have been obtained, the patient is released from the imaging department. Any contrast medium remaining in the body is filtered from the blood by the kidneys and eventually is excreted in the urine. Some physicians suggest having the patient drink extra fluids for a few days to help flush out the contrast medium.

FIG. 16.36 Urogram at 6 minutes.

FIG. 16.37 Urogram at 9 minutes.

FIG. 16.38 Prevoiding filled bladder.

FIG. 16.39 Postvoiding emptied bladder.

Urinary System

AP Projection

Image receptor + grid: Positioned by manufacturer or department protocol for proper anatomy display orientation; CR plate: 14 × 17 inches (35 × 43 cm) lengthwise.

Position of patient

- Place the patient supine on the radiographic table for the AP projection of the urinary system. Preliminary (scout) and postinjection images are most commonly obtained with the patient supine (Fig. 16.40).
- Place a support under the patient's knees to relieve strain on the back.
- Place the patient in an upright or a semiupright position for an AP projection to show the opacified bladder and the mobility of the kidneys (Fig. 16.41).
- To show the lower ends of the ureters, it may be helpful to use the Trendelenburg position and an AP projection with the head of the table lowered 15 to 20 degrees and the central ray directed perpendicular to the IR. In this angled position, the weight of the contained fluid stretches the bladder fundus superiorly, providing an unobstructed image of the lower ureters and the vesicoureteral orifice areas.
- If needed, apply ureteral compression (see Fig. 16.32).

Position of part

- Center the MSP of the patient's body to the midline of the grid device.
- Place the patient's arms out of the collimated field.
- Center the IR at the level of the iliac crests. If the patient is too tall to include the entire urinary system, take a second exposure on a 10 × 12-inch (24 × 30-cm) radiation field (CR plate) centered to the bladder. The 10 × 12-inch (24 × 30-cm) exposure field or CR plate is crosswise and centered 2 to 3 inches (5 to 7.6 cm) above the upper border of the pubic symphysis.
- *Shield gonads.*
- *Respiration:* Suspend at the end of expiration.

FIG. 16.40 Supine urogram: AP projection.

A patient in supine position lies on his back with the knees slightly bent. The knees are supported by a cushion. His hands are folded over the chest. The ureteral compression device is placed above his abdomen.

Central ray

- Perpendicular to the IR at the level of the iliac crests

Collimation

- Adjust the radiation field to no larger than 14 × 17 inches (35 × 43 cm) lengthwise or 10 × 12 inches (24 × 30 cm) crosswise for the additional bladder image (if needed). For smaller patients, collimate to within 1 inch (2.5 cm) of the shadow of the abdomen flanks. Place the correct side marker in the collimated exposure field.

Structures shown

AP projection of the urinary system shows the kidneys, ureters, and bladder filled with contrast medium (Figs. 16.42 through 16.44).

NOTE: The prone position may be recommended to show the ureteropelvic region and to fill the obstructed ureter in the presence of hydronephrosis. The ureters fill better in the prone position, which reverses the curve of their inferior course. The kidneys are situated obliquely, slanting anteriorly in the transverse plane, so the opacified urine tends to collect in and distend the dependent part of the pelvicaliceal system. The supine position allows the more posteriorly placed upper calyces to fill more readily, and the anterior and inferior parts of the pelvicaliceal system fill more easily in the prone position.

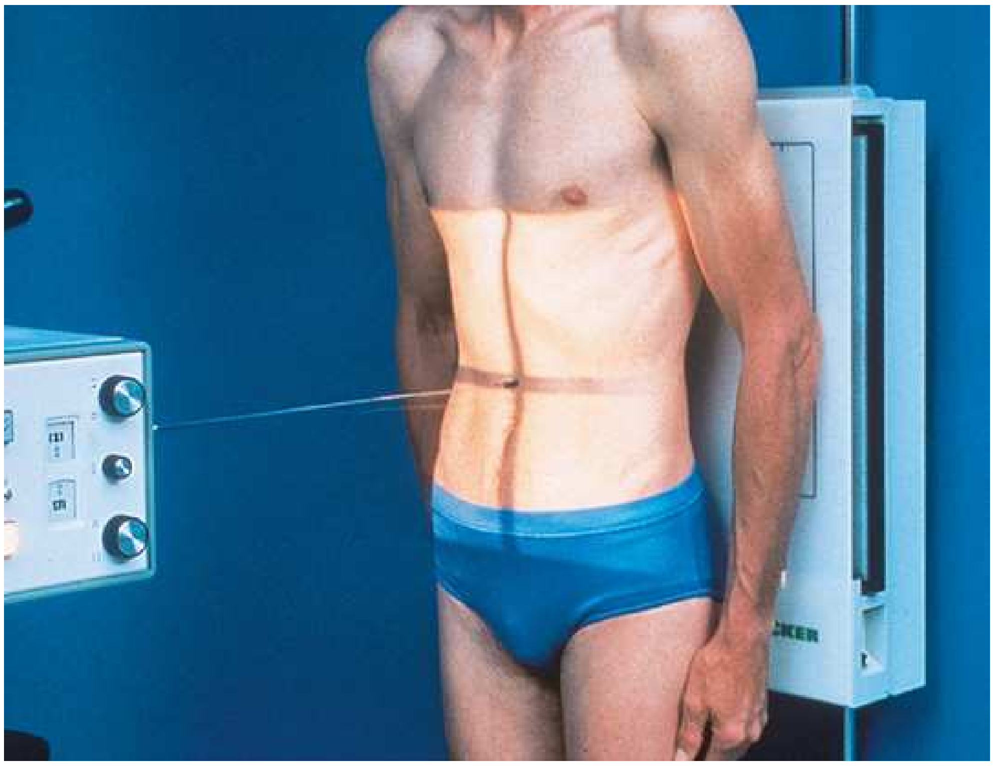


FIG. 16.41 Upright urogram: AP projection.

Evaluation Criteria

The following should be clearly seen:

- Evidence of proper collimation and presence of side marker placed clear of the anatomy of interest

AP and PA projections

- Entire renal outlines
- Bladder and pubic symphysis (a separate image of the bladder area is needed if the bladder was not included)
- No motion
- Contrast medium in the renal area, ureters, and bladder
- Surrounding anatomy
- Compression devices, if used, centered over the upper sacrum and resulting in good renal filling
- Vertebral column centered on the image
- No artifacts from elastic in the patient's underclothing
- Prostatic region inferior to the pubic symphysis on older male patients
- Time marker
- PA projection showing the lower kidneys and entire ureters (bladder included if patient size permits)
- Superimposing intestinal gas in the AP projection moved for the PA projection

AP bladder

- Bladder
- No rotation of the pelvis
- Prostate area in male patients
- Postvoid images clearly labeled and showing only residual contrast medium

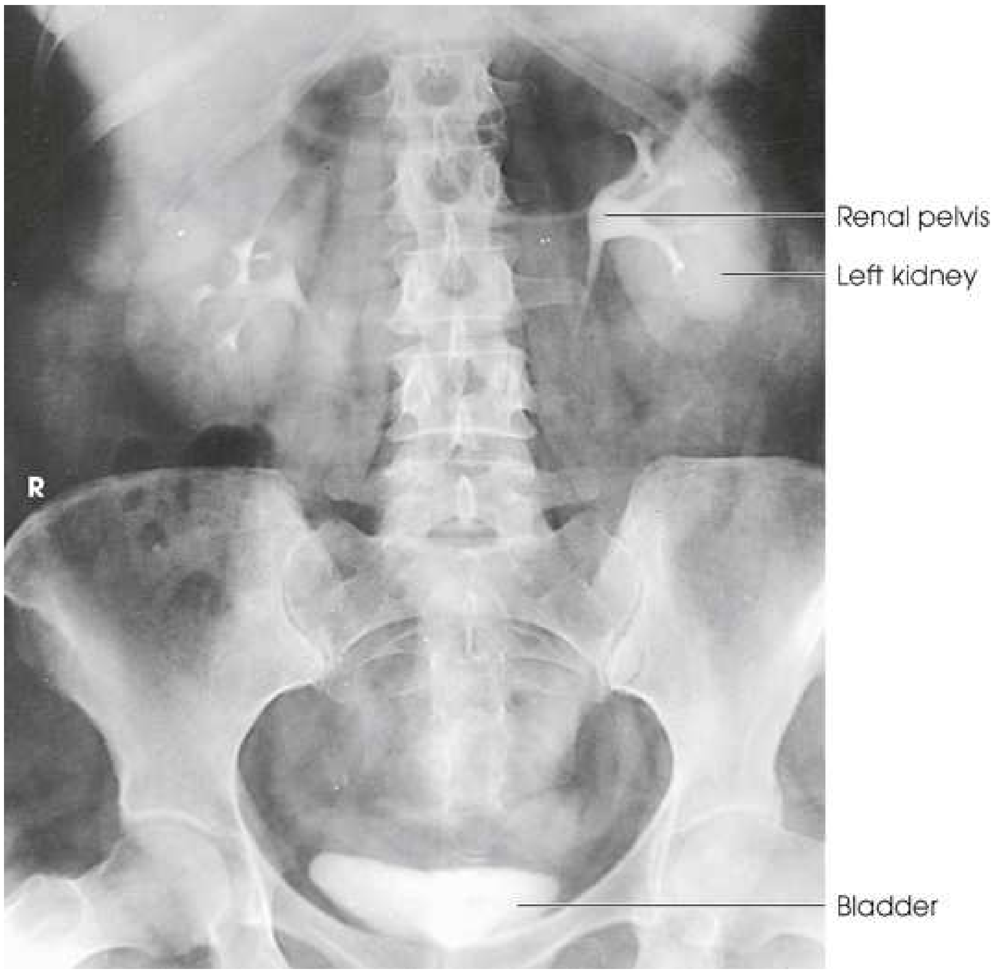


FIG. 16.42 Semiupright urogram: AP projection. Note mobility of kidneys.

FIG. 16.43 Supine urogram: AP projection.

FIG. 16.44 Trendelenburg position urogram: AP projection.

AP Oblique Projection

RPO and LPO positions

Image receptor + grid: Positioned by manufacturer or department protocol for proper anatomy display orientation; CR plate: 14 × 17 inches (35 × 43 cm) lengthwise.

Position of patient

- Place the patient supine on the radiographic table for oblique projections of the urinary system. The kidneys are situated obliquely, slanting anteriorly in the transverse plane.
- When performing AP oblique projections, remember that the kidney closer to the IR is *perpendicular* to the plane of the IR and the kidney farther from the IR is *parallel* with this plane.

Position of part

- Turn the patient so that the midcoronal plane forms an angle of 30 degrees from the IR plane.
- Adjust the patient's shoulders and hips so that they are in the same plane, and place suitable supports under the elevated side as needed.
- Place the arms so that they are not superimposed on the urinary system.
- Center the spine to the grid (Fig. 16.45).
- Center the IR at the level of the iliac crests.
- *Shield gonads.*
- *Respiration:* Suspend at the end of expiration.

Central ray

- Perpendicular to the center of the IR at the level of the iliac crests, entering approximately 2 inches (5 cm) lateral to the midline on the elevated side

Collimation

• Adjust the radiation field to no larger than 14 × 17 inches (35 × 43 cm) lengthwise. For smaller patients, collimate to within 1 inch (2.5 cm) of the shadow of the abdomen flanks. Place the correct side marker in the collimated exposure field.

Structures shown

An AP oblique projection of the urinary system shows the kidneys, ureters, and bladder filled with contrast medium. The elevated kidney is parallel with the IR, and the downside kidney is perpendicular to the IR (Fig. 16.46).

Evaluation Criteria

The following should be clearly seen:

- Evidence of proper collimation and presence of side marker placed clear of the anatomy of interest
- Patient rotated approximately 30 degrees
- No superimposition of the kidney remote from the IR on the vertebrae
- Entire downside kidney
- Bladder and lower ureters on 14 × 17-inch (35 × 43-cm) exposure field if patient size permits
- Contrast medium in the kidneys, ureters, and bladder
- Surrounding anatomy
- Time marker

FIG. 16.45 Urogram: AP oblique projection, 30-degree RPO position.

A patient lies on his back with a slight tilt towards his right for a urogram in A P oblique projection. The left arm is rested above his head and right arm is rested on the table. The urogram device is positioned above his pelvis.

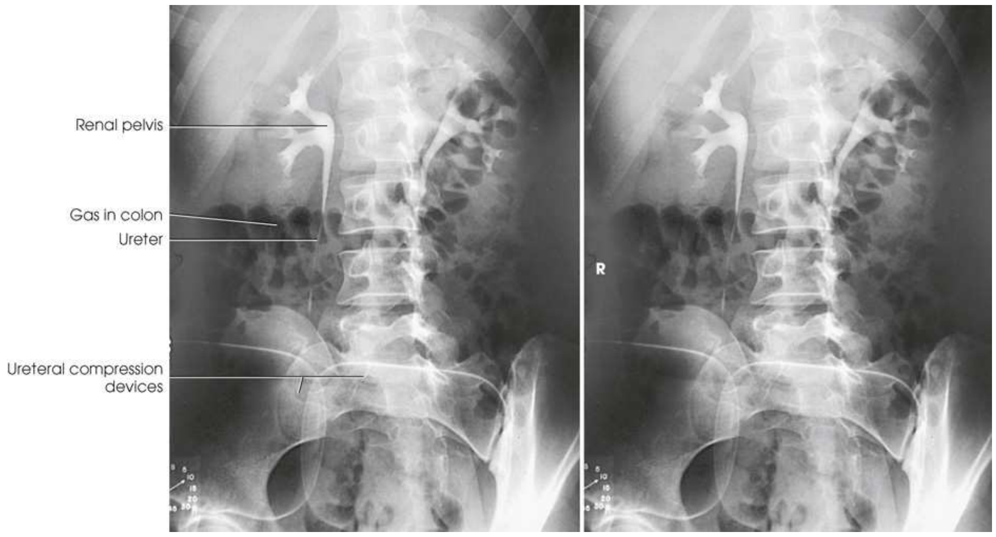


FIG. 16.46 Urogram at 10 minutes: AP oblique projection, RPO position.

Two urogram images of a patient in A P oblique projection in R P O position taken at 10 minutes interval. In the first image the renal pelvis, ureteral compression devices in the pelvis, ureter, and the gas in the colon denoted by dark shaded regions are labeled.

Lateral Projection

Right or left position

Image receptor + grid: Positioned by manufacturer or department protocol for proper anatomy display orientation; CR plate: 14 × 17 inches (35 × 43 cm) lengthwise.

Position of patient

- Turn the patient to a lateral recumbent position on the right or left side, as indicated.

Position of part

- Flex the patient's knees to a comfortable position, and adjust the body so that the midcoronal plane is centered to the midline of the grid.
- Place supports between the patient's knees and ankles.
- Flex the patient's elbows, and place the hands under the patient's head (Fig. 16.47).
- Center the IR at the level of the iliac crests.
- *Shield gonads.*
- *Respiration:* Suspend at the end of expiration.

Central ray

- Perpendicular to the IR, entering the midcoronal plane at the level of the iliac crest

Collimation

- Adjust the radiation field to no larger than 14 × 17 inches (35 × 43 cm) lengthwise. For smaller patients, collimate to within 1 inch (2.5 cm) of the anterior and posterior shadows of the abdomen. Place the correct side marker in the collimated exposure field.

Structures shown

A lateral projection of the abdomen shows the kidneys, ureters, and bladder filled with contrast material. Lateral projections are used to show conditions such as rotation or pressure displacement of a kidney and to localize calcareous areas and tumor masses (Fig. 16.48).

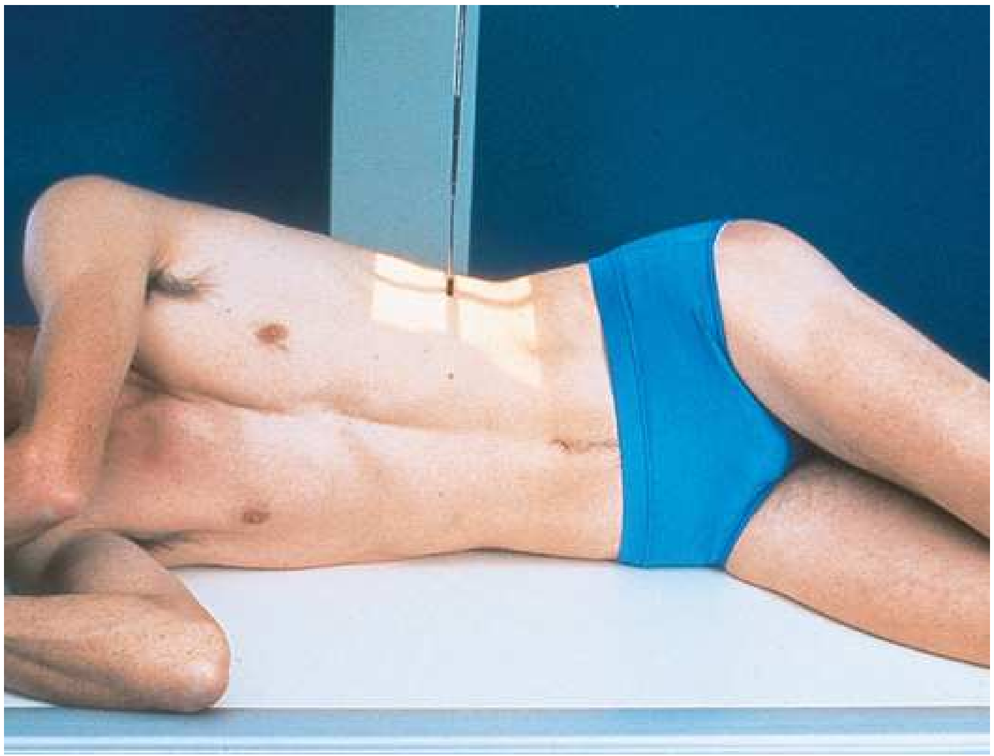


FIG. 16.47 Urogram: lateral projection.

Evaluation Criteria

The following should be clearly seen:

- Evidence of proper collimation and presence of side marker placed clear of the anatomy of interest
- Entire urinary system
- Bladder and pubic symphysis
- Contrast medium in the renal area, ureters, and bladder
- Surrounding anatomy
- No rotation of the patient (check pelvis and lumbar vertebrae)
- Time marker

FIG. 16.48 Urogram: lateral projection.

Lateral Projection

Dorsal decubitus position

Image receptor + grid: Positioned by manufacturer or department protocol for proper anatomy display orientation; CR plate: 14 × 17 inches (35 × 43 cm) lengthwise.

Position of patient

- Place the patient in the supine position on a radiographic cart with the side in question in contact with the vertical grid device. Ensure that the wheels are *locked.*
- Place the patient's arms across the upper chest to ensure that they are not projected over any abdominal contents, or place them behind the head.
- Flex the patient's knees slightly to relieve strain on the back.

Position of part

- Adjust the height of the vertical grid device so that the long axis of the IR is centered to the midcoronal plane of the patient's body.
- Position the patient so that a point approximately at the level of the iliac crests is centered to the IR (Fig. 16.49).
- Adjust the patient to ensure that no rotation from the supine or prone position is present.
- *Shield gonads.*
- *Respiration:* Suspend at the end of expiration.

Central ray

- *Horizontal* and perpendicular to the center of the IR, entering the midcoronal plane at the level of the iliac crests

Collimation

- Adjust the radiation field to no larger than 14 × 17 inches (35 × 43 cm) lengthwise. For smaller patients, collimate to within 1 inch (2.5 cm) of skin shadow. Place the correct side marker in the collimated exposure field.

Structures shown

Rolleston and Reay [8] recommended the ventral decubitus position to show the UPJ in the presence of hydronephrosis. Cook et al. [9] advocated this position to determine whether an extrarenal mass in the flank is intraperitoneal or extraperitoneal, and they stated that the position makes it easy to screen kidneys and ureters for abnormal anterior displacement (Fig. 16.50).

Evaluation Criteria

The following should be clearly seen:

- Evidence of proper collimation and presence of side marker placed clear of the anatomy of interest
- Entire urinary system
- Bladder and pubic symphysis
- Contrast medium in the renal area, ureters, and bladder
- Surrounding anatomy
- No rotation of the patient (check pelvis and lumbar vertebrae)
- Time marker
- Patient elevated so that entire abdomen is visible

FIG. 16.49 Urogram: lateral projection, dorsal decubitus position.

A patient lies on his back on the urogram table with his hands rested under his head. The image receptor is placed adjacent to his abdomen for taking a lateral projection in dorsal decubitus position.

FIG. 16.50 Urogram: lateral projection, dorsal decubitus position.

Renal Parenchyma

Nephrotomography

AP Projection

The renal parenchyma (nephrons and collecting tubes) is best visualized by performing tomography immediately after the introduction of the contrast medium. Evans et al., [10, 11] who introduced nephrotomography, found that by using tomography rather than stationary projections, they could eliminate superimpositions of intestinal contents and more clearly define small intrarenal lesions.

Indications and contraindications

The use of nephrotomography has dramatically declined because of the availability of sectional imaging modalities with greater specificity for renal disease. The ACR states that "nephrotomography may be useful to help distinguish renal calculi from intestinal contents." [12] Contraindications are mainly related to renal failure and contrast media sensitivity, as noted for IVU.

Examination procedure

After a contrast medium has been injected for IVU, the first AP projection of the abdomen is performed during the arterial phase of opacification (Fig. 16.51), and multiple tomograms of the upper abdomen are obtained during the nephrographic phase after the renal parenchyma becomes opacified—hence the term *nephrotomography* (Fig. 16.52). The nephrotic phase normally occurs within 5 minutes after the completion of injection or infusion.

FIG. 16.51 Urogram: AP projection, arterial phase.

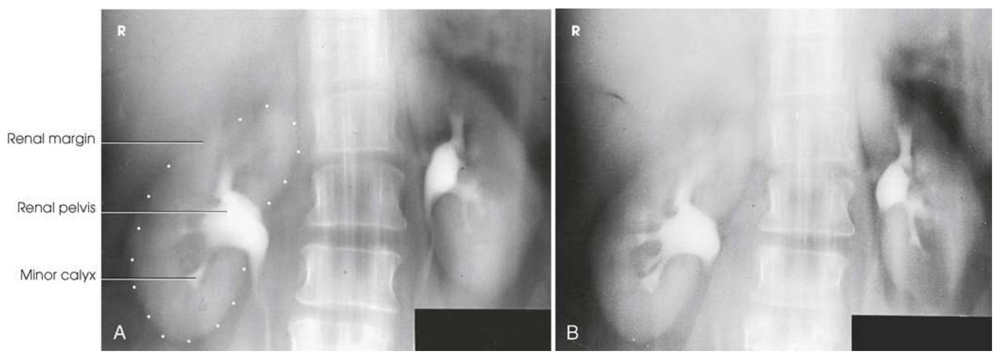


FIG. 16.52 Nephrotomogram: (A and B) AP projection at a level of 9 cm (A) and 10 cm (B) in the same patient as in Fig. 16.51.

Two nephrotomogram images of a patient in A P projection. The first one is taken at a level of 9 centimeters and the second one is taken at a level of 10 centimeters. In the first image the renal margin (denoted by white dots), renal pelvis, and cone-shaped minor calyx are labeled.

Other Renal and Urinary Imaging

US of the kidney has practically eliminated the need for percutaneous renal puncture. Cysts are easily differentiated from solid masses on US images (Fig. 16.53). Most masses that are clearly diagnosed as cystic by ultrasound examination are not surgically managed (Fig. 16.54).

FIG. 16.53 US image of normal kidney. Courtesy NEA Baptist Memorial Hospital, Jonesboro, AR.

FIG. 16.54 US image of kidney with cyst. Note measurement markers in image. Courtesy NEA Baptist Memorial Hospital, Jonesboro, AR.

An ultrasound image of the sagittal view of a right kidney. A small cyst is visible on the left part of the kidney. The measurements recorded are displayed on the right margin and the top-left corner of the image.

The renal pelvis is entered percutaneously for direct contrast filling of the pelvicaliceal system in selected patients with hydronephrosis. [13–15] This procedure is commonly called a *nephrostogram* because the contrast media injection is frequently made through a percutaneous nephrostomy catheter under fluoroscopic guidance in an interventional radiology suite (Fig. 16.55). Another term for this procedure is *percutaneous antegrade pyelography* [15] to distinguish it from the retrograde technique of direct pelvicaliceal filling; this is usually restricted to the investigation of patients with marked hydronephrosis and patients with suspected hydronephrosis, for whom conclusive information is not gained by excretory or retrograde urography.

FIG. 16.55 Nephrostogram image obtained in interventional radiology suite. Note marked hydronephrosis. Courtesy John Youngman, RT[R] and Spencer Haywood, RT[R][CT], NEA Baptist Memorial Hospital, Jonesboro, AR.

Pelvicaliceal System and Ureters

Retrograde Urography

AP Projection

Retrograde urography requires that the ureters be catheterized so that a contrast agent can be injected directly into the pelvicaliceal system. This technique provides improved opacification of the renal collecting system but little physiologic information about the urinary system.

Indications and contraindications

Retrograde urography is indicated for evaluation of the collecting system in patients who have renal insufficiency or who are allergic to iodinated contrast media. Because the contrast medium is not introduced into the circulatory system, the incidence of reactions is reduced.

Examination procedure

Similar to all examinations requiring instrumentation, retrograde urography is classified as an operative procedure. This combined urologic-radiologic examination is performed under careful aseptic conditions by the attending urologist with the assistance of a nurse and radiographer. The procedure is performed in a specially equipped cystoscopic-radiographic examining room, which, because of its collaborative nature, may be located in the urology department or the radiology department. A nurse is responsible for the preparation of the instruments and for the care and draping of the patient. A responsibility of the radiographer is to ensure that overhead parts of the radiographic equipment are free of dust for the protection of the operative field and the sterile layout.

The radiographer positions the patient on the cystoscopic table with knees flexed over the stirrups of the adjustable leg supports (Fig. 16.56). This is a modified lithotomy position; the true lithotomy position requires acute flexion of the hips and knees.

If a general anesthetic is not used, the radiographer explains the breathing procedure to the patient and checks the patient's position on the table. The kidneys and the full extent of the ureters in patients of average height are included on a lengthwise 14 × 17-inch (35 × 43-cm) exposure field or CR plate when the third lumbar vertebra is centered to the grid.

If the elevation of the thighs does not reduce the lumbar curve, a pillow is adjusted under the patient's head and shoulders so that the back is in contact with the table. Most cystoscopic-radiographic tables are equipped with an adjustable leg rest to permit extension of the patient's legs for certain radiographic studies.

The urologist performs catheterization of the ureters through a ureterocystoscope, which is a cystoscope with an arrangement that aids insertion of the catheters into the vesicoureteral orifices. After the endoscopic examination, the urologist passes a ureteral catheter well into one or both ureters (Fig. 16.57) and, while leaving the catheters in position, usually withdraws the cystoscope.

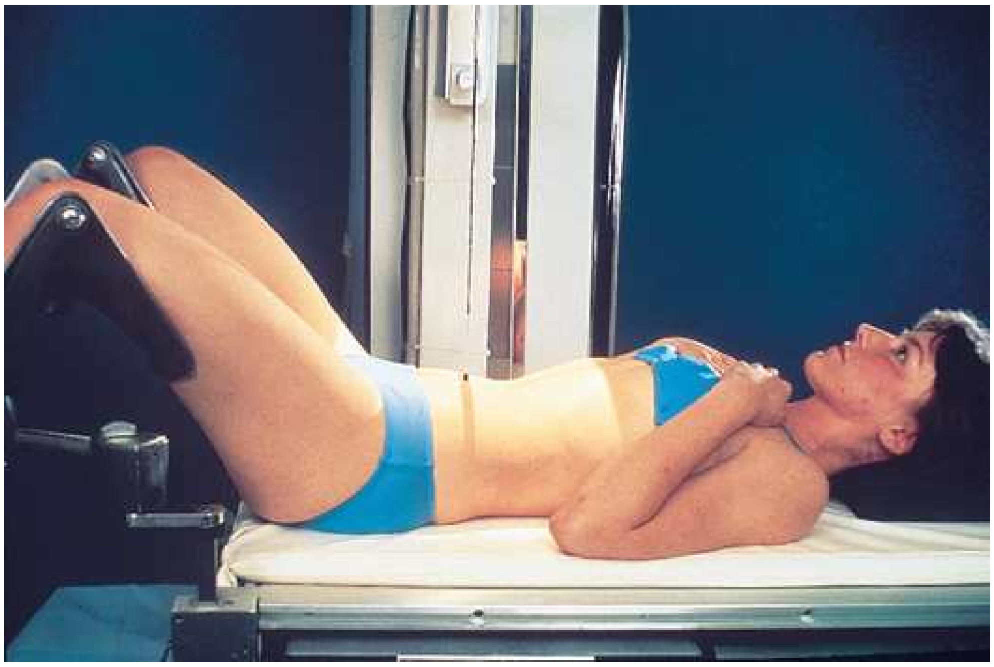


FIG. 16.56 Patient positioned on table for retrograde urography, modified lithotomy position.

FIG. 16.57 Retrograde urogram with catheters in proximal ureters: AP projection.

A retrograde urogram depicts the ureters, urinary bladder, left and right kidneys, pelvic bones, vertebral column, and part of the posterior rib bones. The catheters in the proximal ureters are visible.

After taking two catheterized specimens of urine from each kidney for laboratory tests—one specimen for culture and one for microscopic examination—the urologist tests kidney function. For this test, a color dye is injected intravenously, and the function of each kidney is determined by the specified time required for the dye substance to appear in the urine as it trickles through the respective catheters.

Immediately after the kidney function test, the radiographer rechecks the position of the patient and exposes the preliminary image (if this has not been done previously) so that the images are ready for inspection by the time the kidney function test has been completed. After reviewing the image, the urologist injects contrast medium and proceeds with the urographic examination. When a bilateral examination is to be performed, both sides are filled simultaneously to avoid subjecting the patient to unnecessary radiation exposure. Additional studies in which only one side is refilled may be performed as indicated.

The most commonly used retrograde urographic series usually consists of three AP projections: the preliminary image showing the ureteral catheters in position (see Fig. 16.57), the pyelogram, and the ureterogram. Some urologists recommend that the head of the table be lowered 10 to 15 degrees for the pyelogram to prevent the contrast solution from escaping into the ureters. Other urologists recommend that pressure be maintained on the syringe during the pyelographic exposure to ensure complete filling of the pelvicaliceal system. The head of the table may be elevated 35 to 40 degrees for the ureterogram to show any tortuosity of the ureters and mobility of the kidneys.

Filling of the average normal renal pelvis requires 3 to 5 mL of contrast solution; however, a larger quantity is required when the structure is dilated. The best index of complete filling, and the one most commonly used, is an indication from the patient as soon as a sense of fullness is felt in the back.

When both sides are to be filled, the urologist injects the contrast solution through the catheters in an amount sufficient to fill the renal pelves and calyces. When signaled by the physician, the patient suspends respiration at the end of expiration, and the exposure for the pyelogram is made (Fig. 16.58).

FIG. 16.58 Retrograde urogram with renal pelves filled: AP projection.

A retrograde urogram depicts the ureters, urinary bladder, left and right kidneys, pelvic bones, vertebral column, and part of the posterior rib bones in A P projection. The renal pelves are shady and filled.

After the pyelographic exposure, the head of the table may be elevated in preparation for the ureterogram. For this exposure, the patient is instructed to inspire deeply and then to suspend respiration at the end of full expiration. Simultaneously with the breathing procedure, the catheters are slowly withdrawn to the lower ends of the ureters as the contrast solution is injected into the canals. At a signal from the urologist, the ureterographic exposure is made (Fig. 16.59).

Additional projections are sometimes required, such as AP oblique projections in the RPO and LPO positions. Occasionally, a lateral projection, with the patient turned onto the affected side, is performed to show anterior displacement of a kidney or ureter and to delineate a perinephric abscess. Lateral projections with the patient in the ventral or dorsal decubitus position (as required) are also useful, showing the ureteropelvic region in patients with hydronephrosis.

FIG. 16.59 Retrograde urogram showing renal pelves and contrast medium–filled ureters: AP projection.

A retrograde urogram depicts the ureters, urinary bladder, left and right kidneys, pelvic bones, vertebral column, and part of the posterior rib bones in A P projection. The ureters are highlighted by the contrast medium injected.

Urinary Bladder, Lower Ureters, Urethra, and Prostate

With few exceptions, radiologic examinations of the lower urinary tract are performed with the retrograde technique of introducing contrast material. These examinations are identified according to the specific purpose of the investigation by the terms *cystography*, *cystoureterography*, *cystourethrography*, and *prostatography*. Most often, they are denoted by the general term *cystography*. Cystoscopy is not required before retrograde contrast filling of the lower urinary canals, but when both examinations are indicated, they are usually performed in a single-stage procedure to spare the patient preparation and instrumentation for separate examinations. When cystoscopy is not indicated, these examinations are best carried out on an all-purpose radiographic table unless the combination table is equipped with an extensible leg rest.

Indications and contraindications

Retrograde studies of the lower urinary tract are indicated for vesicoureteral reflux, recurrent lower urinary tract infection, neurogenic bladder, bladder trauma, lower urinary tract fistulae, urethral stricture, and posterior urethral valves. Contraindications to lower urinary tract studies are related to catheterization of the urethra.

Contrast media

The contrast agents used for contrast studies of the lower urinary tracts are the same nonionic organic compounds used for IVU, but their concentration is reduced, usually to 30%, for retrograde urography.

Injection equipment

Examinations are performed under careful aseptic conditions. Infants, children, and usually adults may be catheterized before they are brought to the radiology department. When the patient is to be catheterized in the radiology department, a sterile catheterization tray must be set up to specifications. Because of the danger of contamination in transferring a sterile liquid from one container to another, the use of commercially available premixed contrast solutions is recommended.

Preliminary preparations

The following guidelines are observed in preparing the patient for the examination:

- Protect the examination table from urine soilage with radiolucent plastic sheeting and disposable underpadding. Correctly arranged disposable padding does much to reduce soilage during voiding studies and consequently eliminates the need for extensive cleaning between patients. A suitable disposal receptacle should be available.
- A few minutes before the examination, accompany the patient to a lavatory. Give the patient supplies for perineal care, and instruct the patient to empty the bladder.
- When the patient is prepared, place the patient on the examination table for the catheterization procedure.

Patients are usually tense, primarily because of embarrassment. It is important that they be given as much privacy as possible. Only required personnel should be present during the examination, and patients should be properly draped and covered according to room temperature.

Contrast injection

For retrograde cystography (Figs. 16.60 and 16.61), cystourethrography, and voiding cystourethrography, the contrast material is introduced into the bladder by injection or infusion through a catheter passed into position via the urethral canal. A small, disposable Foley catheter is used to occlude the vesicourethral orifice in the examination of infants and children, and this catheter may be used in the examination of adults when interval studies are to be made for the detection of delayed ureteral reflux.

Studies are made during voiding to delineate the urethral canal and to detect ureteral reflux, which may occur only during urination (Fig. 16.62). When urethral studies are to be made during injection of contrast material, a soft rubber urethral-orifice acorn is fitted directly onto a contrast-loaded syringe for female patients and is usually fitted onto a cannula attached to a clamp device for male patients.

Retrograde Cystography

Contrast injection technique

In preparing for this examination, the following steps are taken:

- With the urethral catheter in place, adjust the patient in the supine position for a preliminary image and the first cystogram.
- Usually take cystograms of adult patients on 10 × 12-inch (24 × 30-cm) exposure field or CR plate placed lengthwise.
- Center the IR at the level of the soft tissue depression just above the most prominent point of the greater trochanters. This centering coincides with the middle area of a filled bladder of average size. The 12-inch (30-cm) exposure field includes the region of the distal end of the ureters to show ureteral reflux and the prostate and proximal part of the male urethra.
- When ureteral reflux is shown, a larger exposure field may be requested. Some radiologists request studies during contrast filling of the bladder and during voiding.
- After the preliminary image is taken, the physician removes the catheter clamp, and the bladder is drained in preparation for the introduction of contrast material. After introducing the contrast agent, the physician clamps the catheter and tapes it to the thigh to keep it from being displaced during position changes.

The initial cystographic images generally consist of four projections: one AP, two AP obliques, and one lateral. Additional studies, including voiding cystourethrograms, are obtained as indicated.

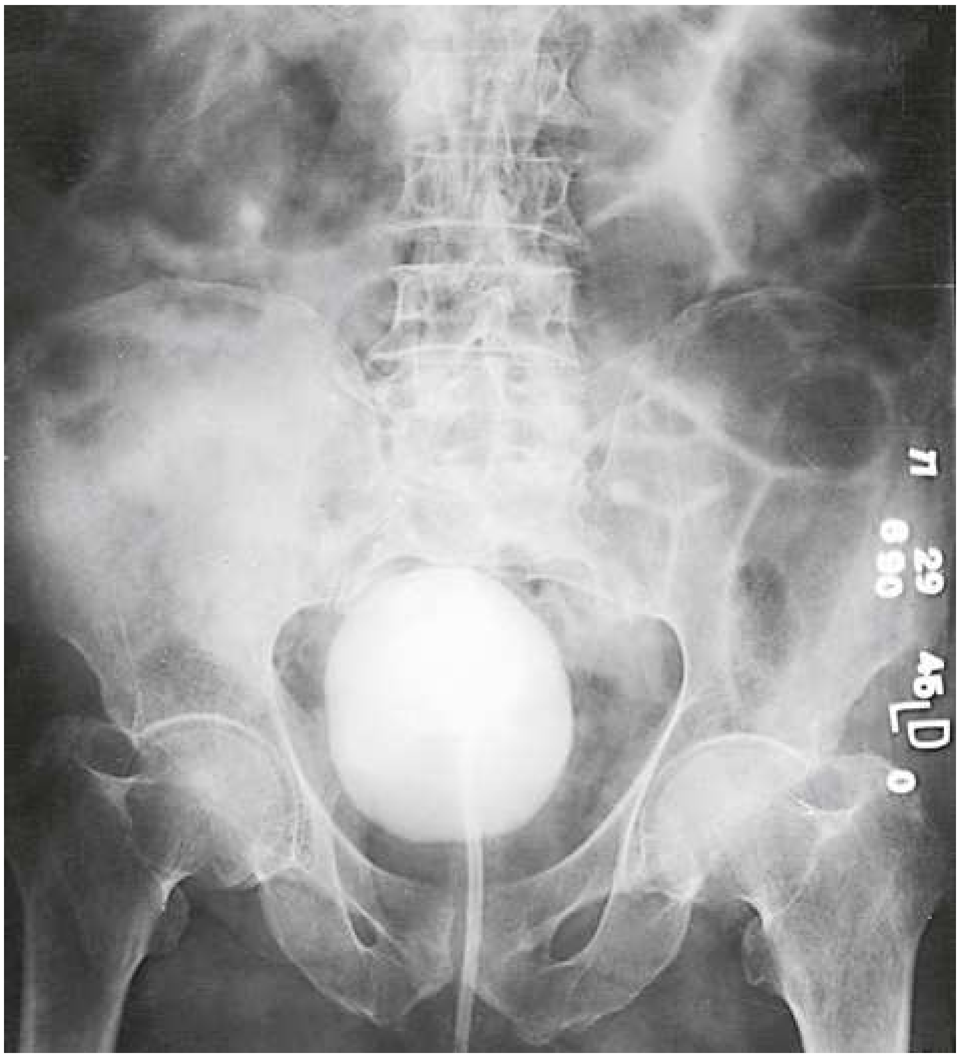


FIG. 16.60 Retrograde cystogram after introduction of contrast medium: AP projection.

A retrograde cystogram depicts the ureters, urinary bladder, left and right kidneys, pelvic bones, vertebral column, and part of the posterior rib bones in A P projection. The bladder has a large circular cyst.

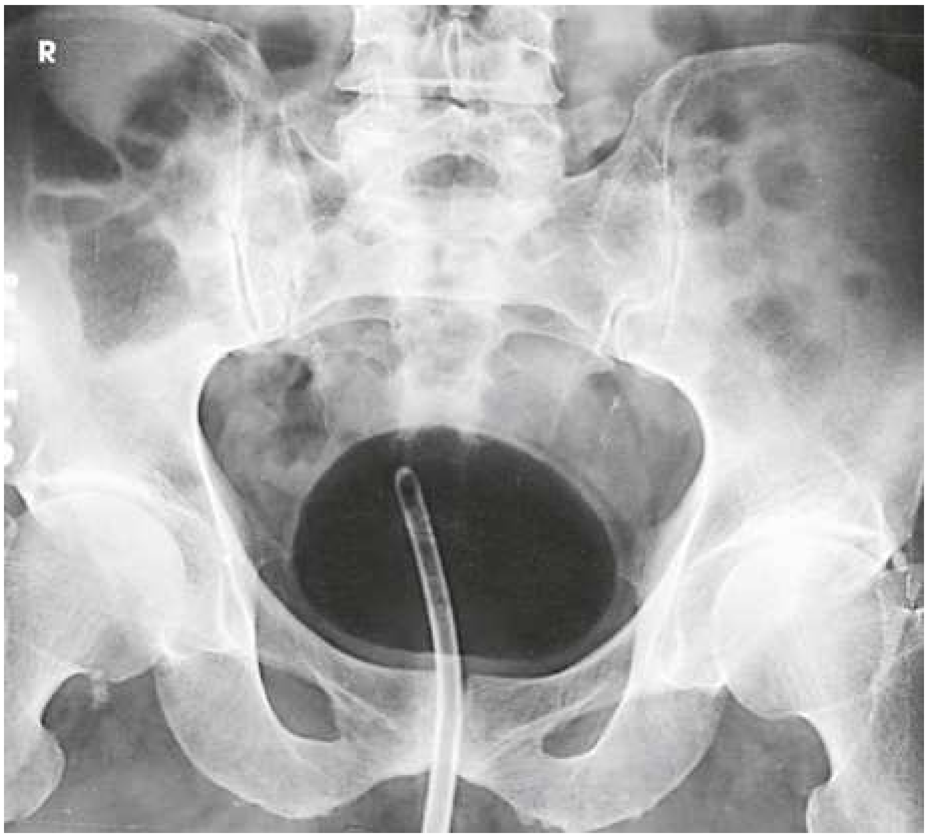


FIG. 16.61 Retrograde cystogram after introduction of air: AP projection.

A retrograde cystogram with the introduction of air depicts the ureters, urinary bladder, left and right kidneys, pelvic bones, vertebral column, and part of the posterior rib bones in A P projection. The bladder has a large circular cyst.

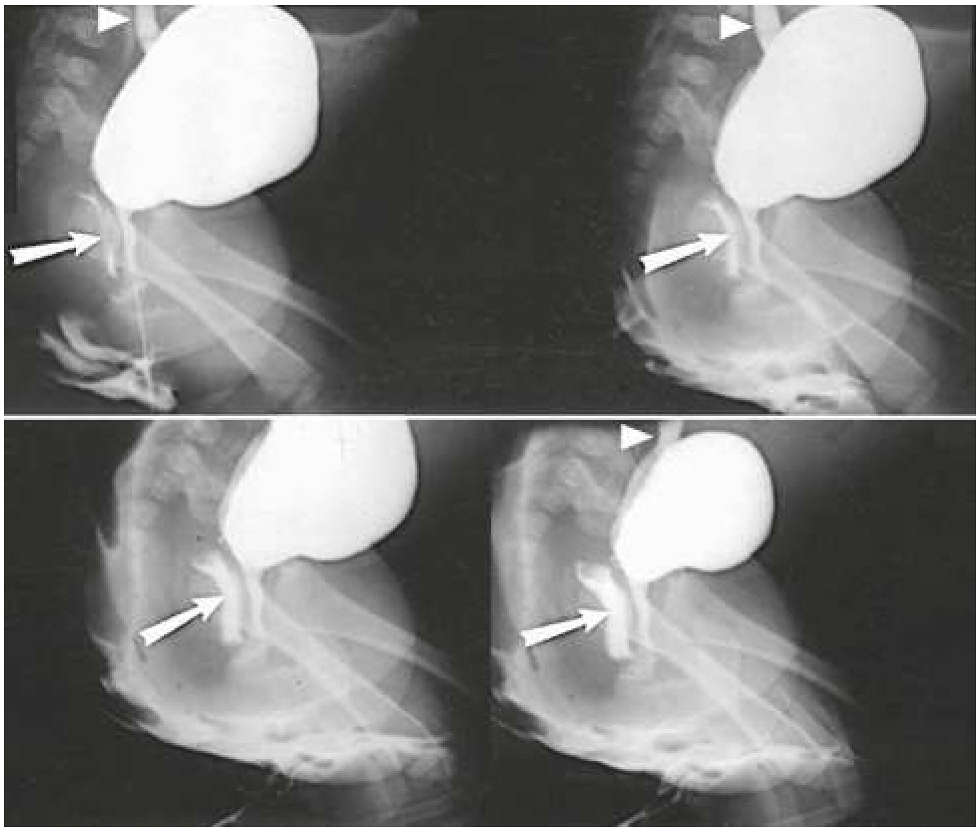


FIG. 16.62 Serial (polygraphic) voiding cystourethrograms in an infant girl with bilateral ureteral reflux *(arrowheads)*. Urethra is normal. Vaginal reflux *(arrows)* is a normal finding.

Four serial voiding cystourethrograms of a patient. The bladder is highlighted by contrast in all the images and an arrow points to the vaginal reflux below the bladder. An arrowhead points to the bilateral ureteral reflux above the bladder.

Urinary Bladder

AP Axial or Pa Axial Projection

Image receptor + grid: Positioned by manufacturer or department protocol for proper anatomy display orientation; CR plate: 10 × 12 inches (24 × 30 cm) lengthwise.

Position of patient

- Place the patient supine on the radiographic table for the AP projection of the urinary bladder.

NOTE: Preliminary (scout) and postinjection images are most commonly obtained with the patient supine. The prone position is sometimes used to image areas of the bladder not clearly seen on the AP axial projection. An AP axial projection using the Trendelenburg position at 15 to 20 degrees and with the central ray directed vertically is sometimes used to show the distal ends of the ureters. In this angled position, the weight of the contained fluid stretches the bladder fundus superiorly, giving an unobstructed projection of the lower ureters and the vesicoureteral orifice areas.

Position of part

- Center the MSP of the patient's body to the midline of the grid device.
- Adjust the patient's shoulders and hips so that they are equidistant from the IR.
- Place the patient's arms where they do not cast shadows on the IR.
- If the patient is positioned for a supine image, have the patient's legs extended so that the lumbosacral area of the spine is arched enough to tilt the anterior pelvic bones inferiorly. In this position, the pubic bones can more easily be projected below the bladder neck and proximal urethra (Fig. 16.63).
- Center the IR 2 inches (5 cm) above the upper border of the pubic symphysis (or at the pubic symphysis for voiding studies).
- *Respiration:* Suspend at the end of expiration.

Central ray

AP axial

- Angled 10 to 15 degrees caudal to the center of the IR. The central ray should enter 2 inches (5 cm) above the upper border of the pubic symphysis. When the bladder neck and proximal urethra are the main areas of interest, 5-degree caudal angulation of the central ray is usually sufficient to project the pubic bones below them. More or less angulation may be necessary, depending on the amount of lordosis of the lumbar spine. With greater lordosis, less angulation may be needed (see Fig. 16.63).

PA axial

- When performing PA axial projections of the bladder, direct the central ray through the region of the bladder neck at an angle 10 to 15 degrees cephalad, entering about 1 inch (2.5 cm) distal to the tip of the coccyx and exiting a little above the superior border of the pubic symphysis. If the prostate is the area of interest, the central ray is directed 20 to 25 degrees cephalad to project it above the pubic bones. For PA axial projections, the IR is centered to the central ray.
- Perpendicular to the pubic symphysis for voiding studies.

Collimation

- Adjust the radiation field to 10 × 12 inches (24 × 30 cm) lengthwise. Place the correct side marker in the collimated exposure field.

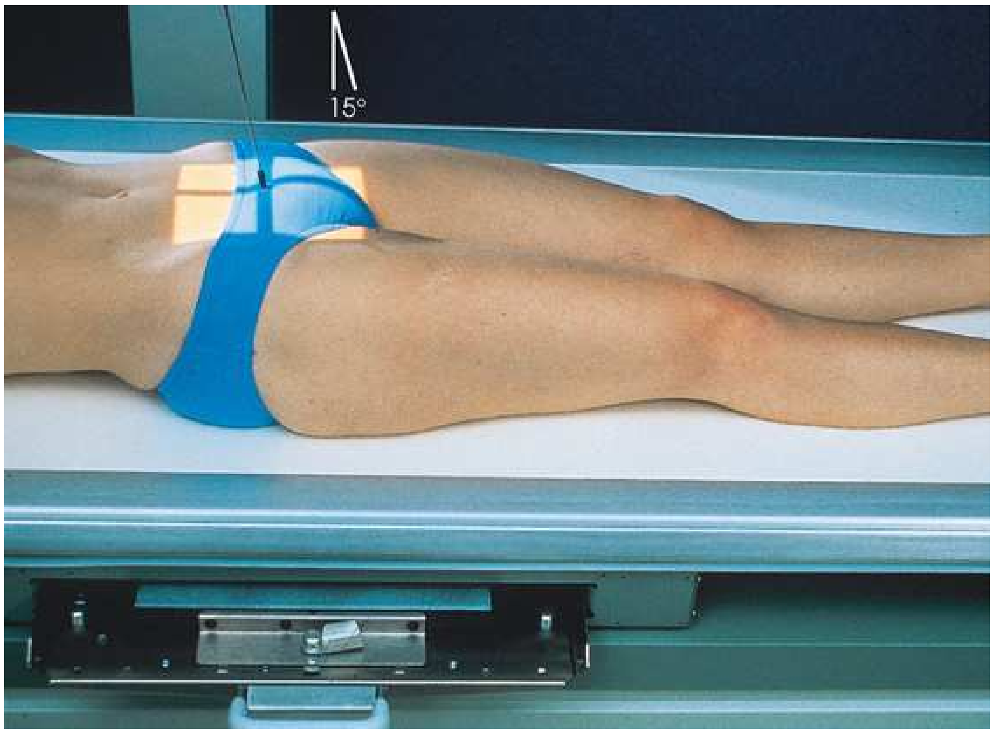


FIG. 16.63 Retrograde cystogram. AP axial bladder with 15-degree caudal angulation of central ray.

Structures shown

AP axial and PA axial projections show the bladder filled with contrast medium (Figs. 16.64 and 16.65). If reflux is present, the distal ureters are also visualized.

Evaluation Criteria

The following should be clearly seen:

- Evidence of proper collimation and presence of side marker placed clear of the anatomy of interest
- Regions of the distal end of the ureters, bladder, and proximal portion of the urethra
- Pubic bones projected below the bladder neck and proximal urethra
- Contrast medium in the bladder, distal ureters, and proximal urethra
- Surrounding anatomy

FIG. 16.64 Excretory cystogram: AP axial projection.

FIG. 16.65 Retrograde cystogram: AP axial projection. Note catheter in bladder.

AP Oblique Projection

RPO or LPO position

Image receptor + grid: Positioned by manufacturer or department protocol for proper anatomy display orientation; CR plate: 10 × 12 inches (24 × 30 cm) lengthwise.

Position of patient

- Place the patient in the supine position on the radiographic table.

Position of part

- Rotate the patient 40 to 60 degrees RPO or LPO, according to the preference of the examining physician (Fig. 16.66).
- Adjust the patient so that the pubic arch closest to the table is aligned over the midline of the grid.
- Extend and abduct the uppermost thigh enough to prevent its superimposition on the bladder area.
- Center the IR 2 inches (5 cm) above the upper border of the pubic symphysis and approximately 2 inches (5 cm) medial to the upper ASIS (or at the pubic symphysis for voiding studies).
- *Respiration:* Suspend at the end of expiration.

Central ray

- Perpendicular to the center of the IR. The central ray enters 2 inches (5 cm) above the upper border of the pubic symphysis and 2 inches (5 cm) medial to the upper ASIS. When the bladder neck and proximal urethra are the main areas of interest, 10-degree caudal angulation of the central ray is usually sufficient to project the pubic bones below them.
- Perpendicular at the level of the pubic symphysis for voiding studies.

Collimation

- Adjust the radiation field to 10 × 12 inches (24 × 30 cm) lengthwise. Place the correct side marker in the collimated exposure field.

Structures shown

Oblique projections show the bladder filled with contrast medium. If reflux is present, the distal ureters are also visualized (Figs. 16.67 and 16.68).

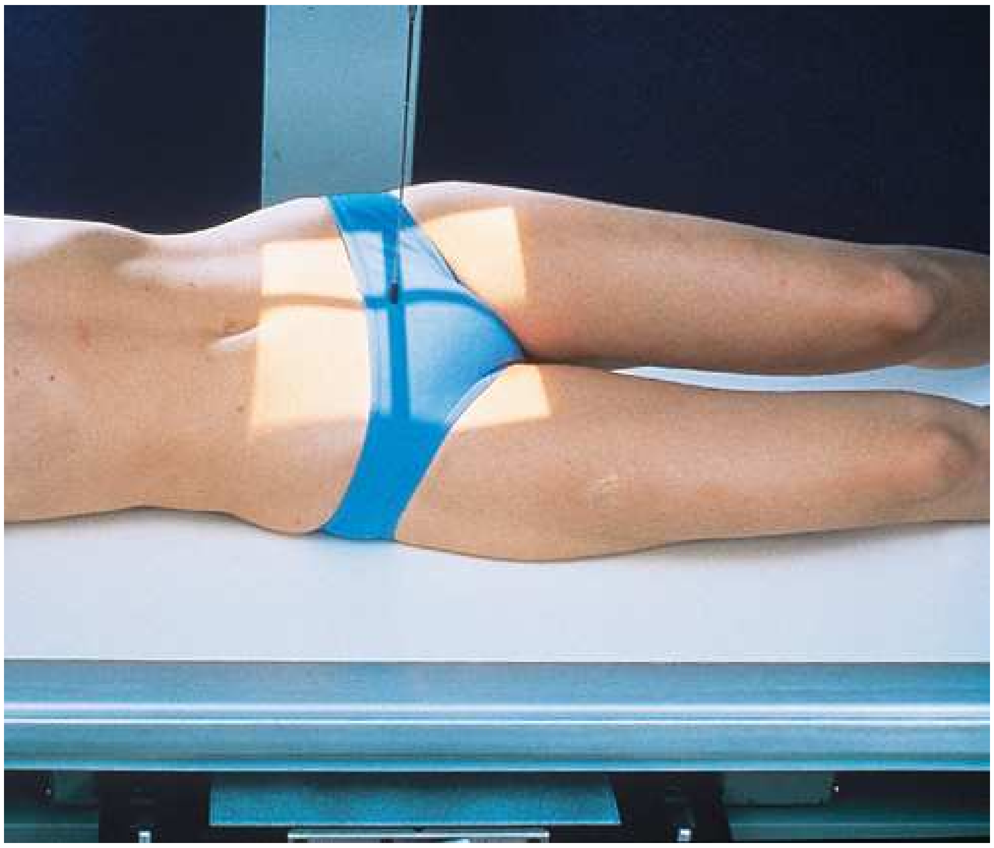


FIG. 16.66 Retrograde cystogram: AP oblique bladder, RPO position.

Evaluation Criteria

The following should be clearly seen:

- Evidence of proper collimation and presence of side marker placed clear of the anatomy of interest
- Regions of the distal ends of the ureters and bladder, and the proximal portion of the urethra
- Pubic bones projected below the bladder neck and the proximal urethra
- Contrast medium in the bladder, distal ureters, and proximal urethra
- Surrounding anatomy
- No superimposition of the bladder by the uppermost thigh

Voiding studies

- Entire urethra visible and filled with contrast medium
- Urethra overlapping the thigh on oblique projections for improved visibility
- Urethra lying posterior to the superimposed pubic and ischial rami on the side down in oblique projections

FIG. 16.67 Excretory cystogram: AP oblique bladder, RPO position.

FIG. 16.68 Retrograde cystogram with catheter in bladder.

Lateral Projection

Right or left position

Image receptor + grid: Positioned by manufacturer or department protocol for proper anatomy display orientation; CR plate: 10 × 12 inches (24 × 30 cm) lengthwise.

Position of patient

- Place the patient in the lateral recumbent position on the right or the left side, as indicated.

Position of part

- Slightly flex the patient's knees to a comfortable position and adjust the body so that the midcoronal plane is centered to the midline of the grid.
- Flex the patient's elbows, and place the hands under the head (Fig. 16.69).
- Center the IR 2 inches (5 cm) above the upper border of the pubic symphysis at the midcoronal plane.
- *Respiration:* Suspend at the end of expiration.

Central ray

- Perpendicular to the IR and 2 inches (5 cm) above the upper border of the pubic symphysis at the midcoronal plane

Collimation

- Adjust the radiation field to 10 × 12 inches (24 × 30 cm) lengthwise. Place the correct side marker in the collimated exposure field.

Structures shown

A lateral image shows the bladder filled with contrast medium. If reflux is present, the distal ureters are also visualized. Lateral projections show the anterior and posterior bladder walls and the base of the bladder (Fig. 16.70).

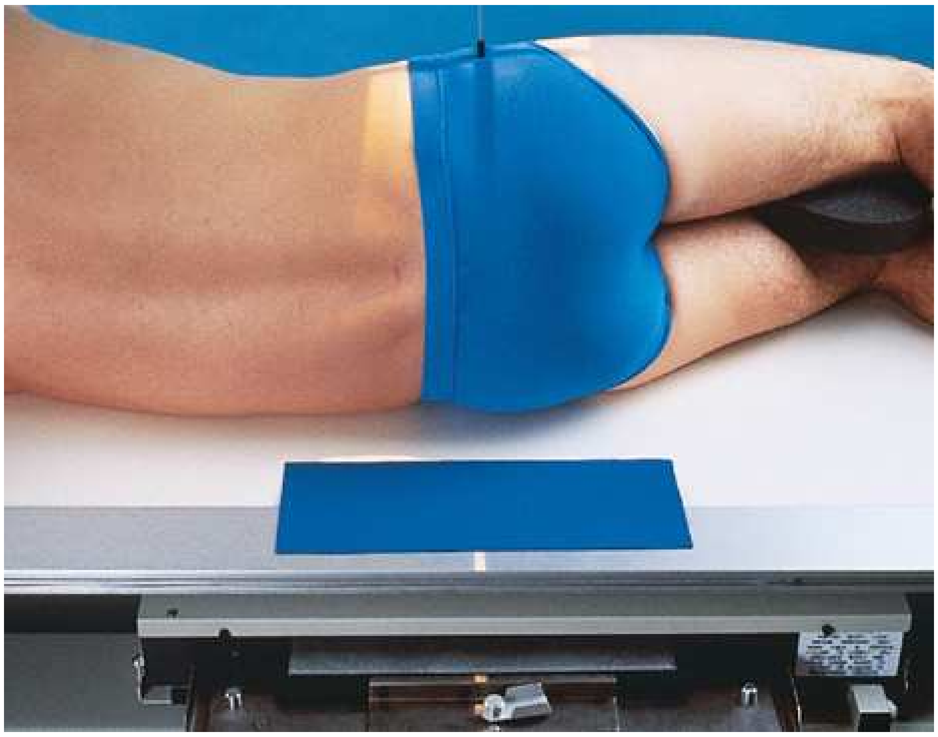


FIG. 16.69 Cystogram: lateral projection.

The posterior view of a patient positioned for a cystogram in lateral projection. The patient lies on his side with his knees bent in a crouch position. The image receptor is placed near his pelvic region.

Evaluation Criteria

The following should be clearly seen:

- Evidence of proper collimation and presence of side marker placed clear of the anatomy of interest
- Regions of the distal end of the ureters, bladder, and proximal portion of the urethra
- Contrast medium in the bladder, distal ureters, and proximal urethra
- Bladder and distal ureters visible through the pelvis
- Superimposed hips and femur

FIG. 16.70 Cystogram: lateral projection.

Male Cystourethrography

AP Oblique Projection

RPO or LPO position

Male cystourethrography may be preceded by an endoscopic examination, after which the bladder is catheterized so that it can be drained just before contrast material is injected.

The following steps are taken:

- Use a 10 × 12-inch (24 × 30-cm) lengthwise radiation field or CR plate with a grid for male cystourethrograms.
- The patient is adjusted on the combination table so that the IR can be centered at the level of the superior border of the pubic symphysis. This centering coincides with the root of the penis, and a 12-inch (30-cm) radiation field includes the bladder and the external urethral orifice.
- After inspecting the preliminary image, the physician drains the bladder and withdraws the catheter.
- The supine patient is adjusted in an oblique position so that the bladder neck and the entire urethra are delineated as free of bony superimposition as possible. Rotate the patient's body 35 to 40 degrees and adjust it so that the elevated pubis is centered to the midline of the grid. The superimposed pubic and ischial rami of the downside and the body of the elevated pubis usually are projected anterior to the bladder neck, proximal urethra, and prostate (Fig. 16.71).
- The patient's lower knee is flexed only slightly to keep the soft tissues on the medial side of the thigh as near to the center of the IR as possible.
- The elevated thigh is extended and retracted enough to prevent overlapping.
- With the patient in the correct position, the physician inserts the contrast medium–loaded urethral syringe or the nozzle of a device such as the Brodney clamp into the urethral orifice. The physician extends the penis along the soft tissues of the medial side of the lower thigh to obtain a uniform density of the deep and cavernous portions of the urethral canal.

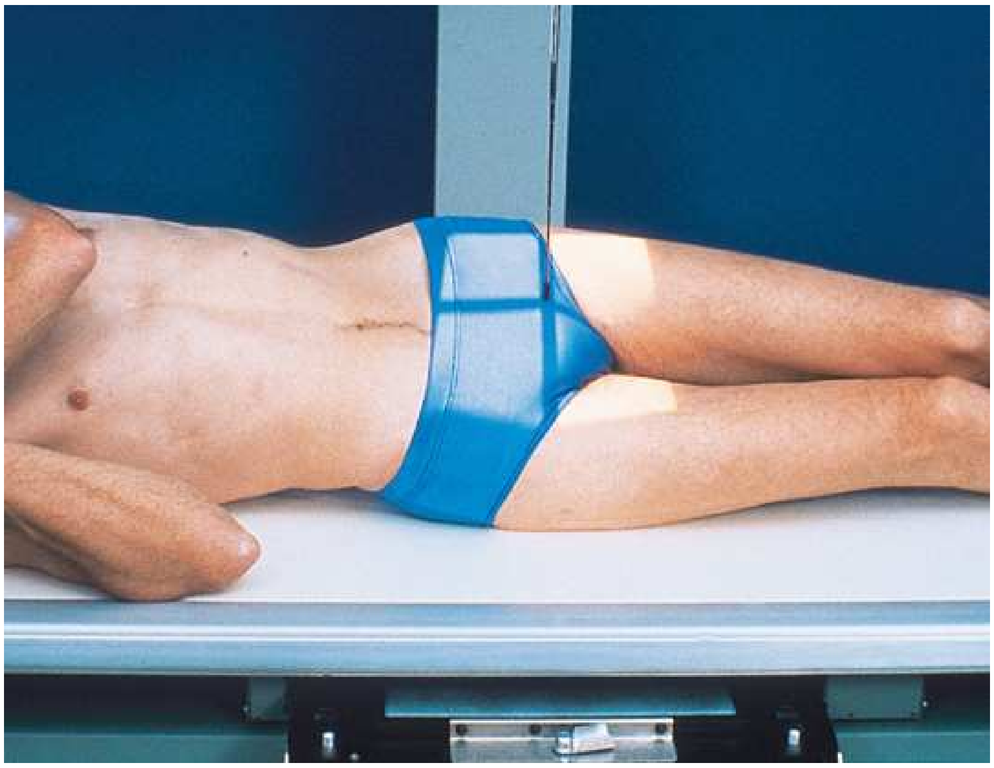


FIG. 16.71 Cystourethrogram: AP oblique projection, RPO position.

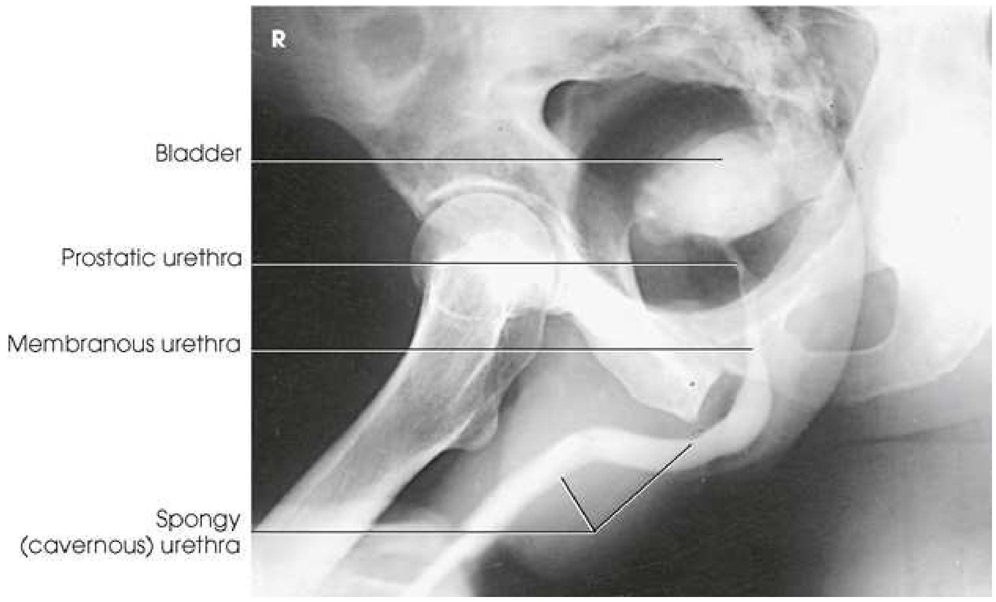


FIG. 16.72 Injection cystourethrogram: AP oblique urethra, RPO position.

An Injection cystourethrogram of a patient in A P oblique, RPO position. The following parts are visible and labeled in the image: Bladder, Prostatic urethra, Membranous urethra, and Spongy (cavernous) urethra.

FIG. 16.73 Voiding cystourethrogram: AP oblique urethra, LPO position.

- At a signal from the physician, instruct the patient to hold still; make the exposure while injection of contrast material is continued to ensure filling of the entire urethra (Fig. 16.72).
- The bladder may be filled with a contrast material so that a voiding study can be performed (Fig. 16.73). This is usually done without changing the patient's position. When a standing-upright voiding study is required, the patient is adjusted before a vertical grid device and is supplied with a urinal. (Further information on positioning is provided on pp. 318-319 of this chapter.)

Female Cystourethrography

AP Projection

INJECTION METHOD

The female urethra averages 1½ inches (3.5 cm) in length. Its opening into the bladder is situated at the level of the superior border of the pubic symphysis. From this point, the vessel slants obliquely inferiorly and anteriorly to its termination in the vestibule of the vulva, about 1 inch (2.5 cm) anterior to the vaginal orifice. The female urethra is subject to conditions such as tumors, abscesses, diverticula, dilation, and strictures. It is also subject to urinary incontinence during the stress of increased intra-abdominal pressure, as occurs during sneezing or coughing. In the investigation of abnormalities other than stress incontinence, contrast studies are made during injection of contrast medium or during voiding.

Cystourethrography is usually preceded by an endoscopic examination. For this reason, it may be performed by the attending urologist or gynecologist with the assistance of a nurse and a radiographer.

The following steps are observed:

- After the physical examination, the cystoscope is removed, and a catheter is inserted into the bladder so that the bladder can be drained just before injection of the contrast solution.
- The patient is adjusted in the supine position on the table.
- A 10 × 12-inch (24 × 30-cm) lengthwise radiation field or CR plate is used with a grid and centered at the level of the superior border of the pubic symphysis.
- A 5-degree caudal angulation of the central ray is usually sufficient to free the bladder neck of superimposition.
- After inspecting the preliminary image, the physician drains the bladder and withdraws the catheter. The physician uses a syringe fitted with a blunt-nosed, soft rubber acorn, which is held firmly against the urethral orifice to prevent reflux as the contrast solution is injected during exposure.

FIG. 16.74 Voiding cystourethrogram: AP projection.

A voiding cystourethrogram of a patient taken in A P projection. The urinary bladder, ureters, and urethra are visible. The urinary bladder at the center is highlighted by the injected contrast medium.

- Oblique projections may be required in addition to the AP projection. For oblique projections, the patient is rotated 35 to 40 degrees so that the urethra is posterior to the pubic symphysis. The uppermost thigh is extended and abducted enough to prevent overlapping.
- Further information on positioning is provided on p. 316 of this chapter.
- The physician fills the bladder for each voiding study to be made.
- For an AP projection (Figs. 16.74 and 16.75), the patient is maintained in the supine position, or the head of the table is elevated enough to place the patient in a semi-seated position.
- A lateral voiding study of the female vesicourethral canal is performed with the patient recumbent or upright. In either case, the IR is centered at the level of the superior border of the pubic symphysis.

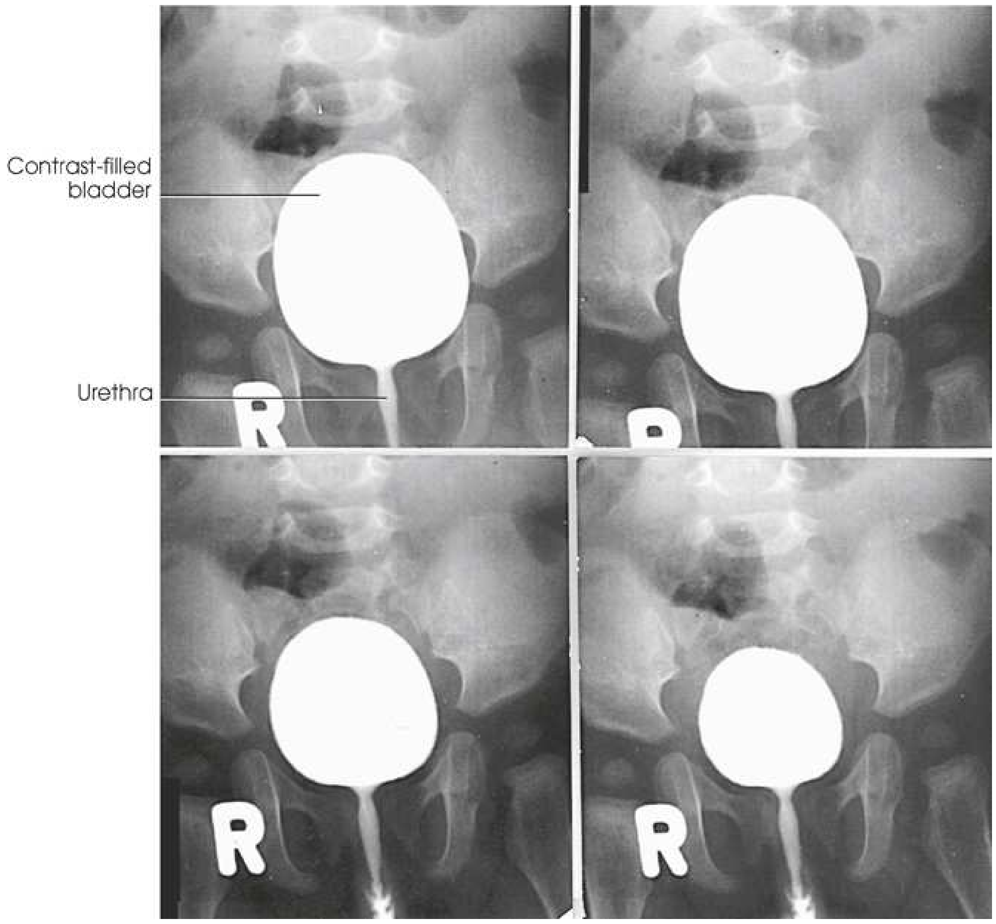


FIG. 16.75 Serial voiding images showing four stages of bladder emptying.

Four serial voiding images of four stages in bladder emptying in a patient. The bladder is highlighted by contrast in all the images. In the first image the contrast filled bladder and urethra are labeled.

Venipuncture and IV Contrast Media Administration

Radiologic technologists may perform venipuncture and administer medications by physician order for specific indications in certain types of intravenous (IV) therapy related to radiographic procedures. Most commonly, this medication consists of some type of radiographic contrast medium. [16] For this reason, this chapter provides additional information on the professional and legal considerations of IV access and medication administration, common medications in the imaging department, patient education and assessment, infection control, venipuncture equipment and procedure, contrast reactions, and documentation.

Professional and Legal Considerations

Because of patient risk and legal liabilities, the radiologic technologist must follow professional recommendations, state regulations, and institutional policies for the administration of medications. The information presented in this section is meant to be an introduction to IV therapy. Competency in this area requires the completion of a formal course of instruction with supervised clinical practice and evaluation.

The American Society of Radiologic Technologists (ASRT) includes venipuncture and IV medication administration in the curriculum guidelines for educational opportunities offered to technologists. Additional support for the administration of medications and venipuncture as part of the technologist's scope of practice is found in the ACR's 2017 Resolution 5 and *Manual on Contrast Media* (2017). [17, 18] These documents support the injection of contrast materials and diagnostic levels of radiopharmaceuticals within specific established guidelines by certified or licensed radiologic technologists. The ASRT Standards of Practice for Radiography also support the administration of medication by technologists.

Technologists who perform venipuncture and contrast media administration must be knowledgeable about the specific state regulations and facility policies that govern these activities. Technologists also are responsible for professional decisions and actions in their practice. Competency in the skills of venipuncture and contrast media administration are based on cognitive knowledge, proficiency in psychomotor skills, positive affective values, and validation in a clinical setting.

Medications

Medications for a specific procedure are prescribed by a physician, who is also responsible for obtaining informed consent for the procedure. A technologist may administer medications for radiographic procedures, which can require medications for sedation, pain management, contrast media administration, and emergencies. [19] Technologists must be knowledgeable of medications used in the radiology department. IV medications are administered into the body via the vascular system; when administered, they cannot be retrieved. Before administering any medication, the technologist must know the medication's name, dosages, indications, contraindications, and possible adverse reactions (Table 16.1).

Patient Education

The manner in which the technologist approaches the patient can have a direct influence on the patient's response to the procedure. Although the technologist may consider the procedure routine, the patient may be totally unfamiliar with its specifics. Apprehension experienced by the patient can cause vasoconstriction, making venipuncture more difficult and painful. [20] Careful explanation and a confident, sympathetic attitude can help the patient relax.

The technologist must provide information about the procedure in terms the patient can understand, including the steps, duration, and limitations or restrictions associated with the procedure. The patient's questions must be answered in "layman's" language. By explaining the details of the procedure, the technologist can help alleviate fears and solicit cooperation from the patient.

The technologist must tell the truth about the procedure, and attempt to provide accurate information regarding the degree of discomfort associated with a procedure. *The patient should never be told that insertion of the needle used in venipuncture does not hurt*. A miscommunication of this type violates patient trust.

TABLE 16.1

Generic Name	Brand NAME	Indications	Action	Adverse Reactions	Interactions	Effects on Diagnostic Imaging Procedures	Contraindications	Patient Care Considerations
Atropine sulfate	Atropine *How supplied:* injection, tablets	Symptomatic bradycardia, bradyarrhythmia	Inhibits acetylcholine at parasympathetic neuroeffector junction, enhancing and increasing heart rate	Bradycardia, headache, dry mouth, nausea, vomiting	May increase anticholinergic drug effects; use together cautiously	None known	Patients with obstructive disease of gastrointestinal tract, paralytic ileus, toxic megacolon, tachycardia, myocardia or ischemia, or asthma	Watch for tachycardia in cardiac patients; may lead to ventricular fibrillation
Diphenhydramine hydrochloride	Benadryl *How supplied:* tablets, capsules, elixir, syrup, injection	Allergic reactions, sedation	Competes with histamine for special receptors on effector cells; prevents but does not reverse histamine-mediated responses	Seizures, sleepiness, insomnia, incoordination, restlessness, nausea, vomiting, diarrhea	Increased effects when used with other CNS depressants	None known	Hypersensitivity to drug during acute asthmatic attacks and in newborns or premature neonates and breastfeeding women	Use with extreme caution in patients with angle-closure glaucoma, asthma, COPD
Meperidine hydrochloride	Demerol *How supplied:* tablets, syrup, injection	Mild to moderate pain; adjunct to anesthesia	Binds with opiate receptors of CNS	Seizures, cardiac arrest, shock, respiratory depression	May be incompatible when mixed in same IV container	None known	Patients with hypersensitivity to drug and patients who have received MAO inhibitors within past 14 days	Give slowly by direct IV injection; oral dose is less than half as effective as parenteral dose; compatible with most IV solutions
Dopamine hydrochloride	Dopamine *How supplied:* injection	Shock, increase cardiac output, correct hypotension	Stimulates dopaminergic and α and β receptors of sympathetic nervous system	Tachycardia, hypotension, nausea, vomiting, anaphylactic reactions	α and β blockers may antagonize effects	None known	Patients with uncorrected tachycardia, pheochromocytoma, or ventricular fibrillation	During infusion, frequently monitor ECG, blood pressure, cardiac output, central venous pressure, pulse rate, urine output, and color and temperature of limbs
Adrenaline	Epinephrine *How supplied:* injection, inhaler	Restore cardiac rhythm in cardiac arrest; bronchospasm; anaphylaxis	Relaxes bronchial smooth muscle by stimulating β_2 receptors and α and β receptors in sympathetic nervous system	Palpations, ventricular fibrillation, shock, nervousness	Avoid using with α blockers (may cause hypotension)	None known	Patients with shock, organic brain damage, cardiac dilation, arrhythmias, coronary insufficiency, or cerebral arteriosclerosis	Drug of choice in emergency treatment of acute anaphylactic reactions; avoid IM use of parenteral suspension into buttocks
Glucagon	Glucagon *How supplied:* injection	Slow peristalsis; prevent or decrease bowel spasm[a]	Increases blood glucose level by promoting catalytic depolymerization of hepatic glycogen to glucose	Bronchospasm, hypotension, nausea, vomiting	Inhibits glucagon-induced insulin release	None known	Patients with hypersensitivity to drug or with pheochromocytoma	Arouse patient from coma as quickly as possible and give additional carbohydrates orally to prevent secondary hypoglycemic reactions

Generic Name	Brand NAME	Indications	Action	Adverse Reactions	Interactions	Effects on Diagnostic Imaging Procedures	Contraindications	Patient Care Considerations
Morphine sulfate	Morphine *How supplied:* tablets, syrup, oral suspension, injection	Severe pain	Binds with opiate receptors of CNS	Bradycardia, shock, cardiac arrest, apnea, respiratory depression, respiratory arrest	In combination with other depressants and narcotics, use with extreme caution	None known	Patients with hypersensitivity to drug or conditions that would preclude administration of IV opioids	Use with extreme caution in patients with head injuries or increased intracranial pressure and in elderly patients
Chloral hydrate	Noctec *How supplied:* capsules, syrup, suppositories	Sedation	Unknown, sedative effects may be caused by its primary metabolite	Drowsiness, nightmares, hallucinations, nausea, vomiting, diarrhea	Alkaline solutions incompatible with aqueous solutions of chloral hydrate	None known	Patients with hepatic or renal impairment, severe cardiac disease, or hypersensitivity to drug	Note two strengths of oral liquid form; double-check dose, especially when administering to children
Promethazine hydrochloride	Phenergan *How supplied:* tablets, syrup, injection, suppositories	Nausea, sedation	Competes with histamine for special receptors on effector cells; prevents but does not reverse histamine-mediated responses	Dry mouth	Increased effects when used with other CNS depressants	Discontinue drug 48h before myelogram because of high risk of seizures	Patients with hypersensitivity to drug; intestinal obstruction, prostatic hyperplasias	Do not administer subcutaneously
Diazepam	Valium *How supplied:* tablets, capsules, oral solutions, injections	Anxiety	Unknown; probably depresses CNS at limbic and subcortical levels	Cardiovascular collapse, bradycardia, respiratory depression, acute withdrawal syndrome	Other CNS depressants	May cause minor changes in ECG patterns	Patients with hypersensitivity to drug or soy protein, shock, coma, or acute alcohol intoxication	Monitor respirations and have emergency resuscitation equipment available before administering
Midazolam hydrochloride	Versed *How supplied:* injection	Preoperative sedation (to induce sleepiness or drowsiness and relieve apprehension)	Unknown; thought to depress CNS at limbic and subcortical levels	Apnea, depressed respiratory rate, nausea, vomiting, hiccups, pain at injection site	CNS depressants may increase risk of apnea	None known	Patients with hypersensitivity to drug, acute angle-closure glaucoma, shock, coma, or acute alcohol intoxication	Use cautiously in patients with uncompensated acute illness and in elderly patients; have emergency resuscitation equipment available before administering
Hydroxyzine hydrochloride	Vistaril *How supplied:* tablets, syrup, capsules, injection	Nausea and vomiting, anxiety, preoperative and postoperative adjunctive therapy	Unknown; actions may be due to suppression of activity in key regions of subcortical area of CNS	Dry mouth, dyspnea, wheezing, chest tightness	Can increase CNS depression	None known	Hypersensitivity to drug, during pregnancy, and in breastfeeding women	If used in conjunction with other CNS medication, observe for oversedation

[a] *ACR Manual on Contrast Media,* v.10.3, 2017, p. 70.

Data from *Nursing 2006 drug handbook*. Ambler, PA: Lippincott Williams & Wilkins; 2006.

Patient Assessment

The patient must be assessed before any medication is administered. A thorough patient history must be obtained, including any allergies the individual may have specifically to medications, foods, or other environmental agents. A history of allergies, particularly a previous reaction to a medication or contrast media, is strongly correlated with the probability of an adverse reaction. This knowledge is essential for a technologist to be well prepared for a contrast administration.

Other assessment criteria include the patient's current medications. Knowledge of some common medication actions can help the radiologic technologist evaluate changes in a patient's condition during a procedure. Certain diabetic medications interact adversely with contrast media. The interaction of medications must be assessed before the procedure is performed.

During the physical evaluation, it is important to determine whether the patient has previously undergone surgical procedures that might affect site selection for venipuncture (e.g., a mastectomy with resultant compromised lymph nodes and vascular abnormalities, such as atrioventricular shunts). To determine the appropriate type and amount of medication to be administered, the physician requires information about the patient's past and current disease processes, such as hypertension and renal disease. Evaluation of the GFR (normal range 90 to 120 mL/min/1.73 m^2), blood urea nitrogen (BUN) level (average range 7 to 20 mg/dL), and creatinine level (average range 0.5 to 1.2 mg/dL) should be included among the assessment criteria.

Infection Control

Each time the body system is entered, the potential for contamination exists. [21] Strict aseptic techniques and universal precautions must always be used when medications are administered with a needle. [22] If a medication is injected incorrectly, a microorganism may enter the body and cause an infection or other complications. The US Centers for Disease Control and Prevention (CDC) has developed specific guidelines to prevent the transmission of infection during the preparation and administration of medications. These guidelines are part of the standard precautions used by every health care facility, and the technologist must strictly adhere to the guidelines when performing radiologic procedures.

Studies using IV filters have shown a significant reduction in infusion phlebitis. Filters are devices located within the tubing used for IV administration. Filters prevent the injection of particulate and microbial matter into the circulatory system. The use of a filter for a bolus injection reduces the rate at which medication can be injected. In addition, the viscosity of a medication may determine whether a filter is used and the rate of injection. Although a filter helps in reducing the possibility of bacteria being introduced into the blood, its use creates additional factors of risks versus benefits. The physician or health care facility should have policies to address these issues.

FIG. 16.76 Plastic disposable syringes.

Venipuncture Supplies and Equipment

Needles and Syringes

The technologist assembles the proper syringe and needle for the planned injection. The syringe may be glass or plastic. Plastic syringes are disposed of after only one use; glass syringes may be cleaned and must be sterilized before they are used again. The syringe has three parts: the *tip*, where the needle attaches to the syringe; the *barrel*, which includes the calibration markings; and the *plunger*, which fits snugly inside the barrel and allows the user to instill the medication (Fig. 16.76). The tip of the syringe for an IV injection has a locking device to hold the needle securely. The size of the syringe depends on the volume of material to be injected. The technologist should select a syringe one size larger than the volume desired. This larger syringe maximizes the accuracy of the dose by allowing the total amount of medication to be drawn into one syringe.

All needles used in venipuncture are disposable and are used only once. During preparation and administration of contrast media, the technologist may use several types of needles, including a hypodermic needle, a butterfly set, and an over-the-needle cannula (Fig. 16.77).

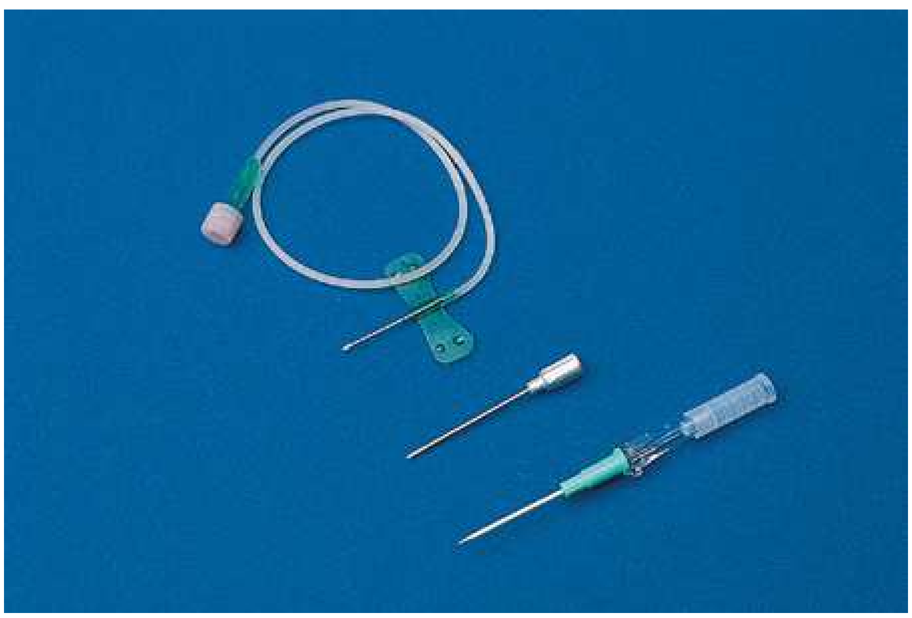


FIG. 16.77 Types of needles: over-the-cannula needle, or angiocatheter *(bottom)*; hypodermic needle *(center)*; and metal butterfly needle *(top)*.

Three types of needles displayed from top to bottom. The first one on top is a metal butterfly needle that has a thin. Long tube attached to the needle through a metal butterfly-like structure. The second one is a hypodermic needle, and the third one is an angiocatheter needle which has a tube-like catheter attached to the needle.

Hypodermic needles vary in gauge and length (see Fig. 16.77). Needle *gauge* refers to the *diameter* of the needle bore, with the gauge increasing as the diameter of the bore decreases. A 16-gauge needle is larger than a 22-gauge needle. As the bore of the needle increases, a given volume of fluid may be administered more rapidly. If the bore size is reduced and fluid volume and rate of administration remain constant, the pressure (force) of the injection increases. The *length* of a needle is measured in inches and may range from ½ inch (1.3 cm; used for intradermal injections) to 4½ inches (11.5 cm; used for intrathecal [spinal] injections). In general, needles 1 to 1½ inches (2.5 to 3.8 cm) long are most commonly used for IV injections. The needle has three parts: the *hub*, which is the part that attaches to the syringe; the *cannula* or *shaft*, which is the length of the needle; and the *bevel*, which is the slanted portion of the needle tip. Needles should be visually examined before and after use to determine whether any structural defects, such as nonbeveled points or bent shafts, are present. [23]

Butterfly sets or *angiocatheters* are preferable to a conventional hypodermic needle for most radiographic IV therapies. The butterfly set consists of a stainless steel needle with plastic appendages on either side and approximately 6 inches of plastic tubing that ends with a connector. The plastic appendages, often called wings, aid in inserting the needle and stabilizing the needle after venous patency has been confirmed.

The *over-the-needle cannula* is a device in which, after the venipuncture is made, the catheter is slipped off the needle into the vein and the steel needle is removed. This type of needle is recommended for long-term therapy or for rapid infusions, such as infusions that use an automated power injector. The choice of needle should be based on assessment of the patient, institutional policy, and technologist preference.

Medication Preparation

Although IV drug administration offers the most immediate results in terms of effect, certain safety precautions must be followed. The technologist must identify the correct patient before medication is administered. During preparation and again before administration, the medication in the container also must be verified.

If medication is supplied in a bottle or vial, the preparation procedure has several variations. First, the solution must be evaluated for contamination. Discoloration and dissolution are the most common signs of contamination. If either of those is observed, the solution should not be used. Then, the protective cap is removed, with care taken not to contaminate the underlying surface. Containers have rubber stoppers through which a hypodermic needle can be inserted. If a single-dose vial is being used, and no contamination has occurred, the rubber stopper requires no additional cleansing. Multiple-dose vial stoppers must be cleaned with an alcohol wipe.

FIG. 16.78 Place tip of needle above level of fluid before injection of air to decrease air bubbles in solution.

For a closed system to be maintained and to reduce the chance of possible infection, a volume of air equal to the amount of desired fluid must be injected into the bottle. The plunger of the syringe is pulled back to the level of the desired amount of medication. The shaft of the plunger must not be contaminated at any time during preparation of the medication. The needle on the syringe is inserted into the rubber stopper, all the way to the hub of the needle. Then, the vial is inverted by placing the end of the needle above the fluid level in the bottle (Fig. 16.78). Next, a small amount of air is *slowly* injected into the vial *above* the level of the fluid. This technique helps decrease air bubbles in the solution. After the air has been injected, the vial and syringe are held inverted and perpendicular to a horizontal plane, and the tip of the needle is pulled *below* the fluid level. The desired amount of medication is aspirated into the syringe by pulling down on the plunger of the syringe. This procedure may have to be repeated several times to expel all of the medication. If air bubbles cling to the syringe casing, the syringe may be lightly tapped to release them. A one-handed method is used to recap the syringe (Fig. 16.79).

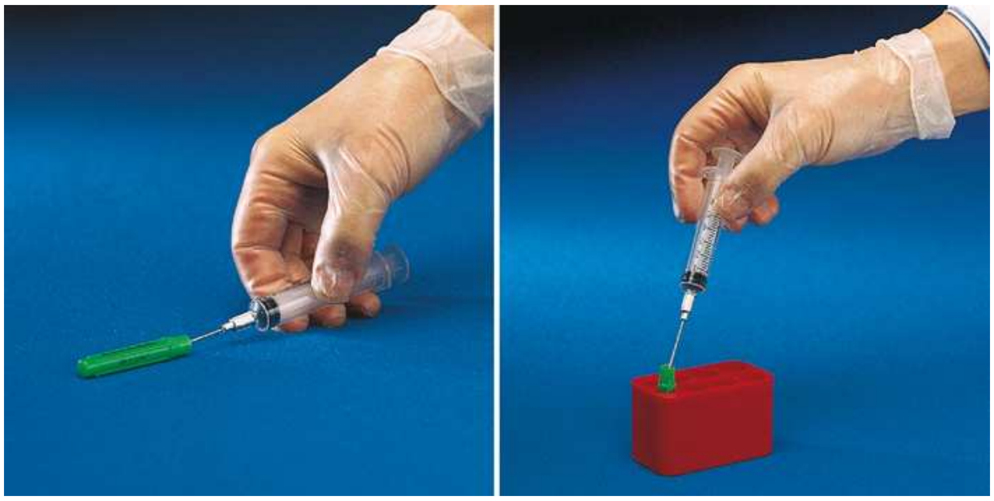


FIG. 16.79 When recapping a syringe, use a one-handed method.

Two photos demonstrate the one-handed method for recapping a syringe. In the first one a needle is recapped by inserting it one-handedly into a cap lying down. In the second one the needle is recapped by inserting it one-handedly into a cap which is held upright in a cap holder.

Preparation of an infusion from a glass bottle or plastic bag begins with identification and verification of the solution and its expiration date (Fig. 16.80). The solution should not contain any visible particles. The tubing used for the infusion is determined by the method of injection and the type of container. Electronic infusion devices require different tubing than gravity infusion devices. A glass container necessitates vented tubing (Fig. 16.81), whereas a plastic container requires nonvented tubing (Fig. 16.82

To prepare for drip infusion of a medication, the technologist removes the tubing from the sterile package and closes the clamp (Fig. 16.83). Failure to close the clamp may result in loss of the vacuum in the solution container. The protective coverings are removed from the port of the solution and the tubing spike. Then, the fill chamber of the tubing is squeezed, and the spike is inserted into the solution. The solution is then inverted, and the chamber is released. The solution should fill the chamber to the measurement line. The tubing is primed by opening the clamp, which allows the solution to travel the length of the tubing, expelling any air. The tube is filled with solution, the clamp is closed, and the protective covering is secured. The solution is then ready for administration.

FIG. 16.80 Identify the correct solution and expiration date.

FIG. 16.81 Vented tubing is required for glass bottle containers.

FIG. 16.82 Solutions in plastic bags require nonvented tubing.

FIG. 16.83 Close tubing clamp before inserting spike into container of solution.

Procedure

Site Selection

Selection of an appropriate vein for venipuncture is crucial. Finding the vein is sometimes difficult, and the most visible veins are not always the best choice. [24] Technologists administer IV medication and contrast media via the venous system. If a pulse is palpated during assessment for a puncture site, that vessel must *not* be used because it is an *artery*. The prime factors to consider in selecting a vein are (1) suitability of location, (2) condition of the vein, (3) purpose of the infusion, and (4) duration of therapy. The veins most often used in establishing IV access are the basilic or cephalic veins on the back of the hand; the basilic vein on the medial, anterior forearm, and elbow; and the cephalic vein on the lateral, anterior forearm, and elbow. The anterior surface of the elbow is also referred to as the *antecubital* space (Fig. 16.84). [25]

A general rule is to select the most distal site that can accept the desired-size needle and tolerate the injection rate and solution. Although the veins located at the antecubital space may be the most accessible, the largest, and the easiest to puncture, they may not be the best choice. Because of their convenient location, these sites may be overused and can become scarred or sclerotic. Antecubital accesses are located over an area of joint flexion; any motion can dislodge the cannula, causing infiltration or resulting in mechanical phlebitis. A flexible IV catheter is the needle of choice for the placement of a venous access in the antecubital space. The patient's arm should be immobilized to inhibit the ability to flex the elbow.

The condition of the vein must also be considered in the selection of an appropriate puncture site. The selected vein must be able to tolerate the needed or desired cannula size. The vein should have resilience qualities and be anchored by surrounding supportive tissues to prevent rolling.

Another consideration in vein selection is the rate of flow required for the procedure and the viscosity and amount of medication to be administered. Larger veins should be selected for infusions of large quantities or for rapid infusions. Large veins are also used for the infusion of highly viscous solutions or solutions that are irritating to vessels. [26]

The expected duration of the therapy and the patient's comfort are other factors that must be considered in selecting a venipuncture site. If a prolonged course of therapy is anticipated, areas over flexion joints should be avoided, and the dorsal surfaces of the upper limbs should be carefully examined. Venous access in these locations provides greater freedom and comfort to the patient.

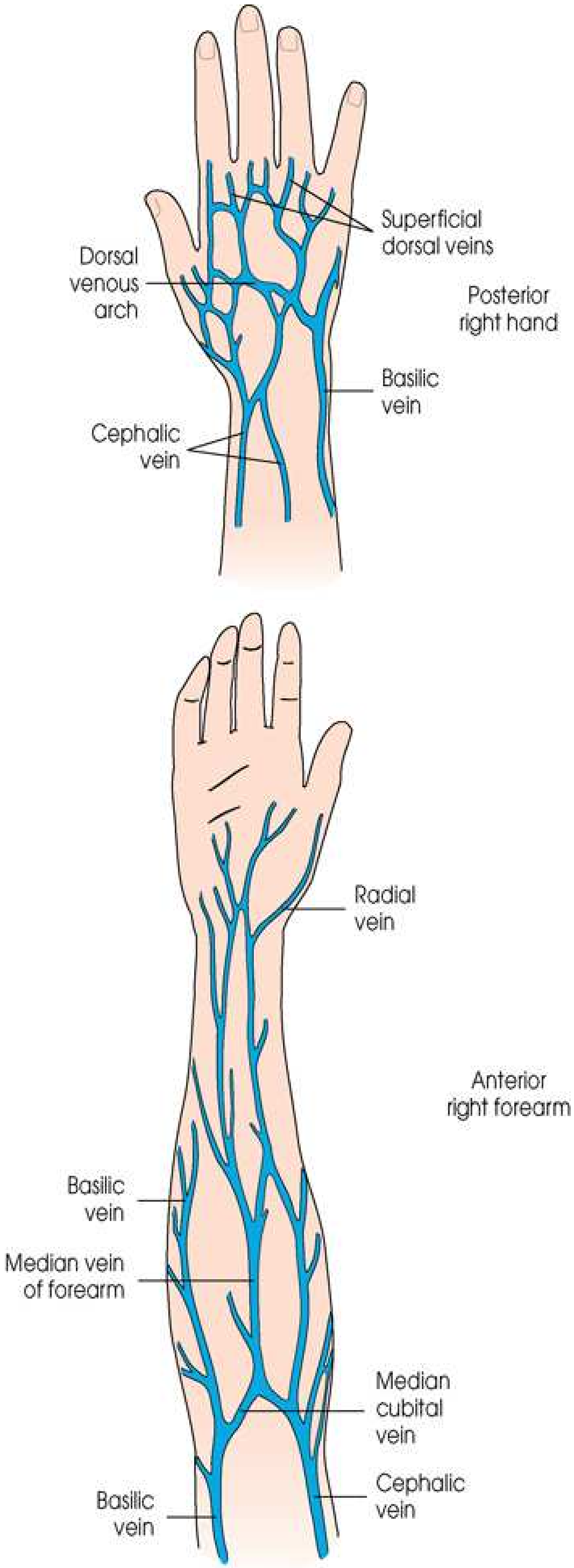


FIG. 16.84 Veins easily accessible for venipuncture.

The posterior hand and anterior forearm with the veins easily available for venipuncture labeled. In the posterior hand, Superficial dorsal veins, Cephalic vein, Basilic vein, and Dorsal venous arch are labeled. In the anterior arm the

Basilic vein, Dorsal venous arch, Median cubital vein, Median vein of forearm, Cephalic vein, and Radial vein are labeled.

Site Preparation

The surface of the skin must be prepared and cleaned. If the area selected for venipuncture is hairy, the hair should be clipped to permit better cleansing of the skin and visualization of the vein; this also makes removal of the cannula less painful when the infusion is terminated. Shaving is not recommended. The skin is cleansed with an antiseptic, which should remain in contact with the skin for at least 30 seconds. The preferred solution is iodine tincture 1% to 2%. Isopropyl alcohol 70% is recommended if the patient is sensitive to iodine. The skin should be cleaned in a *circular motion from the center of the injection site* to approximately a 2-inch circle. When the swab has been placed on the skin, it should not be lifted from the surface until the cleansing process is complete (Fig. 16.85).

Many facilities have a policy that provides the patient an opportunity to request a local anesthetic for IV infusion catheter placement. This technique reduces the pain felt by the patient during the insertion of an angiocatheter or needle. The local anesthetic can be administered topically or by injection. Follow the facility protocol for local anesthetic administration. Typical guidelines are as follows:

FIG. 16.85 Prepare site for venipuncture.

First, 0.1 to 0.2 mL of 1% lidocaine without epinephrine or sterile saline is prepared in a tuberculin or insulin syringe with a 23- to 25-gauge needle. The site for injection is selected and prepared. Then, the anesthetic is injected subcutaneously (beneath the skin, into the soft tissue) or intradermally (immediately under the skin in the dermal layer) at the venipuncture site. Topical anesthesia is achieved by applying 5 g of eutectic mixture of local anesthetic cream and covering the area with an occlusive dressing. Maximal effects are achieved in 45 to 60 minutes.

The medication to be injected should already be prepared, and any tubing should be primed with the solution to prevent the injection of air into the vascular system.

FIG. 16.86 Put on clean gloves.

Venipuncture

After the solution has been prepared, the site has been selected, and the type of syringe and the needle to be used have been determined, the technologist is ready to perform the venipuncture.

Techniques for venipuncture follow one of two courses: (1) the *direct*, or *one-step*, entry method or (2) the *indirect* method. The *direct*, or *one-step*, method is performed by thrusting the cannula through the skin and into the vein in one quick motion. The needle and cannula enter the skin directly over the vein. This technique is excellent as long as large veins are available. [27] The *indirect* method is a two-step technique. First, the over-the-needle cannula is inserted through the skin adjacent to or below the point where the vein is visible. The cannula is advanced and maneuvered to pierce the vein. For the actual venipuncture procedure, the technologist washes the hands. The patient is identified. Next, the technologist instructs the patient about the procedure. The technologist performs the following steps:

FIG. 16.87 Apply tourniquet 6 to 8 inches above intended venipuncture site, with free end directed superiorly.

1. The technologist puts on gloves and cleans the area in accordance with facility protocol (Fig. 16.86).
2. A local anesthetic is administered according to facility policy (optional).
3. A tourniquet is placed 6 to 8 inches (15 to 20 cm) above the intended site of puncture. The tourniquet should be tight enough to distend the vessels but not occlude them. The loose ends of the tourniquet should be placed away from the injection site to prevent contamination of the aseptic area (Fig. 16.87).

FIG. 16.88 Stabilize vein and enter skin with needle at 45-degree angle.

FIG. 16.89 Release tourniquet after venous access has been obtained. Do not permit tourniquet to touch needle.

FIG. 16.90 Anchor needle with tape to secure placement.

FIG. 16.91 Administer medication.

4. The technologist holds the patient's limb with the nondominant hand, using that thumb to stabilize and anchor the selected vein. The best method of accessing the vein—direct or indirect technique—is determined.
5. Using the dominant hand, the technologist places the needle bevel up at a 45-degree angle to the skin's surface. The bevel-up position produces less trauma to the skin and vein (Fig. 16.88).
6. The technologist uses a quick, sharp darting motion to enter the skin with the needle. On entering the skin, the technologist decreases the angle of the needle to 15 degrees from the long axis of the vessel. Using an indirect method, the technologist slowly proceeds with a downward motion on the hub or wings of the needle; while raising the point of the needle, the technologist advances the needle parallel and then punctures the vein. The needle may have to be maneuvered slightly to facilitate actual venous puncture. If the direct method of access is used, the needle is placed on the skin directly over the vein, and entry into the vein is accomplished in one movement of the needle through the skin and vein. When the vein is entered, a backflow of blood may occur—this indicates a successful venipuncture.
7. After the vein is punctured and blood return is noted, the cannula is advanced cautiously up the lumen of the vessel for approximately ¾ inch (1.9 cm).
8. Release the tourniquet (Fig. 16.89).
9. If a backflow of blood does not occur, verify venous access before injecting the medication. Aspiration of blood directly into the syringe of medication verifies placement before injection. Another method of placement verification is to attach a syringe of normal saline to the hub of the needle before aspirating for blood. The advantage of this method is that only saline, an isotonic solution, is injected if

the needle is not in place and extravasation occurs. A successful venipuncture does not guarantee a successful injection. If a bolus injection is desired, the tourniquet may not be released until the injection has been completed. If this technique is used, the protocol must be included in the facility's policies and procedures.

10. Anchor the needle with tape and a dressing, as required by policy (Fig. 16.90). Then administer the medication (Fig. 16.91).

With experience, a technologist's fingers become sensitive to the sensation of the needle entering the vein—the resistance encountered as the needle penetrates the wall of the vein and the "pop" felt at the loss of resistance as the cannula enters the lumen. If both walls of the vein are punctured with a needle, the vessel develops a hematoma. The cannula should be removed immediately, and direct pressure should be applied to the puncture site. If a venipuncture attempt is unsuccessful with an over-the-needle cannula and the needle has been removed from the cannula, the needle should not be reinserted into the catheter. Reinserting the needle into the cannula can shear a portion of the catheter.

Administration

The technologist should administer the medication or contrast medium at the established rate. During the injection process, the injection site should be observed and palpated proximal to the puncture for signs of infiltration. An infiltration, or extravasation, is a process whereby fluid passes into the tissue instead of the vein.

A patient may have a venous access that was established before the radiologic procedure. Careful assessment of site and medication compatibility must be performed before the existing IV line can be used. (Compatibility is the ability of one medication to mix with another.) Special precautions should be taken with a patient who is currently receiving cardiac, blood pressure, heparin, or diabetes medications. The physician, nurse, or pharmacist should be consulted before medication is administered to such a patient. Verification must be obtained to ensure that the medication being infused through the established IV line is compatible with the *contrast medium* to be administered. Before the contrast medium is injected, the infusion should be stopped, and the line should be flushed with normal saline through the port nearest the insertion site. The *contrast medium* is then administered, and the line is flushed again with normal saline. The amount of normal saline used depends on the facility's policies and procedures. After the contrast medium has been administered, the IV infusion solution is restarted.

FIG. 16.92 Remove IV access.

Heparin or saline locks allow intermittent injections through a port. The port is a small adapter with an access that is attached to an IV catheter when more than one injection is anticipated. [28] As determined by procedure criteria, the cannula is flushed with heparin and saline to maintain patency during dormant periods.

FIG. 16.93 Discard needles in puncture-resistant containers.

The patency (open, unobstructed flow) of the intermittent device is verified by aspirating blood and injecting normal saline without infiltration. Then, the medication is administered. Finally, the medication is flushed through the device with saline. Depending on protocols, the device may then be flushed with heparin or normal saline.

After the medication has been administered and the radiologic procedure has been completed, the venous access may be discontinued. The radiologic technologist should carefully remove any tape or protective dressing covering the puncture site. Using a 2 × 2-inch (6 × 6-cm) gauze pad at the injection site, the technologist removes the needle by pulling it straight from the vein. Direct pressure on the site is applied with the gauze only after the needle has been removed (Fig. 16.92). The technologist then puts the contaminated gloves, needles, and gauze in appropriate disposal containers (Fig. 16.93).

Reactions and Complications

Any *medication* has the potential to be harmful if it is not administered properly. [29] Technologists must be aware of possible untoward medication reactions and be able to recognize and report signs and symptoms of side effects as they occur. [30] The technologist who prepares a medication should also perform the administration.

Reactions can be mild, moderate, or severe. Mild reactions can include a sensation of warmth, a metallic taste, or sneezing. Moderate reactions can manifest as nausea, vomiting, or itching. Finally, a severe, or *anaphylactic*, reaction can cause a respiratory or cardiac crisis. The treatment for each category of reaction should be established in the procedures of each facility or department. The role of the radiologic technologist in the case of a reaction should also be defined in these documents. Competent professional standards of practice for the technologist include monitoring the patient's vital signs before, during, and after injection of a contrast medium or certain types of medications. The specific monitoring criteria should be established by institutional policy. If an untoward event should occur, responding personnel would have access to important information about the patient's condition before the event occurred.

Every health care provider should be familiar with emergency procedures in the work environment. Emergency crash carts contain many medications and pieces of equipment that require regular review. Proficiency in the operation of equipment and administration of medications must be maintained. The technologist must have the knowledge, proficiency, and confidence to manage crisis situations.

Infiltration, or *extravasation*, is another complication associated with the administration of contrast media or medications. This complication occurs when the medication or contrast material enters the soft tissue instead of the vein. [31] Signs include swelling, redness, burning, and pain. The most common cause of extravasation is needle displacement. If infiltration occurs, the procedure should be stopped immediately, and venous access should be discontinued. The physician must be notified, and specific treatment instructions must be requested. Although the ACR reports no clear consensus on the most effective treatment for extravasation, common therapies are (1) cold compress to alleviate pain at the injection site and (2) warm compress to increase blood flow to the site for more rapid absorption of the extravasated contrast. [31] The incident should be charted in the manner specified by department protocol.

Documentation

In the administration of any medication, the radiologic technologist should always observe five "rights of medication administration":

- The right patient
- The right medication
- The right route
- The right amount
- The right time

The *right patient* must receive the medication. The identity of the patient must be confirmed before the medication is administered. Methods of patient identification include checking the patient's wristband and asking the patient to restate his or her name. If the patient is unable to speak, seek assistance in identifying the patient from a family member or significant other. Ensuring that the *right medication* is administered requires that the name of the medication be verified at least three times: during the selection process, during preparation, and immediately before administration. The amount of medication is determined by the physician or by departmental protocols. The *right route*, *right amount*, and *right time* are determined by the physician, the type of medication, and the procedure.

Documentation of the five rights of medication administration should be included in every patient's permanent medical record. In addition to these five rights, the documentation should include the size, type, and location of the needle; the number of venipuncture attempts; and the identity of the health care personnel who performed the procedure. Information about how the patient responded to the procedure should also be documented. The following is an example of the correct documentation technique for a technologist performing venipuncture and administering a medication:

> *4-15-99 at 0900 a venous access on Mr. John Q Public was performed using an 18-gauge angiocatheter. The access was established in the dorsum of the left hand after one attempt. Then, 100 mL of [the specific name of the medication] was administered by IV push via the access. The patient tolerated the injection procedure and medication without complaints of pain or discomfort and with no unexpected side effects.*
>
> *Sandy R. Ray, RT*

The objective of medication therapy and administration is to provide maximal benefit to the patient with minimal harm. Medications are intended to help maintain health, treat or prevent disease, relieve symptoms, alter body processes, and diagnose disease. All medications are not ideal in their effects on the human body. It is important that health care providers understand their roles and responsibilities in the administration of medications. Because the medications used by the radiologic technologist are imperfect, caution for the patient's well-being and skill in the administration of medications are priorities. Patients have the right to expect that the personnel who administer medications are informed about dosages, actions, indications, adverse reactions, interactions, contraindications, and special considerations. Education, training, licensing, and experience are crucial in establishing competency in this area of practice.

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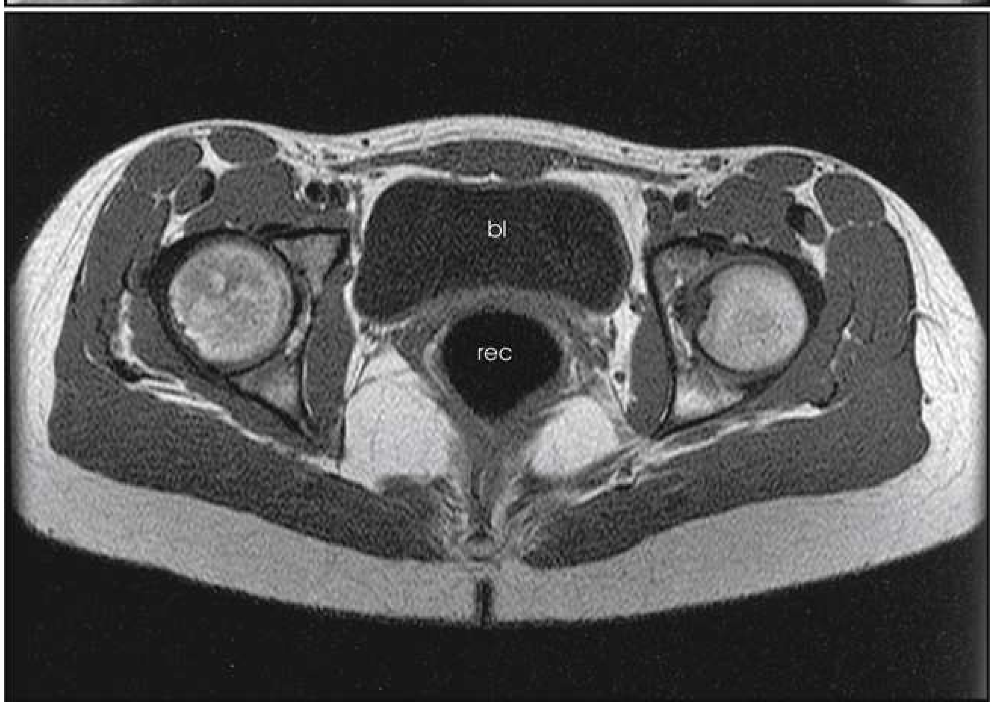
17: Reproductive System



OUTLINE

Summary of Projections

Projections, Positions, and Methods					
Page	**Essential**	**Anatomy**	**Projection**	**Position**	**Method**
344		Hysterosalpingography	AP, lateral, axial, oblique		
351		Male reproductive system			ULTRASOUND

Anatomy

Female Reproductive System

The female reproductive system consists of an internal and an external group of organs connected by the vaginal canal. This chapter does not address the anatomy of the external genitalia because those structures do not require radiographic demonstration. The internal genital organs consist of the female gonads, or *ovaries,* which are two glandular bodies homologous to the male testes, and a system of canals composed of the *uterine tubes, uterus,* and *vagina.*

Ovaries

The two ovaries are small glandular organs with an internal secretion that controls the menstrual cycle and an external secretion containing the *ova,* or female reproductive cells (Fig. 17.1). Each ovary is shaped approximately like an almond. The ovaries lie one on each side, inferior and posterior to the uterine tube and near the lateral wall of the pelvis. They are attached to the posterior surface of the broad ligament of the uterus by the *mesovarium.*

The ovary has a core of vascular tissue, the *medulla,* and an outer portion of glandular tissue, the *cortex.* The cortex contains *ovarian follicles* in all stages of development, and each follicle contains one ovum. A fully developed ovarian follicle is referred to as a *graafian follicle.* As the minute ovum matures, the size of the follicle and its fluid content increase so that the wall of the follicle's sac approaches the surface of the ovary. In time it ruptures, liberating the ovum and follicular fluid into the peritoneal cavity. Extrusion of an ovum by the rupture of a follicle is called *ovulation*, and it usually occurs once during the menstrual cycle. When the ovum is in the pelvic cavity, it is drawn toward the uterine tube.

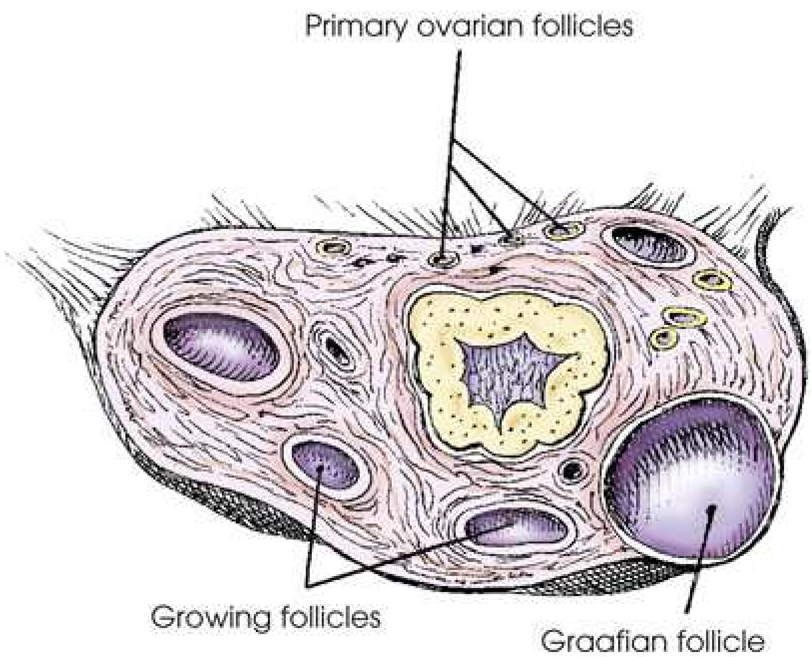


FIG. 17.1 Section of an ovary.

Diagram shows a section of the ovary. The parts labeled in the diagram are as follows: primary ovarian follicles, growing follicles, and Graffian follicle. The griffin follicle is shaped like a circle. The growing follicles are oval-shaped. The primary ovarian follicles are on the top and are tiny.

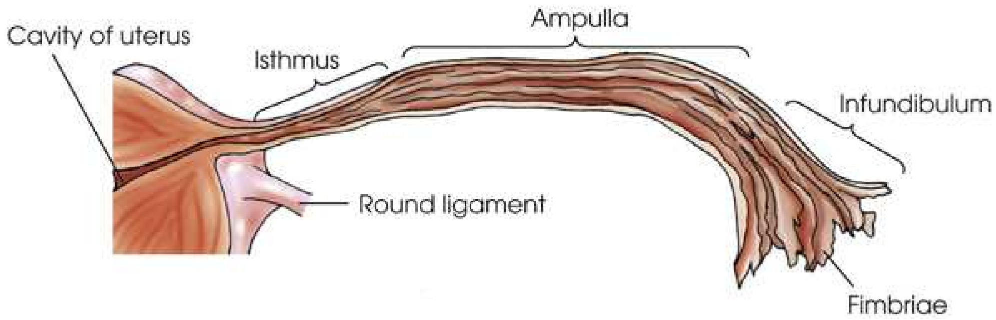


FIG. 17.2 Section of left uterine tube.

Diagram shows a section of the left uterine tube. It has a tube-like structure and is divided into three parts. The isthmus is a short segment near the uterus. The ampulla comprises most of the tube and is wider than the isthmus. The infundibulum ends in a series of irregular prolonged processes. The parts labeled in the diagram are as follows: cavity of the uterus, fimbriae, round ligament, isthmus, ampulla, and infundibulum.

Uterine Tubes

The two *uterine tubes,* or fallopian tubes, arise from the lateral angle of the uterus, pass laterally above the ovaries, and open into the peritoneal cavity. These tubes collect ova released by the ovaries and convey the cells to the uterine cavity. Each tube is 3 to 5 inches (7.6 to 13 cm) long (Fig. 17.2) and has a small diameter at its uterine end, which opens into the cavity of the uterus by a minute orifice. The tube itself is divided into three parts: the isthmus, the ampulla, and the infundibulum. The *isthmus* is a short segment near the uterus. The *ampulla* comprises most of the tube and is wider than the isthmus. The terminal and lateral portion of the tube is the *infundibulum* and is flared in appearance. The infundibulum ends in a series of irregular prolonged processes called *fimbriae*, and one of the fimbriae is attached to or near the ovary.

The mucosal lining of the uterine tube contains hairlike projections called *cilia*. The lining is arranged in folds that increase in number and complexity as they approach the fimbriated extremity of the tube. The cilia draw the ovum into the tube, which then convey it to the uterine cavity by peristaltic movements. Passage of the ovum through the tube requires several days. Fertilization of the cell occurs in the outer part of the tube, and the fertilized ovum migrates to the uterus for implantation.

Uterus

The *uterus* is a pear-shaped, muscular organ (Figs. 17.3 and 17.4). Its primary functions are to receive and retain the fertilized ovum until development of the fetus is complete and, when the fetus is mature, to expel it during birth.

The uterus consists of four parts: fundus, body, isthmus, and cervix. The *fundus* is the bluntly rounded, superiormost portion of the uterus. The *body* narrows from the fundus to the isthmus and is the point of attachment for the ligaments that secure the uterus within the pelvis. The *isthmus* (superior part of the cervix), a constricted area between the body and the cervix, is approximately ½ inch (1.3 cm) long. The *cervix,* the cylindric vaginal end of the uterus, is approximately 1 inch (2.5 cm) long. The vagina is attached around the circumference of the cervix.

The *nulliparous* uterus (i.e., the uterus of a woman who has not given birth) is approximately 3 inches (7.6 cm) in length, almost half of which represents the length of the cervix, which is approximately 3/4 inch (1.9 cm) in diameter. During pregnancy, the body of the uterus gradually expands into the abdominal cavity, reaching the epigastric region in the eighth month. After parturition, the organ shrinks to almost its original size but undergoes characteristic changes in shape.

The uterus is situated in the central part of the pelvic cavity, where it lies posterior and superior to the urinary bladder and anterior to the rectal ampulla. The long axis, which is slightly concave anteriorly, is directed inferiorly and posteriorly at a near right angle to the axis of the vaginal canal, into which the lower end of the cervix projects.

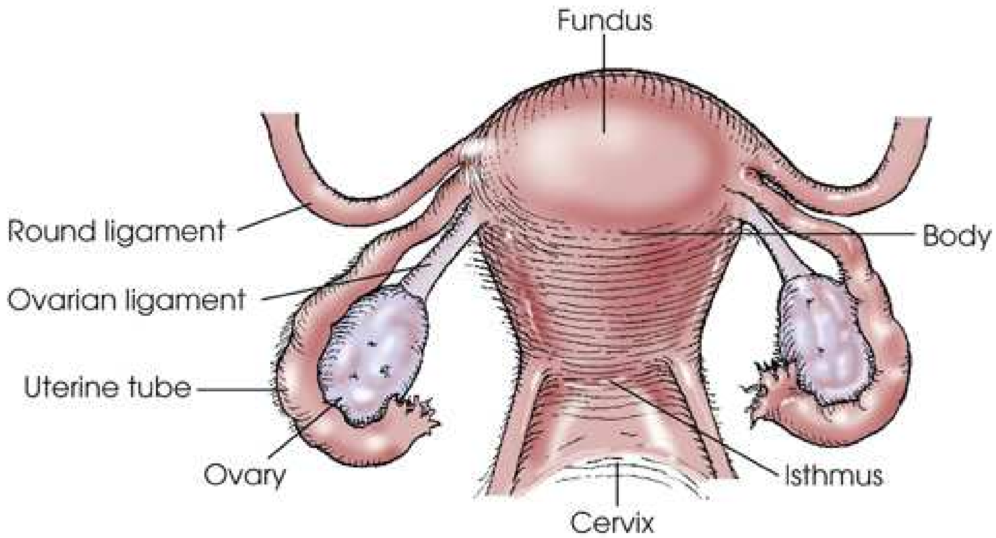


FIG. 17.3 Superoposterior view of uterus, ovaries, and uterine tubes.

Diagram shows a pear-shaped muscular organ. The fundus is the bluntly rounded, superior most portion of the uterus. The body narrows from the fundus to the isthmus. The isthmus is a constricted area between the body and the cervix. The cervix is a cylindric vaginal end of the uterus. The parts labeled in the diagram are as follows: round ligament, ovarian ligament, ovary, uterine tube, fundus, body, isthmus, and cervix.

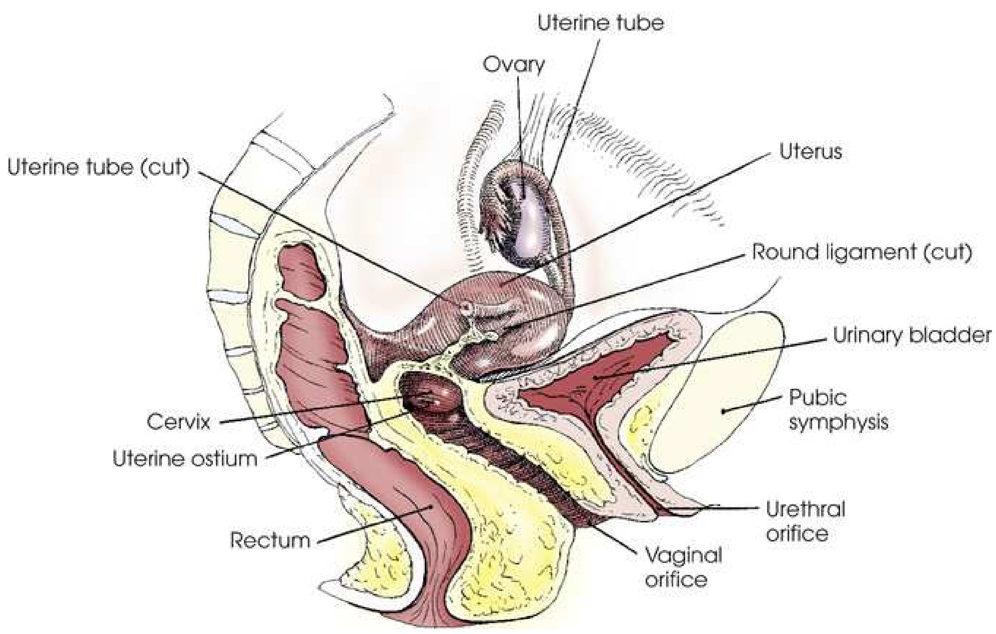


FIG. 17.4 Sagittal section showing relation of internal genitalia to surrounding structures.

Diagram shows the internal genitalia and their surrounding structures. The parts labeled in the diagram are as follows: Rectum, uterine ostium, cervix, uterine tube (cut), ovary, uterine tube, uterus, round ligament (cut), pubic symphysis, urinary bladder, urethral orifice, vaginal orifice.

The cavity of the body of the uterus, or the uterine cavity proper, is triangular in shape when viewed in the frontal plane. The canal of the cervix is dilated in the center and constricted at each extremity, and the proximal end of the canal is continuous with the canal of the isthmus. The distal orifice is called the *uterine ostium*.

The mucosal lining of the uterine cavity is called the *endometrium*. This lining undergoes cyclic changes, called the *menstrual cycle,* at about 4-week intervals from puberty to menopause. During each premenstrual period, the endometrium is prepared for implantation and nutrition of the fertilized ovum. If fertilization has not occurred, the menstrual flow of blood and necrosed particles of uterine mucosa ensues.

Vagina

The *vagina* is a muscular structure with walls and a canal lying posterior to the urinary bladder and urethra, and anterior to the rectum. Averaging about 3 inches (7.6 cm) in length, the vagina extends inferiorly and anteriorly from the uterus to the exterior. The *mucosa* of the vagina is continuous with that of the uterus. The space between the labia minora, which is known as the *vaginal vestibule,* contains the *vaginal orifice* and the *urethral orifice*.

Fetal Development

During the *implantation* process, the fertilized ovum, called a *zygote,* is passed from the uterine tube into the uterine cavity, where it adheres to and becomes embedded in the uterine lining. About 2 weeks after fertilization of the ovum, the *embryo* begins to appear. The embryo becomes a fetus 9 weeks after fertilization and then assumes a human appearance (Fig. 17.5).

During the first 2 weeks of embryonic development, the growing fertilized ovum is primarily concerned with establishing its nutritive and protective covering, the *chorion* and the *amnion*. As the chorion develops, it forms (1) the outer layer of the protective membranes enclosing the embryo, and (2) the embryonic portion of the *placenta,* by which the umbilical cord is attached to the mother's uterus and through which food is supplied to and waste is removed from the fetus. The amnion, often referred to as the "bag of water" by the laity, forms the inner layer of the fetal membranes and contains amniotic fluid, in which the fetus floats. After birth, the uterine lining is expelled with the fetal membranes and the placenta, constituting the afterbirth. A new endometrium is then regenerated.

The fertilized ovum usually becomes embedded near the fundus of the uterine cavity, most frequently on the anterior or posterior wall. Implantation occasionally occurs so low, however, that the fully developed placenta encroaches on or obstructs the cervical canal. This condition results in premature separation of the placenta, termed *placenta previa* (Fig. 17.6).

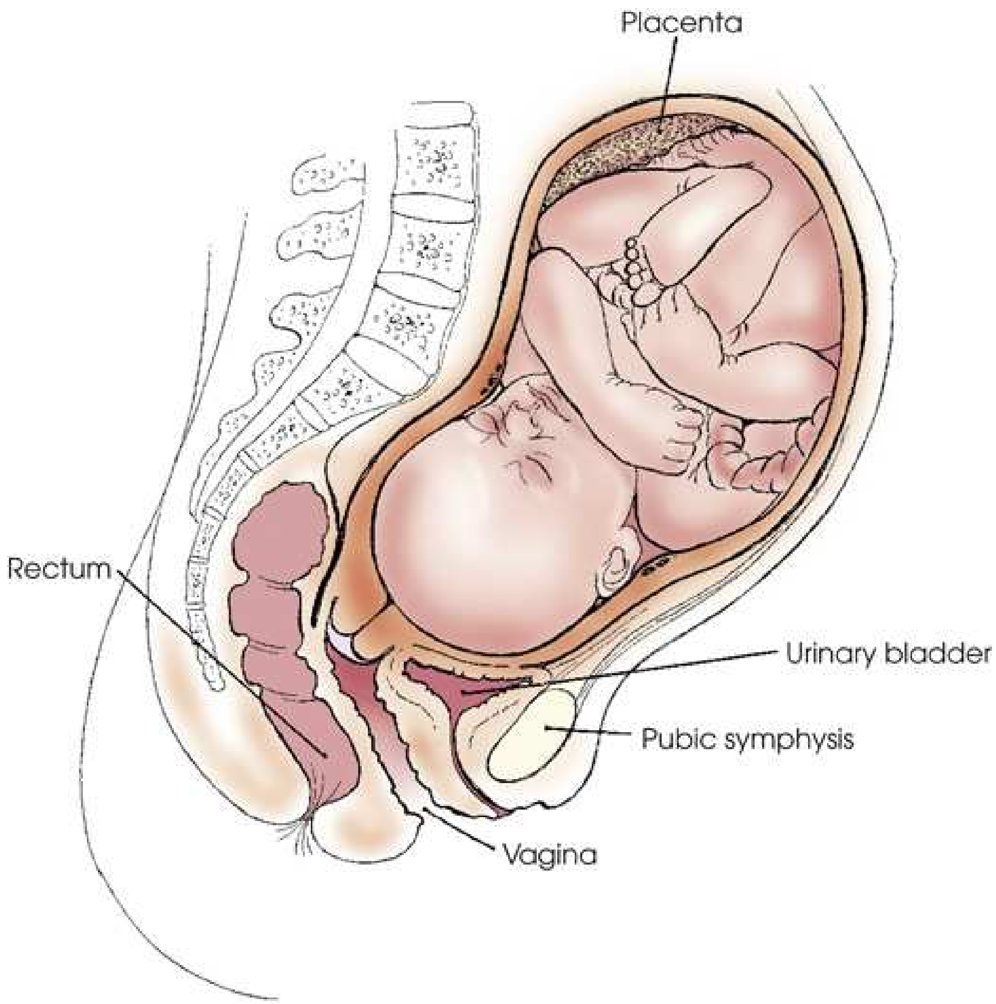


FIG. 17.5 Sagittal section showing fetus of about 7 months of age.

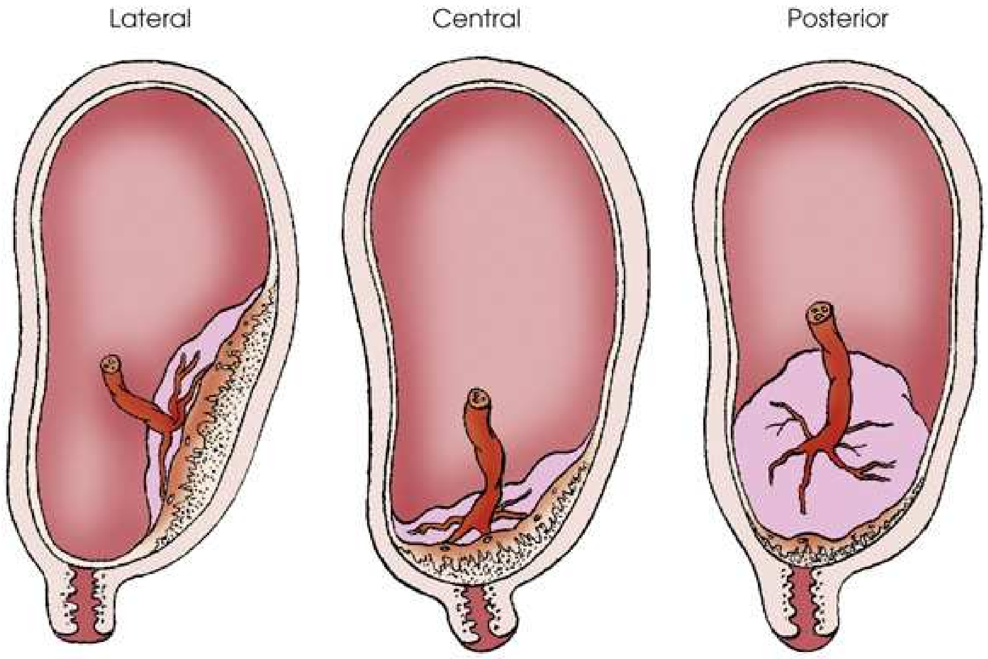


FIG. 17.6 Schematic drawings of several placental sites in low implantation.

Schematic drawings of three placental sites in low implantation is given. The first diagram shows lateral implantation. A tube like structure rises from the lateral surface of the uterus from the placenta. The second diagram shows central implantation. A tube like structure rises from the central surface of the uterus from the placenta. The third diagram shows posterior implantation. A tube like structure a tube like structure rises from the back of the uterus from the placenta.

Male Reproductive System

The male genital system consists of a pair of male *gonads,* the *testes,* which produce spermatozoa, two excretory channels, the *ductus deferens* (vas deferens). the *prostate*, the ejaculatory ducts, the *seminal vesicles*, and a pair of *bulbourethral glands,* which produce secretions that are added to the secretions of the testes and ductal mucosa to constitute the final product of seminal fluid. The *penis,* the *scrotum,* and the structures enclosed by the scrotal sac (testes, epididymides, spermatic cords, and part of the ductus deferens) are the external genital organs.

Testes

The *testes* are ovoid bodies, averaging 1½ inches (3.8 cm) in length and about 1 inch (2.5 cm) in width and depth (Fig. 17.7). Each testis is divided into 200 to 300 partial compartments that constitute the glandular substance of the testis. Each compartment houses one or more convoluted, germ cell–producing tubules; these tubules converge and unite to form 15 to 20 ductules, which emerge from the testis to enter the head of the epididymis.

The *epididymis* is an oblong structure that is attached to the superior and lateroposterior aspects of the testis. The ductules leading out of the testis enter the head of the epididymis to become continuous with the coiled and convoluted ductules that make up this structure. As the ductules pass inferiorly, they progressively unite to form the main duct, which is continuous with the ductus deferens.

Ductus Deferens

The *ductus deferens* is 16 to 18 inches (40 to 45 cm) long and extends from the tail of the epididymis to the posteroinferior surface of the urinary bladder. Only its first part is convoluted. From its beginning, the ductus deferens ascends along the medial side of the epididymis on the posterior surface of the testis to join the other constituents of the spermatic cord, with which it emerges from the scrotal sac and passes into the pelvic cavity through the inguinal canal (Fig. 17.8). Near its termination, the duct expands into an *ampulla* for storage of seminal fluid and ends by uniting with the duct of the seminal vesicle.

Seminal Vesicles

The two *seminal vesicles* are sacculated structures about 2 inches (5 cm) long (Fig. 17.9). They are situated obliquely on the lateroposterior surface of the bladder, where, from the level of the ureterocystic junction, each slants inferiorly and medially to the base of the prostate. Each ampulla of the ductus deferens lies along the medial border of the seminal vesicle to form the ejaculatory duct.

Ejaculatory Ducts

Each *ejaculatory duct* is formed by the union of the ductus deferens and the duct of the seminal vesicle. The ejaculatory ducts average about ½ inch (1.3 cm) in length and originate behind the neck of the bladder. The two ducts enter the base of the prostate and, passing obliquely inferiorly through the substance of the gland, open into the prostatic urethra at the lateral margins of the prostatic utricle. These ducts eject sperm into the urethra before ejaculation.

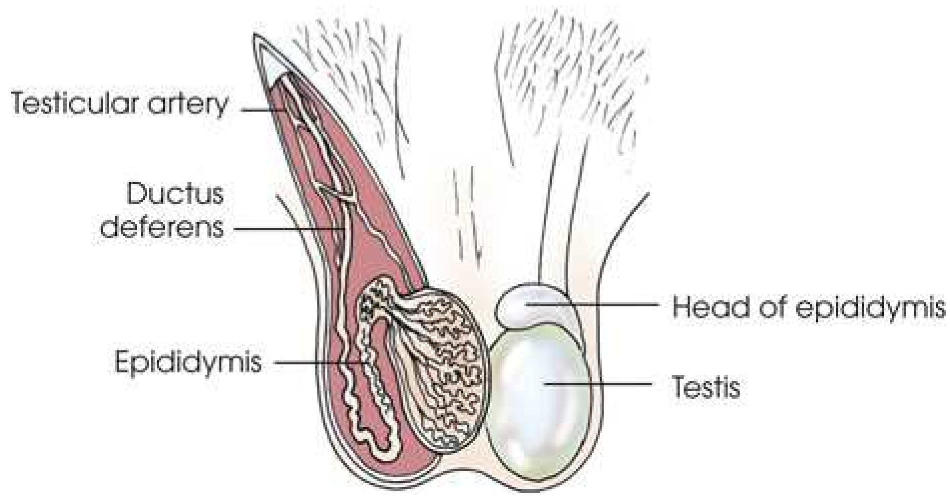


FIG. 17.7 Frontal section of testes and ductus deferens.

Diagram shows the frontal section of the testes and ductus deferens. The testes are oval-shaped. The epididymis is an oblong structure. The ductules leading out of the testis enter the head of the epididymis to become continuous with the coiled and convoluted ductules. The parts labeled in the diagram are as follows: testicular artery, ductus deferens, epididymis, testis, and head of the epididymis.

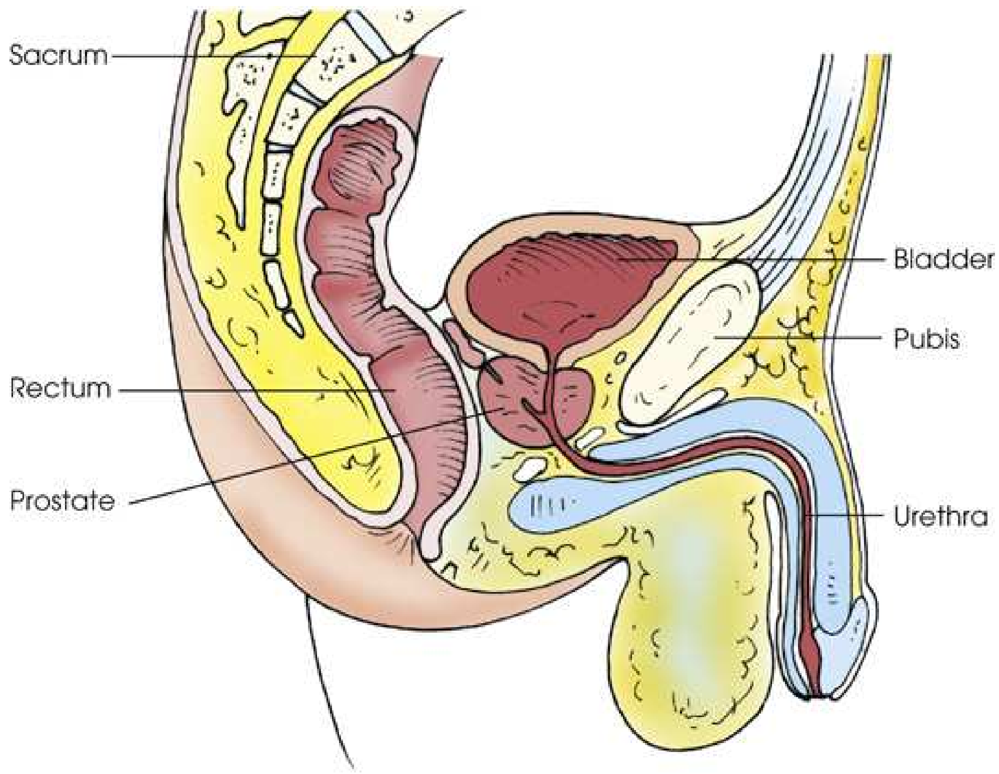


FIG. 17.8 Sagittal section showing male genital system.

Diagram shows the male genital system. The ductus deferens is long and extend from the tail of the epididymis. The parts labeled in the diagram are as follows: sacrum, bladder, pubis, prostate, urethra, and rectum

Prostate

The *prostate,* an accessory genital organ, is a cone-shaped organ that averages 1 ¼ inches (3.2 cm) in length. The prostate encircles the proximal portion of the male urethra and, extending from the bladder neck to the pelvic floor, lies in front of the rectal ampulla approximately 1 inch (2.5 cm) posterior to the lower two-thirds of the pubic symphysis (see Fig. 17.9). The prostate comprises muscular and glandular tissue. The ducts of the prostate open into the prostatic portion of the urethra.

Because of advances in diagnostic ultrasound imaging, radiographic examinations of the male reproductive system are performed less often than in the past. The prostate can be ultrasonically imaged through the urine-filled bladder or by using a special rectal transducer, and the seminal ducts can be imaged when the rectum is filled with an ultrasound gel and a special rectal transducer is used. Testicular ultrasonic scans are performed to evaluate a palpable mass or an enlarged testis and to check for metastasis. Most testicular scans are performed because of a palpable mass or an enlarged testis.

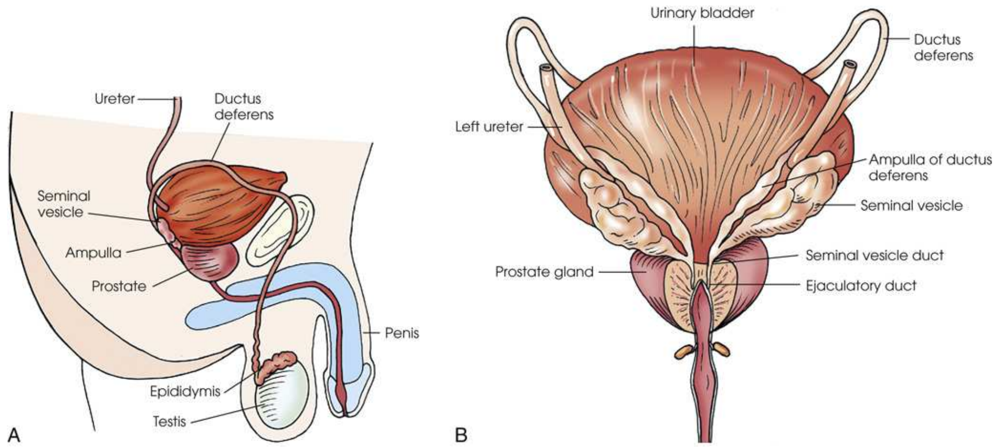


FIG. 17.9 (A) Sagittal section through male pelvis. (B) Posterior view of male reproductive organs.

Diagram (A) shows the male pelvis. The parts labeled in the diagram are as follows: ureter, ductus deferens, seminal vesicle, ampulla, prostate, epididymis, penis, and testis. Diagram (B) shows the male reproductive organs. The parts labeled in the diagram are as follows: urinary bladder, ductus deferens, ampulla of ductus deferens, seminal vesicle, seminal vesicle duct, ejaculatory duct, left ureter, and prostate gland.

Summary of Anatomy

Female reproductive system

Ovaries
Uterine tubes
Uterus
Vagina

Ovaries

Ova
Mesovarium
Medulla
Cortex
Ovarian follicles
Graafian follicle
Ovulation

Uterine tubes (fallopian tubes)

Isthmus
Ampulla
Infundibulum
Fimbriae
Cilia

Uterus

Fundus
Body
Isthmus
Cervix
Uterine ostium
Endometrium

Vagina

Mucosa
Vaginal vestibule
Vaginal orifice
Urethral orifice

Fetal development

- Zygote
- Embryo
- Fetus
- Placenta

Male reproductive system

- Testes
- Ductus deferens (vas deferens)
- Prostate
- Ejaculatory ducts
- Seminal vesicles
- Bulbourethral glands
- Penis
- Scrotum

Testes

- Epididymis

Ductus deferens

- Ampulla

Summary of Pathology

Condition	Definition
Adhesion	Union of two surfaces that are normally separate
Cryptorchidism	Condition of undescended testis
Endometrial polyp	Growth or mass protruding from endometrium
Epididymitis	Inflammation of the epididymis
Uterine tube obstruction	Condition preventing normal flow through uterine tube
Fistula	Abnormal connection between two internal organs or between an organ and the body surface
Testicular torsion	Twisting of the testis at its base, causing acute ischemia
Tumor	New tissue growth where cell proliferation is uncontrolled
Dermoid cyst	Tumor of the ovary filled with sebaceous material and hair
Prostate cancer	Second most common malignancy in men
Seminoma	Most common type of testicular tumor
Uterine fibroid	Smooth muscle tumor of the uterus

Abbreviations Used in Chapter 17

HSG	Hysterosalpingography
IUD	Intrauterine device

See Addendum B for a summary of all abbreviations used in Volume 2.

Radiography

Female Radiography

Nonpregnant Patient

Radiologic investigations of the nonpregnant uterus, accessory organs, and vagina are denoted by the terms *hysterosalpingography* (HSG), *pelvic pneumography,* and *vaginography*. Each procedure requires the use of contrast medium and should be performed under aseptic conditions. *HSG* involves the introduction of a radiopaque contrast medium through a uterine cannula. The procedure is performed to determine the size, shape, and position of the uterus and uterine tubes, to delineate lesions such as polyps, submucous tumor masses, or fistulous tracts, and to investigate the patency of the uterine tubes in patients who have been unable to conceive (Fig. 17.10).

Pelvic pneumography, which requires the introduction of a gaseous contrast medium directly into the peritoneal cavity, is now rarely performed because of the development of ultrasound techniques for evaluating the pelvic cavity. *Vaginography* is performed to investigate congenital abnormalities, vaginal fistulas, and other pathologic conditions involving the vagina.

Contrast media

Various opaque media are used in examinations of the female genital passages; the water-soluble contrast media employed for intravenous urography are widely used for HSG and vaginography.

Preparation of intestinal tract

Preparation of the intestinal tract for any of these examinations usually consists of the following:

1. A non–gas-forming laxative is administered on the preceding evening if the patient is constipated.
2. Before reporting for the examination, the patient receives cleansing enemas until the return flow is clear.
3. The meal preceding the examination is withheld.

Appointment date and care of patient

Gynecologic examinations should be scheduled approximately 10 days after the onset of menstruation, as this is the interval during which the endometrium is least congested. More important, because this time interval is a few days before ovulation normally occurs, there is little danger of irradiating a recently fertilized ovum.

The relatively minor instrumentation required for the introduction of contrast medium in these examinations normally does not necessitate hospitalization or premedication. Some patients experience unpleasant but transitory aftereffects. The radiology department should have facilities in which an outpatient can rest in the recumbent position before returning home.

The patient is requested to empty her bladder completely immediately before the examination in order to prevent pressure displacement and superimposition of the bladder on the pelvic genitalia. In addition, the patient's vagina is irrigated just before the examination. At this time, the patient should be given the necessary supplies and instructed to cleanse the perineal region.

Radiation protection

To deliver the least possible amount of radiation to the gonads, the radiologist restricts fluoroscopy and imaging to the minimum required for a satisfactory examination.

Hysterosalpingography

HSG is performed by a physician, with spot images made while the patient is in the supine position on a fluoroscopy table. The examination may also be performed by the physician with conventional radiographic images obtained using an overhead tube. When fluoroscopy is used, spot images may be the only images obtained. Preparation of the patient for the examination includes the following steps:

- After irrigation of the vaginal canal, complete emptying of the bladder and perineal cleansing, and place the patient on the examining table.
- Adjust the patient in the lithotomy position, with the knees flexed over leg rests.
- When a combination table is used, adjust the patient's position to permit the IRs to be centered to a point 2 inches (5 cm) proximal to the pubic symphysis; lengthwise 10 × 12-inch (24 × 30-cm) IRs or collimated field sizes are used for all studies.

FIG. 17.10 HSG reveals bilateral hydrosalpinx of uterine tubes *(arrows)*. Contrast medium–filled uterine cavity is normal *(arrowheads)*.

After inspection of the preliminary image and with a vaginal speculum in position, the physician inserts a uterine cannula through the cervical canal, fits the attached rubber plug or acorn firmly against the external cervical os, applies counterpressure with a tenaculum to prevent reflux of the contrast medium, and withdraws the speculum unless it is radiolucent. An opaque or a gaseous contrast medium may be injected via the cannula into the uterine cavity; the contrast material flows through patent uterine tubes and "spills" into the peritoneal cavity (Figs. 17.11–17.13). Patency of the uterine tubes can be determined by transuterine gas insufflation (the Rubin test), but the length, position, and course of the ducts can be shown only by opacifying the lumina.

Free-flowing, iodinated organic contrast agents are usually injected at room temperature. These agents pass through patent uterine tubes quickly, and the resultant peritoneal spill is absorbed and eliminated via the urinary system, usually within 2 hours.

The contrast medium may be injected with a pressometer or a syringe. Intrauterine pressure is maintained for radiographic studies by closing the cannula's valve. In the absence of fluoroscopy, the contrast medium is introduced in two to four fractional doses so that excessive peritoneal spillage does not occur. Each fractional dose is followed by a radiographic study to determine whether the filling is adequate as shown by the peritoneal spill.

The images may consist of no more than a single anteroposterior (AP) projection taken at the end of each fractional injection. Other projections (oblique, axial, and lateral) are taken as indicated.

Evaluation Criteria

The following should be clearly seen:

- The pelvic region 2 inches (5 cm) above the pubic symphysis centered on the image
- All contrast media visible, including any "spill" areas
- Soft tissues and contrast media

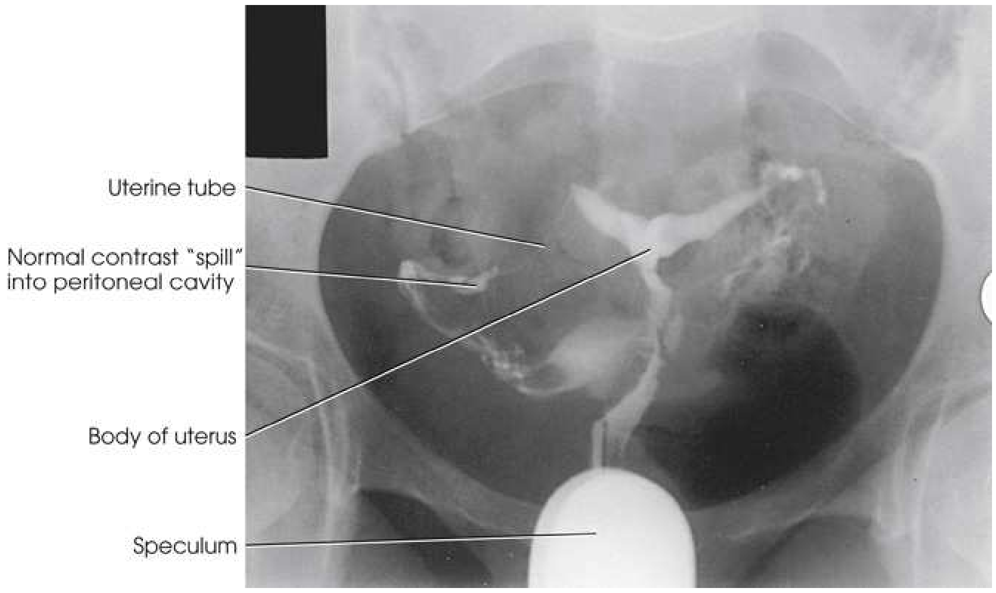


FIG. 17.11 Hysterosalpingogram, AP projection, showing normal uterus and uterine tubes.

Hysterosalpingography shows uterus and uterine tubes. The uterine tube is Y-shaped and it appears white. The speculum below appears radiopaque. The parts labeled are as follows: uterine tube, normal contrast "spill" into peritoneal cavity, the body of uterus, speculum.

FIG. 17.12 Hysterosalpingogram, AP projection, showing submucous fibroid occupying entire uterine cavity *(arrowheads)*.

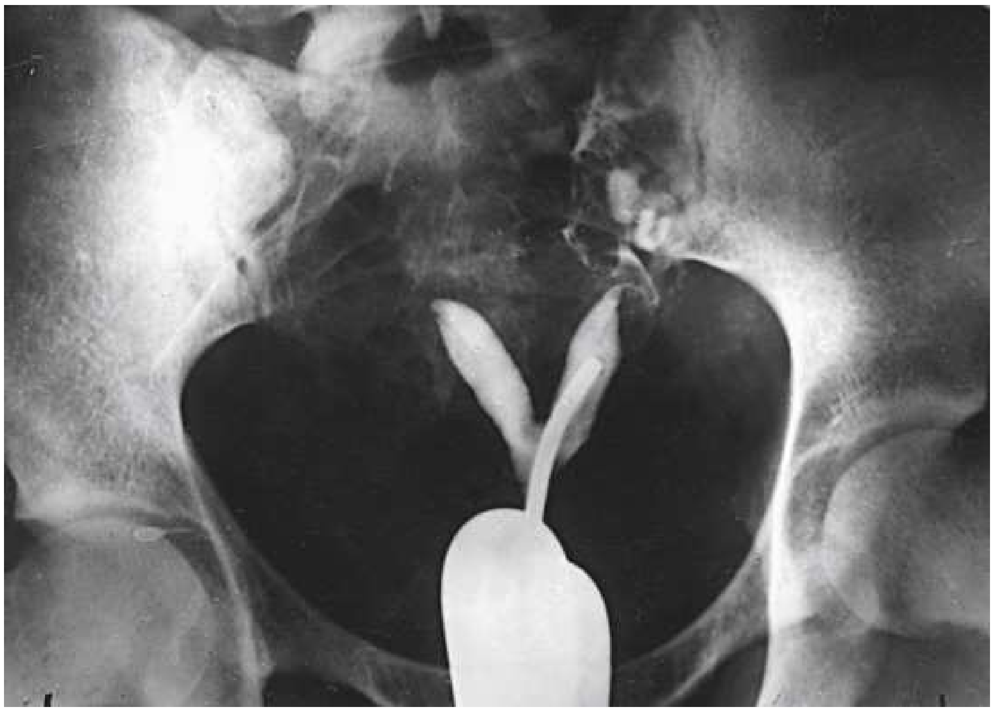


FIG. 17.13 Hysterosalpingogram, AP projection, revealing uterine cavity as bicornuate in outline.

Imaging of female contraceptive devices

HSG is performed about 3 months after insertion of the permanent type of intrauterine device (IUD) (Fig. 17.14). Additionally, HSG and other imaging modalities, such as ultrasound, may also be used to check for proper placement of temporary IUDs and in cases of suspected displacement. For these reasons, radiographers should be acquainted with the appearance of IUDs in images. IUDs have been used for contraception for many decades. Currently there are only two forms of temporary IUDs and one for permanent contraception (Figs. 17.15 and 17.16). IUD insertion is usually performed in an outpatient procedure in a physician's office; however, conscious sedation is required to insert the permanent IUD. [1] Although an HSG is required to ensure that the permanent IUD is functioning properly, insertion of this device is much less invasive than the other permanent sterility option, tubal ligation.

AP and lateral projections of the abdomen are suggested for IUD localization. Occasionally, oblique projections are indicated. Most IUDs are radiopaque because of their metallic composition. Radiography alone is *not* a reliable method of extrauterine localization of an IUD.

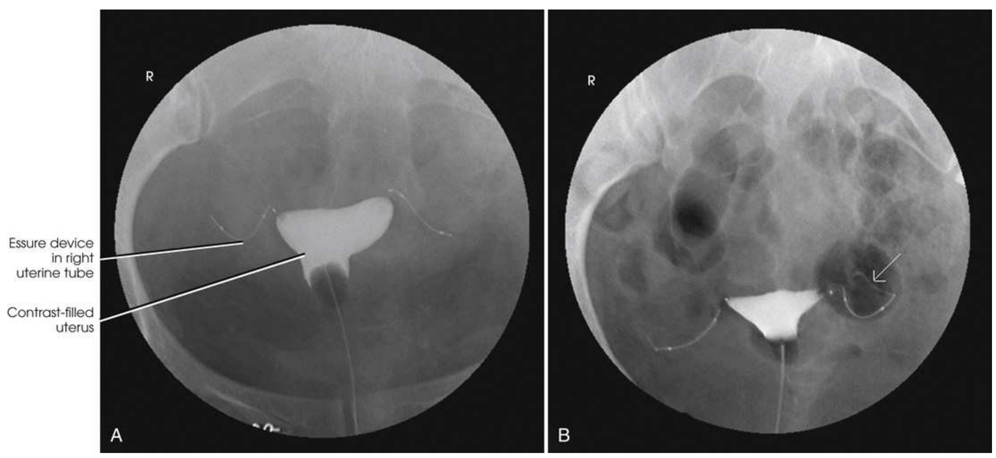


FIG. 17.14 Hysterosalpingogram 3-months post Essure insertion. (Essure confirmation test.) (A) HSG spot image confirms occlusion of uterine tubes. (B) HSG spot demonstrates failure of left uterine tube occlusion (*arrow* points to contrast spill into peritoneum). Courtesy NEA Baptist Memorial Hospital, Jonesboro, AR.

(A) A hysterosalpingography shows a circle inside a square. A small white line extends both sides from a grey area in the center of the circle. The parts labeled are as follows: pressure device in right uterine tube, contrast-filled uterus. (B) Hysterosalpingography shows a circle inside a square. A small white outline is in a darker region on the left side extending from the radiopaque region.

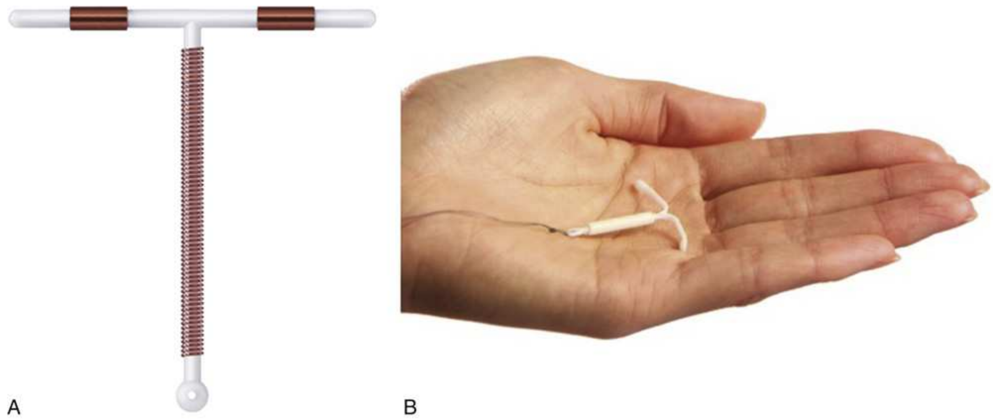


FIG. 17.15 Temporary intrauterine contraceptive device (IUD). (A) ParaGard (intrauterine copper contraceptive) manufactured by Teva Women's Health, Inc. Actual size is 32 × 36 mm. (B) Mirena (levonorgestrel-releasing intrauterine system) manufactured by Bayer Healthcare Pharmaceuticals.

FIG. 17.16 Permanent contraceptive IUD, Essure by Bayer Healthcare Pharmaceuticals.

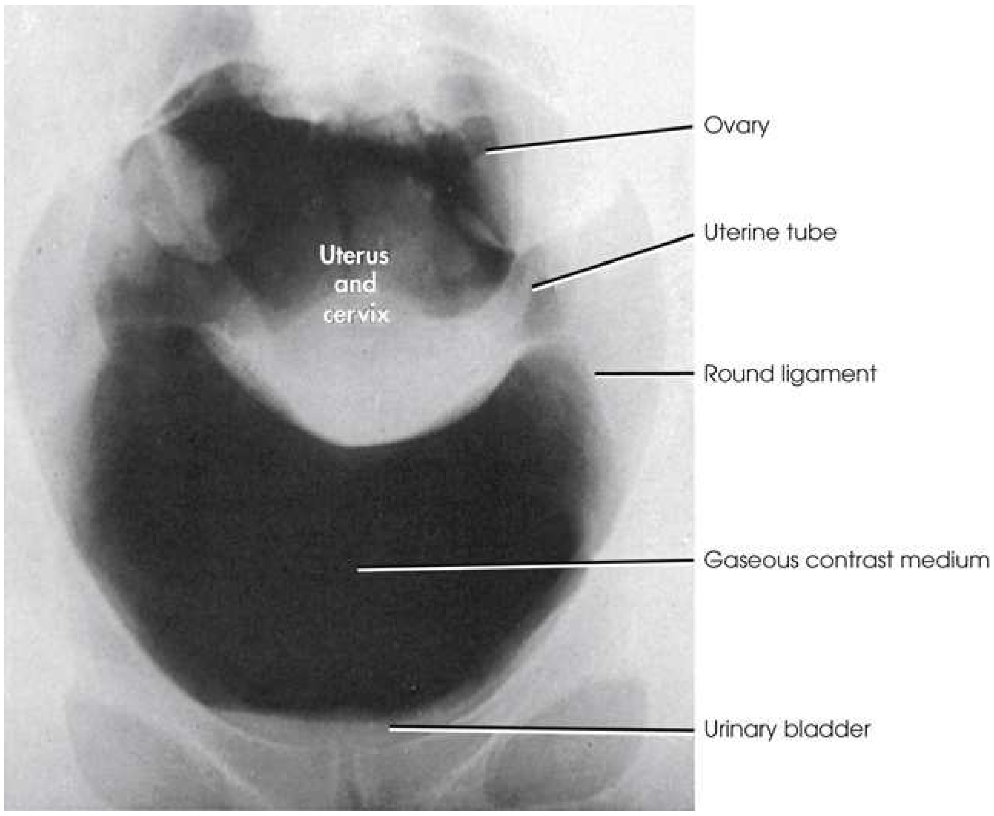


FIG. 17.17 Normal pelvic pneumogram. (See Fig. 17.3 for correlation with image.)

A pneumogram shows a small dark region on top and a bean-shaped dark region below. The surrounding region appears white and hazy. The parts labeled are as follows: ovary, uterine tube, round ligament, gaseous contrast medium, uterus, cervix, and urinary bladder.

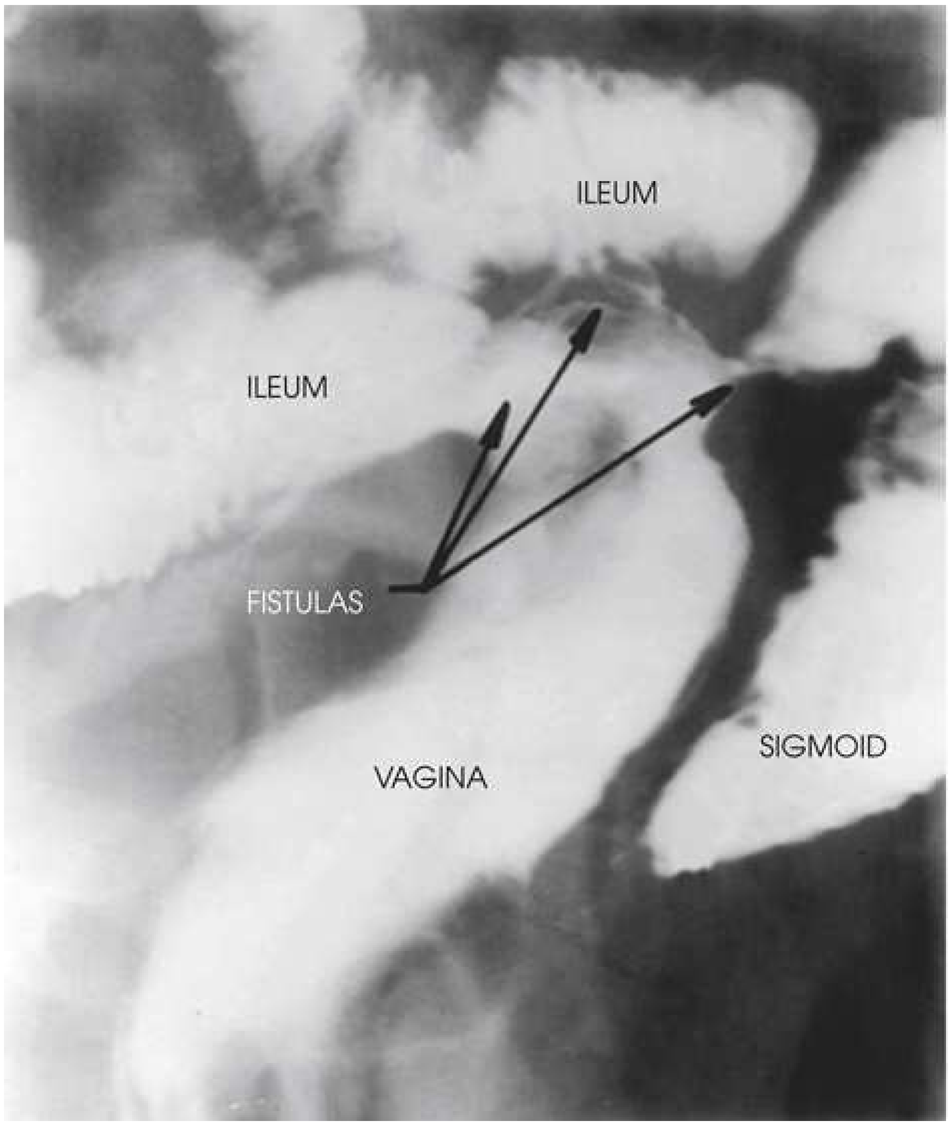


FIG. 17.18 Vaginogram, spot image, PA oblique projection, LAO position. Sigmoid fistula and two ileal fistulas are shown.

Pelvic pneumography

Pelvic pneumography, gynecography, and *pangynecography* are the terms used to denote radiologic examinations of the female pelvic organs via intraperitoneal gas insufflation (Fig. 17.17). These procedures have essentially been replaced by ultrasonography and other diagnostic techniques. (Pelvic pneumography is described in Volume 3 of the fourth edition of this atlas.)

Vaginography

Vaginography is used in the investigation of congenital malformations and pathologic conditions such as vesicovaginal and enterovaginal fistulas. The examination is performed by introducing a contrast medium into the vaginal canal. Lambie et al. [2] recommended using a thin barium sulfate mixture to investigate fistulous communications with the intestine. At the end of the examination, the patient is instructed to expel as much of the barium mixture as possible, and the canal is cleansed by vaginal irrigation. To investigate other conditions, Coe [3] advocated the use of an iodinated organic compound.

A rectal retention tube is employed to introduce the contrast medium so that a moderately inflated balloon can be used to prevent reflux. In one technique, the physician inserts only the tip of the tube into the vaginal orifice. The patient is then asked to extend her thighs and to hold them in close approximation to keep the inflated balloon pressed firmly against the vaginal entrance. In another technique, the tube is inserted far enough to place the deflated balloon within the distal end of the vagina and the balloon is inflated under fluoroscopic observation. The barium mixture is introduced with the usual enema equipment. The water-soluble medium is injected with a syringe.

Vaginography is performed on a combination fluoroscopy-radiography table. Contrast medium is injected under fluoroscopic control, and spot images are exposed as indicated during the filling (Fig. 17.18).

The images in Figs. 17.19 through 17.21 were taken with the central ray directed perpendicular to the midpoint of the IR. For localized studies, the central ray is centered at the level of the superior border of the pubic symphysis.

In each examination, the radiographic projections required are determined by the radiologist according to fluoroscopic findings. Low rectovaginal fistulas are best shown in the lateral projection, and fistulous communications with the sigmoid or ileum or both are best shown in oblique projections.

Evaluation Criteria

The following should be clearly seen:

- Superior border of the pubic symphysis centered on the image
- Any fistulas in their entirety
- Pelvis on oblique projections not superimposed by the proximal thigh
- Superimposed hips and femora in the lateral image
- The vagina and any fistula

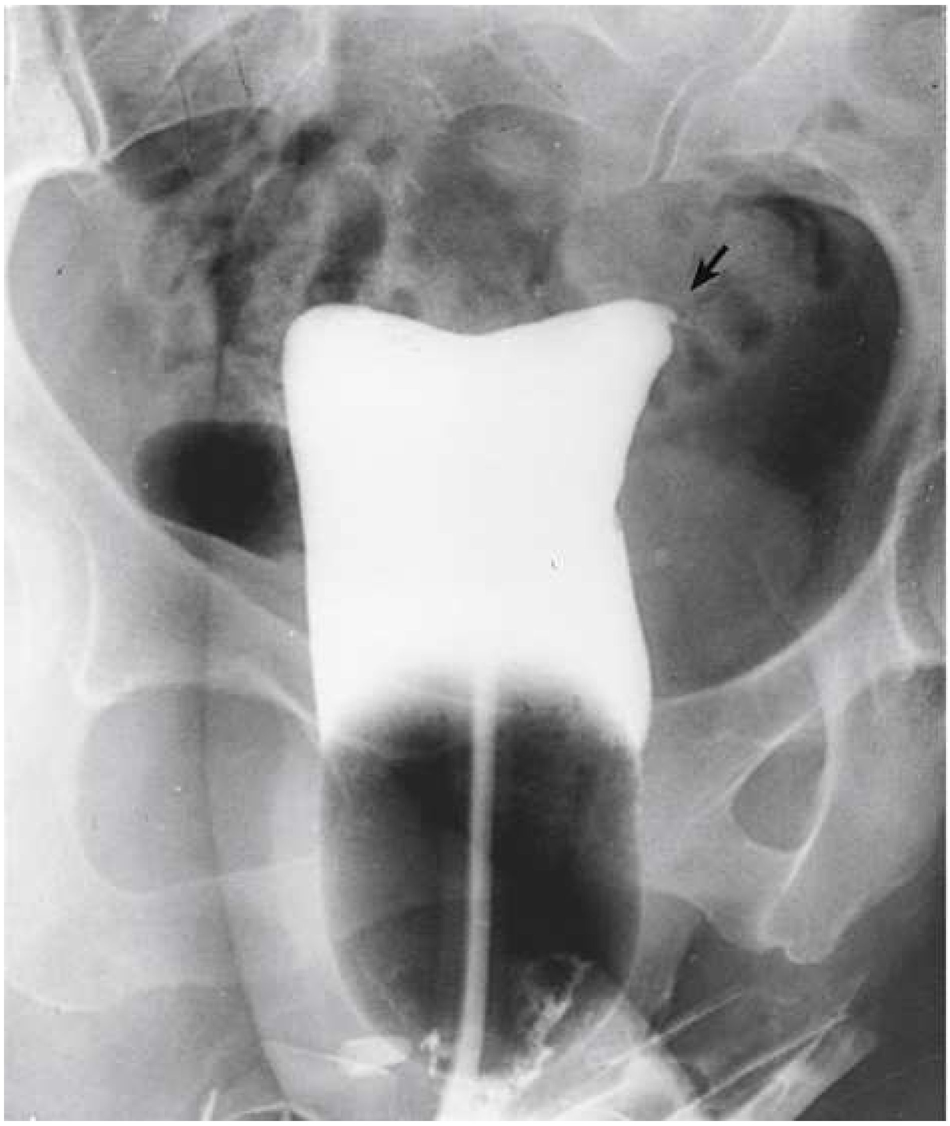


FIG. 17.19 Vaginogram, AP projection, showing small fistulous tract *(arrow)* projecting laterally from apex of vagina and ending in abscess.

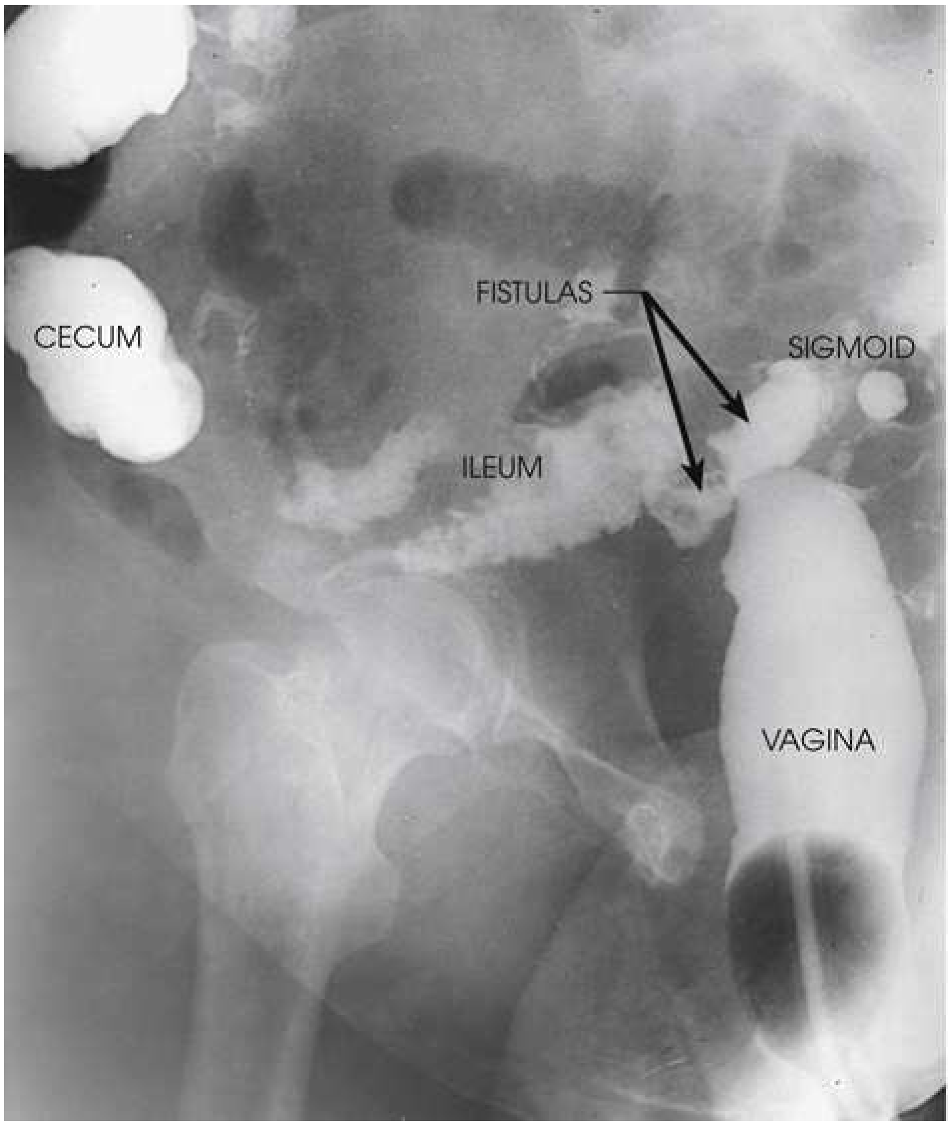


FIG. 17.20 Vaginogram, AP oblique projection, RPO position. Fistulas to ileum and sigmoid are shown.

A vaginogram shows pale white cloudy regions and some white regions. The surrounding regions appear hazy. The pale white regions are labeled as vagina, ileum, sigmoid, ileum and the white area is labeled as cecum. The fistulas are indicated by two black arrows.

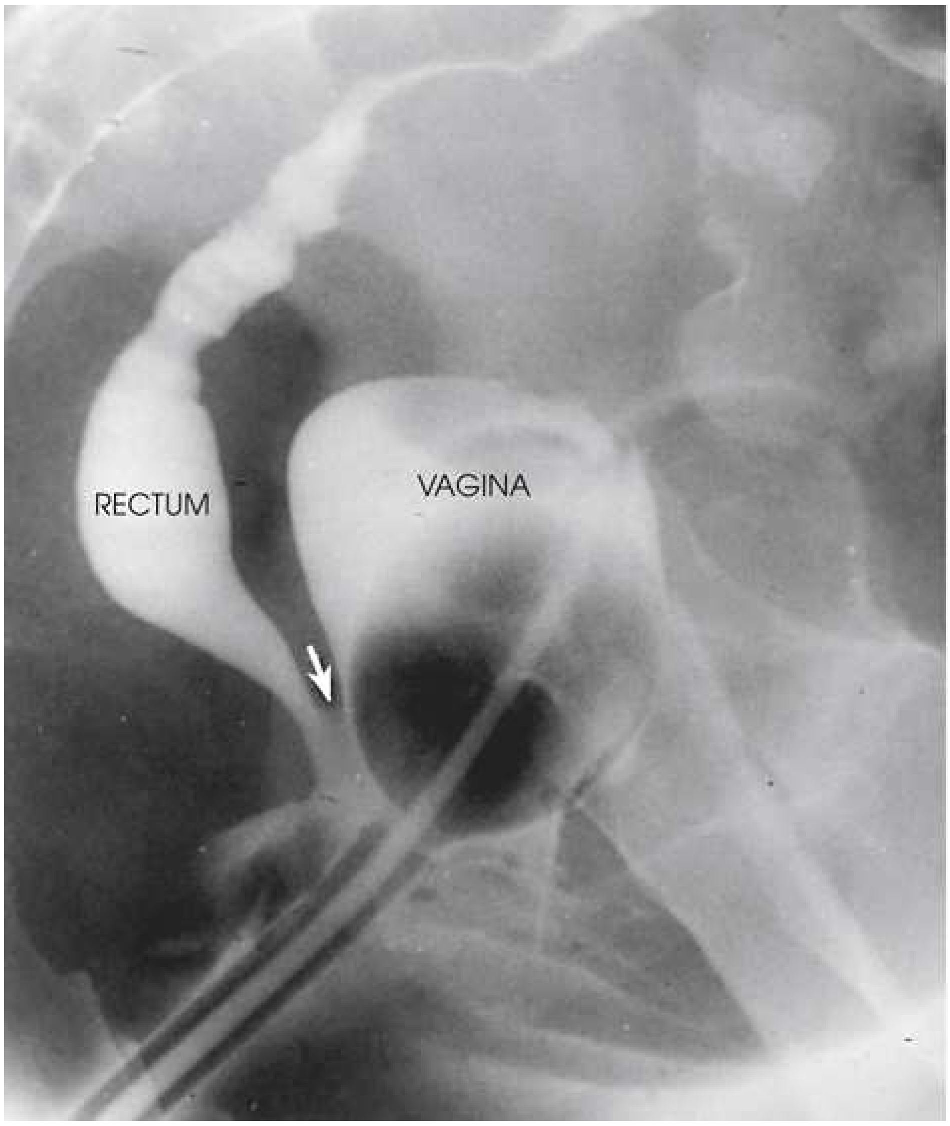


FIG. 17.21 Vaginogram, lateral projection, showing low rectovaginal fistula.

A vaginogram shows a radiolucent area in the middle. A pale white region above is labeled as vagina. A tube-like structure that gets broader and then gets narrow is labeled as rectum. A white arrow indicates a low rectovaginal fistula.

Pregnant Patient

Ultrasonography provides visualization of the fetus and placenta with no apparent risk to the patient or fetus. Diagnostic sonography is the preferred diagnostic tool for examining a pregnant woman. For informational purposes, the following radiographic procedures are defined:

- *Fetography*—radiographic examination of the fetus in utero to detect suspected abnormalities of development, to confirm suspected fetal death, to determine the presentation and position of the fetus, and to determine whether the pregnancy is single or multiple (Fig. 17.22). This examination should be performed after the 18th week of gestation due to the danger of radiation-induced fetal malformations.

FIG. 17.22 Fetography, PA projection. Twin pregnancy showing two fetal heads *(arrows and arrowheads)*.

- *Pelvimetry*—radiographic examination to demonstrate the architecture of the maternal pelvis and the size of the fetal head so as to determine the necessity of a cesarean section.
- *Placentography*—radiographic examination to demonstrate the walls of the uterus for localization of the placenta in cases of suspected placenta previa.
- For more detailed information on these procedures, refer to the 12th and earlier editions of this atlas.

Radiation protection

Radiologic examinations of pregnant patients are performed only when the required information can be obtained in no other way. In addition to the danger of genetic changes that may result from reproductive cell irradiation is the danger of radiation-induced malformations of the developing fetus. When possible, radiation for any purpose is avoided during pregnancy, especially during the first trimester of gestation. If examination of the abdominopelvic region is necessary, it is restricted to the absolute minimum number of images. The radiographer's responsibility is to perform the work carefully and thoughtfully so that repeat exposures will not be unnecessary.

Male Imaging

Seminal Ducts

Imaging examinations of the seminal ducts are performed to investigate certain genitourinary abnormalities, such as cysts, abscesses, tumors, inflammation, and sterility. Ultrasound is the most commonly used modality for examination of the male reproductive organs.

Contrast studies of the seminal vesicles may be studied in the 13th and previous editions of this atlas. [4–6] Ultrasound now demonstrates the anatomy of the male reproductive system as well as the previously mentioned pathologies, as shown in Figs. 17.23 through 17.26.

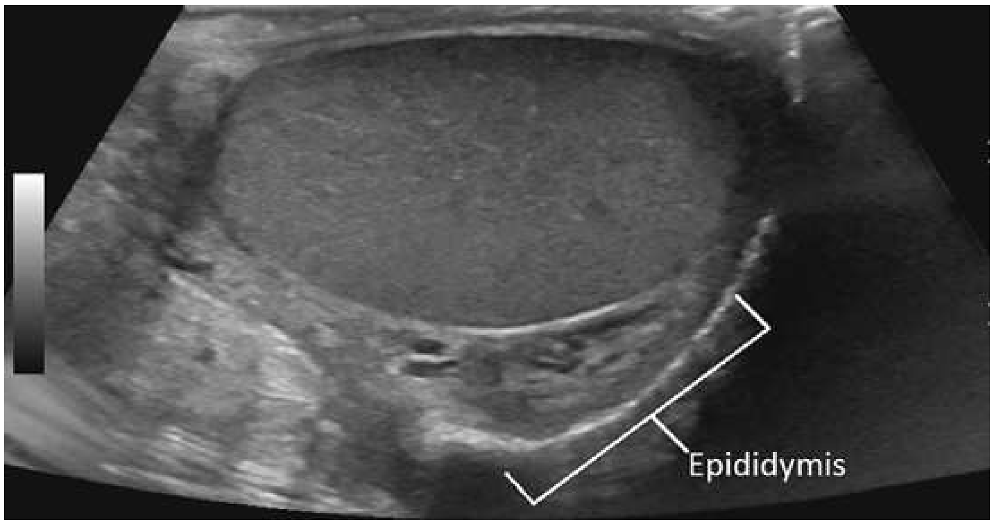


FIG. 17.23 Ultrasound image of normal left testicle and epididymis, sagittal plane. Courtesy Nisa Hinklin, RT[R], RDMS[AB], NEA Baptist Memorial Hospital, Jonesboro, AR.

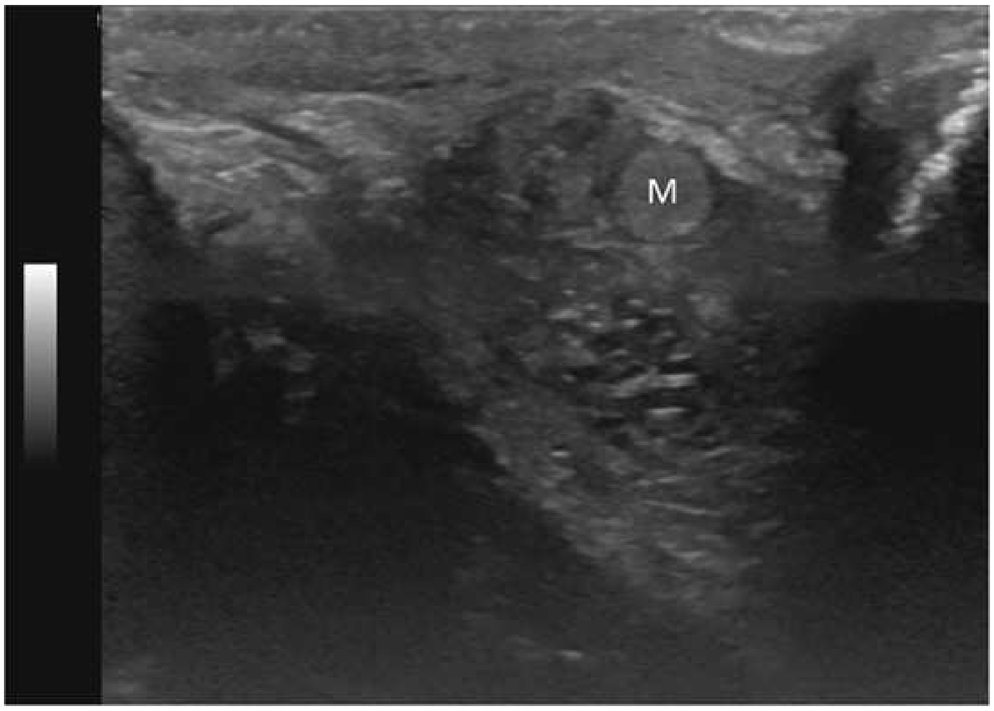


FIG. 17.24 Ultrasound image, sagittal plane. Epididymitis and scrotal mass *(M)*. Note enlarged and patchy, mottled echogenicity, as compared with normal epididymis in Fig. 17.23. Courtesy Natalie Cox, RT[R], RDMS[AB][OB], NEA Baptist Memorial Hospital, Jonesboro, AR.

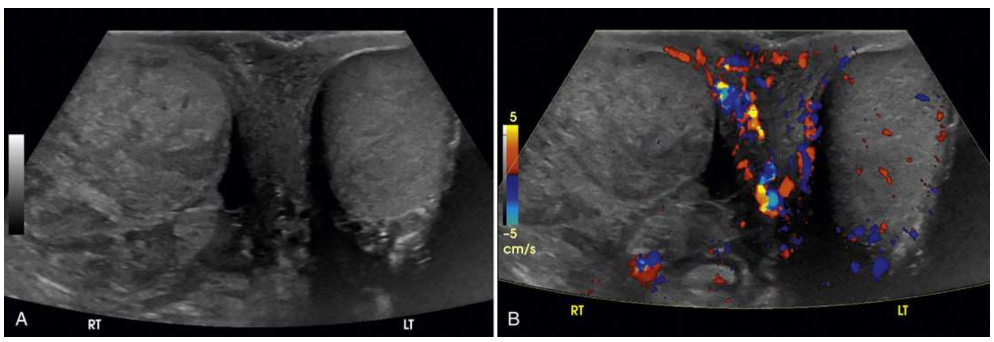


FIG. 17.25 Bilateral midline transverse images of testicles. Testicular torsion, right side. (A) Ultrasound image showing enlarged right testicle and patchy echogenicity (note homogeneous echogenicity of normal left testicle). (B) Color Doppler in same patient, same plane. Note lack of color in right testicle. Evidence of torsion. Courtesy Nisa Hinklin, RT[R], RDMS[AB], NEA Baptist Memorial Hospital, Jonesboro, AR.

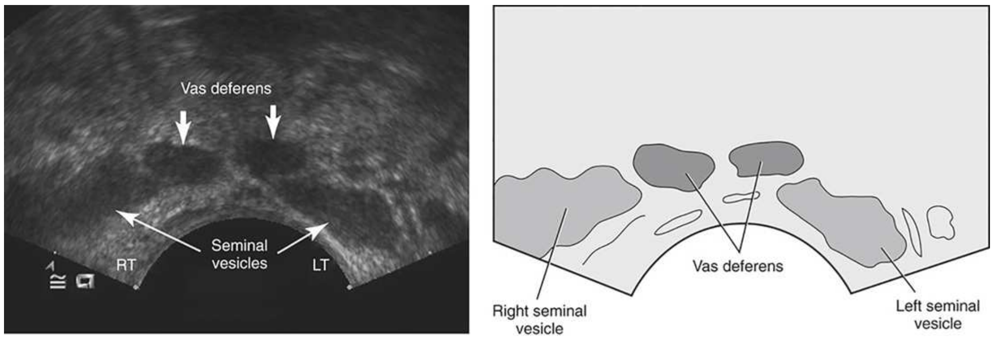


FIG. 17.26 Transrectal ultrasound image of normal seminal vesicles (long axis). From Curry R, Tempkin B. *Sonography: Introduction to normal structure and function.* ed 4. St. Louis: Elsevier; 2016.

An ultrasound image shows a concave area at the bottom. There are two dark oval regions labeled as vas deference and a few irregular dark regions around it labeled as seminal vesicles. A diagram next to it shows a concave area at the bottom. There are two dark oval regions labeled as vas deference and a few irregular dark regions around it labeled as seminal vesicles.

Prostate

Prostatography is a term applied to investigation of the prostate by radiographic, cystographic, or vesiculographic procedures. It is seldom performed today because of advances in diagnostic sonography (Fig. 17.27). Radiographic examination of the prostate gland is described in the 8th and earlier editions of this atlas.

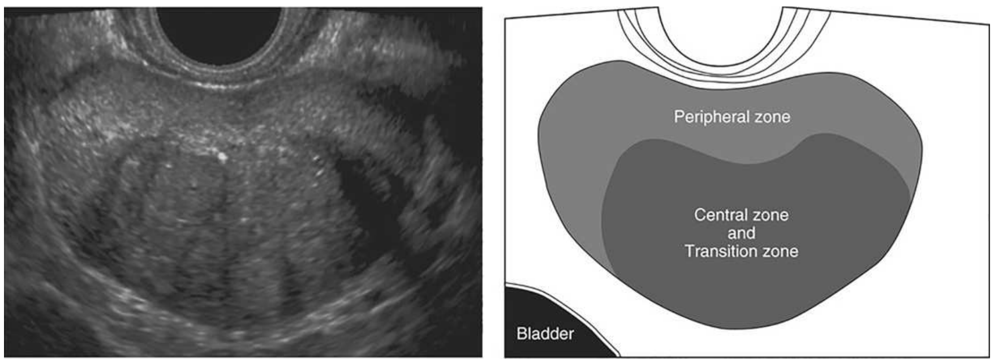


FIG. 17.27 Transrectal ultrasound image of normal prostate gland showing zonal anatomy. From Curry R, Tempkin B. *Sonography: Introduction to normal structure and function,* 4th ed. St. Louis: Elsevier; 2016.

A transrectal ultrasound image shows a heart-shaped dark region surrounded by a grey region. A diagram next to it shows a heart-shaped dark region labeled as central zone and transition zone is surrounded by a grey region labeled as peripheral zone.

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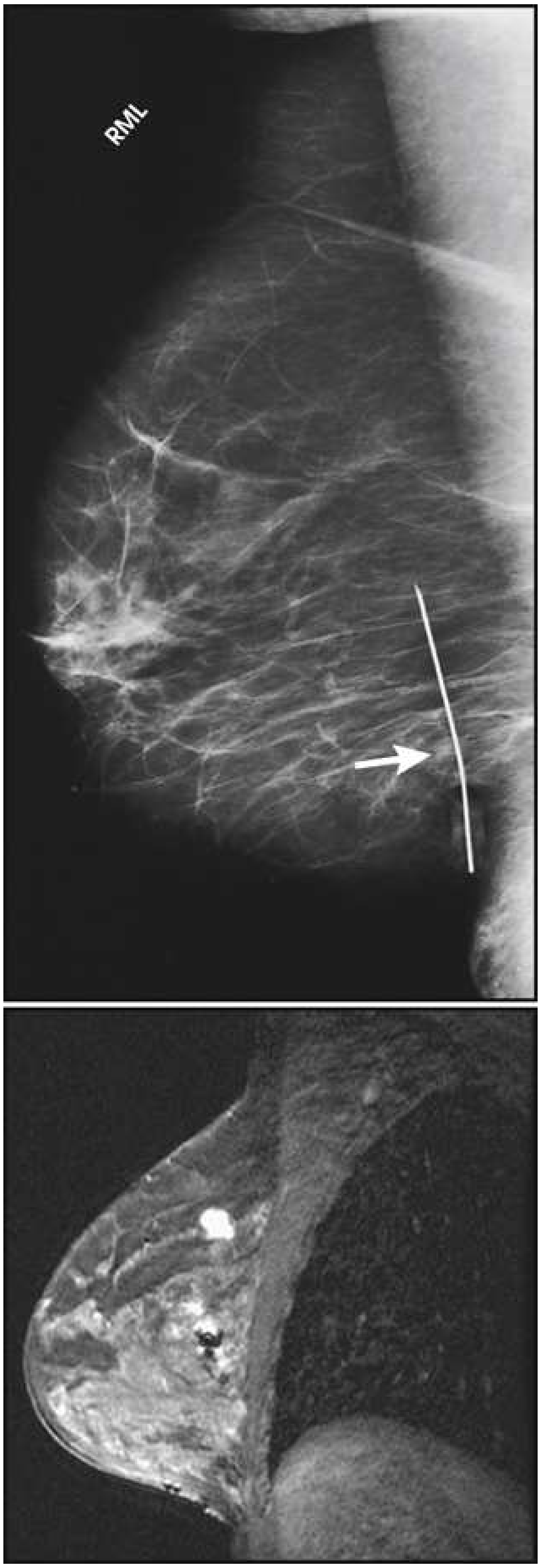

RML

OUTLINE

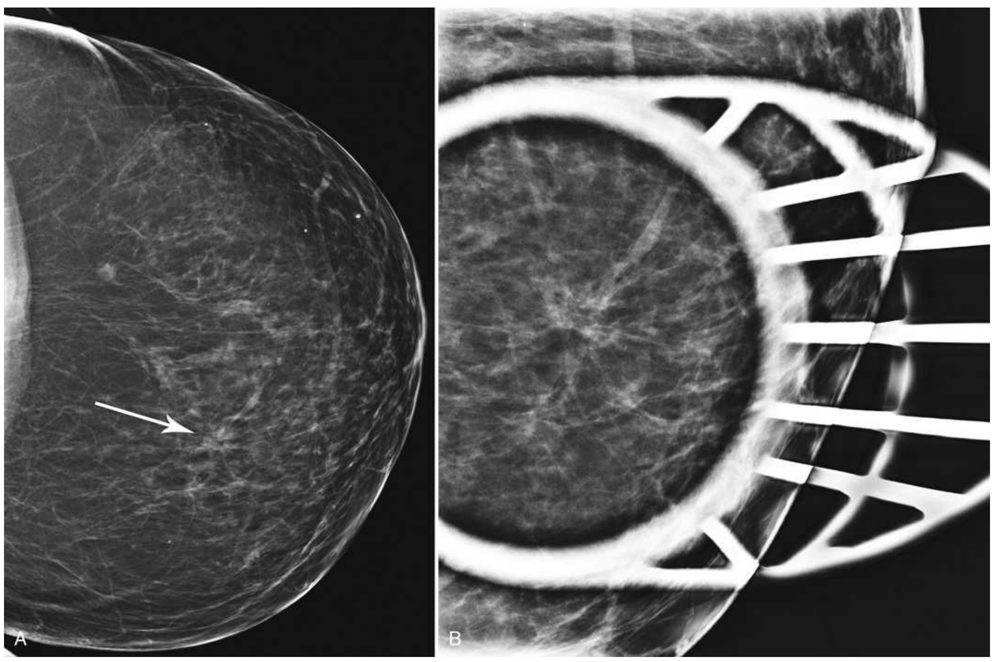


FIG. 18.20 Architectural distortion is seen on this CC projection (A). Spot compression view (B) of this area confirms that this is a mass, not overlapped tissue. This proved to be invasive ductal carcinoma on biopsy.

(A) A mammogram shows a network of a white spot on the breast tissue. It is indicated by an arrow. (B) A mammogram shows an enlarged view of the white spot that is concentrated in the center of the breast tissue.

Summary of Projections

Projections, Positions, and Methods				
Page	**Essential**	**Anatomy**	**Projection**	**Method**
400		Breast	Craniocaudal *(CC)*	
402		Breast	Mediolateral oblique *(MLO)*	
406		Breast	Craniocaudal *(CC)*	IMPLANT
408		Breast	Craniocaudal *(CC ID)*	IMPLANT DISPLACED
410		Breast	Mediolateral oblique *(MLO)*	IMPLANT
411		Breast	Mediolateral oblique *(MLO ID)*	IMPLANT DISPLACED
414		Breast	Variable *(M)*	MAGNIFICATION
415		Breast	Variable	SPOT COMPRESSION
419		Breast	Mediolateral *(ML)*	
421		Breast	Lateromedial *(LM)*	
423		Breast	Exaggerated craniocaudal *(XCCL)*	
425		Breast	Craniocaudal *(CV)*	CLEAVAGE
427		Breast	Craniocaudal *(RL)*	ROLL LATERAL
427		Breast	Craniocaudal *(RM)*	ROLL MEDIAL
429		Breast	Tangential *(TAN)*	
431		Breast	Variable *(CL)*	CAPTURED LESION
434		Breast	Caudocranial *(FB)*	FROM BELOW
436		Breast	Mediolateral oblique *(AT)*	AXILLARY TAIL
440		Breast	Lateromedial oblique *(LMO)*	
442		Breast	Superolateral to inferomedial oblique *(SIO)*	

Icons in the Essential column indicate projections frequently performed in the United States and Canada. Students should be competent in these projections.

Principles of Mammography

Introduction and Historical Development

The worldwide incidence of breast cancer is increasing. In the United States, one in eight women who live to age 95 years develop breast cancer some time during their lifetime. Breast cancer is one of the most common malignancies diagnosed in women; only lung cancer has a greater overall mortality in women. Research has failed to reveal the precise etiology of breast cancer, and only a few major factors, such as family history, are known to increase a woman's risk of developing the disease. Most women who develop breast cancer have no family history of the disease, however.

Despite its frequency, breast cancer is one of the most treatable cancers. Because this malignancy is most treatable when it is detected early, efforts have been directed toward developing breast cancer screening and early detection methods. Death rates for breast cancer in the United States have declined by 38% since 1989, [1] with larger decreases in younger women; from 2005 to 2009, rates decreased 3.0% per year in women younger than 50 and 2.0% per year in women 50 and older. [2] The decrease in breast cancer death rates represents progress in earlier detection, improved treatment, and possibly decreased incidence as a result of declining use of menopausal hormone therapy (MHT).

Before the radical mastectomy was introduced by Halstead in 1898, breast cancer was considered a fatal disease. Less than 5% of patients survived 4 years after diagnosis, and the local recurrence rate for surgically treated breast cancer was >80%. Radical mastectomy increased the 4-year survival rate to 40% and reduced the rate of local recurrence to approximately 10%. No additional improvement in breast cancer survival rates occurred over the next 60 years. Some of the principles of breast cancer management were developed during this time, however, and these remain valid:

1. Patients in the early stage of the disease respond well to treatment.
2. Patients with advanced disease do poorly.
3. The earlier the diagnosis, the better the chance of survival.

Reflecting these principles, the theory of removing all palpable breast masses in hopes of finding earlier cancers was developed, and it was recognized that careful physical examination of the breast could lead to the detection of some early breast cancers. Most patients with breast cancer still were not diagnosed until their disease was advanced, however. This fact, coupled with the dismal breast cancer survival statistics, highlighted the need for a tool for the early detection of breast cancer. Mammography filled that need (Fig. 18.1).

FIG. 18.1 Four-image, bilateral mammogram. Craniocaudal and mediolateral oblique projections show normal, symmetric, heterogeneously dense breast parenchyma.

In 1913, Albert Soloman, a German physician, reported the radiographic appearance of breast cancers. Using radiographic studies of cancerous breasts removed at surgery, he described the mechanism of how breast cancer spread. Stafford Warren of Rochester, New York, noted in 1926 that he was able to see a reasonable image of the female breast during thoracic aortic fluoroscopy and published a report of 119 women, 48 with breast cancer.[3] The first published radiograph of a living person's breast, made by Otto Kleinschmidt, appeared in a 1927 German medical textbook on malignant tumors. Although publications on mammography appeared in South America, the United States, and Europe during the 1930s, the use of mammography for the diagnosis of breast cancer received little clinical interest. A few pioneers, including LeBorgne in Uruguay, Gershon-Cohen in the United States, and Gros in Germany, published excellent comparisons of mammographic and pathologic anatomy and developed some of the clinical techniques of mammography. At that time, the significance of breast microcalcifications was also well understood.

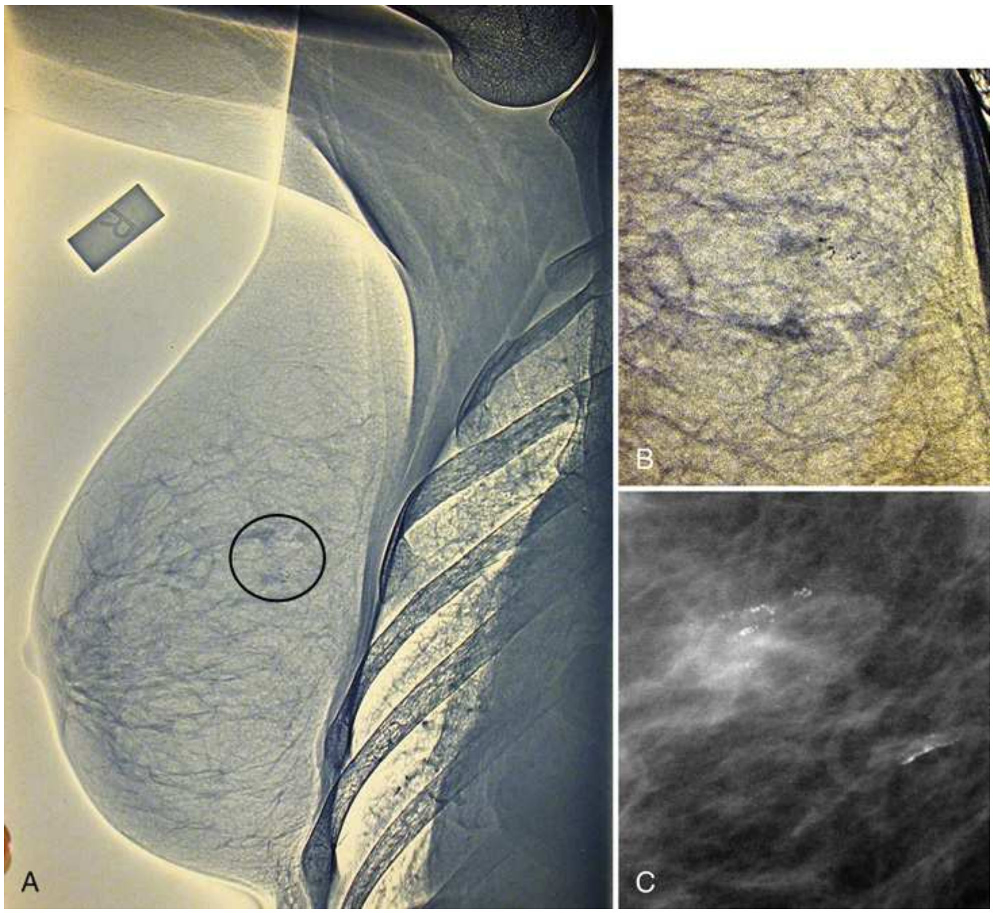


FIG. 18.2 (A) Right lateral xeromammogram, circa 1981. (B) *Circled area* from (A) is photographically magnified, showing small area of microcalcifications. (C) Film-screen magnification study 10 years later shows same calcifications. This was proven to be ductal carcinoma in situ on biopsy.

By the mid-1950s, mammography was considered a reliable clinical tool because of such refinements as low-kilovoltage x-ray tubes with molybdenum targets and high-detail, industrial-grade x-ray film. During this time, Egan in the United States and Gros in Germany popularized the use of mammography by utilizing industrial-grade x-ray film for diagnosing and evaluating breast cancer. Breast xerography was introduced in the 1960s and was popularized by Wolfe and Ruzicka. Xerography substantially reduced the radiation dose received by the patient compared with the dose received using industrial-grade x-ray film (Fig. 18.2). Because many physicians found xerographic images easier to understand and evaluate, xeromammography became widely used for evaluating breast disease. The first attempts at widespread population screening began at this time.

The combination of higher-resolution, faster x-ray film, and an intensifying screen was first introduced by the DuPont Company. As a result, radiation exposure to the patient was reduced even more. Improved screen-film combinations were developed by Kodak and DuPont in 1975. By this time, extremely high-quality mammography images could be produced with very low patient radiation exposure. After 1975, faster lower-dose films, the magnification technique, and grids for scatter reduction were introduced. These factors, along with improved positioning and clinical techniques, catapulted mammography into use as a mainstream diagnostic and screening tool for breast cancer.

Evolution of Mammography Systems

Because the breast is composed of tissues with very similar densities and effective atomic numbers, little difference in attenuation is noticed when conventional x-ray equipment and techniques are used. Therefore, manufacturers have developed imaging systems that optimally and consistently produce images with high contrast and resolution.

Diligent research and development began in the 1960s, and the first dedicated mammography unit was introduced in 1967 by CGR (France) (Fig. 18.3). In the 1970s, increased awareness of the elevated radiation doses prevalent in mammography served as the catalyst for the rapid progression of imaging systems. In the 1970s and the early 1980s, xeromammography, named for the Xerox Corporation that developed it, was widely used (see Fig. 18.2). This method, which utilized charged selenium plates as an image receptor (IR), used much less radiation than the direct-exposure, silver-based films that were available. The charged plates were processed using a device that sprayed blue powder, which adhered to the plates according to the charged latent image. The powder was then transferred to paper, giving xerography its distinctive look.

Eventually, film manufacturers introduced several generations of mammography film-screen systems that used even less exposure and improved tissue visualization. Each subsequent new system showed improvement in contrast and resolution while minimizing patient dose.

In the 1980s, the American College of Radiology (ACR) accreditation program established quality standards for breast imaging to optimize mammographic equipment, processors, and screen-film systems to ensure the production of high-quality images. This program was expanded in the 1990s to include quality control and personnel qualifications and training. The voluntary ACR program became the model from which the Mammography Quality Standards Act of 1992 (MQSA) operates, and the ACR has been instrumental in designing clinical practice guidelines for quality mammography in the United States. The evolution of mammography has resulted in the implementation of radiographic systems designed specifically for breast imaging.

Mammography Equipment

Over the years, equipment manufacturers have produced dedicated mammography units with high-frequency generators, various tube and filter materials, focal spot sizes that allow tissue magnification, specialized grids to help improve image quality, digital imaging capabilities, and streamlined designs with ergonomic patient positioning aids.

The high-frequency generators offer more precise control of kilovolt (peak) (kVp), milliamperes (mA), and exposure time. The linearity and reproducibility of radiographic exposures using high-frequency generators are uniformly excellent. The greatest benefit of these generators may be the efficient waveform output that produces a higher effective energy x-ray beam per set kVp and mA. High-frequency generators are not as bulky and can be installed within the single-standing mammography unit operating on single-phase incoming line power, facilitating installation and creating a less intimidating appearance (see Fig. 18.3).

FIG. 18.3 (A) First dedicated mammography system: Senographe by CGR (France). (B) Senographe DMR film-screen mammography unit by General Electric (Milwaukee, WI). (C) Dimensions 3D digital breast tomosynthesis unit by Hologic (Bedford, MA).

As manufacturers of dedicated mammography equipment have sought to improve image quality, they have tried many different combinations of tube and filter materials. The most widely accepted combinations used at this time are molybdenum target with molybdenum filter (Mo/Mo), molybdenum target with rhodium filter (Mo/Rh), rhodium target with rhodium filter (Rh/Rh), tungsten/rhodium (W/Rh), and tungsten/silver (W/Ag). The Mo/Rh and Rh/Rh combinations are most commonly used; W/Rh and W/Ag are used for better penetration of extremely dense, thick breasts.

Specialized grids were developed for mammography during the 1980s to reduce scatter radiation and increase image contrast in mammography. Many units employ moving linear focused grids, but other manufacturers have developed very specialized grids. The Hologic (Lorad) High Transmission Cellular (HTC) grid employs a honeycomb-pattern, multidirectional design. All dedicated mammography units today, with the exception of slit-scan digital units, still employ grids.

Manufacturers also knew that technologists and physicians were interested in the comfort of their patients. They worked to make the examination more tolerable for patients, more ergonomically acceptable, and more efficient for the technologist performing the examination while developing positioning aids to increase visualization of the tissue. Some of these aids include rounded corners on breast platforms and compression paddles, automatic release of compression after exposure, and foot pedal controls.

The next logical step toward improved breast imaging has been the adoption of full-field digital mammography (FFDM), which was first approved by the FDA in 2000, and digital breast tomosynthesis (DBT), also referred to as 3D breast imaging, which was approved in 2011. To bring mammography into the digital world was no simple task. To achieve the resolution and detail necessary for breast imaging, entire systems, from acquisition to diagnostic review workstations, were developed by competing manufacturers. Each of these included proprietary components that made integration of the units into a current picture archiving and communication system (PACS) network difficult. Integrating the Healthcare Enterprise (IHE) has brought together manufacturers of the many components necessary in a FFDM system to work out problems of compatibility and language, allowing facilities the opportunity to transition more seamlessly into digital mammography. More work will be needed in this arena as structural (mammography, CT, DBT) and functional (MR, single photon emission computed tomography [SPECT], positron emission tomography [PET], molecular) imaging are combined.

Full-Field Digital Mammography

Mammography has been the last area in the field of radiography to take advantage of digital technology. In addition to the many technical issues associated with FFDM, the prohibitive cost of the equipment and its maintenance made digital mammography not practical for all facilities. Its many advantages in imaging dense breast tissue have provided the motive, however, for more than 98% of mammography facilities in the United States to transition to this technology over the past decade; 38% of these facilities have also moved forward into DBT. [4]

FFDM units allow radiologists to manipulate digital images electronically, potentially saving patients from undergoing additional projections and additional radiation. The ability to manipulate digital images improves the sensitivity of mammography, especially in women with dense breast tissue. Results of the American College of Radiology Imaging Network Digital Mammographic Imaging Screening Trial (ACRIN DMIST) study, a multifacility, multiunit study comparing film-screen mammography with digital mammography, were published in September 2005. [5] The authors of this study concluded that FFDM would benefit some patients, specifically women younger than age 50, premenopausal and perimenopausal women, and women of any age with dense breast tissue.

Digital breast imaging requires much finer resolution than other body imaging. FFDM images are extremely large files that require a great deal of archival space in PACS. Because of regulations safeguarding the image quality of mammography, the images cannot be interpreted on a traditional PACS workstation; they can be interpreted only on high-resolution 5-megapixel or better monitors.

Innovative solutions and approaches to FFDM continue to be developed. In 2011, the FDA approved DBT for clinical use, and since then, it has consistently proven advantageous. It is now considered the new standard of patient care in many practices.

Digital Breast Tomosynthesis

DBT is a three-dimensional imaging technology that acquires images of a stationary, compressed breast at multiple angles during a short scan. These images are reconstructed into thin, high-resolution slices that can be displayed individually or in a dynamic cine mode. With the ability to view each separate slice representing breast tissue as thin as 1 mm, DBT allows for improved image detail in mammography. While the positioning of the breast remains unchanged, each DBT unit differs in its acquisition of the images.

DBT utilizes the same mammographic positioning and compression used with conventional FFDM, but instead of taking one image perpendicular to the compressed breast, the x-ray tube arches over the patient, taking a series of low-dose images. Each manufacturer's machine differs in how the tomosynthesis image is acquired. These variations include tube angle range, movement of the tube as it acquires images, and a stationary versus arching detector.

As the x-ray unit begins taking tomosynthesis exposures, the tube shifts in one direction, then moves over the central pivot point of the breast to a corresponding angle from the opposite direction. This tube angular range can vary from 11 to 60 degrees depending on the manufacturer. The number of images taken depends on the thickness of the breast; the thicker the breast, the more images or slices. Typically, each exam acquires between 7 and 30 low-dose tomosynthesis projections.

Different manufacturers' DBT machines also vary on the movement of the tube. One method is the sweep mode, which rotates the tube in a smooth, continuous manner from one point to the other as images are pulsed at the frame rate of the detector. With the step-and-shoot method, the tube stops at each angle or position to acquire an image while the tube is stationary. The tube then moves between each image either in an arch or sweeps across a linear path depending on a stationary or mobile detector. Tubes with a stationary detector arch over the compressed breast. In moving systems, the tube and receptor are synchronized as they sweep across a linear field. [6]

While each system varies on when and how the tomosynthesis images are taken, all DBT systems on the market have the same capabilities to acquire these images in numerous ways. Tomosynthesis views can be taken at any position or angle and with spot compression paddles, but not as magnified views. [7] Each unit can also take an FFDM image alone, a series of just DBT images, FFDM-DBT combination, or a DBT synthesized view. The DBT machines can simultaneously combine the two-dimensional FFDM and the additional exposures necessary to reconstruct a three-dimensional image while the patient is positioned and compressed once. Some machines include a procedure that takes only the series of tomographic low-dose images and processes them to form one two-dimensional image. This synthesized mammography image is essentially each tomographic slice put into focus through a mathematical algorithm. Research has proven that the quality of synthesized images is equivalent to FFDM images, while gaining the benefits of tomosynthesis views with the same patient dose as FFDM alone. [8]

Patient dose has been a concern since the introduction of DBT. For radiologists to assess changes in breast tissue, a two-dimensional image is needed to compare with prior images for evaluating if tissue abnormalities or microcalcification clusters are present in the breast. [8] The initial application of DBT in the clinical practice primarily used FFDM-DBT combination images. This nearly doubles the patient dose; however, the mean glandular dose is still below the limits approved by the FDA, which constitutes an acceptable risk. [9] By eliminating the FFDM and utilizing synthesized mammography, the mean glandular dose decreases by 40% to 50% compared to FFDM-DBT. This dose is equivalent to FFDM images, thus becoming the preferred modality. [8]

The benefits of DBT include increased visualization of breast abnormalities and decreased patient recall rates. Numerous studies have found an increased detection rate for invasive breast cancer with FFDM-DBT versus FFDM. A large study by Friedewald et al. accredited FFDM-DBT with a 41% increase in detection among the screening population. [9] With DBT, radiologists can better visualize areas of architectural distortion (AD), masses and focal asymmetries otherwise obscured by overlying tissue (Fig. 18.4). Microcalcification clusters can also be discerned from adjacent masses. DBT helps physicians determine mammographic extent of disease with a more precise assessment of tumor sizes. It also aids in localizing single-view abnormalities by determining where the lesion is located within the tomographic slices. [7]

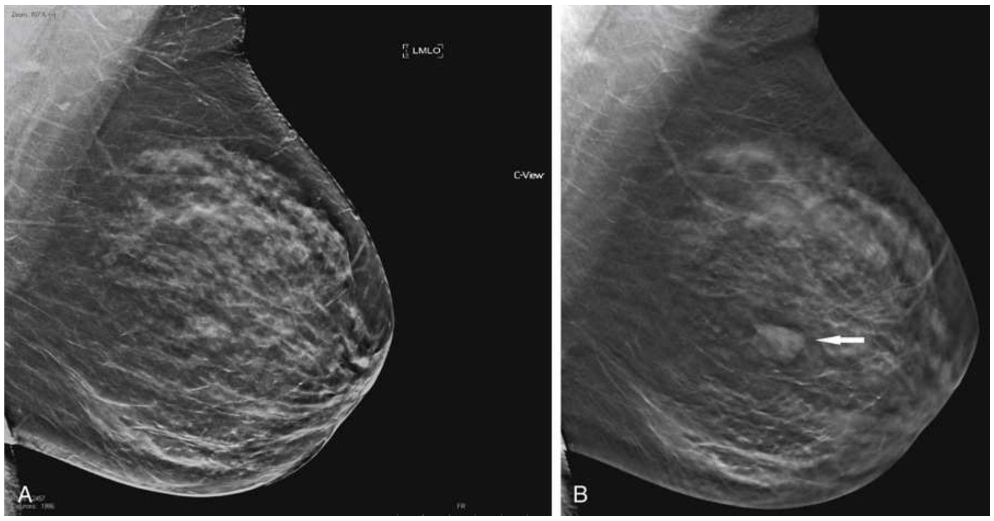


FIG. 18.4 (A) Digital breast tomosynthesis view utilizing synthesized mammography. (B) One of the tomosynthesis slices taken at the same time; note a mass *(arrow)* is better defined than in the two-dimensional view.

As DBT imaging separates breast tissue with each slice, it reduces tissue overlap, thus considerably reducing recall rates. [8] Skin calcifications are easier to distinguish, and other benign findings such as lymph nodes are more evident. [7] These advantages have made DBT with synthetic mammography the current modality of choice for breast cancer screening.

Computer-Aided Detection

When performing mammographic interpretation, the radiologist must locate any suspicious lesions (sensitivity) and then determine the probability that the lesion is malignant or benign (specificity). Even with high-quality mammography, some breast cancers are missed on initial interpretation. Double-reading of screening mammograms by a second radiologist can improve detection rates by approximately 10%. [10] It has also been found that double-reading plus the use of computer-aided detection (CAD) can increase detection rates by an additional 8%. [11] Efforts have been made to develop and apply a CAD system to achieve the same result as double-reading. The use of CAD with a single reader has shown a 17% increase in ductal carcinoma in situ (DCIS) diagnoses and a 6% increase in early-stage invasive cancer diagnoses. However, these results do come with an increase in false positive exams, leading to increased additional testing and biopsies. [12]

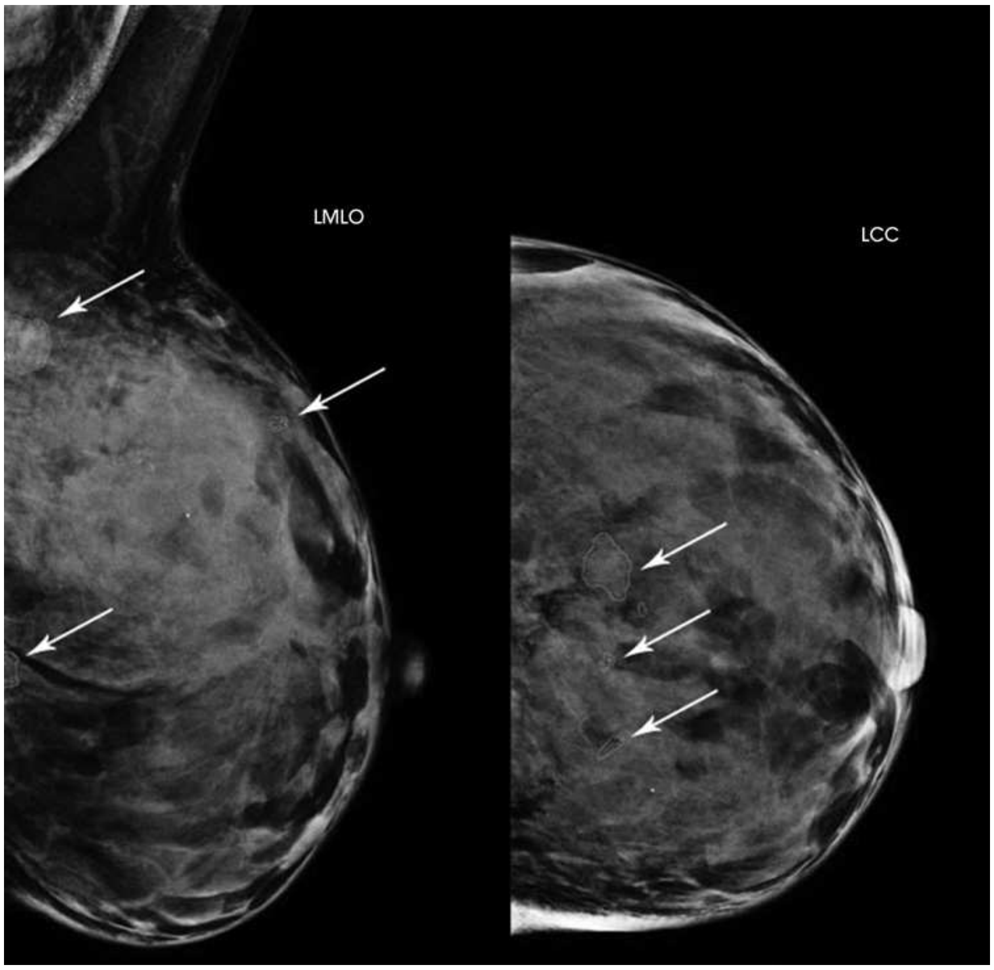


FIG. 18.5 Left mediolateral oblique (LMLO) and left craniocaudal (LCC) projections of extremely dense breast with CAD markers *(arrows)* indicating areas of suspicion that proved to be cancer.

CAD is a method by which a radiologist can use computer analysis of digitally acquired images as a "second opinion" before making a final interpretation. CAD works similarly to a spell-check on a computer; an area is pointed out for the radiologist to check, but it is up to the radiologist to decide whether the area is suspicious enough to warrant additional procedures. CAD requires that the mammographic image exists in a digital format to facilitate computer input. The computer may detect lesions that are missed by the radiologist, minimizing the possibility of false-negative readings (Fig. 18.5). When a lesion is detected, the computer can be programmed with basic algorithms to estimate the likelihood of malignancy, increasing true-positive rates. Ultimately, the objective of this technology is to improve early detection rates and minimize the number of unnecessary breast biopsies. Another advantage of CAD is that computers are not subject to the bias, fatigue, or distractions to which a radiologist may be subject. Because of the high rates of sensitivity and specificity shown by CAD, it has been implemented in many mammography practices.

Breast Cancer Screening

It is now known that high-quality mammography, careful physical examination, and monthly breast self-examination (BSE) can result in the detection of breast cancer at an early stage—when it is most curable.

The 5-year relative survival rate for female invasive breast cancer patients has improved from 75% in the mid-1970s to 90% today. The 5-year relative survival for women diagnosed with localized breast cancer (cancer that has not spread to lymph nodes or other locations outside the breast) is 99% [13] ; 61% of breast cancers are diagnosed at the localized stage. [14] If the cancer has spread to nearby lymph nodes (regional stage) or distant lymph nodes or organs (distant stage), the survival rate falls to 85% or 26%, respectively. [13]

Mammography must be performed well to be fully effective. The ACR had been a proponent of high standards in breast imaging since 1967 and implemented an optional Mammography Accreditation Program in 1989. In 1992, the MQSA was implemented to mandate the maintenance of high-quality breast cancer screening programs. In 1994, mammography became the only radiographic examination to be fully regulated by the federal government. MQSA requires formal training and continuing education for all members of the breast imaging team. In addition, imaging equipment must be inspected regularly, and all quality assurance activities must be documented. Facilities are also required to provide protocols documenting responsibility for communicating mammogram results to the patient and the referring physician, providing follow-up, tracking patients, and monitoring outcomes. The goal of MQSA is for high-quality mammography to be performed by individuals most qualified to do so and by individuals who are willing to accept full responsibility for providing that service with continuity of care.

Risk Versus Benefit

In the mid-1970s, the media-influenced public perception was that radiation exposure from diagnostic x-rays would induce more breast cancers than would be detected. Although radiation dosage during a mammography examination has decreased dramatically since the 1970s, fear of radiation exposure still causes some women to refuse mammography, and many women who undergo the examination are concerned about exposure levels and the resultant risk of carcinogenesis. To assuage these fears, the radiographer must understand the relationship between breast irradiation and breast cancer and the relative risks of mammography in light of the natural incidence of breast cancer and the potential benefit of the examination. [15] No direct evidence exists to suggest that the small doses of diagnostic x-rays used in mammography can induce breast cancer.

It has been shown, however, that large radiation doses can increase the incidence of breast cancer, and that the risk is dose dependent. Evidence to support an increased risk of breast cancer from breast irradiation comes from studies of three groups of women in whom the incidence of breast cancer increased after they were exposed to large doses of radiation: (1) women exposed to the atomic bombs at Hiroshima and Nagasaki, (2) women with tuberculosis who received multiple fluoroscopic examinations of the chest, and (3) women who were treated with radiation for postpartum mastitis. The radiation dose received by these women (600 to 700 rads) was many times higher than the dose received from mammography.

An important observation in the previously mentioned population studies is that the breast tissue of young women in their teenage years to early 20s seems to be much more sensitive to radiation than the breast tissue of women older than 30 years. Because breast irradiation is a concern, radiologic examinations need to be performed with only the radiation dose that is necessary for providing accurate detection.

Screening versus diagnostic mammography

The frequency with which women should undergo screening mammography depends on their age and personal risk of developing breast cancer. Current recommendations from the American Cancer Society, the ACR, and the Society of Breast Imaging are that all women older than 40 years should undergo annual mammography and should continue yearly mammography for as long as they are in reasonably good health otherwise. A baseline examination performed sometime before the onset of menopause is useful for comparison during subsequent evaluations. High-risk patients should consider beginning screening mammography at an earlier age.

The term *screening mammography* is applied to a procedure performed on an asymptomatic patient or a patient who presents without any known breast problems. For a procedure to be used as a screening method, it must meet the following criteria:

1. It must be simple.
2. It must be acceptable.
3. It must show high sensitivity.
4. It must show high specificity.
5. It must be reproducible.
6. It must be cost-effective.
7. It must have a low risk-to-benefit ratio.

Mammography is a relatively simple procedure that takes only about 15 minutes to complete. The acceptability of mammography has been confirmed in numerous studies. Mammography cannot detect all cancerous lesions, however. An annual clinical breast examination is recommended by the American Cancer Society. Many physicians also recommend that women perform monthly BSE. Even when mammography is performed properly, approximately 10% of cancers remain radiographically occult, particularly in dense breasts and augmented breasts. Even so, mammography has greater sensitivity and specificity for detecting breast tumors than any other currently available noninvasive diagnostic technique. When compared with magnetic resonance imaging (MRI) and ultrasonography, mammography is more cost-effective and more reproducible when quality control standards are maintained. Mammography must be performed properly to maintain these characteristics, however. As with other imaging modalities, high-quality mammography requires an extremely dedicated staff with the appropriate training and expertise.

Breast cancer screening studies have shown that early detection is essential for reducing mortality and that the most effective approach is to combine clinical breast examination with mammography at directed intervals. Although massive screening efforts initially may seem cost-prohibitive, the actual cost of screening in the long term is much less than the expenses involved in caring for patients with advanced breast disease. To this end, screening patients at high risk for breast cancer with the addition of annual breast MRI has been added to screening recommendations.

The preceding paragraphs describe the screening of patients who do not have significant breast symptoms. All patients with clinical evidence of significant or potentially significant breast disease should undergo a *diagnostic mammogram* and subsequent work-up as necessary. Diagnostic mammograms are problem-solving examinations in which specific projections are obtained to rule out cancer or to get a better view of a suspicious area seen on routine screening projections. They are also indicated if a woman presents with a palpable mass or other symptoms. The area of interest may be better shown using image enhancement methods, such as spot compression and the magnification technique. Further work-up may be necessary if mammography does not show a correlative mass. Alternative imaging modalities such as ultrasonography are often used to complete a successful work-up. The radiologist and radiographer direct and conduct the diagnostic mammogram to facilitate an accurate interpretation.

Although most diagnostic mammograms conclude with probable benign findings, some women are asked to return for subsequent mammograms in 3 or 6 months to assess for interval changes. Other women must consult with a specialist or surgeon about possible options such as fine-needle aspiration biopsy (FNAB), core biopsy, or excisional biopsy.

Although it is an excellent tool for detecting breast cancer, mammography does *not* permit diagnosis of breast cancer. Some lesions may appear consistent with malignant disease but turn out to be completely benign conditions. Breast cancer can be diagnosed only by a pathologist through evaluation of tissue extracted from the lesion. After interpreting the diagnostic work-up, the radiologist must carefully determine whether core biopsy and/or surgical intervention is warranted.

Risk Factors

Assessing a woman's risk for developing breast cancer is complicated. An accurate patient history must be elicited to identify potential individual risk factors. The radiologist considers these known risks after interpreting the mammogram. Other than gender, factors that are known to influence the development of breast cancer include age, hormonal history, and family history.

Besides being female, increasing age is the most important risk factor for breast cancer. Potentially modifiable risk factors include weight gain after age 18, being overweight or obese (for postmenopausal breast cancer), use of menopausal hormone therapy (combined estrogen and progestin), physical inactivity, and alcohol consumption. Medical findings that predict higher risk include high breast tissue density (a mammographic measure of the amount of glandular tissue relative to fatty tissue), high bone mineral density (women with low density are at increased risk for osteoporosis), and biopsy-confirmed hyperplasia (overgrowth of cells), especially atypical hyperplasia (overgrowth of abnormal cells). High-dose radiation to the chest for cancer treatment also increases risk. Reproductive factors that increase risk include a long menstrual history (menstrual periods that start early and/or end later in life), recent use of oral contraceptives, never having children, and having one's first child after age 30.

Risk is also increased by a family history of breast cancer, particularly having one or more first-degree relatives with breast cancer (although most women with breast cancer do not have a family history of the disease). Inherited mutations (alterations) in breast cancer susceptibility genes account for approximately 5% to 10% of all female breast cancers and an estimated 4% to 40% of all male breast cancers but are very rare in the general population (much <1%). [16] Most of these mutations are located in *BRCA1* and *BRCA2* genes, although mutations in other known genes have also been identified. Individuals with a strong family history of breast and certain other cancers, such as ovarian and colon cancer, should consider counseling to determine whether genetic testing is appropriate. Prevention measures may be possible for individuals with breast cancer susceptibility mutations. [17] In *BRCA1* and *BRCA2* mutation carriers, studies suggest that prophylactic removal of the ovaries and/or breasts decreases the risk of breast cancer considerably, although not all women who choose this surgery would have developed breast cancer. Women who consider prophylactic surgery should undergo counseling before reaching a decision. The drugs tamoxifen and raloxifene have been approved to reduce breast cancer risk in women at high risk. Raloxifene appears to have a lower risk of certain side effects, such as uterine cancer and blood clots; however, it is approved only for use in postmenopausal women.

Limited but accumulating evidence suggests that long-term heavy smoking increases the risk of breast cancer, particularly among women who began smoking at an early age. The International Agency for Research on Cancer has concluded that limited evidence indicates that shift work, particularly at night, is also associated with an increased risk of breast cancer. [18]

Anatomy

Breast

The terms *breast* and *mammary gland* are often used synonymously. Anatomy textbooks tend to use the term *mammary gland*, whereas radiography textbooks tend to use the term *breast*. The breasts (mammary glands) are lobulated glandular structures located within the *superficial fascia* of the anterolateral surface of the thorax of both males and females. The mammary glands divide the superficial fascia into anterior and posterior components. The mammary tissue is completely surrounded by fascia and is enveloped between the anterior and posterior layers of the superficial fascia. In females, the breasts are secondary sex characteristics and function as accessory glands to the reproductive system by producing and secreting milk during lactation. In males, the breasts are rudimentary and without function. Male breasts are subject to abnormalities such as neoplasms that require radiologic evaluation; however, this occurs more rarely than in female breasts.

Female breasts vary considerably in size and shape, depending on the amount of fat and glandular tissue and the condition of the suspensory ligaments. Each breast is usually cone-shaped, with the base or posterior surface of the breast overlying the *pectoralis major* and *serratus anterior* muscles. These muscles extend from the second or third rib inferiorly to the sixth or seventh rib, and from near the lateral margin of the sternum laterally toward the anterior axillary plane. An additional portion of breast tissue, the *axillary prolongation* or *axillary tail* (*AT*), extends from the upper lateral base of the breasts into the *axillary fossa* (Fig. 18.6).

The breast tapers anteriorly from the base, ending in the *nipple*, which is surrounded by a circular area of pigmented skin called the *areola*. The breasts are supported by *Cooper's ligaments*, suspensory ligaments that extend from the posterior layers of the superficial fascia through the anterior fascia into the subcutaneous tissue and skin. It is the condition of these ligaments—not the relative fat content—that gives the breasts their firmness or lack of firmness.

The adult female breast consists of 15 to 20 *lobes*, which are distributed such that more lobes are superior and lateral than inferior and medial. Each lobe is divided into many *lobules*, which are the basic structural units of the breast. The lobules contain the glandular elements, or *acini*. Each lobule consists of several acini, numerous draining ducts, and the interlobular stroma or connective tissue. These elements are part of the breast parenchyma and participate in hormonal changes. By the late teenage years to early 20s, each breast contains several hundred lobules. These lobules tend to decrease in size with increasing age, particularly after pregnancy—a normal process called *involution*.

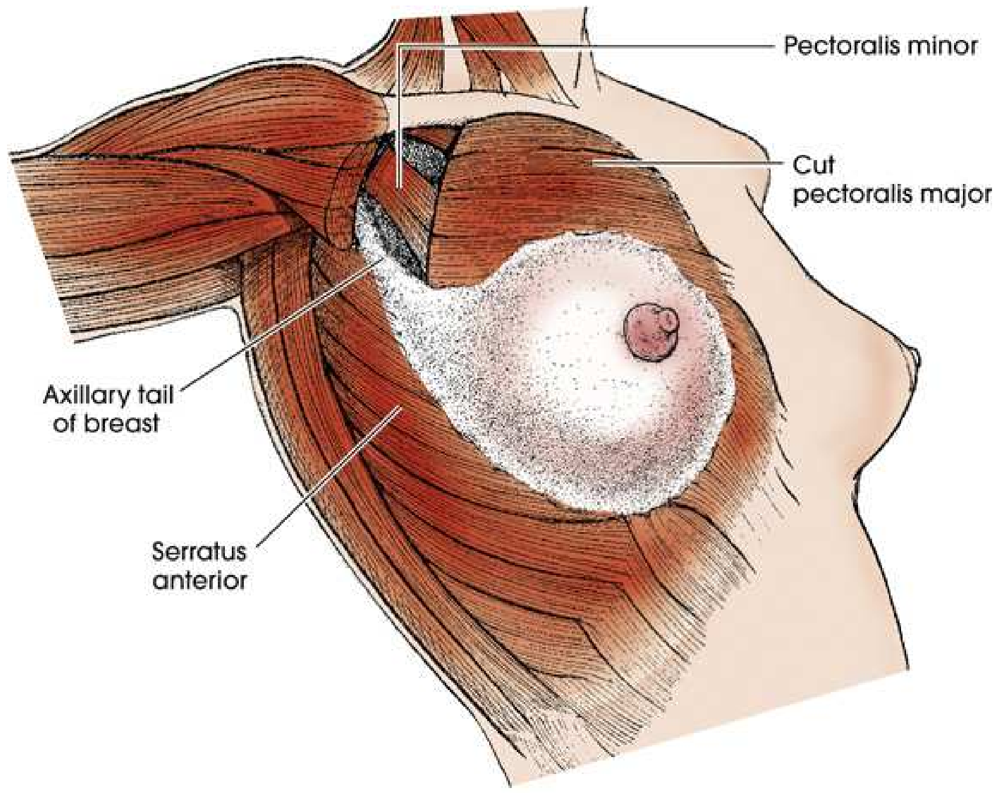


FIG. 18.6 Relationship of breast to chest wall. Note extension of breast tissue posteriorly into axilla.

Diagram shows the breast and the chest wall. The muscles are shaded in red. Each breast is usually cone-shaped, with the base or posterior surface of the breast overlying the pectoralis major and serratus anterior muscles. The parts labeled in the diagram are as follows: axillary tail of breast, serratus anterior, pectoralis minor, and cut pectoralis major.

The openings of each *acinus* join to form *lactiferous ductules* that drain the lobules, which join to form 15 to 20 lactiferous ducts, one for each lobe. Several lactiferous ducts may combine before emptying directly into the nipple. As a result, there are usually fewer duct openings on the nipple than there are breast ducts and lobes. The individual lobes are incompletely separated from each other by Cooper's ligaments. The space between the lobes contains fatty tissue and additional connective tissue. A layer of fatty tissue surrounds the gland, except in the area immediately under the areola and nipple (Fig. 18.7).

The lymphatic vessels of the breast drain laterally into the *axillary lymph nodes* and medially into the chain of *internal mammary lymph nodes* (Fig. 18.8). Approximately 75% of lymph drainage is toward the axilla, and 25% is toward the internal mammary chain. The number of axillary nodes varies from 12 to 30 (sometimes more). The axilla is occasionally radiographed during breast examinations so the axillary nodes can be evaluated. The internal mammary nodes are situated behind the sternum and manubrium and, if enlarged, are occasionally visible on a lateral chest radiograph.

The radiographer must take into account breast anatomy and patient body habitus to successfully image as much breast tissue as possible. The compression paddle size determines the size of the exposure field, so it must be appropriate for the breast being imaged. Smaller breasts should not be imaged using the larger compression paddle because other body structures may interfere with the compression device, resulting in an unacceptable image, and compression of more than the breast tissue often increases patient discomfort. Breasts that are larger than the image receptor device and the larger compression paddle must be carefully positioned and imaged in sections, termed *mosaic* or *tiling* imaging.

The natural mobility of the breast is another important consideration. The lateral and inferior aspects of the breast are mobile, whereas the medial and superior aspects are fixed. The breast is most effectively positioned by moving the mobile aspects toward the fixed tissues. Likewise, the radiographer should avoid moving the compression paddle against fixed tissues because this would cause less breast tissue to be imaged.

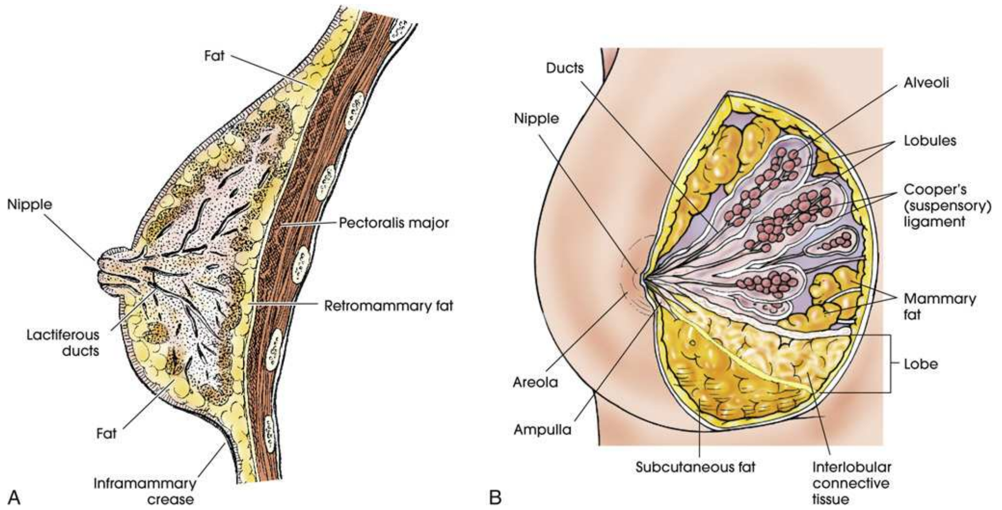


FIG. 18.7 (A) Sagittal section through female breast, illustrating structural anatomy. (B) Breast anterior view.

Diagram (A) shows the female breast anatomy. The parts labeled in the diagram are as follows: fat, nipple, lactiferous ducts, fat, inframammary crease, pectoralis major, and retromammary fat. Diagram (B) shows an anterior view of the breast. The space between the lobes contains fatty tissue and additional connective tissue. The individual lobes are incompletely separated from each other by cooper's ligaments. A layer of fatty tissue surrounds the gland, except in the area immediately under the areola and nipple. The parts labeled in the diagram are as follows: The parts labeled in the diagram are as follows: alveoli, subcutaneous fat, cooper's (suspensory) ligament, interlobular connective tissue, lobules, lobe, mammary fat, ducts, nipple, areola, and ampulla.

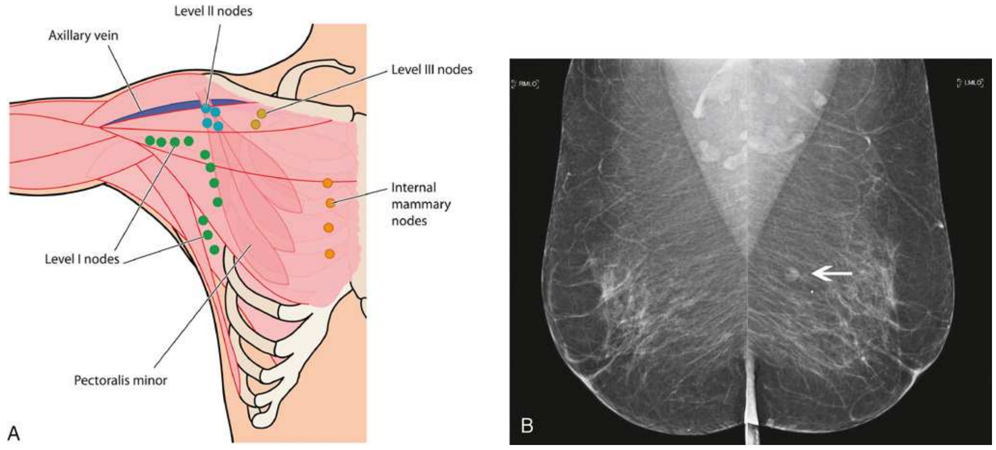


FIG. 18.8 (A) Schematic drawing of lymph node system surrounding the breast. (B) MLO views of the breast often include axillary lymph nodes; occasionally intramammary lymph nodes may also be seen *(arrow)*.

(A) A schematic drawing shows the lymph node and the surrounding breast. The parts labeled in the diagram are as follows: axillary vein, level two nodes, level three nodes, internal mammary nodes, pectoralis minor, level one nodes. (B) A mammogram shows a circular white patch on the right side. It is indicated by a white arrow.

Tissue Variations

The *glandular* and *connective tissues* of the breasts are soft tissue-density structures. The ability to show radiographic detail within the breast depends on the fat within and between the breast lobules and the fat surrounding the breasts. The postpubertal adolescent breast contains primarily dense connective tissue and casts a relatively homogeneous radiographic image with little tissue differentiation. The development of glandular tissue decreases radiographic contrast. During pregnancy, significant hypertrophy of glands and ducts occurs within the breasts. This change causes the breasts to become extremely dense and opaque (Fig. 18.9). After the end of lactation, considerable involution of glandular and parenchymal tissues usually occurs, and these tissues are replaced with increased amounts of *fatty tissue*. Fat accumulation varies markedly among individuals. This normal fat accumulation significantly increases the natural radiographic contrast within the breasts. The breasts of patients with fibrocystic parenchymal conditions may not undergo this involution.

FIG. 18.9 CC and MLO projections of a nursing mother. During lactation, the breasts become very dense and opaque as the ducts and glands become hypertrophic and engorged with milk. If mammography must be performed on a nursing mother, it is best to have the patient nurse or pump her breasts immediately before imaging.

The glandular and connective tissue elements of the breast can regenerate as needed for subsequent pregnancies. After menopause, the glandular and stromal elements undergo gradual atrophy. External factors, such as surgical menopause and hormone replacement therapy (HRT) may inhibit this normal process. From puberty through menopause, mammotrophic hormones influence cyclic changes in the breasts. The glandular and connective tissues are in a state of constant change (Fig. 18.10).

Breast tissue density is the ratio of fatty to glandular tissue within the breast. The more glandular tissue, the denser the breast, meaning that it is more difficult for x-rays to penetrate the tissue. Breasts are classified into four density ranges: fatty, scattered, heterogeneously dense, and extremely dense (Fig. 18.11). Breast density has been brought to the forefront recently, with several states mandating that patients are told the composition of their personal breast density and the classification that the radiologist has reported.

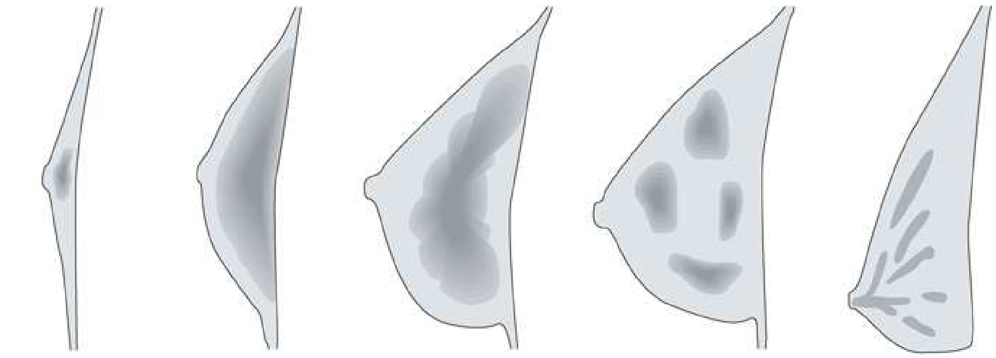


FIG. 18.10 Diagrammatic profile drawings of breast, illustrating most likely variation and distribution of radiographic density *(shaded areas)* related to the normal life cycle from adolescence to senescence. This normal sequence may be altered by external factors, such as pregnancy, hormone medications, surgical menopause, and fibrocystic breast condition.

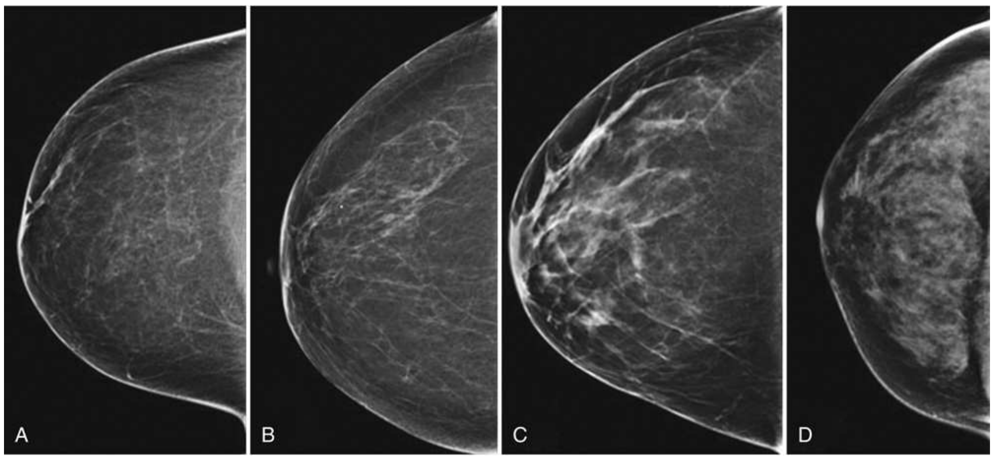


FIG. 18.11 When reading the mammogram, the radiologist classifies the tissue density into one of four categories based on the ratio of fatty to glandular tissue within the breast: (A) Fatty. (B) Scattered. (C) Heterogeneously dense. (D) Extremely dense.

(A) A mammogram shows fatty tissues. It appears full. (B) A mammogram shows scattered breast tissues. There are several white streaks on it. (C) A mammogram shows heterogeneously dense breast tissues. There are a lot of white areas in the front. (D) A mammogram shows extremely dense white areas.

Pathologic and Mammographic Findings

Numerous radiographic findings, benign or malignant, can be evident within the breast tissue on any mammogram. Distinguishing the characteristics of a finding is the main function of the mammogram. From these characteristics, the radiologist can make a determination of the probability of malignancy. This helps the radiologist determine whether biopsy of the lesion is necessary, if the lesion is most likely benign, or if the area should be followed carefully for indications of change. Characterization of a finding helps the radiologist make these determinations, but it must be kept in mind that cancer is a very tricky disease, and sometimes even the most benign-appearing lesion can be found to be malignant. Therefore, sometimes biopsies are performed on probable benign lesions to ensure that they truly are benign.

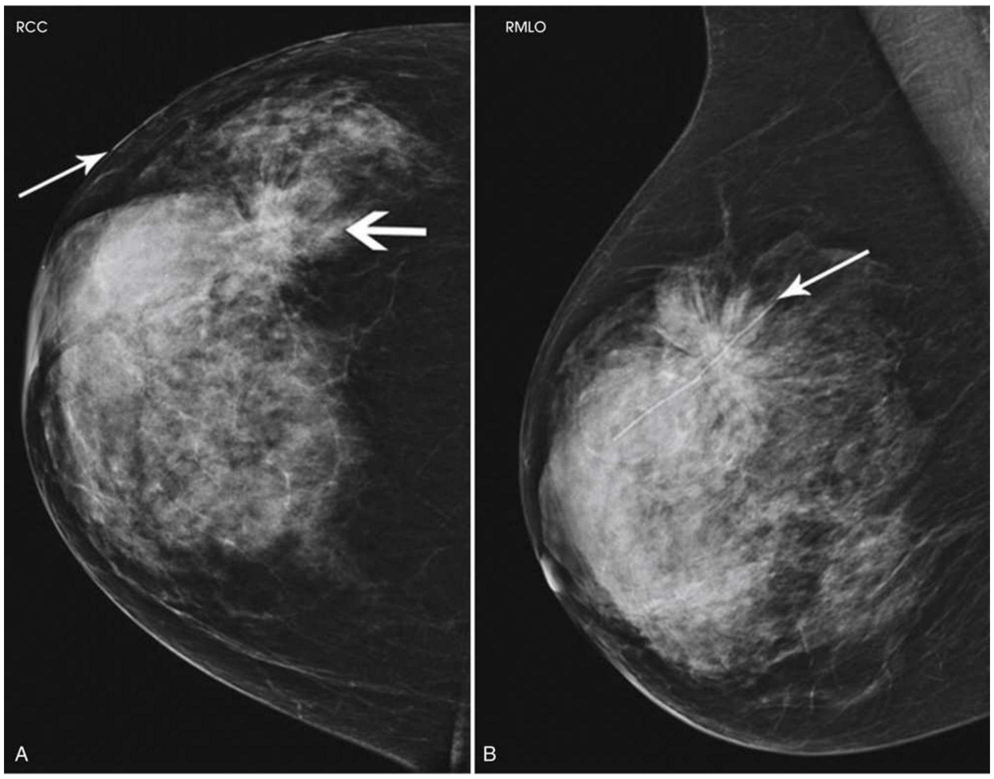


FIG. 18.12 (A) Right CC projection of a patient who had previously undergone surgical biopsy for removal of a benign mass reveals an area of architectural distortion with spiculated borders *(thick arrow)*. (B) MLO projection reveals that the area coincides with the surgical scar. Note the radiopaque skin marker that the technologist placed over the site of the scar *(thin arrows)*.

Each breast is a symmetric mirror image of the other. Subtle variations may normally occur from one breast to the other, but an asymmetric variation that is new or enlarging can be cause for concern and can lead to a more thorough work-up. These variations generally present as a mass or density, calcifications within the tissue, or distortion within the architecture of the breast tissue. When these findings are noted on a screening mammogram, the radiologist will often request additional diagnostic mammography views or specialized imaging such as ultrasonography for a more clear view of the area of concern.

Masses

A mass is generally categorized by its shape, by the margins of the mass, and by its radiographic density.

- The *shape* of a lesion is described as round, oval, lobular, or irregular. A round or oval mass is more likely to indicate benign pathology such as a cyst (a fluid-filled pocket within the tissue) or a lymph node (depending on its location). An irregularly shaped mass can more likely indicate a malignancy, or it can be an indication of trauma to an area of breast tissue. This illustrates the importance of taking a thorough patient history.
- The *margins*, or borders, of the mass are described as circumscribed (meaning well defined or sharply defined), microlobulated (having small undulations throughout the contour, such as a blackberry), obscured (meaning that parts are hidden by superimposed tissue), indistinct or ill-defined, or spiculated (showing fine spicules, or lines, radiating from the center of the mass). Margin characteristics help the clinician to predict whether a mass is malignant or benign. A mass with a well-defined border is more likely to be benign. Masses with obscured, ill-defined, indistinct margins are suspicious, and a spiculated mass is more worrisome. Microlobulated masses have a 50% chance of being malignant. Post-biopsy scarring may appear as a spiculated mass, and an accurate patient history revealing previous breast biopsies can prevent an unnecessary work-up (Fig. 18.12).

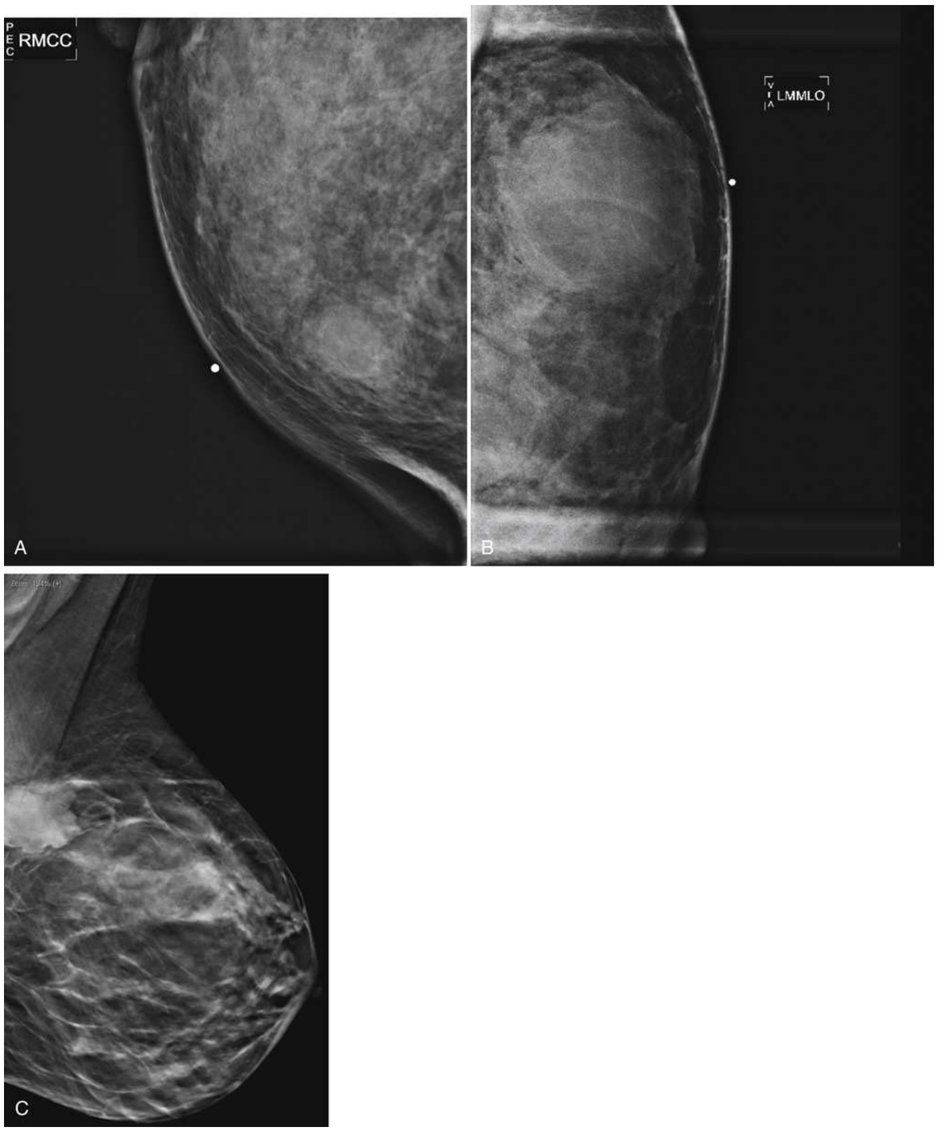


FIG. 18.13 Circumscribed masses are often benign. (A) TAN MAG projection of a fibroadenoma. (B) Magnified view of a retroareolar cyst. A mass is determined to be solid or cystic (fluid-filled) on ultrasound. (C) DBT slice of a microlobulated mass, which proved to be malignant on biopsy.

(A) A mammogram shows dense breast tissues on the right. It appears white and hazy. (B) A mammogram shows a retroareolar cyst with a dense grey appearance on the left. (C) A mammogram shows a projected view of the breast with streaks of white areas on it.

- Examples of benign stellate or spiculated lesions include radial scar, fat necrosis, breast abscess, and sclerosing adenosis. Examples of benign circumscribed masses include fibroadenoma (Fig. 18.13), cyst, intramammary lymph node, hematoma, and galactocele.

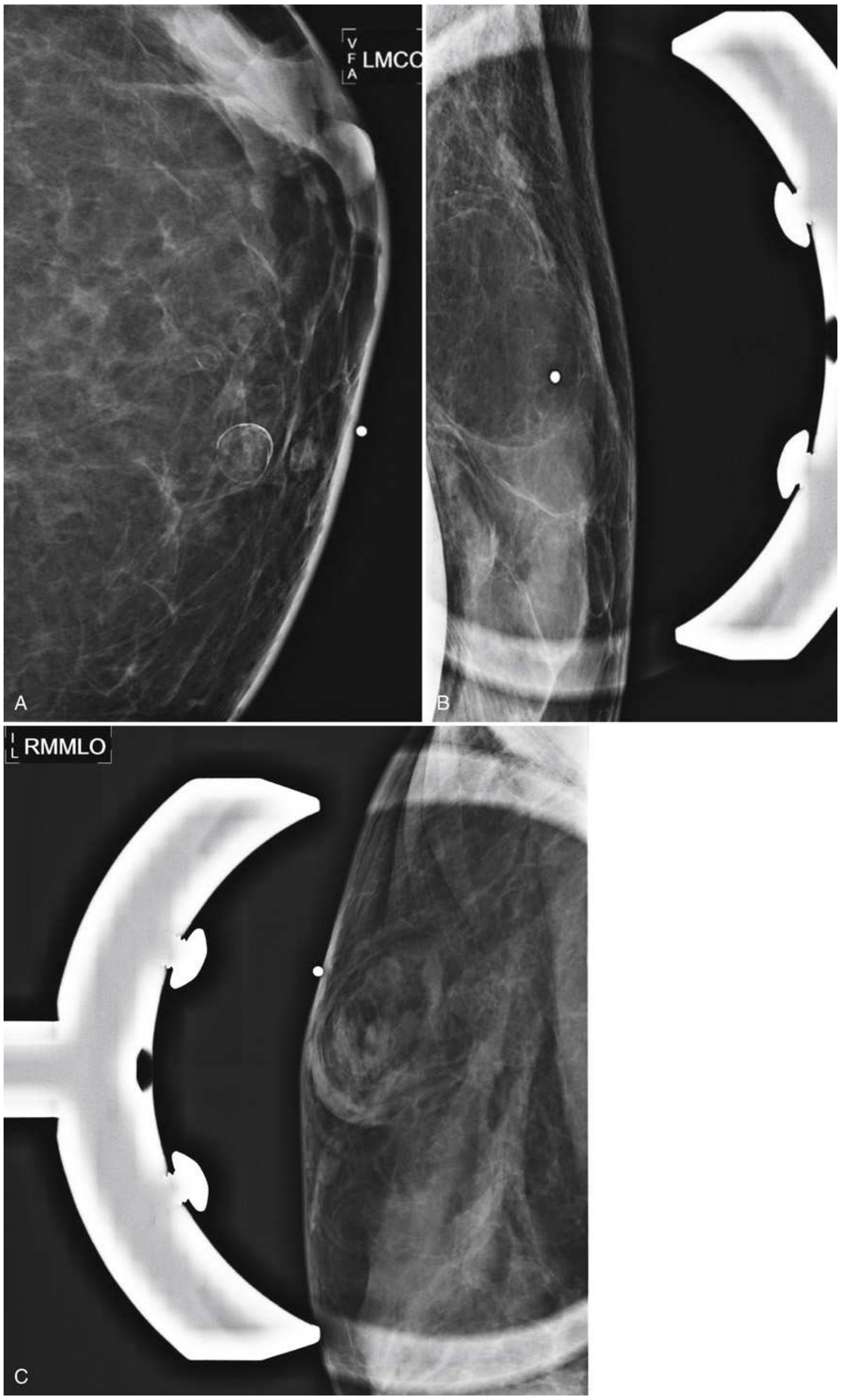


FIG. 18.14 Radiolucent masses include (A) oil cyst with a calcified rim. Oil cysts are formed when trauma or surgical intervention causes necrosis of fatty tissue. In time, a calcific rim is formed by the body to isolate the necrotic tissue. (B) Lipoma—a lesion consisting of fatty tissue. (C) Hamartoma—a lesion consisting of a mixture of fatty and fibrous tissue.

(A) A mammogram shows bright white outlines along the side of the breast. (B) A mammogram shows a radiopaque object concave object on the right. (C) A mammogram shows a radiopaque object concave object on the left. A grey-white area is on the breast tissue.

- *Density* may be described as high density, equal density or isodense, low density, or radiolucent. Breast cancer that forms a visible mass is more likely to be higher in density than the fibroglandular tissue surrounding it, but it can be of equal density. However, breast cancers never contain fatty tissue. Masses that are radiolucent contain fat and are overwhelmingly benign appearing. These include oil cysts, lipomas, galactoceles, and mixed tissue lesions such as hamartomas and fibroadenomas (Fig. 18.14).

The malignant or benign nature of a mass cannot be determined on the basis of *location*. Most cancers are detected in the upper outer quadrant (UOQ) of the breast; however, most breast lesions—both malignant and benign—are found in that quadrant. Cancer can occur in any region of the breast with a certain degree of probability. It is important to determine the location of a lesion for additional diagnostic procedures such as core biopsy or open surgical biopsy.

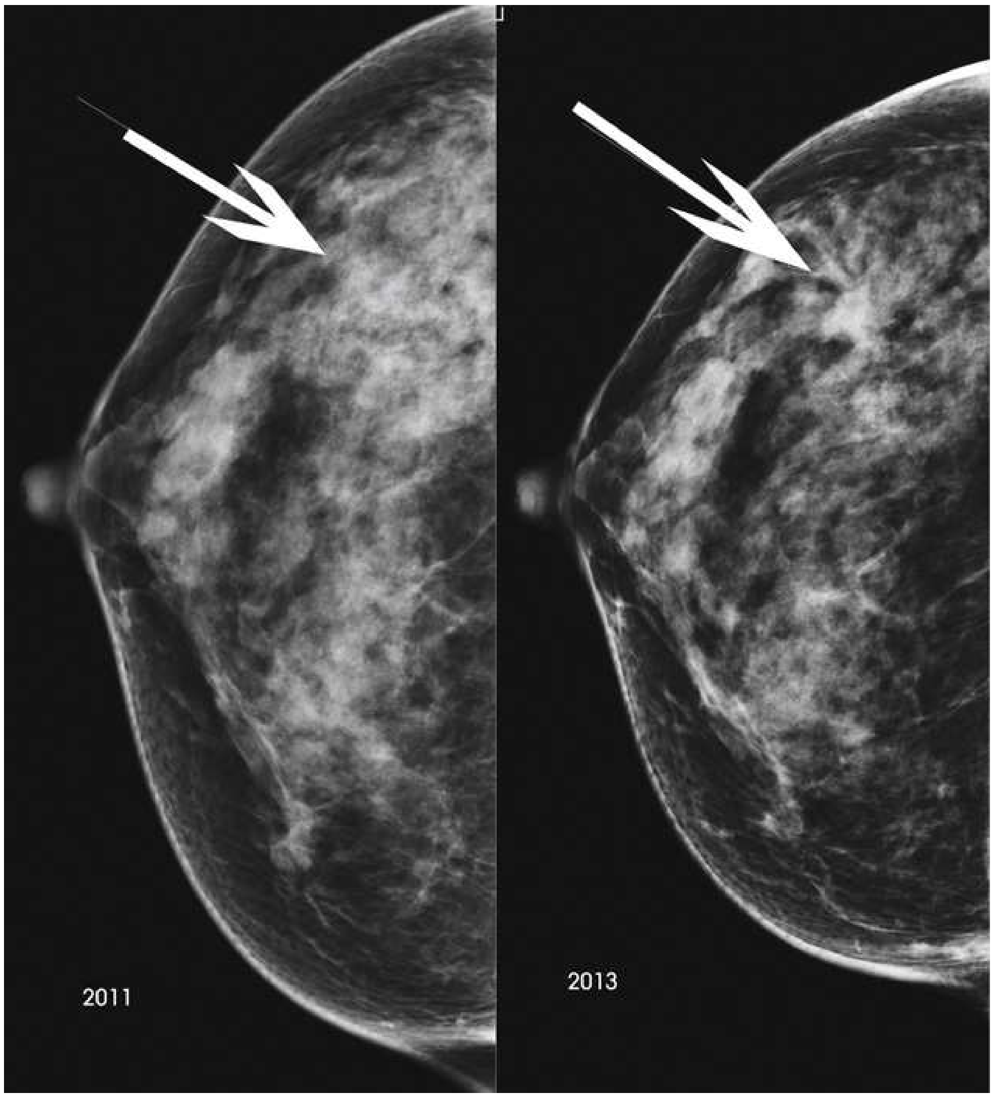


FIG. 18.15 Interval change. A change in tissue architecture and density was noted during a screening mammogram on this 51-year-old woman. Core biopsy of this area was positive for invasive ductal carcinoma.

Interval change may increase the suspicion of malignancy. The radiologist carefully compares current images with previous ones and notes whether the mass is newly apparent, an interval enlargement is present, the borders have become nodular or ill defined, a mass has increased in density, or calcifications have appeared (Fig. 18.15).

Almost all (98%) of the axillary lymph nodes are located in the UOQ. These nodes are well circumscribed, may have a central or peripheral area of fat, and can be kidney bean-shaped (see Fig. 18.8). If the lymph nodes appear normal, they are rarely mentioned in the context of an identifiable mass on the radiology report.

A *density* that is seen on only one projection is not confirmed three-dimensionally and may represent superimposed structures. These may appear to have scalloped edges or concave borders or both. The radiologist may request spot compression projections, rolled projections, or angled projections to confirm or rule out the presence of a real density. A suspicious density seen on only one projection within the breast is often a summation shadow of superimposed breast parenchyma and disappears when the breast tissue is spread apart (Fig. 18.16).

Calcifications

Calcifications are often normal metabolic occurrences within the breast and are usually benign. Approximately 15% to 25% of microcalcifications found in asymptomatic women are associated with cancer, however. These calcifications can have definitive characteristics. Because of size, some microcalcifications are more difficult to interpret. The most valuable tool for defining microcalcifications is a properly performed image obtained using the magnification technique. Using this image, the radiologist can determine better whether calcifications are suspicious and warrant further work-up.

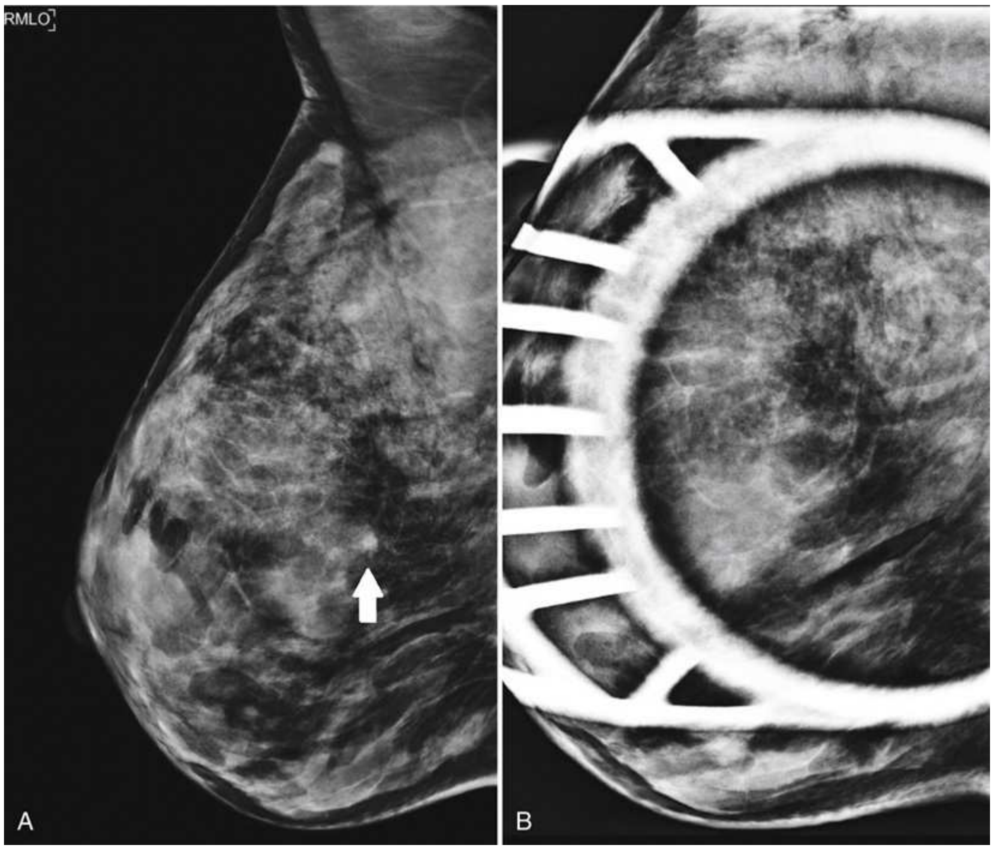


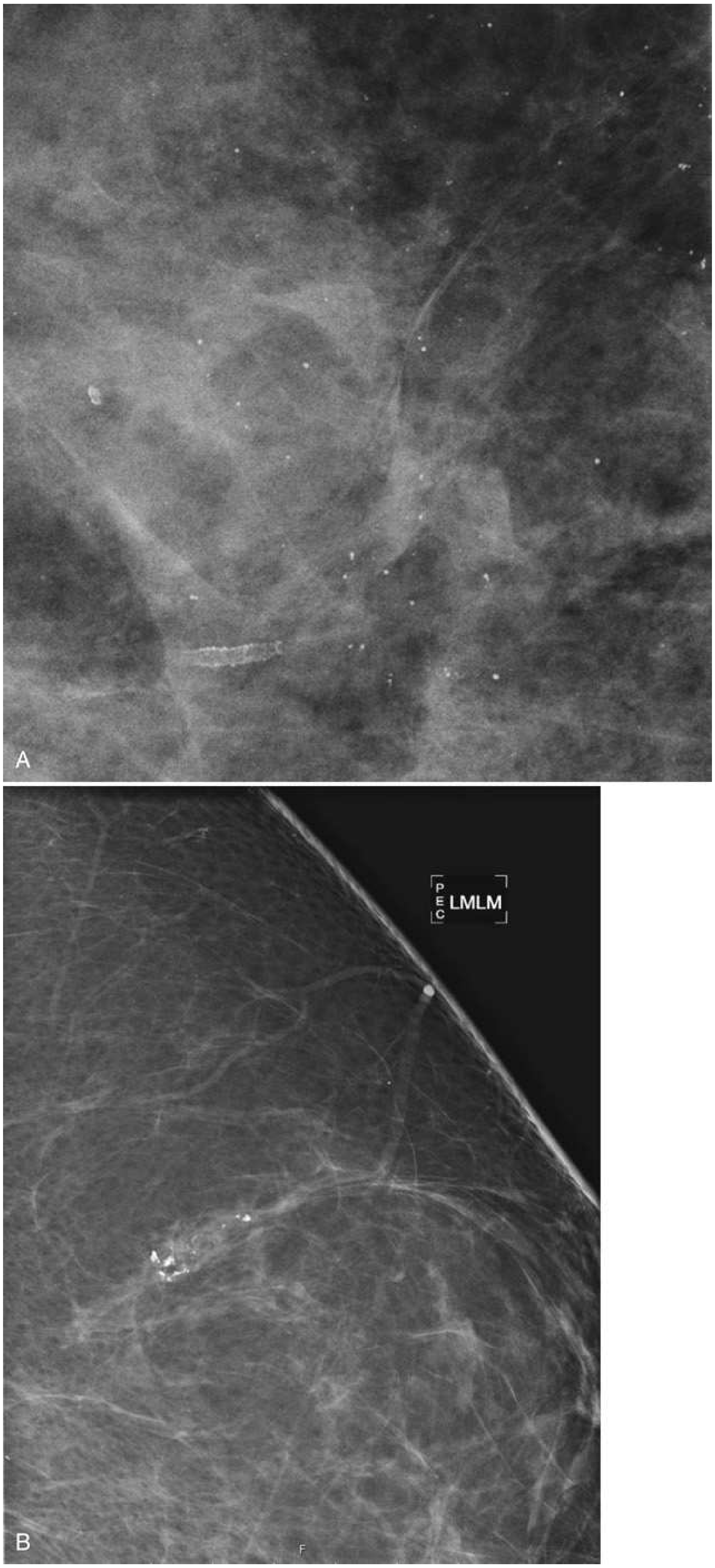
FIG. 18.16 An area of increased density was noted on this MLO projection of the right breast (A). Spot compression of this area (B), also performed in the MLO position, spreads the tissue out more uniformly. The density was no longer seen, indicating that overlapped tissue was causing a summation shadow.

(A) A mammogram shows a white spot in the breast tissue. (B) A mammogram shows a shadow of superimposed breast parenchyma. The overlapped tissues form arterial (parallel tracks). (A) A mammogram shows white-colored coarse and round calcification in the breast tissue. (B) A mammogram shows pale white patches in the middle of the breast tissue.

Calcifications are categorized by size, shape, and distribution. Benign calcifications are generally larger, coarser, rounder, and smoother. Typically, they are easily seen on the mammogram, whereas malignant calcifications are usually very small, often requiring magnification to be seen (Fig. 18.17).

Benign calcifications may have one or more of the following attributes: moderate size, scattered location, round shape, and, usually, bilateral occurrence. In addition, they may be eggshell (lucent center), arterial (parallel tracks), crescent, or sedimented ("teacup" milk of calcium). Calcifications may represent a fibroadenoma ("popcorn"), postsurgical scarring (sheets or large strands of calcium), skin calcifications (which can mimic suspicious microcalcifications within the breast parenchyma), and vascular calcifications. Vascular calcifications are often noted, and studies have indicated that vascular calcifications in women younger than 50 years of age may suggest potential risk for coronary artery disease.

- The projection suggested for better defined sedimented milk of calcium is the 90-degree lateral projection—lateromedial (LM) or mediolateral (ML). If possible, the mammographer should select the lateral projection that places the suspected area closest to the IR. The 90-degree lateral is also used as a triangulation projection before needle localization and to show air-fluid-fat levels (Fig. 18.18).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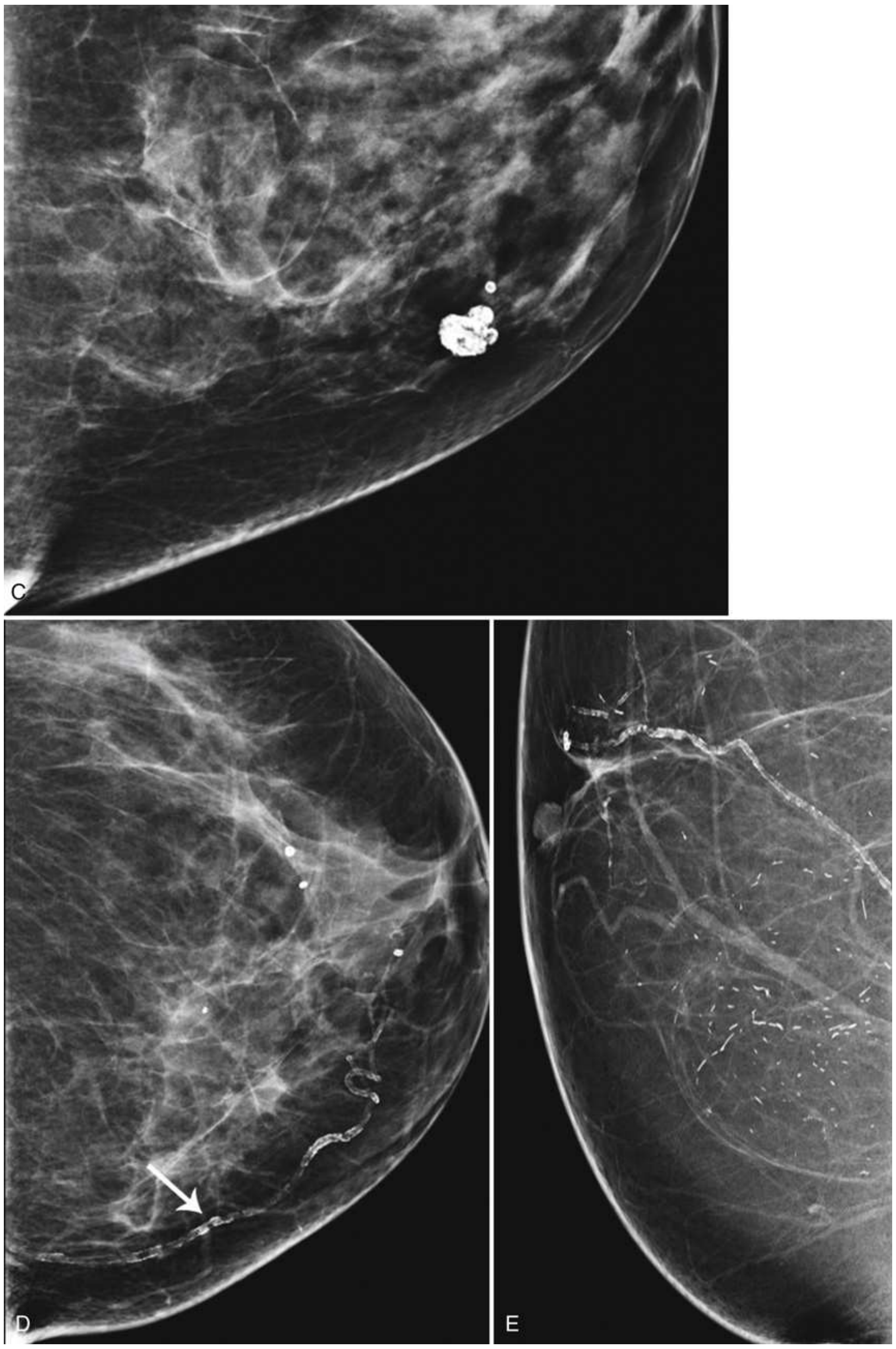


FIG. 18.17 Examples of benign calcifications seen on mammography. (A) Coarse and round calcification. (B) Calcifications caused by dystrophic fat necrosis.(C) Popcorn calcification. (D) Vascular calcification. (E) Rod-like secretory calcifications.

Calcifications that are suspicious and arouse intermediate concern are categorized as amorphous or indistinct, or coarse heterogeneous calcifications. Amorphous or indistinct calcifications appear small and hazy. When diffusely scattered, they can usually be dismissed as benign, but when clustered, they may warrant biopsy. Coarse heterogeneous calcifications that are conspicuous and irregularly shaped, are generally larger than 0.5 mm, and can be associated with malignancy, but these calcifications may also be present in areas of fibrosis, within fibroadenomas, or in areas of trauma.

Fine pleomorphic calcifications and fine linear or branching calcifications indicate a higher probability of malignancy. The fine linear type suggests filling of the lumen of a duct involved in a breast cancer. Fine pleomorphic forms vary in shape but are generally smaller than 0.5 mm (Fig. 18.19).

The distribution of the calcifications describes the arrangement of calcifications in the breast. Diffuse or scattered calcifications are usually benign and usually bilateral. Regional distribution of calcifications indicates that a large volume of breast tissue contains calcifications. A group or cluster of calcifications indicates a minimum of five calcifications occupying a small volume of breast tissue. Linear distribution calcifications are arranged in a line, suggesting deposits within a duct. Segmental distribution suggests deposits in ducts and the possibility of extensive or multifocal breast cancer. Although benign causes of segmental calcifications are known, segmental distribution of otherwise benign-appearing calcifications elevates suspicion of carcinoma.

Architectural distortions

When the normal architecture of the breast tissue is distorted but no definitive mass is visible, this is called AD. AD is seen as a presentation of thin lines or spiculations radiating from a central point. Focal retraction or distortion of the edge of the parenchyma may also be present. AD can be associated with a mass or with asymmetry or calcifications. A history of trauma or prior surgery may present as AD, but in the absence of this history, AD is suspicious for malignancy or radial scar, and biopsy of the area is appropriate (Fig. 18.20).

Compressed thickness	Target	Fatty breast filter	kVp	mAs	Target	50% fatty–50% dense filter	kVp	mAs	Target	Dense breast filter	kVp	mAs
Amorphous selenium detector												
<3cm	Mo	Mo	28	70	Mo	Mo	28	80	Mo	Mo	28	90
3–5cm	Mo	Mo	28	80	Mo	Mo	28	80	Mo	Mo	28	90
5–7cm	Mo	Rh	29	100	Rh	Rh	29	100	Rh	Rh	29	100
>7cm	Rh	Rh	30	120	Rh	Rh	30	140	Rh	Rh	30	160
Charge-coupled device (CCD) detector												
<3cm	Mo	Mo	25	32	Mo	Mo	26	28	Mo	Mo	26	36
3–4cm	Mo	Mo	36	36	Mo	Rh	26	45	Mo	Rh	27	50
4–5cm	Rh	Rh	28	50	Rh	Rh	29	56	Rh	Rh	29	63
5–6cm	Rh	Rh	29	56	Rh	Rh	29	63	Rh	Rh	30	71
6–7cm	Rh	Rh	29	71	Rh	Rh	29	80	Rh	Rh	30	80
7–8cm	Rh	Rh	29	80	Rh	Rh	30	90	Rh	Rh	31	80
>8cm	Rh	Rh	30	90	Rh	Rh	30	140	Rh	Rh	31	140

Note: Manual techniques based on use of grid and taut compression.

Summary of Anatomy

Mammary gland (breast)

Axillary fossa

- Nipple
- Areola
- Cooper's ligaments
- Lobes
- Acini
- Lactiferous ductules
- Axillary lymph nodes
- Internal mammary lymph nodes
- Glandular tissue
- Connective tissue
- Fatty tissue
- Superficial fascia
- Pectoralis major muscle
- Serratus anterior muscle
- Axillary prolongation (axillary tail)

Summary of Pathology

Radiographic Findings	Definition
Masses and margins	
• **Circumscribed**	Smooth borders; mostly benign
• **Indistinct**	Ill-defined borders
• **Spiculated**	Mass with thin, elongated lines of tissue emerging from its center
Architectural distortion	The interruption of a regular pattern; when tissue opposes the natural breast pattern flowing from ducts to nipple
Calcifications	
Radiographic description	
• **Round or punctate**	Benign spherical calcium that can vary in size with well-defined margins
• **Amorphous or indistinct**	Small or hazy calcium with no clearly defined shape or form
• **Coarse heterogeneous**	Large calcium deposits of various sizes clustered together
• **Fine heterogeneous**	Small calcium deposits of various sizes clustered together. Usually <0.5 mm in diameter with a high probability of malignancy.
Benign calcifications	
• **Popcorn-type**	Large, thick, dense, popcorn shaped; often result from involuting fibroadenomas
• **Rim calcifications**	Calcifications residing along the border of benign masses such as cysts, oil cysts, or sebaceous cysts
• **Milk of calcium (teacup)**	Found in microcysts, which contain radiopaque particles mixed with fluid
• **Arterial calcifications**	Found within vessels resulting from arterial atherosclerosis
• **Skin calcifications**	Found within the dermal layer of the breast, usually with smooth outlines and radiolucent centers
Benign pathologies	
• **Cyst**	Fluid-filled sac with distinct edges and round or oval in shape
• **Galactocele**	Milk-filled cyst typically found in lactating women
• **Fibroadenoma**	Solid benign tumor of glandular and connective tissue with clearly defined margins; often easy to move
• **Lipoma**	Growth of fatty cells
• **Hamartoma**	Typically well-circumscribed lesion comprised of fibrous, glandular, and fatty tissue
• **Papilloma**	Growth inside the ducts; may cause discharge
• **Ductal ectasia**	Dilation of milk ducts with thickening of the walls; may cause discharge or fluid blockage
• **Hematoma**	Collection of blood within the tissue, typically resulting from trauma
• **Abscess and inflammation**	Accumulation of pus with swelling as a result of infection
• **Fat necrosis/oil cyst**	Lucent area within the breast resulting from trauma, surgery, or radiation therapy
• **Gynecomastia**	Benign proliferation of tissue in the male breast
High-risk conditions	
• **Lobular carcinoma in situ (LCIS)**	Abnormal cell growth within the lobules or milk glands
• **Atypical ductal hyperplasia (ADH)**	Increased production or growth within breast ducts causing architectural abnormalities
• **Atypical lobular hyperplasia**	Increased cell growth within breast lobes
• **Radial scar**	Complex sclerosing lesion. Benign mass with spiculated borders not related to surgery; caused by abnormal cell growth
• **Papilloma with atypia**	The presence of atypical hyperplasia within a papilloma
Malignant pathologies	
• **Ductal carcinoma in situ (DCIS)**	Abnormal, cancerous cells within the milk ducts
• **Invasive/infiltrating ductal carcinoma**	Cancerous cells that started in the milk ducts and have spread to surrounding breast tissue; most common type of breast cancer
• **Invasive lobular carcinoma**	Cancerous cells that spread from a lobule to other breast tissue
• **Inflammatory carcinoma**	Aggressive carcinoma that blocks the lymph vessels in the skin of the breast, causing signs of inflammation such as swelling, reddening of the skin, or an orange peel-like texture to the skin (peau d'orange)
• **Paget's disease**	Carcinoma in the skin of the nipple causing a sore, reddened appearance of the nipple and areola; commonly associated with other types of carcinoma within the breast tissue
• **Sarcoma**	Cancerous cells that begin in the connective tissue supporting the lobules and ducts of the breast

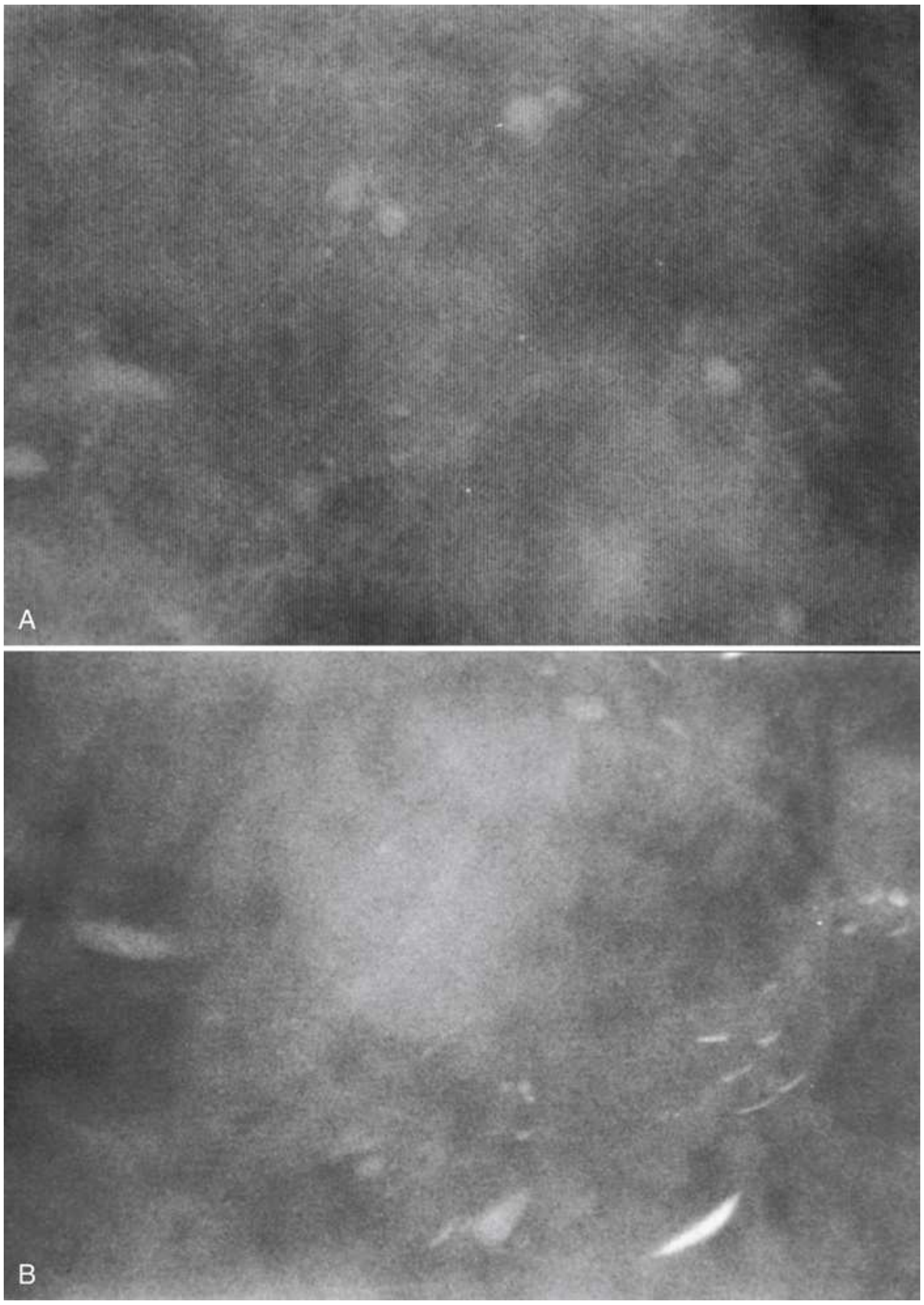
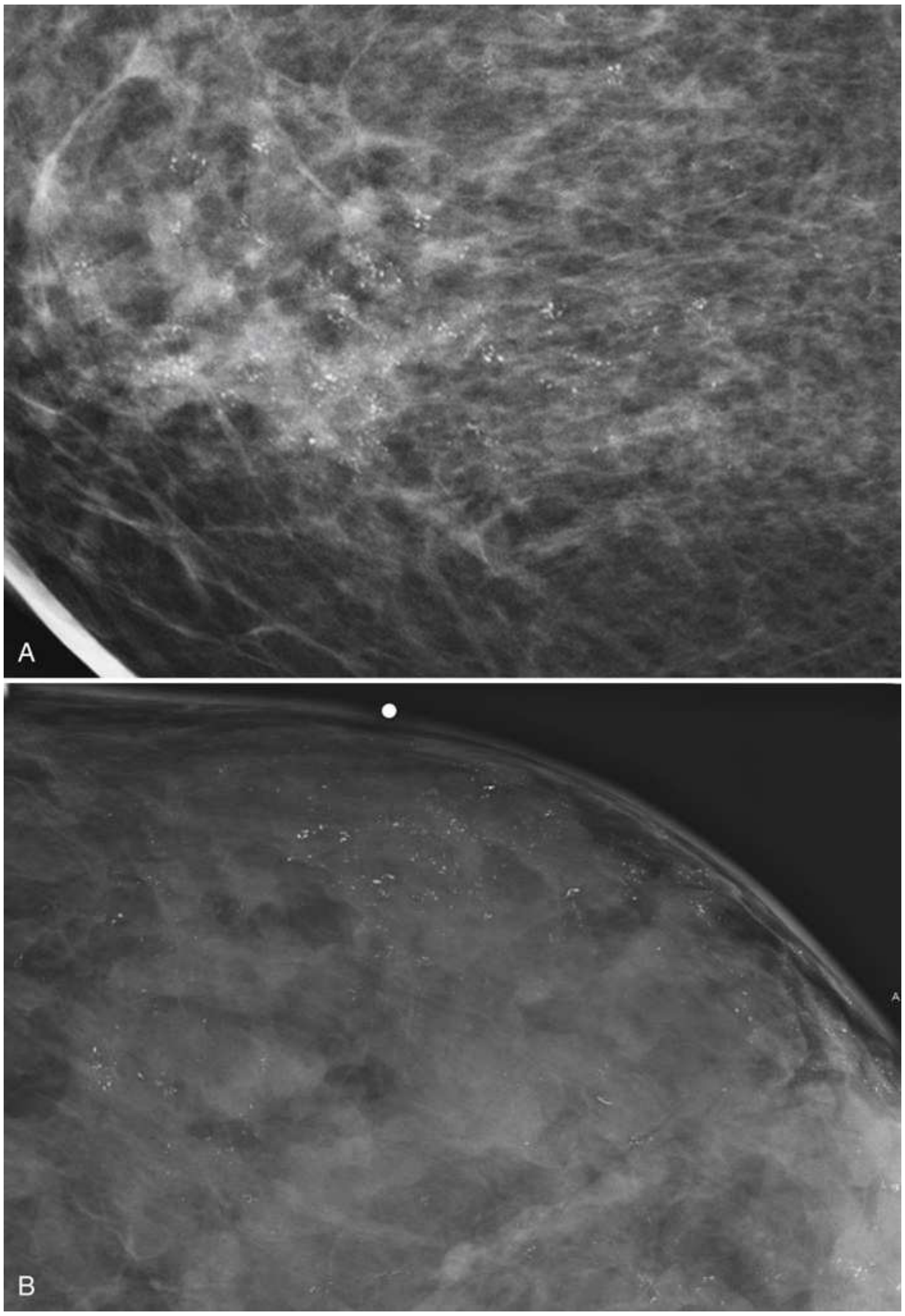


FIG. 18.18 Milk of calcium occurs when residual milk remains in the alveoli following lactation. Over time, the calcium within the milk solidifies into tiny particles that become sediment. On the CC projection, it appears as rounded low-density areas (A). On the ML projection, the sediment appears crescent shaped as it settles, in a “teacup” appearance (B).


A
B

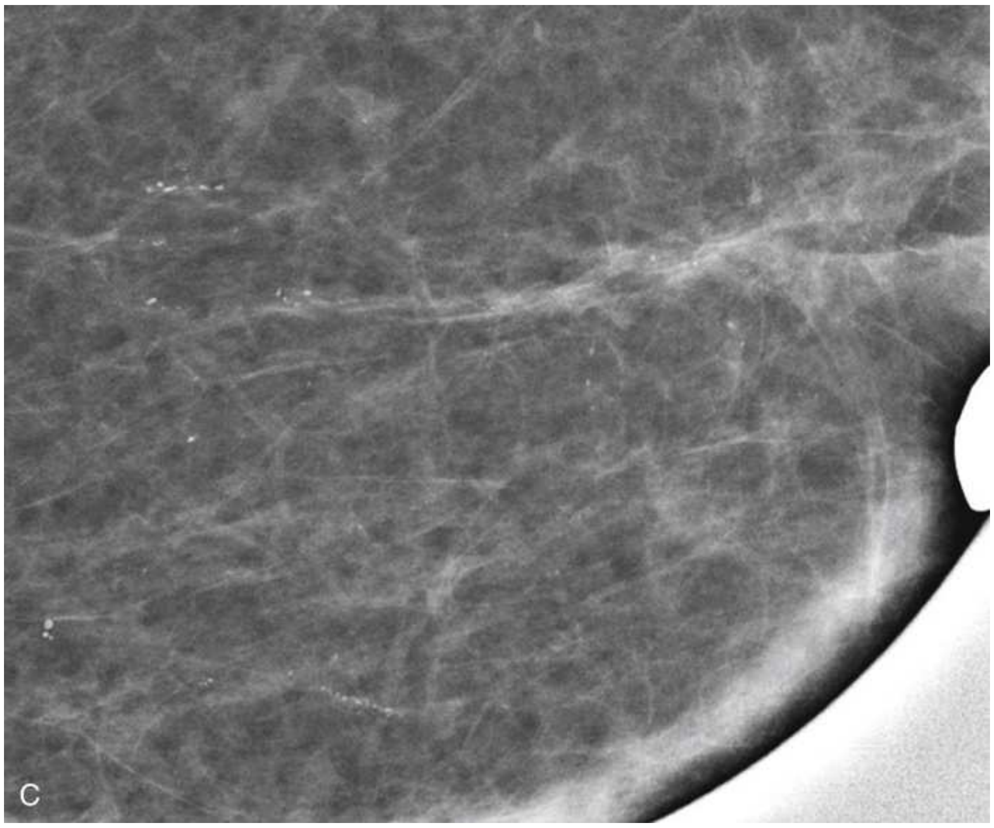


FIG. 18.19 Examples of calcifications seen on mammography that are suspicious or have a high probability of indicating cancer. (A) These amorphous, diffuse calcifications proved to be ductal carcinoma in situ (DCIS) on biopsy. (B) These linear, branching calcifications proved to be invasive ductal carcinoma on biopsy. (C) Pleomorphic linear calcifications proved to be DCIS.

Radiography

Method of Examination

Both breasts are routinely radiographed obtaining craniocaudal (CC) and mediolateral oblique (MLO) projections. Image enhancement methods, such as spot compression and the magnification technique, are often useful as diagnostic tools. It is sometimes necessary to enhance images or vary projections to better characterize lesions and calcifications. In symptomatic patients, the examination should not be limited to the symptomatic breast. Both breasts should be examined for comparison purposes and because significant radiographic findings may be shown in a clinically normal breast.

Patient Preparation

No specific patient preparations are needed before a mammographic examination to enhance image quality. However, during the mammography procedure, the breasts will be compressed, and this may cause some discomfort to the patient. To help alleviate the discomfort and solicit patient cooperation, some practices recommend that the patient refrain from or reduce caffeine intake for 2 weeks before the examination or take ibuprofen approximately an hour before the examination.

Artifacts are common in mammography because of the sensitivity of the imaging techniques and the design of the equipment used for mammography (Fig. 18.21). To prevent artifacts caused by objects protruding into the image, you may need to ask the patient to remove eyeglasses, earrings, and necklaces. Some hairstyles may need to be pulled or clipped back to prevent the hair from falling forward into the image. It is advisable to dress patients in open-front gowns because the breast must be bared for the examination. The technologist needs to ensure before each exposure that all of the above items, as well as chins, fingers, and other body parts, are outside of the field of radiation.

Some radiology practices require that patients remove any deodorant and powder from the axillary and inframammary regions because these substances can resemble calcifications on the resultant image (Fig. 18.22). Before the breast is radiographed, a complete history is taken, and a careful physical assessment is performed, noting all biopsy scars, palpable masses, suspicious thickenings, skin abnormalities, and nipple alterations (Fig. 18.23).

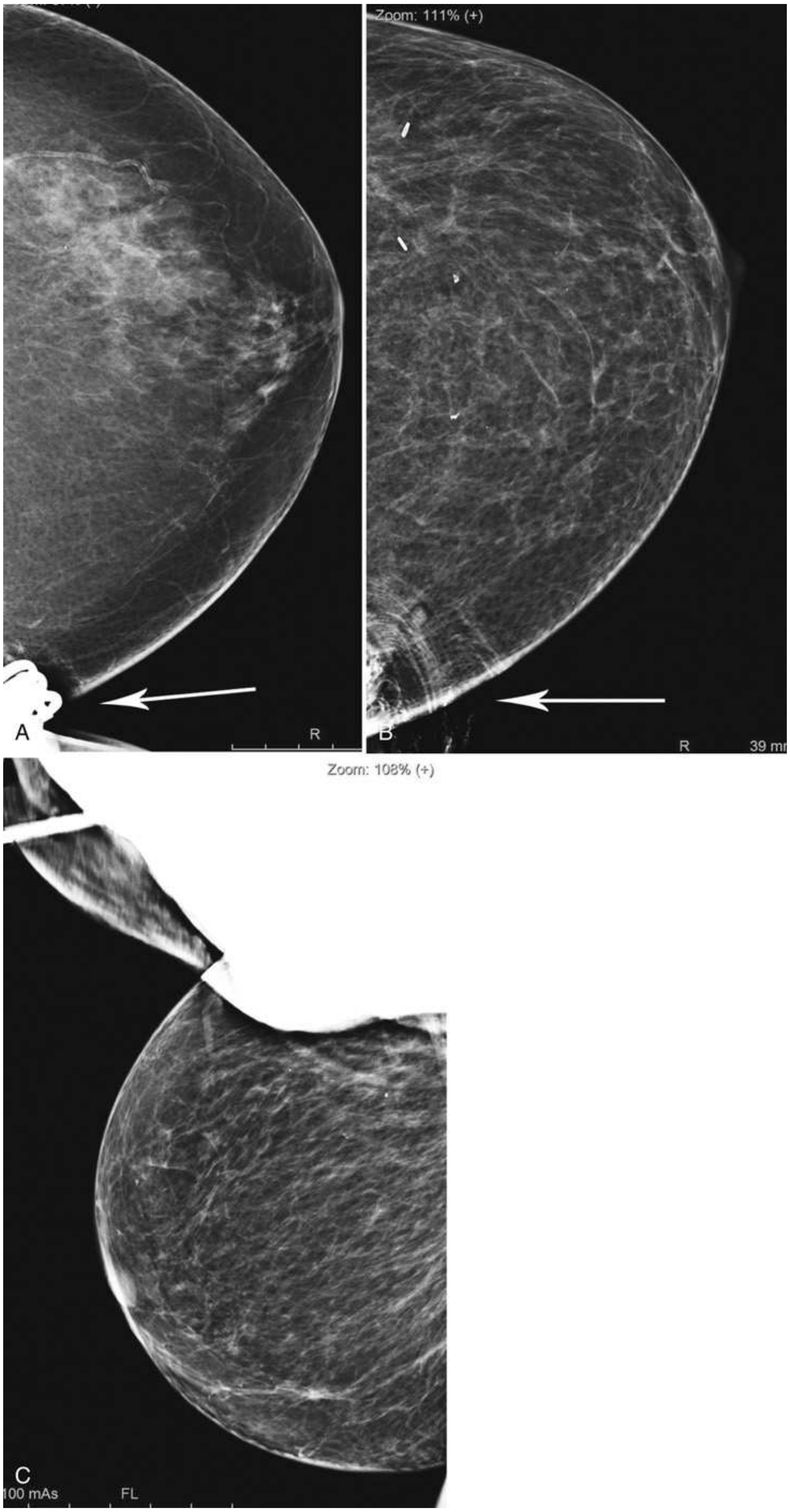


FIG. 18.21 Frequently seen artifacts caused by positional, rather than technical, errors include (A) earring superimposed over the medial portion of the breast on a CC projection; (B) hair superimposed over the breast; and (C) the patient's chin superimposed over the breast tissue as the result of patient motion or physical limitations.

(A) A mammogram shows an earring superimposed over the medial portion of the breast. It is indicated by a white arrow. (B) A mammogram shows a hair superimposed over the breast. It is indicated by a white arrow. (C) A mammogram shows a bright white region above the breast tissue.

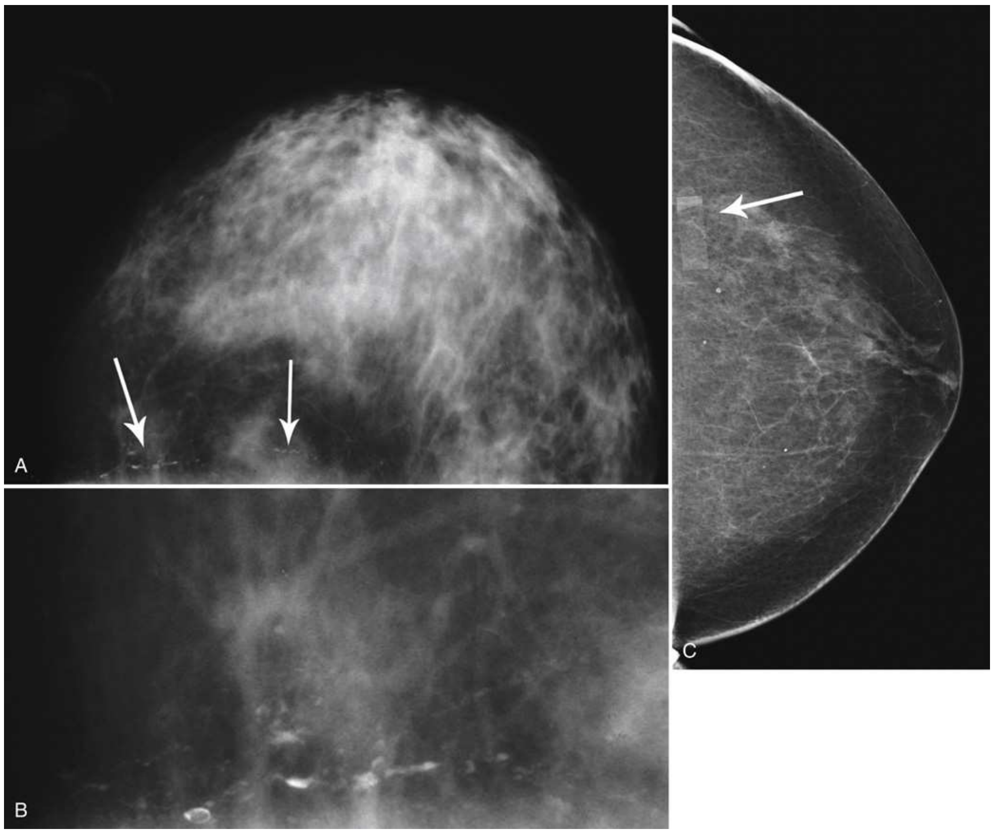


FIG. 18.22 Artifacts are often the result of poor patient preparation. (A and B) These show pseudocalcifications along the inframammary crease—the result of caked powder. (C) This shows a band-aid applied by the patient on the posterior aspect of the breast that was not noticed by the technologist until it was seen on the mammogram.

(A) A mammogram shows dark regions above the white area at the bottom. It is indicated by two white arrows. (B) A mammogram shows an enlarged view of the breast tissue showing pale white spots scattered on it. (C) A mammogram shows a rectangular region at the left. It is indicated by an arrow.

*PLEASE BRING FORM AT TIME OF APPOINTMENT—**DO NOT MAIL**. THANK YOU.*

EWBC MEDICAL HISTORY FORM

M.R.#__________

— please remember to **sign the back** *of this form AND* **only use ink** *to fill out this form—*

1. Purpose of today's visit? ____________________

2. Do you use:

a. Hormones? Yes No Brand ______ Dosage ______ How long? ____ If discontinued when? ______

b. Oral Contraceptive? Yes No Brand ____________

c. Anti-Estrogen/Breast Cancer Prevention? Yes No Brand ____________

3. Do you have breast implants? Yes No *(type)* Silicone Gel Saline Combination Unknown

4. Are you taking aspirin or blood thinners? Yes No

5. Are you allergic to any of the following?

a. Medicine(s)? Yes No *(type)* ____________

b. Adhesive Tape? Yes No

c. Lidocaine? Yes No

d. Iodine Contrast Material? Yes No

e. Latex? Yes No

f. Others? ____________

6. Do you currently have any of the following? *– please check only those that apply to you and explain below:*

☐ Fever/Chills ☐ Weakness ☐ Leg Swelling ☐ Seasonal Allergies

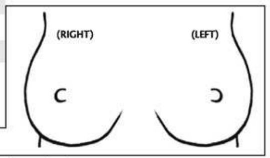
☐ Eye Problems ☐ Depression ☐ Joint Aches ☐ Stomach Problems

☐ Kidney Problems Explanation ____________

OFFICE USE ONLY ☐ All other systems negative

7. Questions for female patients: *(please circle your answers)*

1. How many months since your physician examined your breasts? ______ months
2. Your age at birth of your 1st child. ____ No biological children ☐
3. Your age at time of 1st menstrual cycle. ____
   a. Are your periods regular? Yes No *if no, date of your last period* ________
4. Age you entered menopause. ____ (If you are no longer having periods for at least one year).
5. Are you pregnant? Yes No
6. Are you breastfeeding? Yes No
7. Do you have your ovaries? Yes No
8. Do you have your uterus? Yes No
9. Have you had breast surgery? Yes No



If yes, please mark the area of surgery with the year it was done.

10. Have you ever had radiation therapy to your breast/chest area? ☐ Yes ☐ No if yes, when? ________
11. Have you ever had chemotherapy? ☐ Yes ☐ No if yes, when? ______ for what? ______

8. Social History: ☐ **Male** ☐ **Female**

Marital Status: ☐ **Single** ☐ **Married** ☐ **Divorced** ☐ **Partner** ☐ **Widowed**

Occupation: ____________

Do you drink alcohol? ☐ Yes ☐ No **if yes,** how often? ____________

Do you smoke? check one: ☐ Daily ☐ Occasional ☐ Never Smoked ☐ Former Smoker ☐ Unknown

Race: ☐ American Indian ☐ Alaska Native ☐ Asian ☐ Black or African American

☐ Native Hawaiian or Pacific Islander ☐ White

Ethnicity: ☐ Hispanic or Latino ☐ Not Hispanic or Latino

Preferred Language: ☐ English ☐ Other ____________

Please list medications *(include non-prescription medications and birth control pills, write "none" if no medications are used)*

____________ ____________ ____________

____________ ____________ ____________

____________ ____________ ____________

____________ ____________ ____________

(over)

9. Medical/Family History: Directions-Check "None" if neither you nor anyone in your family has had this problem. Check "Self" if this is true for you. Check "Family" if a member of your family has had this problem.

	NONE	SELF	FAMILY	
Breast Cysts	☐	☐		
Breast Pain	☐	☐		
Nipple Changes				
Inversion: ☐ Left ☐ Right				
Discharge: ☐ Left ☐ Right				
Rash: ☐ Left ☐ Right				
HIV	☐	☐		
Heart Valve Replacement	☐	☐		
High Blood Pressure	☐	☐		
Pacemaker/Cardiac Stent	☐	☐		
Heart Attack	☐	☐		
Stroke	☐	☐		
Hepatitis/Liver Problems	☐	☐		*type:* ______
Asthma	☐	☐		
Diabetes	☐	☐	☐	
Arthritis	☐	☐	☐	*type:* ______
Hives	☐	☐	☐	
Pancreatic Cancer	☐	☐	☐	
Melanoma	☐	☐	☐	
Lymphoma	☐	☐	☐	*type:* ______
Leukemia	☐	☐	☐	*type:* ______
Other Cancers *(Please list breast and ovarian history below)*	☐	☐	☐	*type:* ______

Have you ever been tested for BRCA1/BRCA2 Mutations?

☐ **NO** ☐ **YES** If yes, were the results: ☐ **Positive** ☐ **Negative** ☐ **Uncertain Variant**

Are you of Ashkenazi Jewish Ancestry? ☐ **NO** ☐ **YES**

HISTORY OF BREAST CANCER:

☐ **NO** ☐ **YES**

	Age at diagnosis	Age if diagnosed with a second NEW Breast Cancer	Mother *or* Father's side (PLEASE CIRCLE)
Self			
Mother			
Sister			
Daughter			
Brother			
Father			
Son			
Niece			
Nephew			
Grandmother			M F
Grandfather			M F
Aunt			M F
Uncle			M F
Cousin			M F

HISTORY OF OVARIAN CANCER:

☐ **NO** ☐ **YES**

	Age at diagnosis	Mother *or* Father's side (PLEASE CIRCLE)
Self		
Mother		
Sister		
Daughter		
Niece		
Grandmother		M F
Cousin		M F
Aunt		M F

If we may contact you by email, please list your email address: ______

Print Name: ______ Date of birth: ______ Date: ______

Signature: ______ Date: ______

Patient Review: ______ Date: ______ Patient Review: ______ Date: ______

OFFICE USE ONLY	MD Review: ______ Date: ______	MD Review: ______ Date: ______	MD Review: ______ Date: ______

The above information is accurate and any unanswered questions are considered not applicable or negative.

May 3.12

FIG. 18.23 Sample mammography patient history questionnaire. Note that a good amount of emphasis is placed on patient and family history to determine risk and inclusion for *BRCA* testing and breast MRI. Courtesy Elizabeth Wende Breast Care, LLC, Rochester, NY.

E W B C medical history from. The contents of the form are as follows. 1. Purpose of visit. 2. Do you use: a) hormones. b) oral contraceptive c) anti estrogen or breast cancer prevention. 3. Do you have breast implants. 4. Are you taking aspirin or blood thinners. 5. Are you allergic to any of the followings. a) medicine b) adhesive tape. c) lidocaine. d) iodine contrast material e) latex f) others. 6. Do you currently have any of the following. 7. Questions for female patients. 1. How many months since your physician examined your breast. 2. Your age at birth of your 1st child. 3. Your age at time of 1st menstrual cycle. 4. Age you entered menopause. 5. Are you pregnant. 6. Are you breastfeeding. 7. Do you have your ovaries. 8. Do you have your uterus. 9. Have you had breast surgery. 10. Have you ever had breast surgery. 11. Have you ever had chemotherapy. 8. Social History. 9. Medical or family history. Each of the following problem has three check boxes. the first check box is labeled none. The second check box is labeled self, and the third check box is labeled family. The problems listed are as follows: breast cysts, breast pain, nipple changes, H I V, heart valve replacement, high blood pressure, pacemaker or cardiac stent, heart attack, stroke, hepatitis or liver problems, asthma, diabetes, arthritis, hives, pancreatic cancer, melanoma, lymphoma, leukemia, other cancers. Have you ever been treated for b r c a 1 or b r c a 2 mutations. History of breast cancer. History of ovarian cancer.

Examination Procedures

This section describes procedures for conducting mammographic examinations. Only dedicated breast imaging equipment should be used to perform mammography. The following steps should be taken:

- If possible, examine previous mammographic studies of patients who are undergoing subsequent mammography screening. These images should be evaluated for positioning, compression, and exposure factors to determine whether any improvement in image quality can be obtained with the current study. Position the breast consistently so that any lesion can be accurately localized and a valid comparison with prior studies can be made.
- Determine the correct compression paddle size for the patient, and use the smallest possible size to image all of the breast tissue fully. Positioning the breast on a surface and detector that is too large causes the skin and muscles to overextend, reducing the amount of posterior tissue imaged, and may compromise the technical image quality. Occasionally, a patient may present with oversized breasts that do not fit completely on the largest detector field and compression paddle. When this happens, overlapping images are taken to visualize all of the breast tissue. This is referred to as "mosaic" imaging or tiling, as image tiles are fitted together to form a complete picture (Fig. 18.24).
- Explain the procedure simply and completely to the patient before beginning the examination. It should never be assumed that the patient is fully aware of what the mammographer is about to do, even if the patient has had prior examinations.
- In many cases, routine projections do not sufficiently show all of the breast tissue, and additional projections may be necessary. To allay patient concerns, the mammographer should explain to the patient, before beginning the procedure, why additional projections are sometimes needed and that they do not indicate a potential problem.
- Before positioning the patient's breast and applying compression, consider the natural mobility of the breast, so that patient discomfort can be minimized. The inferior and lateral portions of the breast are mobile, whereas the superior and medial portions are fixed. When possible, the mobile tissues should be moved toward the fixed tissues.
- For each of the two basic breast projections, ensure that the breast is firmly supported and adjusted, so that the nipple is directed forward.
- Profile the nipple, if possible. Obtaining an image of the posterior breast tissue should be the primary consideration, but positioning of the nipple in profile is not always possible. An additional projection can be obtained to profile the nipple, if necessary. Alternatively, a marker may be used to locate clearly the nipple that is not in profile, in which case an additional image may not be needed.

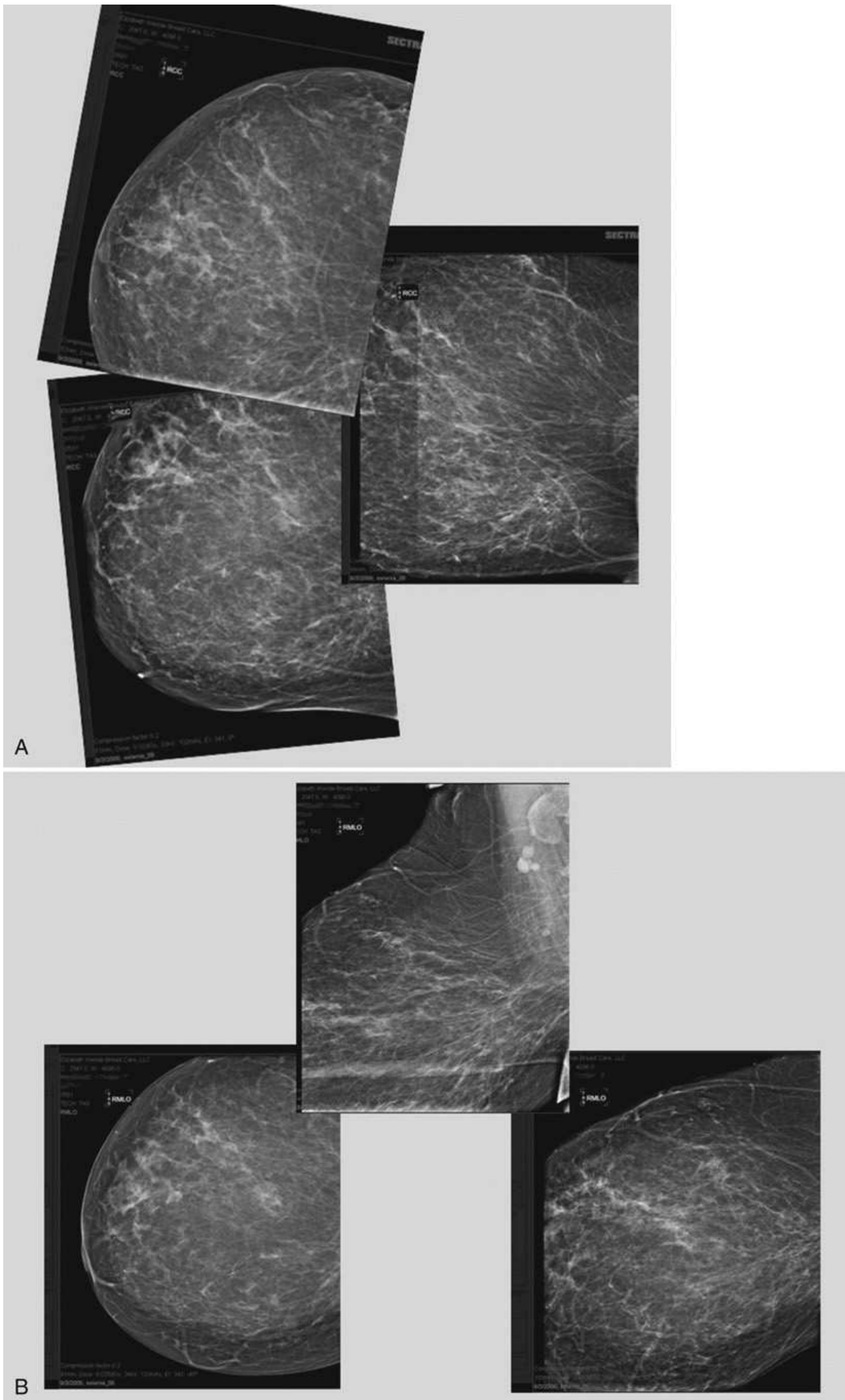


FIG. 18.24 When the breast is larger than the image receptor, several images of the breast should be taken to visualize all of the tissue. (A) Three mosaic images of the CC projection, taken to image anteromedial, anterolateral, and posterior tissue. (B) Mosaic images of the MLO view, imaging inferoposterior, anterior, and posteroaxillary tissue. Reprinted with permission from Andolina V, Lille S: *Mammographic imaging: a practical guide*, ed 3, Baltimore, 2011, Wolters Kluwer Health/Lippincott Williams & Wilkins.

(A) Three mammograms show mosaic images of the breast tissue. (B) Three mammograms show mosaic images of the breast tissue. The image in the middle shows white circular patches on the top right of the breast tissue.

- Apply adequate compression to the breast. Compression is an important factor in achieving a high-quality mammogram. The primary objective of compression is to produce uniform breast thickness from the nipple to the most posterior aspect of the breast. Properly applied compression spreads the breast so that the tissue thickness is more evenly distributed over the image and better separation of the glandular elements is achieved. A rigid, radiolucent mammography compression paddle facilitates breast compression. Generally, compression is applied initially using a hands-free control and is applied manually during the final phase of compression. The compression should be taut but not painful. The skin of a properly compressed breast should feel tight when lightly tapped with the fingertips. When evaluating images, compare the degree of compression with that of previous mammograms, and note any variations. If a patient is unable to tolerate an adequate amount of compression, document this information on the patient history form for the radiologist. Use only as much compression as the patient can tolerate.

Be sure that standard identification information is included on the image. For FFDM images, all of the pertinent information should be included in the Digital imaging and communications in medicine (DICOM) header. Often, this DICOM overlay can be turned on or off as needed by the radiologist to prevent interference during interpretation of the image. Image labeling for all mammographic images should be in accordance with ACR and FDA requirements (Table 18.1). Workstations used for interpretation have the capability to temporarily switch off the image identification information with a default setting. Image labeling for hardcopy and softcopy images must include the following information in a permanent, legible, and distinct manner, set where anatomic structures are not obscured:

1. Facility name and location, including city, state, and zip code
2. Patient's first and last names
3. Unique identification number and/or date of birth
4. Examination date
5. Technologist's initials or identification number
6. Cassette (screen) number for screen-film and computed radiography images
7. Mammographic unit identification if there is more than one unit in the facility
8. Laterality and view, placed on the image in a position near the axilla
    - Facilities with more than one unit must identify the mammographic unit used (Roman numerals are suggested by the ACR).
    - For patients with palpable masses, a radiopaque marker may be used to identify the location of the mass. A different type of radiopaque marker may be used to identify skin lesions, scars, or moles. This is determined by the policy of the facility, at the discretion of the reading radiologists.
    - When using automatic exposure control (AEC), position the variable-position detector at the chest wall, the mid-breast, or the anterior breast, depending on breast composition and size. The appropriate location of the AEC detector must be determined for each individual patient. If possible, the detector should be placed under the most glandular portion of the breast, usually just posterior to the nipple. Most FFDM units will automatically determine these settings based on the technology used by the manufacturer.
    - When reviewing images, assess contrast and density for optimal differentiation of breast tissues. Anatomic markers should be visible. The projections of one breast should be compared with the same projections of the contralateral breast so that symmetry and consistency of positioning can be evaluated. All images should be absent of motion blur, artifacts, and skin folds. Images must be evaluated for potentially suspicious lesions and calcifications that may require image enhancement methods.
    - To evaluate whether sufficient breast tissue is shown, the radiographer should measure the depth of the breast from the nipple to the chest wall on the CC and MLO projections. The posterior nipple line (PNL) is an imaginary line that is "drawn" obliquely from the nipple to the pectoralis muscle or the edge of the image, whichever comes first on the MLO projection. On the CC projection, the PNL is "drawn" from the nipple to the chest wall or to the edge of the image, whichever comes first. The PNL on the CC should be within ⅓ inch (1 cm) of depth of the PNL on the MLO projection (Fig. 18.25).
    - Between examinations, use a disinfectant to clean the breast tray surface, compression paddle, patient handle grips, and face guard.
    - Breast cushions available through several manufacturers provide a warmer and more comfortable examination for the patient (Fig. 18.26). Check with the unit's manufacturer before implementing any patient comfort modifications.
    - Mammography is a team effort involving the patient and the mammographer. Acknowledge the individual needs of each patient to facilitate the cooperation and trust necessary to complete the procedure successfully. The nature of the interaction between the radiographer and the patient is likely to determine whether the patient chooses to have subsequent mammograms.

Respiration

- To avoid patient motion and image blurring, the patient may be asked to suspend respiration during the exposure. The preferred method is to ask the patient to simply "stop breathing" rather than "hold your breath." Saying "hold your breath" often implies to the patient that she will need to take a deep breath in. This may result in an unintentional movement of the ribs and therefore the breast tissue, causing blurring or a change in the position of the breast. Alternatively, some mammographers prefer to avoid suspending respiration and simply ask the patient to remain still throughout the exposure. The verbal command to remain still is used for 3D imaging procedures, as the exposure time for these examinations lasts longer, and the patient will be unable to suspend breathing for the duration of the exam. Holding still during 3D examinations helps prevent a blurry image resulting from motion. Once the breast is vigorously compressed, the patient is not liable to take deep breaths, especially if the patient is concentrating on not moving.

TABLE 18.1

View	ACR ID	Suggested ID	Projection	C-arm angle	Image receptor placement	Tissue best visualized	Applications
Mediolateral Lateral	ML		Med-Lat	90 degrees	Diagram shows one of the patient's medial sides of the right breast placed against the image receptor. An arrow indicates an x-ray beam is directed 90 degrees towards the image receptor from the left.	Lateral, central, superior, and inferior	True orthogonal to CC for lesion localization, opens tissue for structural overlap
Lateromedial Lateral	LM		Lat-Med	90 degrees	Diagram shows the image receptor is placed against the lateral side of one breast and the medial side of the other breast. An arrow indicates an x-ray beam is directed 90 degrees towards the image receptor from the right.	Medial, central, superior, and inferior	True orthogonal to CC for lesion localization, opens tissue for structural overlap
Medial-Lateral Oblique	MLO		SM-IL	30–60 degrees	Diagram shows the image receptor is in the superior medial and inferior lateral sides of the right breast. An arrow indicates an x-ray beam is directed 30 to 60 degrees towards the image receptor from the left.	Posterior, upper outer quadrant, axillary tail, lower inner quadrant	Routine
Superolateral-Inferomedial Oblique	SIO		SL-IM	1–90 degrees	Diagram shows the image receptor is in the superior lateral and inferior medial side of the left breast. An arrow indicates an x-ray beam is directed 1 to 90 degrees towards the image receptor from the right.	Posterior, medial, upper inner quadrant, lower outer quadrant	Additional view for encapsulated implants, non-conforming pt, orthogonal to MLO for localization
Inferolateral-Superomedial Oblique	LMO		IL-SM	90–180 degrees	Diagram shows the image receptor is placed in the superior medial and inferior lateral sides of the right breast. An arrow indicates an x-ray beam is directed 70 to 90 degrees towards the image receptor.	Posterior, medial, upper outer quadrant, lower inner quadrant	Can replace MLO in pts with pacemakers, open heart surgical scars
Inferomedial-Superolateral Oblique	None	ISO	IM-SL	90–180 degrees	Diagram shows the image receptor is placed in the superior-inferior side of both breasts. An arrow indicates an x-ray beam is directed perpendicular to the image receptor.	Lateral, upper inner quadrant, lower outer quadrant	Stereotactic positioning
Axillary Tail	AT		SM-IL	60–80 degrees	Diagram shows the image receptor is placed in the superior-inferior side of the right breast. An arrow indicates an x-ray beam is directed perpendicular to the image receptor. Two arrows on the breast point in opposite directions.	Posterior-lateral, axillary tail	
Axilla	None	AX	SM-IL	70–90 degrees	Diagram shows the image receptor is placed in the superior-inferior side of the right breast. An arrow indicates an x-ray beam is directed perpendicular to the image receptor. Two arrows on the breast point in opposite directions.	Axillary content	Additional view for cancer patients on affected side, suspected inflammatory ca, lymphadenopathy, search for primary ca
Cleavage View	CV		Sup-Inf	0 degrees	Diagram shows the image receptor is placed in the superior-inferior side of the right breast. An arrow indicates an x-ray beam is directed perpendicular to the image receptor. Two arrows on the breast point in opposite directions.	Medial	Extreme medial tissue, slippery medial lesions
Rolled Lateral	RL		Sup-Inf	0 degrees	Diagram shows the image receptor is placed on the posterior side of the right breast.	Subareolar, central, medial, and posteromedial tissue	Separation of superimposed glandular tissue
Rolled Medial	RM		Sup-Inf	0 degrees	Diagram shows the image receptor is in the superior medial and inferior lateral sides of the right breast. Two arrows indicate an x-ray beam is directed 0 to 90 degrees to the image receptor.	Subareolar, central, medial, and posteromedial tissue	Separation of superimposed glandular tissue

View	ACR ID	Suggested ID	Projection	C-arm angle	Image receptor placement	Tissue best visualized	Applications
Captured Lesion (Coat-Hanger View)	None	CL	All	0–90 degrees		Posterior	Palpable abnormality near chest wall or implant, often performed with magnification
Tangential View	TAN		All	0–90 degrees		All	Palpable abnormality, to visualize borders with better detail; often used in conjunction with magnification
Techniques							
Magnification	M						Improved resolution; better shows calcifications and borders of lesions
Implant Displacement	ID					Tissue anterior to subpectoral implants	Patients with implants
Nipple In Profile		NIP				Subareolar	
Spot Compression		S					Palpable abnormality, to visualize borders with better detail; often used in conjunction with magnification

ACR, American College of Radiology.

From Andolina V, Lille S: *Mammographic imaging: a practical guide*, ed 3, Baltimore, MD, 2011, Lippincott Williams & Wilkins.

Best Practices in Mammography

Mammography is a specialty with a goal to obtain radiographic images of breast anatomy to help aid in diagnosis. Due to the nature of the body part being examined, technologists should exhibit professionalism, sensitivity, and empathy while maintaining patient comfort. The following best practices provide some universal guidelines for the mammographer to-achieve these goals.

1. *Positioning:* Careful positioning will result in high quality images to aid in accurate diagnoses. Technologists should aim to include all breast anatomy to create diagnostically useful radiographs. The images are most useful when anatomy is clearly shown and is viewable in different projections, which is a product of precise positioning. In addition to providing useful information, precise imaging also prevents repeated projections, saving patients from unnecessary radiation exposure.

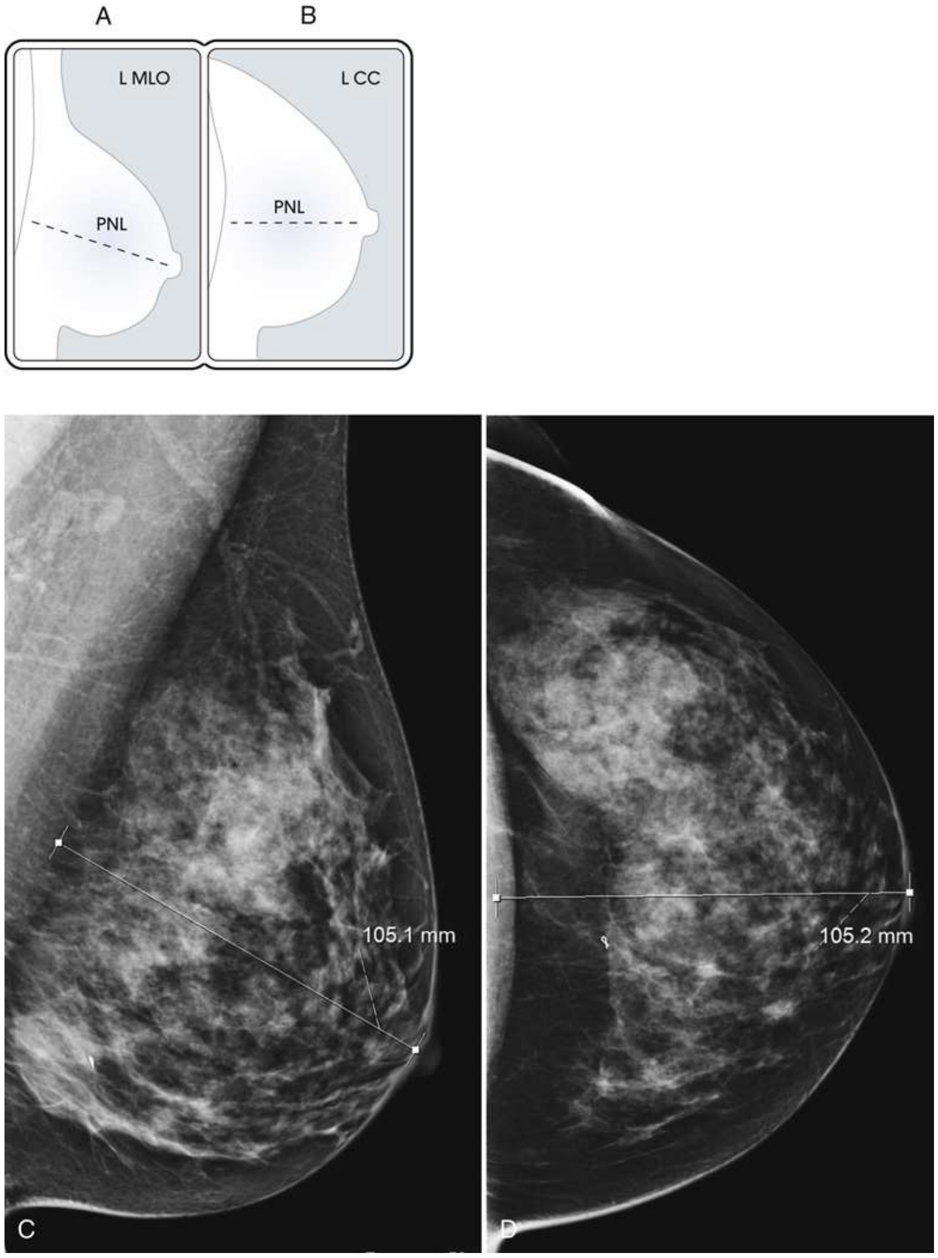


FIG. 18.25 (A) Schematic MLO projection with PNL drawn. (B) Schematic CC projection with PNL drawn. PNL of CC projection should be within 1 cm of PNL of MLO projection, as noted on the MLO (C) and CC (D) projections of this mammogram.

Diagram (A) titled L M L O shows a horizontal decreasing dashed line labeled P N L drawn towards the nipple. Diagram (B) titled L C C shows a horizontal dashed line labeled P N L drawn towards the nipple. (C) A mammogram shows a horizontal decreasing line labeled 105.1 millimeters drawn towards the nipple. (D) A mammogram shows a horizontal line labeled 105.2 millimeters drawn towards the nipple.

2. *Empathy:* Every medical professional should be empathetic towards patients, especially in mammography, as these patients are more vulnerable because their breasts are exposed. These are very personal examinations; therefore, it is important for technologists to show compassion towards patients and empathize with them. Technologists can show empathy by demonstrating caring attributes, patience, and desire to promote a positive patient experience.
3. *Professionalism:* Ethical conduct and professionalism are especially imperative with mammography. Because the relationship between the patient and technologist is intimate, it is critical for the technologist to display professional behavior since the patient is exposed. Conversing with the patient in a respectable manner demonstrates competence and professionalism.
4. *Comforting:* This is a private and personal examination, and patients are often nervous during these procedures or stressed concerning possible test results. It is the responsibility of the technologist to maximize patient comfort during an already uncomfortable exam. A relaxed conversation about any topic, ranging from the weather to complimenting the patient's shoes, helps the technologist make a connection with the patient. Prior to the exam, the technologist should explain the procedure to the patient in detail to aid in her relaxation. In addition to explaining the procedure, technologists should answer any questions the patient may have to acknowledge their concerns and alleviate their fears.

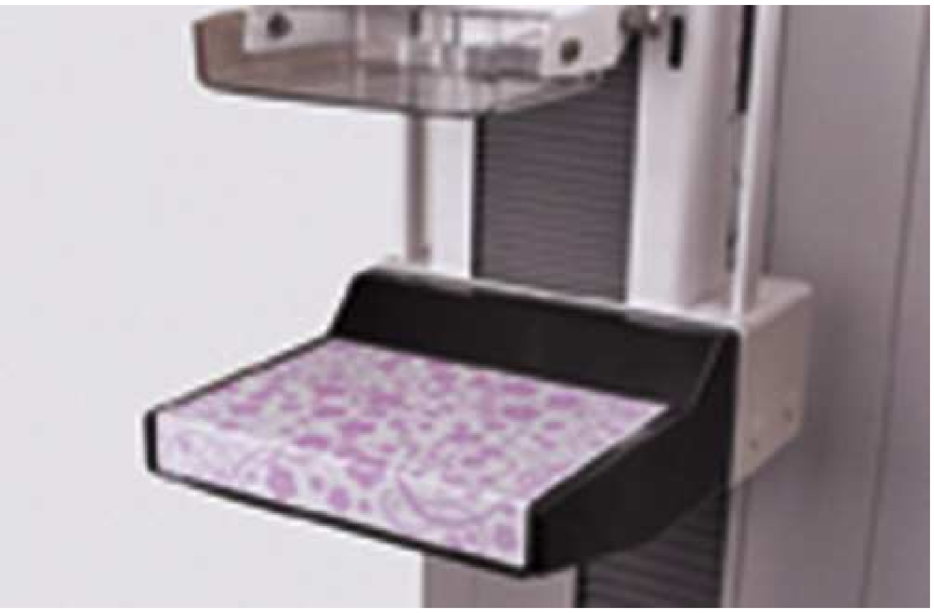


FIG. 18.26 Breast cushions are sometimes used to provide a more comfortable environment and examination for the patient. Courtesy Beekley Corp., Bristol, CT.

5. *Assessment:* Technologists must pay close attention to the patient's state and tolerability for compression. Some patients can be more sensitive or have a lower tolerance for pain than others. Technologists must use their best judgment to ensure that that they are obtaining optimal images without causing any pain or further harming patients. It is essential for technologists to be gentle with patients and practice safety measures.
6. *Communication:* Effective communication is of great importance when positioning patients for different projections. Communicating clear and specific instructions to the patients about what the technologist needs them to do during the exam increases patient cooperation. Speaking to the patient throughout the examination reduces anxiety. During the examination, the technologists need to tell the patients how they are going to position them before making any sudden movements.
7. *Support:* Uncertainty of results causes anxiety in patients. Patients are anxious during routine mammogram procedures; however, they are especially anxious when they are called back for a diagnostic exam or undergo a breast biopsy procedure. Technologists should be the patients' support and assure them that certain procedures are protocol and that they should not worry until there is something to worry about. When patients are emotional, technologists may support them by giving them hugs or letting them cry. Technologists can inform patients about support groups or other resources that may provide them with support during these times.

Summary of Mammography Projections

Before beginning to learn mammography projections, the student of radiography should carefully study the illustrative summary of mammography projections shown in the box. Familiarity with the different projection names and abbreviations would enhance the student's understanding of the detailed discussions of the projections presented in this chapter.

Descriptive Terminology for Lesion Location

Descriptive terminology has been developed for the referring physician, the technologist, and the radiologist to communicate efficiently regarding an area of concern within a breast. When describing an area of concern, the laterality (right or left) must accompany the description (Fig. 18.27).

Each breast is divided into four quadrants: the upper outer quadrant (UOQ), the lower outer quadrant (LOQ), the upper inner quadrant (UIQ), and the lower inner quadrant (LIQ). Clock time is also used to describe the location of a specific area of concern within the breast, but it changes from the right to the left breast, that is, 2:00 in the right breast is in the UIQ, whereas 2:00 in the left breast is in the UOQ. This opposite labeling applies to all clock times; therefore, it is important to identify the correct breast, clock time, and quadrant. The distance of the abnormality from the nipple, which is the only fixed point of reference in the breast, is also noted. The terms *subareolar* and *periareolar* describe the area directly beneath the nipple and near (or around) the nipple area. Central describes a lesion located directly behind the nipple in both radiographic projections.

The location of a lesion seen on the mammogram is described using the clinical orientation (described above) extrapolated from the image location. The location of an imaged lesion is described by its laterality, quadrant, clock location, and depth, thus providing a consistency check for possible right-left confusion. [19] Depth of a lesion on the mammogram is described as anterior (nipple), middle, or posterior.

Routine Projections of the Breast

Mammography is routinely performed using the CC and MLO projections. The combination of these two views best allows visualization of the greatest amount of breast tissue for screening purposes. When diagnostic examinations are performed for specific areas of concern, additional views may be indicated as desired by the radiologist.

Craniocaudal (CC)[a]	Mediolateral oblique (MLO)[a]	
Mediolateral (ML)[a]	Lateromedial (LM)	
Exaggerated craniocaudal (XCCL)[a]	Craniocaudal for cleavage (CV)	Craniocaudal with roll lateral (RL)
Craniocaudal with roll medial (RM)	Tangential (TAN)	Caudocranial (FB)
Mediolateral oblique for axillary tail (AT)	Lateromedial oblique (LMO)	Superolateral to inferomedial oblique (SIO)

[a] Essential projection.

Breast

Craniocaudal (Cc) Projection

Paddle:

8 × 10 inches (18 × 24 cm) or 10 × 12 inches (24 × 30 cm).

Position of patient

- Have the patient stand facing the IR, with her feet pointing perpendicular to the mammography unit. If the patient is unable to stand for the duration of the exam, have the patient seated on an adjustable stool facing the unit.

Position of part

- While standing on the medial side of the breast to be imaged, elevate the inframammary fold to its maximal height.
- Adjust the height of the C-arm to the level of the inferior surface of the patient's breast.

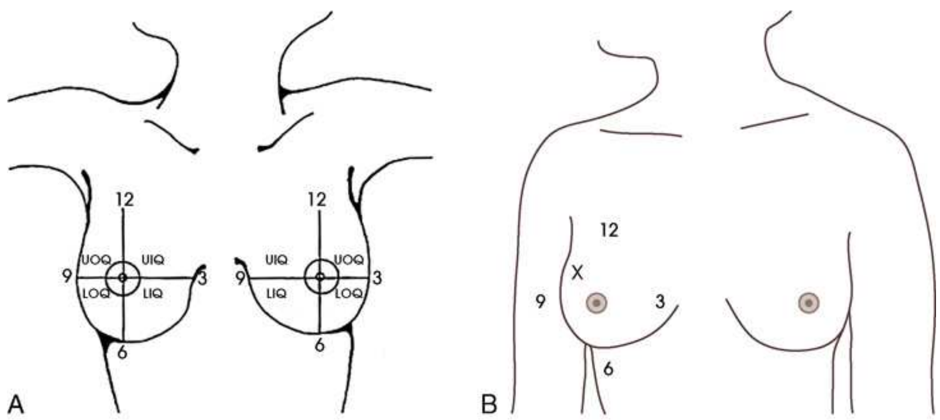


FIG. 18.27 (A) Each breast is viewed as a clock and is divided into four quadrants to describe the location of a lesion: upper outer quadrant (UOQ), upper inner quadrant (UIQ), lower outer quadrant (LOQ), and lower inner quadrant (LIQ). (B) An abnormality should always be described in a consistent manner. For example, the location of the abnormality denoted by the *x* would be described as "right breast UOQ at approximately 10:30 position."

Diagram (A) shows the left and right breast viewed as a clock and is divided into four quadrants by two perpendicular planes intersected at the nipple. Right side: They are the upper outer quadrant (U O Q), upper inner quadrant (U I Q), lower outer quadrant (L O Q), and lower inner quadrant (L I Q). Left side: They are the upper inner quadrant (U I Q), upper outer quadrant (U O Q), lower inner quadrant (L I Q), and lower outer quadrant (L O Q). Diagram (B) shows the right breast viewed as a clock. An x mark is made at the upper outer quadrant (U O Q) at 10:30 position.

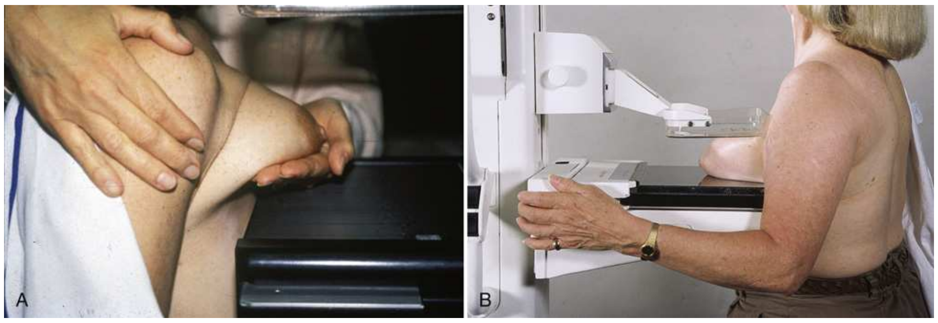


FIG. 18.28 (A) Lift breast to adjust level of C-arm to elevated inframammary fold. (B) CC projection.

(A) A hand is holding the shoulder of the patient and the other hand is sliding the skin of the breast up over the clavicle. (B) A patient is standing next to the mammography unit with her left breast on the image receptor. The compression paddle is over the breast.

- Have the patient lean slightly forward from the waist. Use both hands to pull the breast gently onto the IR surface, while instructing the patient to press the thorax against the IR.
- Drape the opposite breast over the corner of the IR. This maneuver improves demonstration of the medial tissue.
- Have the patient hold onto the grab bar with the contralateral hand; this helps steady the patient as you continue positioning.
- Keep the breast perpendicular to the chest wall. The technologist should use his or her fingertips to pull the inferior posterior tissue gently forward onto the IR.
- Center the breast over the AEC detector, with the nipple in profile if possible.
- Immobilize the breast with one hand, while taking care not to remove this hand until compression begins.
- While placing your arm against the patient's back with your hand on the shoulder of the affected side, make certain the patient's shoulder is relaxed and in external rotation.
- Rotate the patient's head away from the affected side, and rest the patient's head against the face guard.
- Make certain that no other objects such as jewelry or hair obstruct the path of the beam.
- With your hand on the patient's shoulder, gently slide the skin up over the clavicle.
- Using the hand that is anchoring the patient's breast, pull the lateral tissue onto the IR without sacrificing medial tissue. While holding the breast in place, use that same hand to smooth skin wrinkles anteriorly toward the nipple.
- Inform the patient that compression of the breast will begin. Using foot pedal compression controls, bring the compression paddle into contact with the breast while sliding the hand toward the nipple.
- Slowly apply compression manually until the breast feels taut.
- Check the medial and lateral aspects of the breast for adequate compression.
- Instruct the patient to indicate whether the compression becomes uncomfortable.
- After full compression is achieved and checked, instruct the patient to stop breathing (Fig. 18.28).
- Make the exposure.
- Release breast compression immediately.

Central ray

- Perpendicular to the base of the breast

Structures shown

The CC projection shows the central, subareolar, and medial fibroglandular breast tissue. The pectoral muscle is shown in approximately 30% of all CC images.[20, 21]

Evaluation Criteria

The following should be clearly shown:

- The PNL extending posteriorly to the edge of the image and measuring within ⅓ inch (1 cm) of the depth of the PNL on MLO projection (see Fig. 18.29)
- All medial tissue, as shown by visualization of medial retroglandular fat and the absence of fibroglandular tissue extending to the posteromedial edge of the image
- Nipple in profile (if possible) and at midline, indicating no exaggeration of positioning
- For emphasis of medial tissue, some lateral tissue may be excluded.
- Pectoral muscle seen posterior to medial retroglandular fat in about 30% of properly positioned CC images
- Slight medial skin reflection at the cleavage, ensuring adequate inclusion of posterior medial tissue
- Uniform tissue exposure if compression is adequate

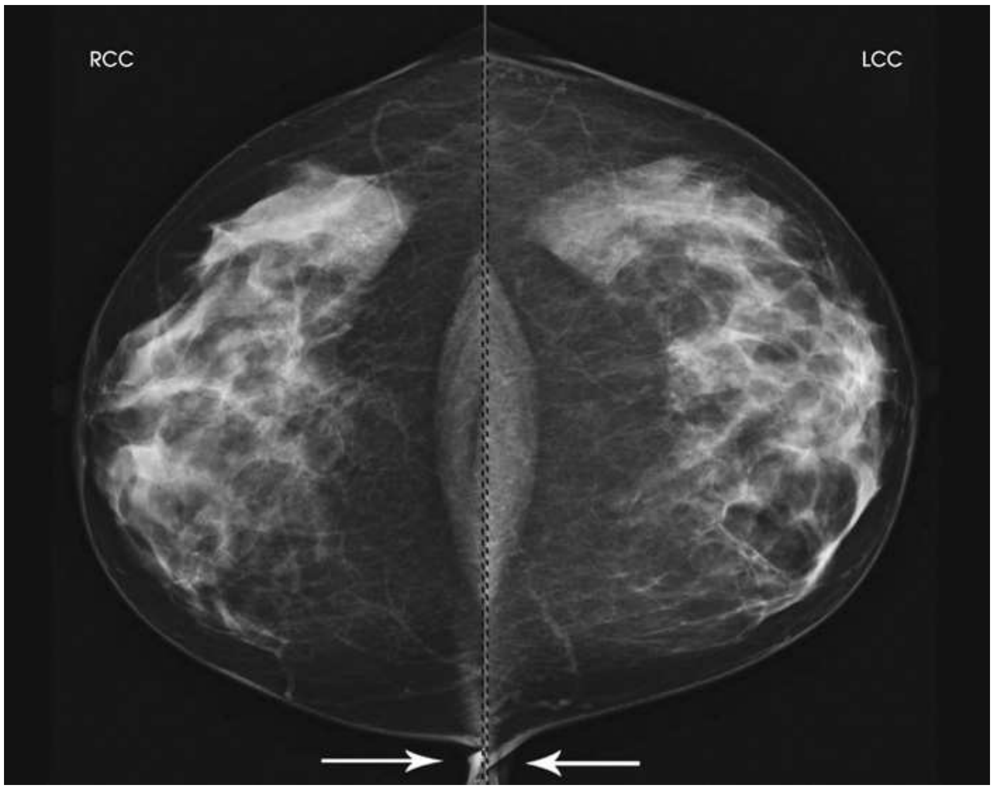


FIG. 18.29 Bilateral CC projections show proper positioning and compression. The CC projection should include maximal medial breast tissue *(arrows)* with the nipple centered and in profile. As much lateral and inferior tissue as possible should be pulled onto the image receptor without compromising visualization of medial tissue. Note that pectoral muscle is seen posteriorly on these images, but this may not be possible to achieve on most CC projections.

Mediolateral Oblique (MLO) Projection

Paddle:

8 × 10 inches (18 × 24 cm) or 10 × 12 inches (24 × 30 cm).

Position of patient

- Have the patient stand facing the IR with her feet pointed forward or seat the patient on an adjustable stool facing the unit.

Position of part

- Determine the degree of obliquity of the C-arm. The degree of obliquity should be approximately 45 degrees but will vary from 30 to 60 degrees, depending on the patient's body habitus. Draw an imaginary line from the patient's shoulder to midsternum and angle the C-arm to parallel this line.
- Adjust the height of the C-arm so that the superior border of the IR is level with the axilla.
- Instruct the patient to lean slightly forward from the waist.
- Elevate the arm of the affected side over the corner of the IR and rest the hand on the adjacent handgrip. The patient's elbow should be flexed and resting posterior to the IR.
- Place the upper corner of the IR as high as possible into the patient's axilla between the pectoral and latissimus dorsi muscles, so that the IR is behind the pectoral fold.

FIG. 18.30 MLO projection.

- Ensure that the patient's affected shoulder is relaxed and leaning slightly anterior. While placing the flat surface of the hand along the lateral aspect of the breast, gently pull the patient's breast and pectoral muscle anteriorly and medially.
- Holding the breast between the thumb and fingers, gently lift it up, out, and away from the chest wall.
- Center the breast on the IR with the nipple in profile, if possible, and hold the breast in position.
- Hold the breast up and out from the body by rotating the hand so that the base of the thumb and the heel of the hand support the breast.
- Inform the patient that compression of the breast will begin. Continue to hold the breast up and out while sliding the hand toward the nipple as the compression paddle is brought into contact with the breast. Loosen the skin at the clavicle with the opposite hand to ensure that posterior tissue is imaged while preventing injury to the shoulder. Roll the contralateral shoulder toward the unit to ensure that medial tissue is visualized.
- Slowly apply compression until the breast feels taut. The corner of the compression paddle should be inferior to the clavicle.
- Check the superior and inferior aspects of the breast for adequate compression.
- Instruct the patient to indicate whether the compression becomes uncomfortable.
- Gently pull down on the patient's abdominal tissue to open the inframammary fold.
- Instruct the patient to hold the opposite breast away from the path of the beam if necessary.
- Instruct the patient to lift her chin to clear the field of potential artifacts.
- After full compression is achieved, instruct the patient to stop breathing (Fig. 18.30).
- Make the exposure.
- Release breast compression immediately.

Central ray

- Perpendicular to the base of the breast
- The C-arm apparatus is positioned at an angle determined by the slope of the patient's pectoral muscle (30 to 60 degrees). The actual angle is determined by the patient's body habitus: Tall, thin patients require steep angulation, whereas short, stout patients require shallow angulation.

Structures shown

The MLO projection usually shows most of the breast tissue, with emphasis on the lateral aspect and AT.

Evaluation Criteria

The following should be clearly shown:

- PNL measuring within ⅓ inch (1 cm) of the depth of the PNL on CC projection [5, 19]
- While drawing the imaginary PNL obliquely following the orientation of breast tissue toward the pectoral muscle, use the fingers to measure its depth from nipple to pectoral muscle or to the edge of the image, whichever comes first (Fig. 18.31).
- Inferior aspect of the pectoral muscle extending to the PNL or below it if possible
- Pectoral muscle showing anterior convexity to ensure relaxed shoulder and axilla
- Nipple in profile if possible
- Open inframammary fold
- Deep and superficial breast tissues well separated when breast is adequately maneuvered up and out from the chest wall
- Retroglandular fat well visualized to ensure inclusion of deep fibroglandular breast tissue

- Uniform tissue exposure if compression is adequate

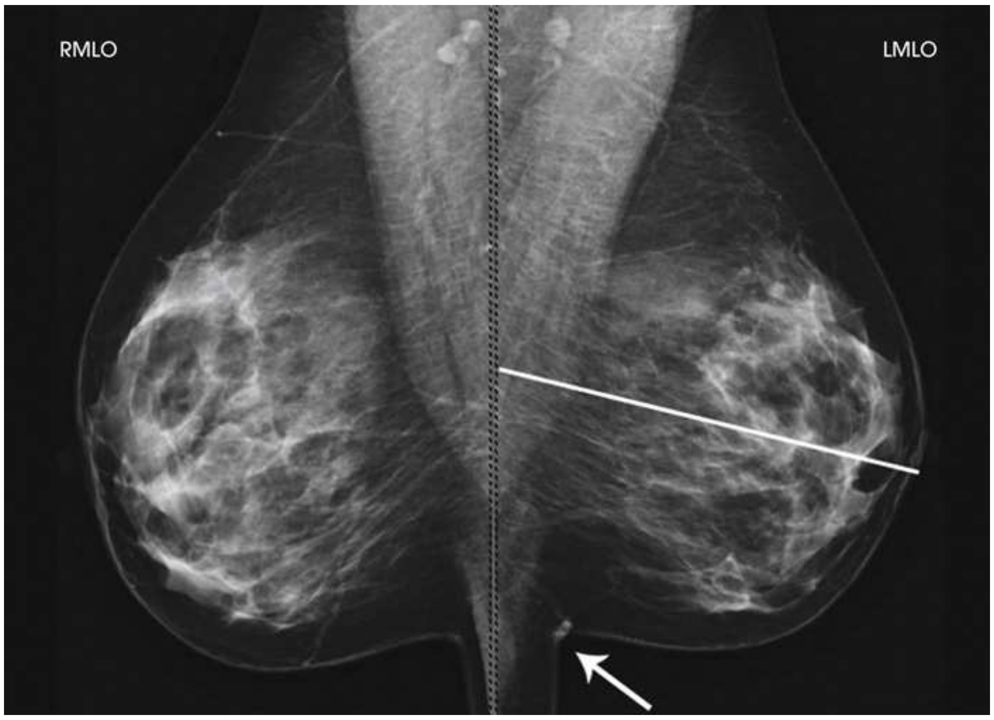


FIG. 18.31 Bilateral MLO projections show proper positioning. Images should include pectoral muscle to level of nipple *(white line)*, posterior breast tissue, and junction of inframammary fold and abdominal skin *(arrow)*.

A bilateral mammogram shows a vertical line in the middle. A white line slanting horizontal line is drawn towards the vertical line. A white region is visible at the posterior breast tissue. It is indicated by a white arrow.

Routine Projections of the Augmented Breast

Mammography has an 80% to 90% true-positive rate for detecting cancer in breasts that do not contain implants. For the millions of women in the United States who have undergone augmentation mammoplasty for cosmetic or reconstructive purposes, the true-positive (pathologic-mammographic) breast cancer detection rate decreases to approximately 60% because implants can obscure 85% of the breast's structures, potentially hiding a small cancer that could normally be detected with mammography at an early and curable stage.

Successful radiography of an augmented breast requires a highly skilled mammographer. During the examination, precautions must be taken to avoid rupture of the augmentation device.

Mammography of the augmented breast presents a challenge that cannot be met with the standard two-view examination of each breast. An eight-radiograph examination (four views of each breast) is preferred when possible. The tissue within the posterior and superior aspects of the augmented breast can be satisfactorily evaluated using the standard CC and MLO projections. However, these four images do not adequately show the surrounding breast parenchyma. The addition of a second set of images utilizing the implant displacement (ID) technique, also known as the Eklund method or maneuver, improves compression of the breast tissue and visualization of breast structures. For the Eklund method, the implant is pushed posteriorly against the chest wall so that it is excluded from the image, and the breast tissue surrounding the implant is pulled anteriorly and compressed. This technique is most effective when used on patients with implants that have been placed posterior to the pectoral muscle. It can be used when the implant is placed anterior to the pectoral muscle, but notably less tissue will be able to be pulled onto the IR (Fig. 18.32).

Complications frequently associated with breast augmentation include fibrosis, increased fibrous tissue surrounding the implant, shrinking, hardening, leakage, and pain. Breast augmentation does not increase the risk for developing cancer in the breast; however, the presence of the implant may make detection of cancer on a screening mammogram more difficult. [22] Because mammography alone cannot fully show all complications, ultrasonography and MRI are also used for breast examinations in symptomatic patients. Whether ultrasonography or MRI is used as the adjunct imaging after mammography for patients with suspected implant rupture varies from practice to practice.

Ultrasonography of the breast has proved useful in identifying implant leakage when implant rupture is suggested by mammographic findings and clinical examination, and occasionally when leakage is not suspected. It has also successfully identified leakage that has migrated to the axillary lymph nodes. Although ultrasonography is not yet recommended as a screening modality for implant leakage, it does enhance the mammographic examination.

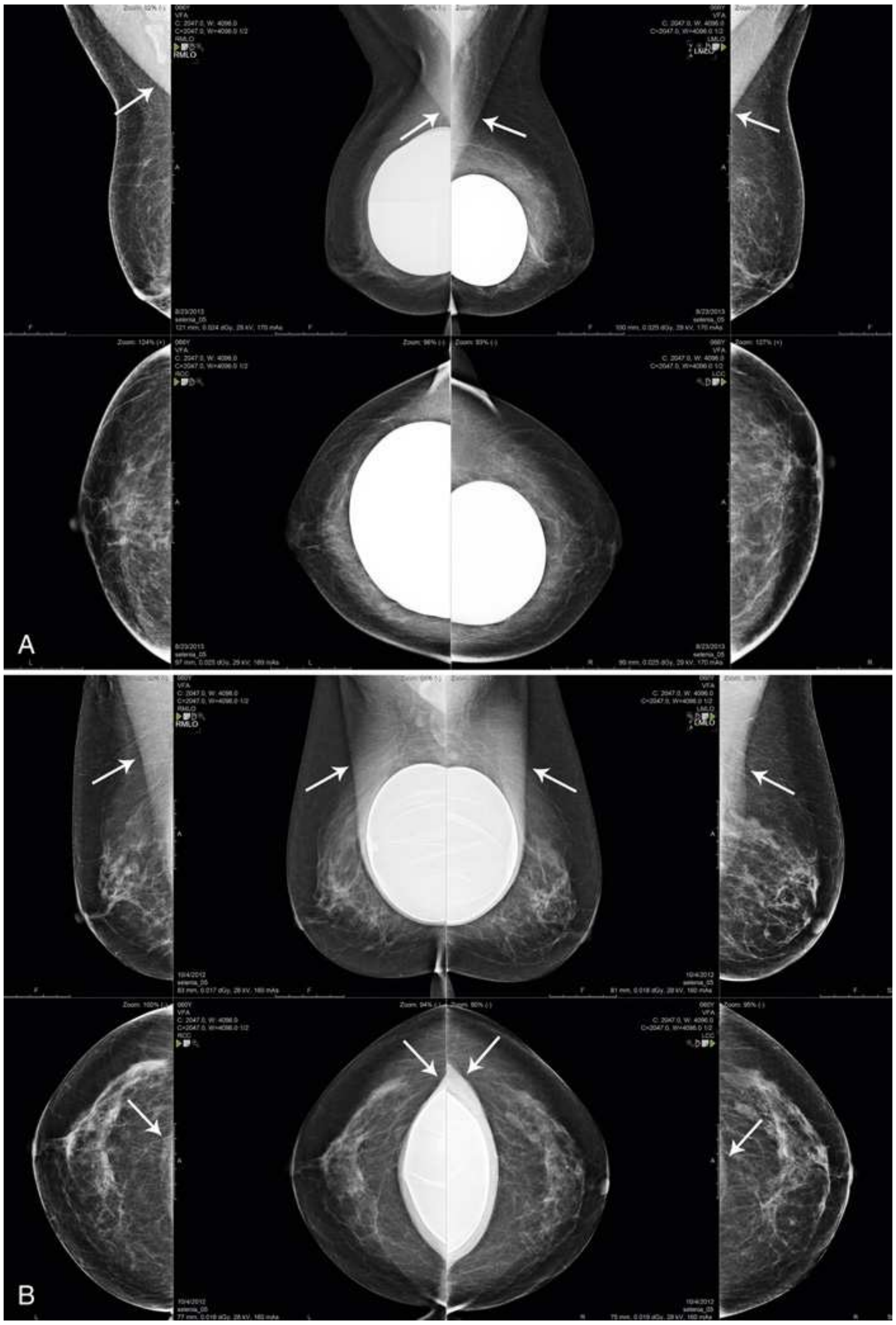


FIG. 18.32 (A) Eight-view mammogram of a patient with implants placed anterior to the pectoralis muscle *(arrows)*. (B) Eight-view mammogram of a patient with implants placed posterior to the pectoralis muscle *(arrows)*. Note that more pectoral muscle and breast tissue are seen when the implant is placed posterior to the muscle.

(A) An eight view mammogram shows radiopaque circular regions anterior to the pectoralis muscle. It is indicated by white arrows. (B) An eight-view mammogram shows radiopaque circular and oval regions posterior to the pectoralis muscle. It is indicated by white arrows. The dense breast tissues are visible.

MRI is also commonly used for diagnostic and screening evaluation of augmented breasts, particularly silicone-filled implants, but there is disagreement over the appropriateness of guidelines for its use. [23, 24] Although MRI offers several diagnostic advantages, the cost and time-consuming nature of the procedure inhibit its use as a screening modality for patients who have undergone augmentation. It may be used as a screening tool for women who have undergone reconstruction after breast cancer surgery. MRI has proved useful as a preoperative tool in locating the position of an implant, identifying the contour of the deformity, and confirming rupture and leakage migration patterns. [25]

Augmented Breast

Craniocaudal Projection With Full Implant (CC)

Paddle:

8 × 10 inches (18 × 24 cm) or 10 × 12 inches (24 × 30 cm).

Position of patient

- Have the patient stand facing the IR or seat the patient on an adjustable stool facing the unit.

Position of part

- Turn the AEC *off*, and preselect a *manual* technique. For FFDM units, be sure that Implant View processing settings are chosen if applicable.
- Follow the same positioning sequence as for the standard CC projection.
- Inform the patient that minimal compression of the breast will be used. Bring the compression paddle into contact with the breast, and slowly apply only enough compression to immobilize the breast. Compression should be *minimal.* The anterior breast tissue should still feel soft.
- Select the appropriate exposure factors and instruct the patient to stop breathing.
- Make the exposure.
- Release compression immediately.

Central ray

- Perpendicular to the base of the breast

Structures shown

The image should show the entire implant and surrounding posterior breast tissue with suboptimal compression of the anterior fibroglandular breast tissue (Fig. 18.33).

Evaluation Criteria

The following should be clearly shown:

- Implant projected over fibroglandular tissue, extending to posterior edge of image
- Posterior breast tissue on medial and lateral aspects extending to chest wall

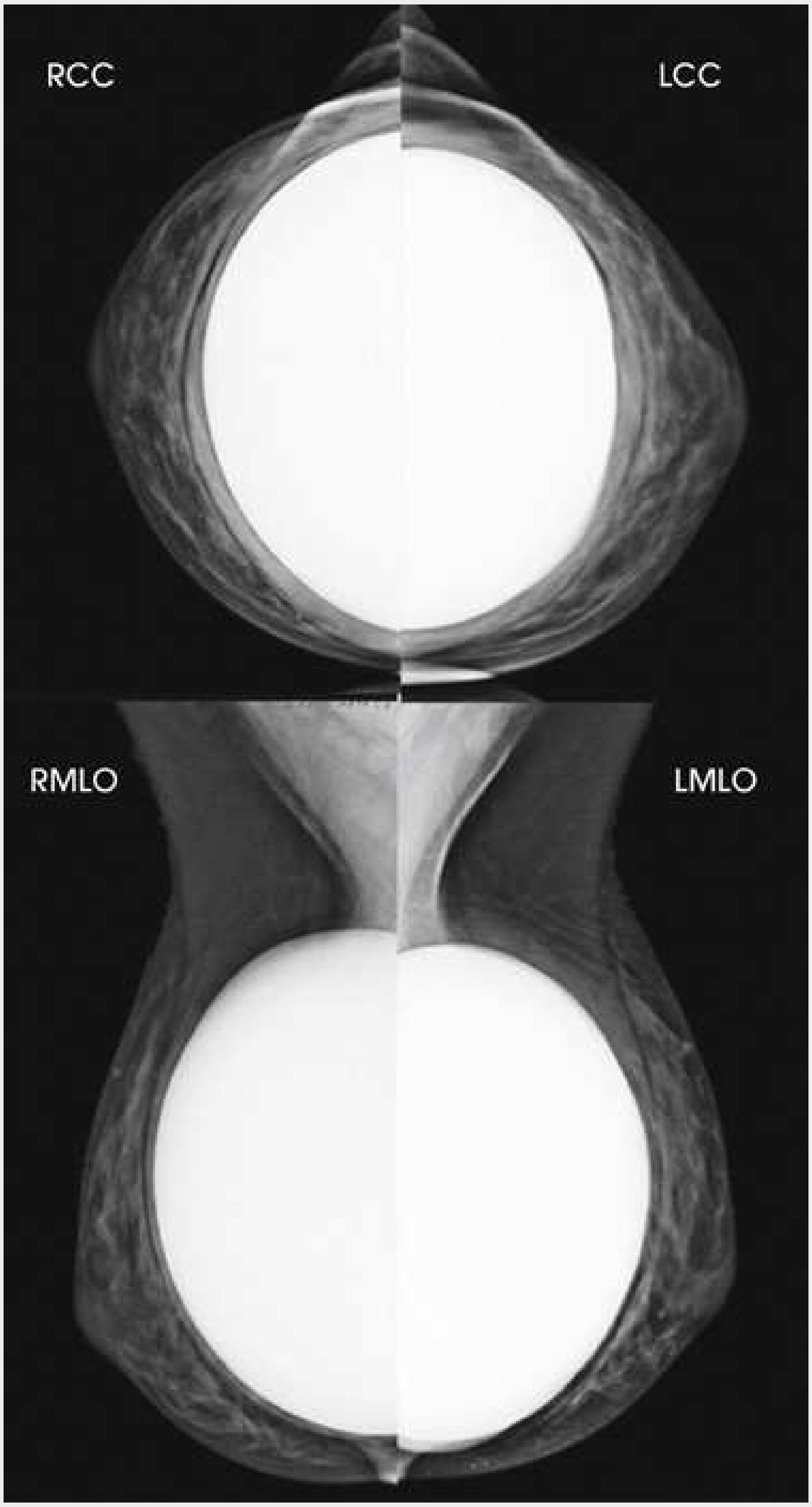


FIG. 18.33 Bilateral, four-image CC and MLO examination of augmented breasts. Implants have been surgically placed behind the pectoral muscle. Additional radiographs should be obtained using the Eklund (ID) technique to complete the eight-radiograph study (see Fig. 18.35).

A bilateral four-image mammogram shows the entire implant and surrounding posterior breast tissue with suboptimal compression of the anterior fibroglandular breast tissue. The implant appears circular and radiopaque.

- Nipple in profile, if possible, and at midline, indicating no exaggeration of positioning
- Nonuniform compression of anterior breast tissue

Craniocaudal Projection With Implant Displaced (CC ID)

Paddle:

8 × 10 inches (18 × 24 cm) or 10 × 12 inches (24 × 30 cm).

Position of patient

- Have the patient stand facing the IR or seat the patient on an adjustable stool facing the unit. Select an AEC technique. For FFDM units, be sure that Implant View processing settings are chosen if applicable.

Position of part

- While standing on the medial side of the breast to be imaged, elevate the inframammary fold to its maximal height.
- Adjust the height of the C-arm to the level of the inferior surface of the breast.

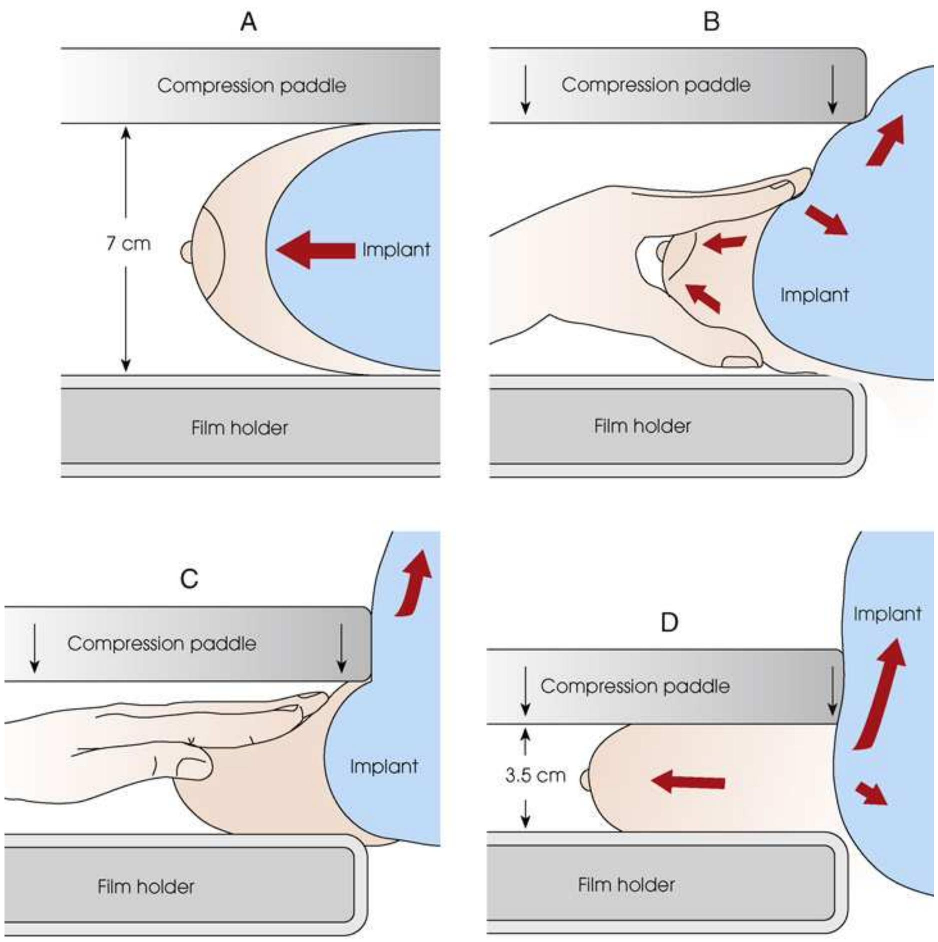


FIG. 18.34 (A) Breast with implant and normal positioning techniques. (B–D) Eklund technique of pushing implant posteriorly against chest wall, pulling breast anteriorly, and compressing tissue.
From Eklund GW, Busby RC, Miller SH, Job JS: Improved imaging of the augmented breast. *AJR Am J Roentgenol* 151:469, 1988.

(A) A breast is placed between the compression paddle and the film holder. The implant is marked by a red arrow pointing left. The distance between the compression paddle and the film holder is 7 centimeters. (B) A breast is placed between the compression paddle and the film holder. A hand is pushing the implant posteriorly against the chest wall and is pulling the breast anteriorly as it is compressing the tissue. It is indicated by red arrows. (C) A breast is placed between the compression paddle and the film holder. A hand is compressing the anterior part of the breast as the implant moves away. It is indicated by a red arrow. (D) A breast is placed between the compression paddle and the film holder. The implant is moving away as it compresses. The distance between the compression paddle and the film holder is 3.5 centimeters.

- Standing behind the patient, place both arms around the patient and locate the anterior border of the implant by walking the fingers back from the nipple toward the chest wall, or
- Stand beside the patient lateral to the breast being imaged. Have the patient hold the grip with the opposite hand to retain her balance. Locate the anterior border of the implant by walking the fingers back from the nipple toward the chest wall.
- When the anterior border of the implant has been located, gently pull the anterior breast tissue forward onto the IR (Fig. 18.34). Use the hands and the edge of the IR to keep the implant displaced posteriorly.
- Center the breast over the AEC detector with the nipple in profile if possible.

- Hold the implant back against the chest wall. Slowly apply compression to the anterior skin surface, being careful not to allow the implant to slip under the compression paddle. As compression continues, the implant should be seen bulging behind the compression paddle.
- Apply compression until the anterior breast tissue is taut. Compared with the full-implant projection, an additional ¾ to 2 inches (2 to 5 cm) of compression should be achieved with the implant displaced.
- Instruct the patient to indicate if the compression becomes too uncomfortable or intolerable.
- When full compression is achieved, move the AEC detector to the appropriate position and instruct the patient to stop breathing.
- Make the exposure.
- Release breast compression immediately.

Central ray

- Perpendicular to the base of the breast

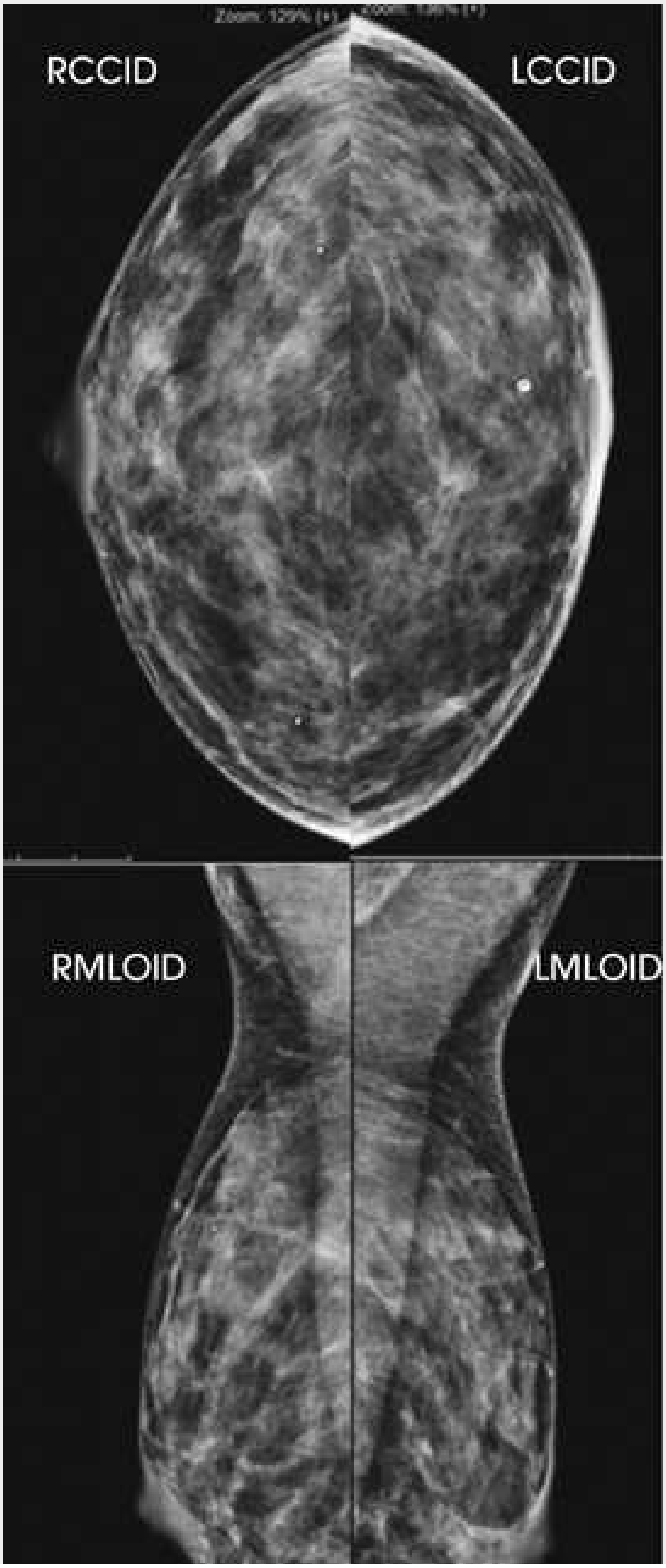
Structures shown

This projection shows the anterior and central breast tissue projected free of superimposition with uniform compression and improved tissue differentiation. The implant is displaced posteriorly and should not be visualized on the image (Fig. 18.35).

Evaluation Criteria

The following should be clearly shown:

- Breast tissue superior and inferior to the implant pulled forward with the anterior breast tissue projected free of the implant
- PNL extending posteriorly to edge of implant, measuring within ⅓ inch (1 cm) of depth of PNL on MLO projection with implant displaced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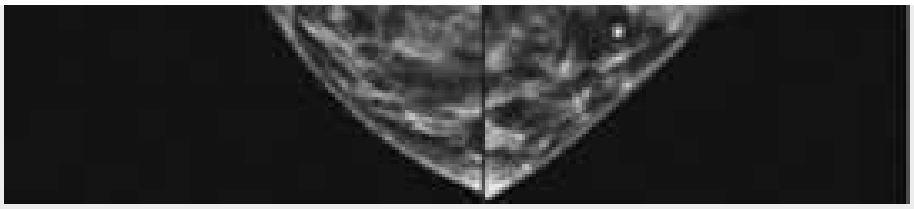


FIG. 18.35 Bilateral, four-image CC and MLO projections with ID of the same patient as in Fig. 18.33, using Eklund (ID) technique. Implants are pushed back for better visualization of surrounding breast tissue.

- Implant along posterior edge of image, flattened against chest wall, should not be visualized on the image, but often remnants of the implant may be seen.
- Image sharpness is enhanced by increased compression of the breast tissue and reduced scatter due to removal of the implant from the path of the beam.

Mediolateral Oblique (MLO) Projection With Full Implant

Paddle:

8 × 10 inches (18 × 24 cm) or 10 × 12 inches (24 × 30 cm).

Position of patient

- Have the patient stand facing the IR or seat the patient on an adjustable stool facing the unit.

Position of part

- Turn the AEC *off*, and preselect a *manual* technique. For FFDM units, be sure that Implant View processing settings are chosen if applicable.
- Follow the same positioning sequence as for the standard MLO projection.
- Inform the patient that minimal compression of the breast will be used. Continue to hold the breast up and out while sliding the hand toward the nipple as the compression paddle is brought into contact with the breast.
- Slowly apply only enough compression to immobilize the breast. Compression should be minimal, and the anterior breast tissue should still feel soft.
- Pull down on the patient's abdominal tissue to open the inframammary fold.
- Select the appropriate exposure factors and instruct the patient to stop breathing.
- Make the exposure.
- Release breast compression immediately.

Central ray

- Perpendicular to the IR
- The C-arm apparatus is positioned at an angle determined by the slope of the patient's pectoral muscle (30 to 60 degrees). The actual angle is determined by the patient's body habitus: Tall, thin patients require steep angulation, whereas short, stout patients require shallow angulation.

Structures shown

The image shows the entire implant and surrounding posterior breast tissue as well as axillary tissue and pectoral muscle, with suboptimal compression of the anterior fibroglandular breast tissue (see Fig. 18.33).

Evaluation Criteria

The following should be clearly shown:

- Implant projected over fibroglandular tissue, extending to posterior edge of image
- Posterior breast tissue on the inferior aspect, extending to chest wall
- Nipple in profile if possible
- Open inframammary fold
- Breast adequately maneuvered up and out from chest wall
- Nonuniform compression of anterior breast tissue

Mediolateral Oblique Projection With Implant Displaced (MLO ID)

Paddle:

8 × 10 inches (18 × 24 cm) or 10 × 12 inches (24 × 30 cm).

Position of patient

- Have the patient stand facing the IR or seat the patient on an adjustable stool facing the unit.
- Select an AEC technique. For FFDM units, be sure that Implant View processing settings are chosen if applicable.

Position of part

- Determine the degree of obliquity of the C-arm apparatus by rotating the tube until the long edge of the IR is parallel to the upper third of the pectoral muscle of the affected side. The degree of obliquity should be between 30 and 60 degrees, depending on the patient's body habitus.
- Adjust the height of the C-arm so that the superior border is level with the axilla.
- Instruct the patient to elevate the arm of the affected side over the corner of the IR and to rest the hand on the adjacent handgrip. The patient's elbow should be flexed.
- Standing in front of the patient, locate the anterior border of the implant by walking the fingers back from the patient's nipple toward the chest wall.
- After locating the anterior border of the implant, gently pull the anterior breast tissue forward onto the IR. Use the edge of the IR and the hands to keep the implant displaced posteriorly.
- Center the breast tissue over the AEC detector with the nipple in profile if possible.
- Hold the anterior breast tissue up and out so that the base of the thumb and the heel of the hand support the breast.
- Hold the implant back against the chest wall while using fingers to bring the anterior breast tissue forward onto the IR. Slowly apply compression to the anterior skin surface, taking care not to allow the implant to slip under the compression paddle. As compression continues, the implant should be seen bulging behind the compression paddle.
- Apply compression until the anterior breast tissue is taut. Compared with the full-implant projection, an additional ¾ to 2 inches (2 to 5 cm) of tissue should be adequately visualized with the implant displaced.
- Instruct the patient to indicate if the compression becomes uncomfortable or intolerable.
- Pull down on the patient's abdominal tissue to open the inframammary fold.
- Instruct the patient to hold the opposite breast away from the path of the beam, as necessary.
- When full compression is achieved, move the AEC detector to the appropriate position if necessary and instruct the patient to stop breathing.
- Make the exposure.
- Release breast compression immediately.

Central ray

- Perpendicular to the IR
- The C-arm apparatus is positioned at an angle determined by the slope of the patient's pectoral muscle (30 to 60 degrees). The actual angle is determined by the patient's body habitus: Tall, thin patients require steep angulation, whereas short, stout patients require shallow angulation.

Structures shown

This image shows the anterior and central breast tissue projected free of superimposition of the implant, with uniform compression and improved tissue differentiation (see Fig. 18.35).

Evaluation Criteria

The following should be clearly shown:

- Breast tissue superomedial and inferolateral to the implant with anterior breast tissue projected free of the implant
- Pectoral muscle showing anterior convexity to ensure relaxed shoulder and axilla
- PNL extending obliquely to edge of implant, measuring within ⅓ inch (1 cm) of depth of PNL on CC projection with implant displaced
- Implant should not be visualized on the image, but often some remnants of the implant may be seen posteriorly.
- Posterior breast tissue on inferior aspect of breast, extending to chest wall
- Nipple in profile if possible
- Open inframammary fold
- Breast adequately maneuvered up and out from chest wall
- Image sharpness is enhanced by increased compression of the breast tissue and reduced scatter due to removal of the implant from the path of the beam.

Male Mammography

Epidemiology of Male Breast Disease

In the United States, more than 2400 men develop invasive breast cancer every year, and nearly 20% of these men die of the disease. [1] Although most men who develop breast cancer are 60 years of age and older, juvenile cases have been reported. Nearly all male breast cancers are primary tumors. An estimated 4% to 40% of male breast cancers are due to inherited mutations. Men typically have significantly less breast tissue and screening mammograms typically are not performed for male patients; therefore, most male breast cancers are diagnosed as palpable lumps and are more likely to be diagnosed at advanced stages. The overall 5-year survival rate for male breast cancer is 84%, compared to 90% in women, which reflects this fact. [26] Other symptoms of breast cancer in men include nipple retraction, crusting, discharge, and ulceration.

Gynecomastia, a benign excessive development of the male mammary gland, can make malignant breast lesions more elusive to palpation. Gynecomastia occurs in 40% of male breast cancer patients; however, a histologic relationship between gynecomastia and male breast cancer has not been definitively established. Because gynecomastia is caused by a hormonal imbalance, it is believed that abnormal hormonal function may increase the risk of male breast cancer in these patients. [27] Other associated risk factors for male breast cancer include increasing age, positive family history, *BRCA1* and *BRCA2* gene mutations, and Klinefelter syndrome. [28]

Breast cancer treatment options are limited among male patients. Because men have less breast tissue, lumpectomy is not considered practical. Most of the male glandular tissue is located directly posterior to the nipple. Therefore, a modified radical mastectomy, including dissection of the nipple, is usually the preferred surgical procedure. [29–31] Radiation and systemic therapy are considered when the tumor is located near the chest wall or when indicated by lymph node analysis. Similar to female breast cancer, the prognosis for male breast cancer is directly related to the stage of the disease at diagnosis. An early diagnosis indicates a better chance of survival. Survival rates among male patients with localized breast carcinomas are positive: 98% survive for 5 years. [26]

Routine Projections of the Male Breast

Male breast anatomy varies significantly from female breast anatomy. The pectoral muscle is more highly developed in men, and most of the glandular breast tissue is located directly posterior to the nipple. The radiographer must take this variance into consideration. The standard CC and MLO projections may be applied with success in most male patients (Figs. 18.36–18.38). For men (or women) with large pectoral muscles, the radiographer may perform the caudocranial (FB) projection instead of the standard CC because it may be easier to compress the inferior portion of the breast. In addition, the lateromedial oblique (LMO) projection may replace the standard MLO.

Keep in mind that these unconventional views are rarely necessary but are viable alternatives in extreme cases. These projections may allow the radiographer to accommodate more successfully a patient with prominent pectoral muscles. Some facilities also use narrower quadrant compression paddles (3 inches [8 cm] wide) to compress the male breast or the extremely small female breast. [32] The smaller paddle permits the radiographer to hold the breast in position while applying final compression. A wooden spoon or a plastic spatula can be used to hold the breast in place, then can be slowly removed as the compression paddle replaces it.

FIG. 18.36 Positioning for CC projection of male breast.

FIG. 18.37 Positioning for MLO projections of male breast.

Because most men who undergo mammography present with outward symptoms, mammography of the male breast is usually considered a diagnostic examination. It can be considered a screening examination for men who know they carry the *BRCA1* or *BRCA2* gene, or who have a history of breast cancer. The radiographer should work closely with the radiologist to achieve a thorough demonstration of the potential abnormality. In the male breast, most tumors are located in the subareolar region. Careful attention should be given to positioning the nipple in profile and to providing adequate compression of this area to allow the best visualization of this tissue.

Calcifications are rare in male breast cancer cases. When present, they are usually larger, rounder, and more scattered than the calcifications associated with female breast cancer. Spot compression and the magnification technique are common image enhancement methods for showing the morphology of calcifications.

Procedures other than mammography are used to diagnose male breast cancer. FNAB and excisional biopsy of palpable lesions are standard methods of diagnosis. Histologically, most breast cancers in men are ductal, and most are infiltrating ductal carcinomas. Very few in situ cancers are found in male patients.

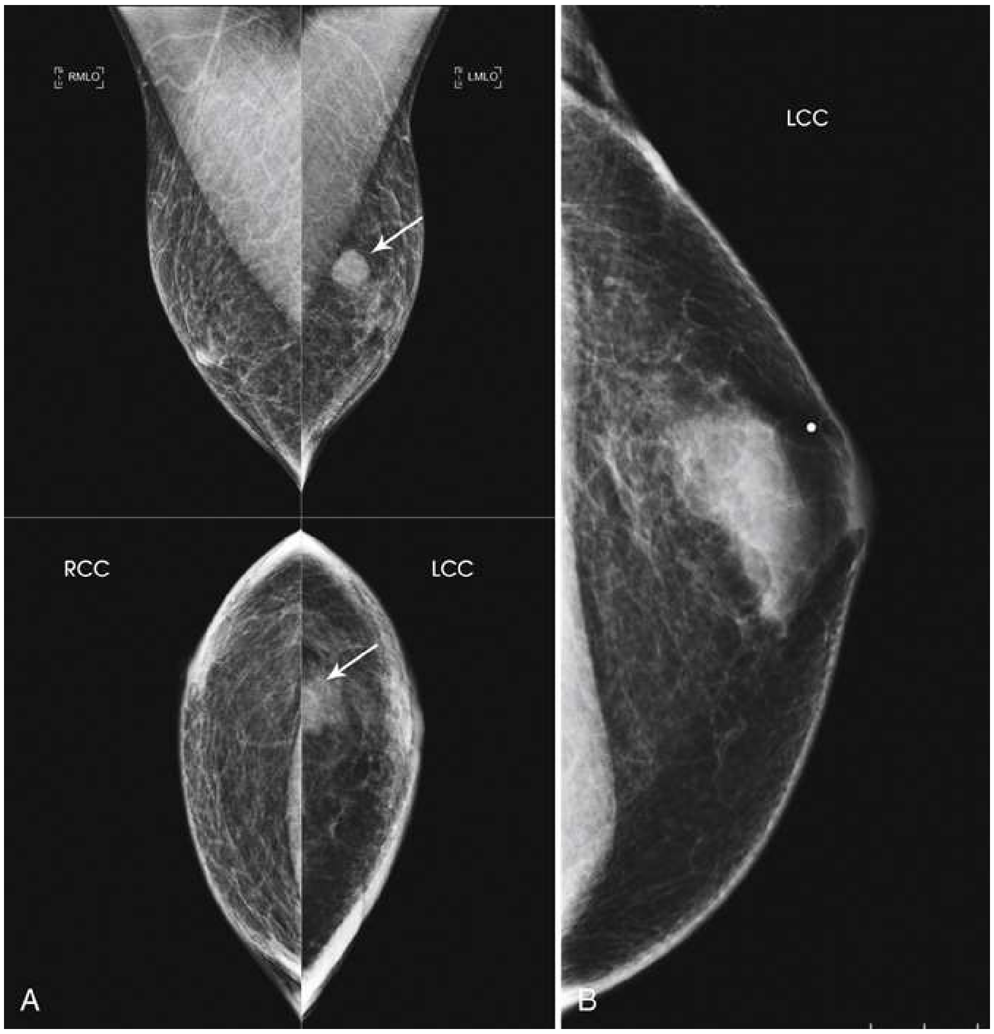


FIG. 18.38 (A) Four-view mammogram of a 55-year-old man with a new palpable lump *(arrow)*. This proved to be cancer on biopsy. (B) Left CC view of a 49-year-old male with a new lump. This proved to be gynecomastia, a benign process, on biopsy.

Because breast cancer is traditionally considered a "woman's disease," the radiographer should remain sensitive to the feelings of the male patient by offering not only physical comfort but also psychological and emotional support during the procedure.

Image Enhancement Methods

The spot compression technique and the magnification technique are designed to enhance the image of the area under investigation.

Breast

Magnification Technique (M Used as Prefix)

Paddle:

8 × 10 inches (18 × 24 cm).

Position of patient

- Have the patient stand facing the IR or seat the patient on an adjustable stool facing the unit.
- Use only equipment designed to be used for magnification mammography to perform this maneuver and use the equipment according to the manufacturer's directions.

Position of part

- Attach the firm, radiolucent magnification platform to the unit. The patient's breast is positioned on the platform between the compression device and a nongrid IR.
- Select the smallest focal spot target size (≤0.1 mm is preferred). Most units allow magnification images to be exposed only when the correct focal spot size is used.
- Select the appropriate compression paddle (regular, quadrant, or spot compression). Collimate according to the size of the compression paddle.
- Position the patient's breast to obtain the projection that best shows the area of interest. The angle of the C-arm can be adjusted to accommodate any projection normally performed using a traditional grid technique.
- When full compression is achieved, move the AEC detector to the chest wall position (if necessary) and instruct the patient to stop breathing (Fig. 18.39).
- Make the exposure.
- Release breast compression immediately.

FIG. 18.39 Radiolucent platform placed between breast and film holder causes breast image to be enlarged. Courtesy Lorad Corp.

A female patient is standing facing the I R. The breast is positioned on the mammography unit between the film holder and the compression paddle. One of her arms is grabbing the side of the unit. Her face is turned away.

Central ray

- Perpendicular to the area of interest

Structures shown

This technique optically magnifies the compressed area of interest with improved detail, facilitating determination of the characteristics of microcalcifications (Fig. 18.40) [33, 34] and the margins (or lack of definitive margins) of suspected lesions (Fig. 18.41).

Evaluation Criteria

The following should be clearly shown:

- Area of interest within collimated and compressed margins
- Improved delineation of number, distribution, and morphology of microcalcifications
- Enhanced architectural characteristics of focal density or mass
- Uniform tissue exposure if compression is adequate

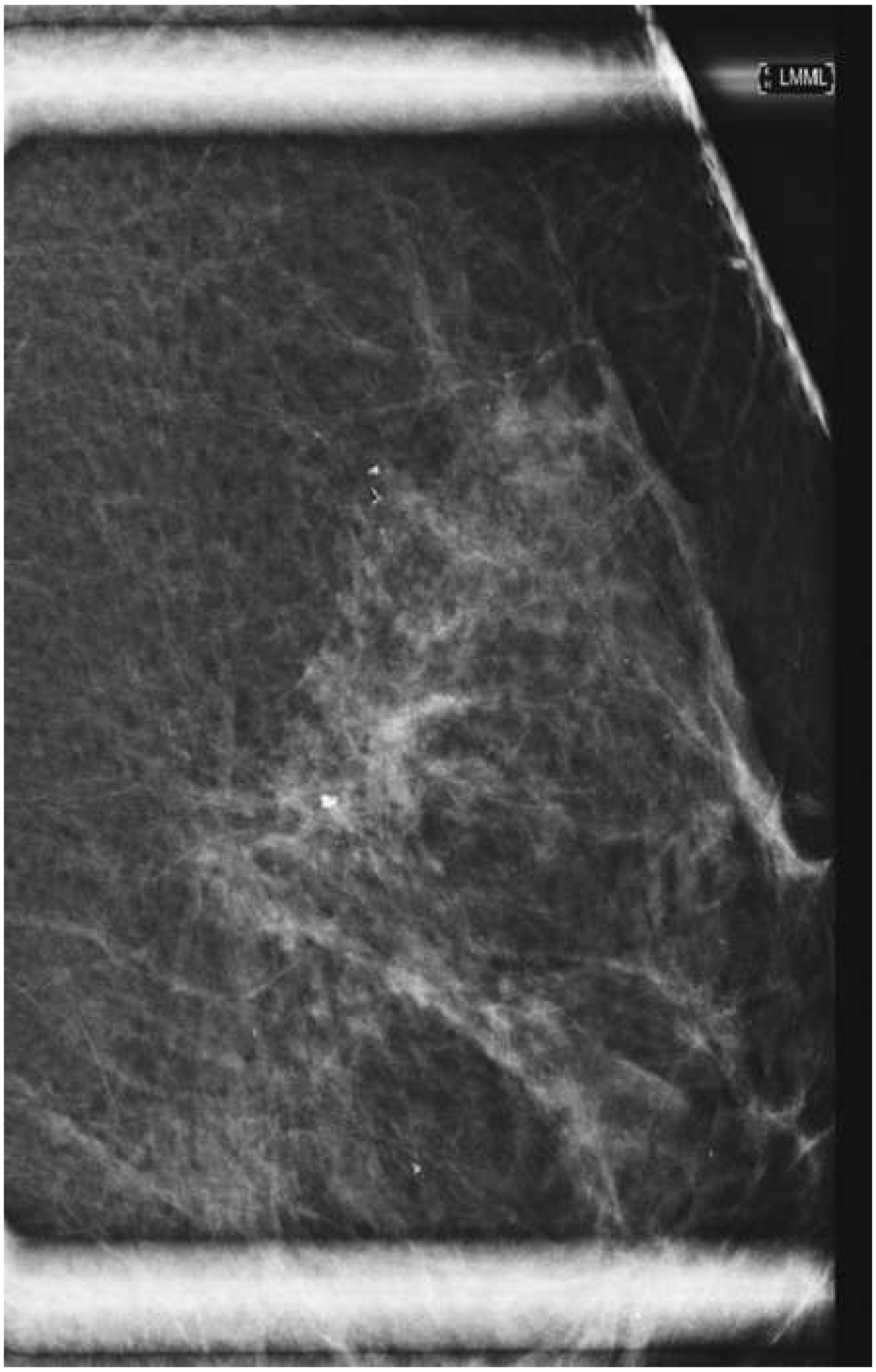


FIG. 18.40 MLO projection using the magnification technique and a quad paddle to better visualize microcalcifications.

Spot Compression Technique

Image receptor:

8 × 10 inches (18 × 24 cm).

Position of patient

- Have the patient stand facing the IR or seat the patient on an adjustable stool facing the unit.
- This technique is often performed in conjunction with the magnification technique, especially for determination of number, distribution, and morphology of microcalcifications.

Position of part

In conjunction with magnification technique

- Place a firm, radiolucent magnification platform, designed for use with the dedicated mammography equipment on the unit, between the patient's breast and a nongrid IR.
- Select the smallest focal spot target size (≤0.1 mm is preferred).

For palpable masses

A tangential (TAN) projection combined with spot compression and the magnification technique is most often used to image a palpable mass; however, the spot compression technique in a previously imaged projection is also requested by many radiologists.

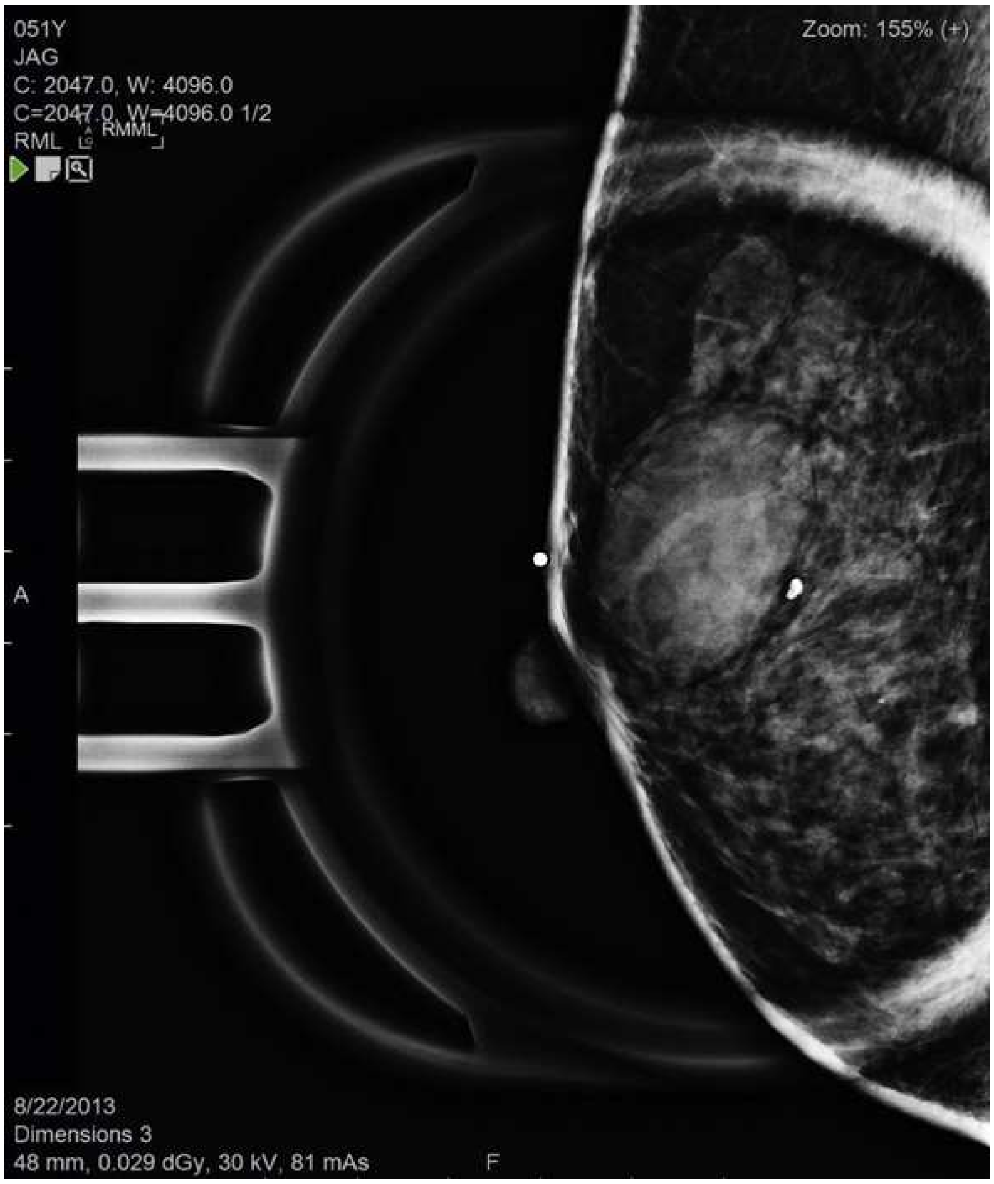


FIG. 18.41 Right MLO projection using the magnification technique and a spot paddle to perform a tangential view of a palpable mass. This proved that the mass was smoothly outlined with uniform edges and was shown to be a cyst on ultrasound.

- Select the appropriate spot compression device.
- Mark the location of the palpable mass with a felt-tip pen or with a radiopaque beebee (BB) marker placed on the lump, according to the policy of the facility.
- Center the area of interest under the compression device in the position indicated by the radiologist.
- Inform the patient that compression of the breast will be used and may be uncomfortable. Bring the compression paddle into contact with the breast, and slowly apply compression until the breast feels taut.
- Instruct the patient to indicate if the compression becomes too uncomfortable.
- When full compression is achieved, move the AEC detector to the chest wall position if necessary, and instruct the patient to stop breathing (Fig. 18.42).
- Make the exposure.
- Release breast compression immediately.

For nonpalpable masses

- While viewing the routine mammogram, measure the location of the area of interest from a reference point (the nipple), using a tape measure or the fingertips (Fig. 18.43).
- Select the appropriate spot compression device.
- Reposition the patient's breast to obtain the projection from which the measurements were taken.
- Using the same reference point, transfer onto the patient the measurements taken from the mammogram.
- Mark the area of interest with a felt-tip pen, or mentally note the location on the breast.

- Center the area of interest under the compression device in the requested view, which may be different from the original projection.
- Inform the patient that compression of the breast will be used. Bring the compression paddle into contact with the breast, and slowly apply compression until the breast feels taut. Adequate compression is especially important for spot views of nonpalpable masses, as the objective is to use targeted compression to separate tissue islands that may be overlapped, causing an area of suspicious density.
- Instruct the patient to indicate if the compression becomes too uncomfortable.
- When full compression is achieved, move the AEC detector to the appropriate position if necessary, and instruct the patient to stop breathing.
- Make the exposure.
- Release breast compression immediately.

FIG. 18.42 Spot compression used with CC projection.

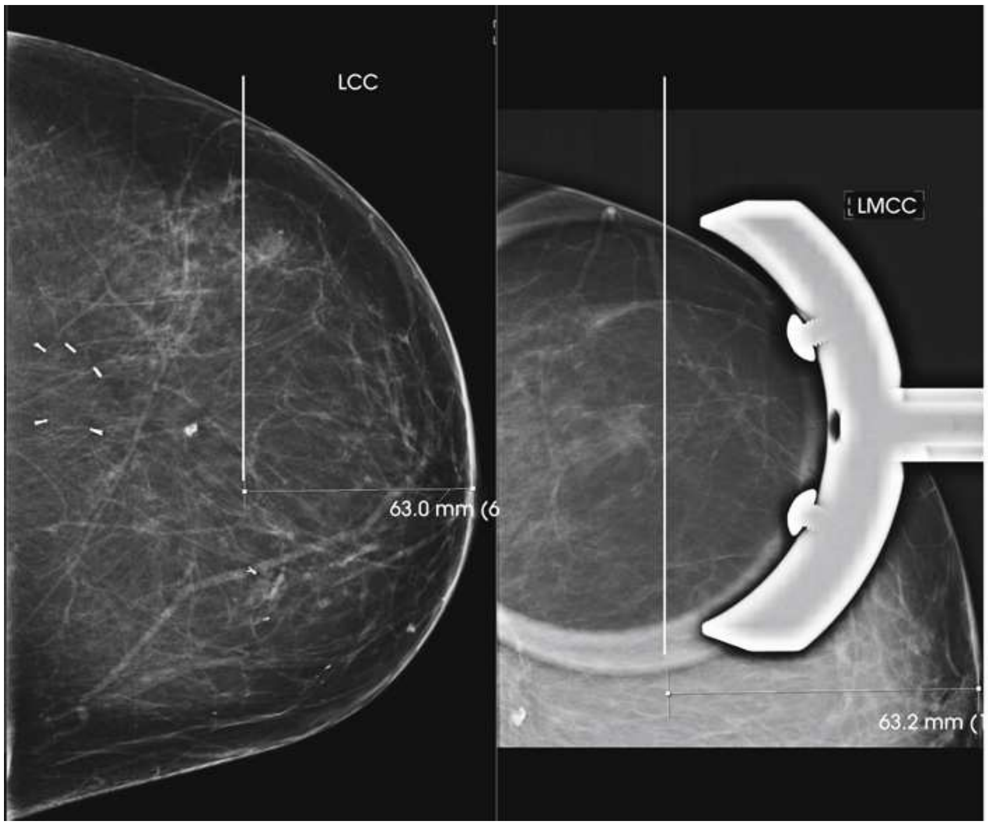


FIG. 18.43 To find the area of interest in the breast for a spot view, measure how far posterior the area is by using the nipple as a reference point. This image illustrates how measurement of the lesion from the nipple on the CC view approximates measurement of the lesion from the nipple on the magnified spot view.

A mammogram on the left shows a horizontal and vertical line drawn on it. It is labeled as 63.0 millimeters. A mammogram on the right shows a concave white region on the right that is next to the breast tissue.

Central ray

- Perpendicular to the area of interest

Structures shown

The spot compression technique resolves superimposed structures seen on only one projection, better visualizes small lesions located in the extreme posterior breast, separates superimposed ductal structures in the subareolar region, and improves visualization in areas of dense tissue through localized compression (Fig. 18.44).

NOTE: Densities caused by the superimposition of normal breast parenchyma disappear on spot compression images.

Evaluation Criteria

The following should be clearly shown:

- Area of interest clearly seen within compressed margins
- Close collimation to the area of interest unless contraindicated by radiologist
- Improved recorded detail through the use of close collimation and the magnification technique employing a spot compression device
- Uniform tissue exposure if compression is adequate

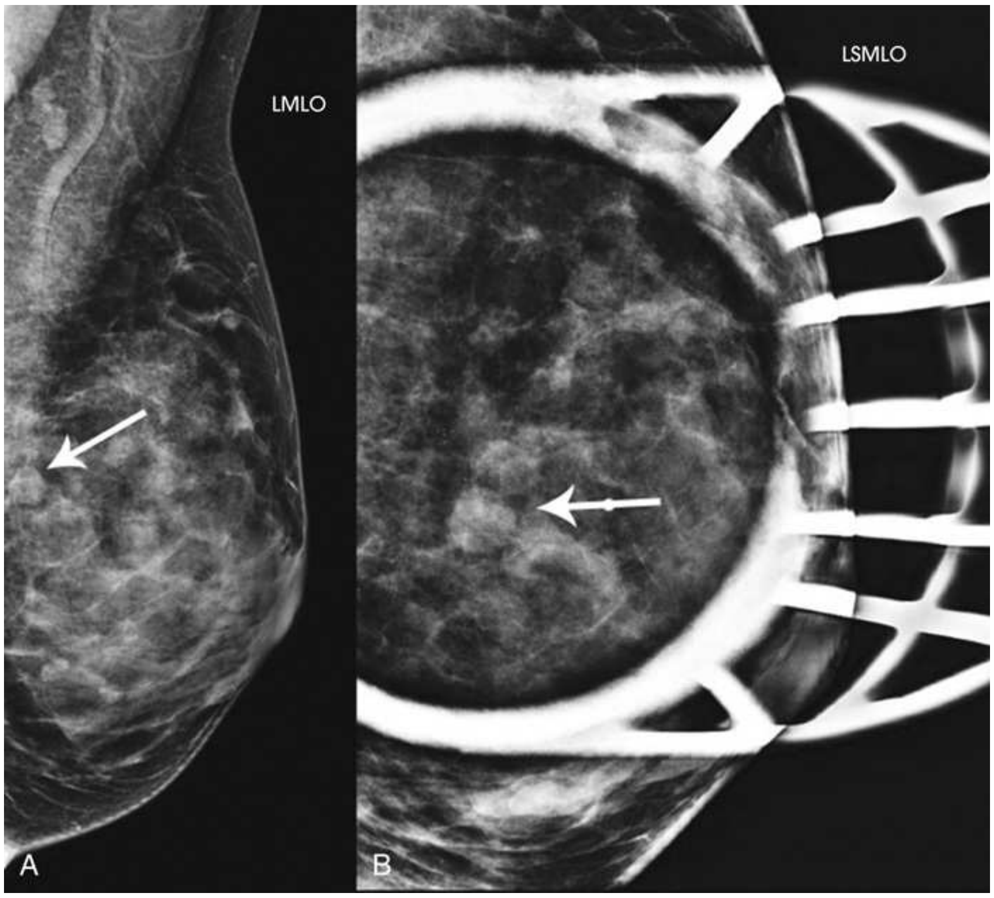


FIG. 18.44 (A) This 45-year-old woman with extremely dense tissue was recalled for a questionable mass *(arrow)* in the left breast on screening mammography. (B) A spot view was performed to spread the tissue and more clearly delineate the borders of the mass. This proved to be a fibroadenoma on biopsy.

(A) A mammogram shows a mass of extremely dense tissue on the breast tissue. It is indicated by an arrow. (B) A mammogram shows an enlarged view of the white spot that is concentrated in the center of the breast tissue.

Supplemental Projections

The routine projections are not always adequate in completely showing a patient's breast tissue, or a specific area may require clearer delineation. Supplemental projections complement the routine projections and have distinct applications (Table 18.2). The mammographer should fully understand the value of each projection and its potential to show significant findings in the breast. This section provides a brief overview of significant mammographic findings in their most common radiographic presentation and provides suggested correlative supplemental projections. The language related to mammographic findings must be appreciated for the mammographer and the radiologist to work collaboratively toward a successful diagnostic examination.

The mass is the most common presentation of a potential abnormality in the breast. It is identified on two projections of the affected breast. A mass has a convex shape or an outward contour to its margins. If a suspected mass is identified on only one projection, the mammographer must strive to position the breast so that the area in question is shown on at least two projections. If the suspected mass is seen only on the MLO projection in the deep medial aspect of the breast, a CC projection for cleavage may complement the standard CC projection. Conversely, if the mass is seen in the extreme lateral aspect, an exaggerated craniocaudal (XCCL) projection laterally would be the projection of choice. In a sense, the radiographer is collecting evidence to prove whether the mass is real or is merely a summation shadow of superimposed breast parenchyma.

TABLE 18.2

Supplemental projections or methods and their suggested applications

Projection or method	Application
Spot compression	Defines lesion or area through focal compression; separates overlying parenchyma
Magnification (M)	Combines with spot compression to show margins of lesion; delineates microcalcifications
Mediolateral (ML)	Localization; shows air-fluid-fat levels; defines lesion located in lateral aspect of breast; complements mediolateral oblique (MLO) projection
Lateromedial (LM)	Localization; shows air-fluid-fat levels; defines lesion located in medial aspect of breast
Exaggerated craniocaudal (XCCL)	Visualizes lesions in deep outer aspect of breast that are not seen on standard CC
CC for cleavage (CV)	Visualizes deep medial breast tissue; shows medial lesion in true transverse or axial plane
CC with roll (RL, RM)	Triangulates lesion seen only on CC projection; defines location of lesion as in superior or inferior aspect of breast
Tangential (TAN)	Confirms dermal vs. breast calcifications; shows obscure palpable lump over subcutaneous fat
Captured lesion	Shows palpable lump in posterior tissue that is difficult to immobilize with conventional techniques
Caudocranial (FB)	Visualizes superior breast tissue; defines lesion located in superior aspect of breast; replaces standard CC for patients with kyphosis or prominent pectoral muscles
MLO for axillary tail (AT)	Focal compression projection of AT
Lateromedial oblique (LMO)	Shows medial breast tissue; replaces standard MLO for patients with pectus excavatum, prominent pacemakers, prominent pectoral muscles, Hickman catheters, and postoperative open heart surgery
Superolateral to inferomedial oblique (SIO)	Visualizes upper-inner quadrant and lower-outer quadrant, which normally are superimposed on MLO and LMO projections

Other supplemental projections are intended to offer alternative methods for tailoring the mammographic procedure to the specific abilities of the patient and the requirements of the interpreting physician. Often the need for additional projections is determined only after careful examination of the standard projections. Throughout mammographic procedures, the radiographer should consistently evaluate the images, keeping foremost in mind the optimal demonstration of possible findings. For example, when performing lateral projections, the mammographer should place the area of interest closest to the IR. The mammographer may develop the expertise to predict and perform supplemental projections that confirm or rule out suspected breast abnormalities. As with all radiographic procedures, image evaluation is a crucial component of high-quality imaging. In evaluating images, the mammographer becomes an integral member of the breast imaging team, actively participating in the work-up of an asymptomatic patient.

90-Degree Mediolateral (ML) Projection

Paddle:

8 × 10 inches (18 × 24 cm) or 10 × 12 inches (24 × 30 cm).

Position of patient

- Have the patient stand facing the IR or seat the patient on an adjustable stool facing the unit.

Position of part

- Rotate the C-arm assembly 90 degrees, with the x-ray tube placed on the medial side of the patient's breast.
- Have the patient bend slightly forward from the waist. Position the superior corner of the IR high into the axilla, with the patient's elbow flexed and the affected arm resting behind the IR.
- Ask the patient to relax the affected shoulder.
- Pull the breast tissue and the pectoral muscle superiorly and anteriorly, ensuring that the lateral rib margin is pressed firmly against the edge of the IR.

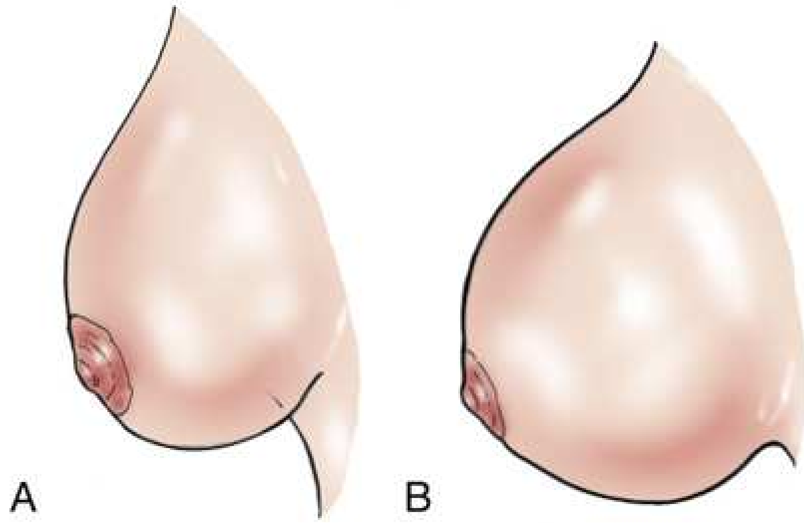


FIG. 18.45 (A) Lateral profile of breast showing inadequate compression and drooping breast. (B) Lateral profile of properly compressed breast. Note how compression has overcome the effect of gravity and how the breast is spread out over a greater area.

FIG. 18.46 ML projection.

A female patient is slightly bent forward and is standing against the mammography unit. The lateral rib margin is pressed firmly against the edge of the I R. The breast is placed between the film holder and the compression paddle. One arm of the patient is flexed and is holding the side of the unit. The other hand is holding the other breast.

- Rotate the patient slightly laterally to help bring the medial tissue forward.
- Gently pull the medial breast tissue forward from the sternum and position the nipple in profile.
- Hold the patient's breast up and out by rotating the hand so that the base of the thumb and the heel of the hand support the breast.
- Inform the patient that compression of the breast will be used. Continue to hold the patient's breast up and out while sliding the hand toward the nipple as the compression paddle is brought into contact with the breast. Do not allow the breast to droop (Fig. 18.45).
- Slowly apply compression until the breast feels taut.
- Instruct the patient to indicate if compression becomes too uncomfortable.
- Ask the patient to hold the opposite breast away from the path of the beam.
- Instruct the patient to lift her chin to clear the field of potential artifacts.
- When full compression is achieved, move the AEC detector to the appropriate position if necessary, and instruct the patient to stop breathing (Fig. 18.46).
- Make the exposure.
- Release breast compression immediately.

Central ray

• Perpendicular to the base of the breast

Structures shown

This projection shows lesions on the lateral aspect of the breast in the superior and inferior aspects. It resolves superimposed structures seen on the MLO projection, localizes a lesion seen on one (or both) of the initial projections, and shows air-fluid and fat-fluid levels in breast structures (e.g., milk of calcium, galactoceles) and in pneumocystography (a rarely performed procedure involving injection of air into an aspirated cyst to image the cyst lining for intracystic lesions). The ML view is an orthogonal view to the CC and is often used to localize the depth of breast lesions.

Evaluation Criteria

The following should be clearly shown:

- Nipple in profile
- Open inframammary fold
- Deep and superficial breast tissues well separated when breast is adequately maneuvered up and out from chest wall (Fig. 18.47)
- Retroglandular fat well visualized to ensure inclusion of deep fibroglandular breast tissue
- Uniform tissue exposure if compression is adequate

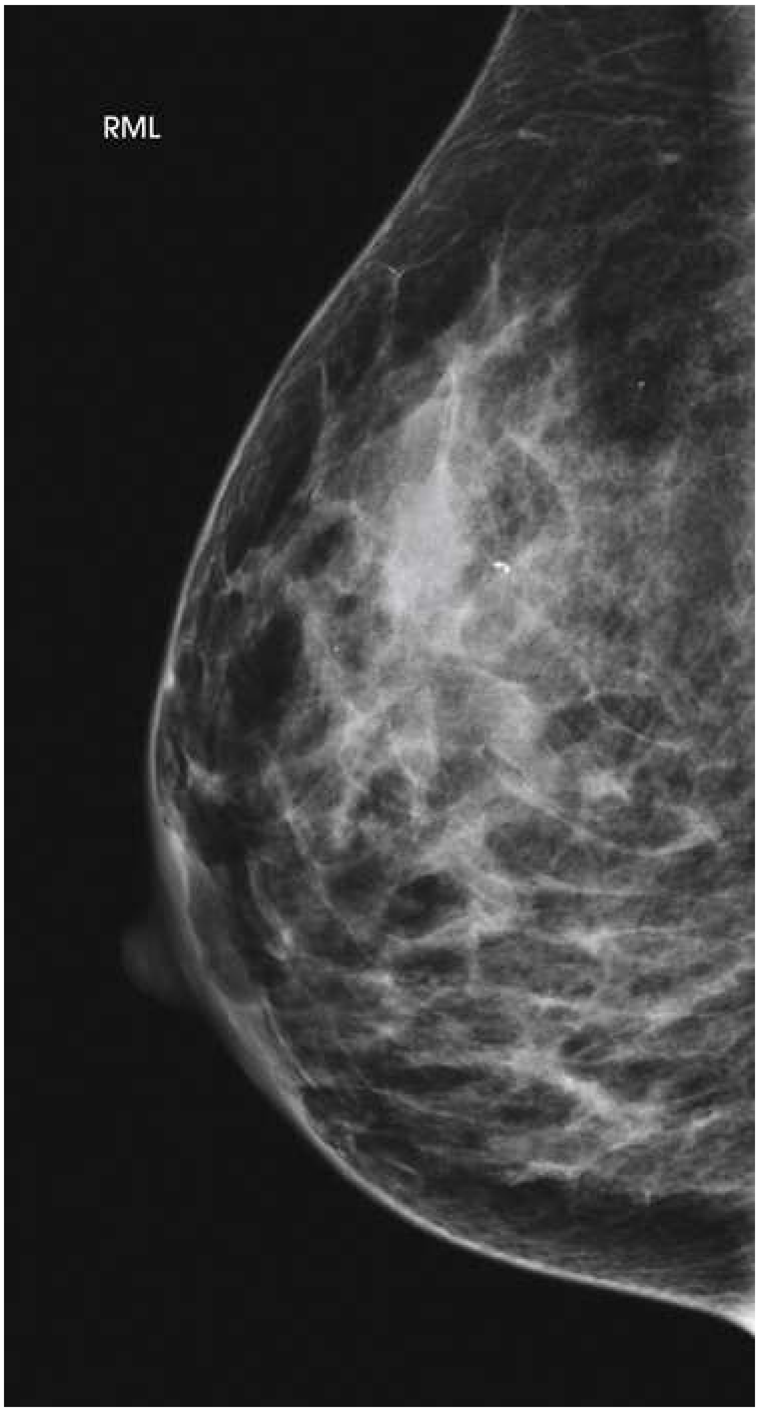


FIG. 18.47 ML projection.

90-Degree Lateromedial (LM) Projection

Paddle:

8 × 10 inches (18 × 24 cm) or 10 × 12 inches (24 × 30 cm).

Position of patient

- Have the patient stand facing the IR or seat the patient on an adjustable stool facing the unit.

Position of part

- Rotate the C-arm assembly 90 degrees, with the x-ray tube placed on the lateral side of the patient's breast.
- Position the superior corner of the IR at the level of the jugular notch.
- Have the patient flex the neck slightly forward.
- Have the patient relax the affected shoulder, raise her arm on the affected side and flex the elbow, then rest the affected arm over the top of the IR.
- Pull the breast tissue and pectoral muscle superiorly and anteriorly, ensuring that the patient's sternum is pressed firmly against the edge of the IR.
- Rotate the patient slightly medially to help bring the lateral tissue forward.
- Have the patient rest the chin on the top edge of the IR to help loosen the skin in the medial aspect of the breast.
- Position the nipple in profile.
- Hold the patient's breast up and out. Do not let it droop.
- Inform the patient that compression of the breast will be used. Bring the compression paddle past the latissimus dorsi muscle and into contact with the breast. Slowly apply compression while sliding the hand out toward the nipple until the patient's breast feels taut.
- Instruct the patient to indicate whether the compression becomes uncomfortable.
- When full compression is achieved, move the AEC detector to the appropriate position if necessary, and instruct the patient to stop breathing (Fig. 18.48).
- Make the exposure.
- Release breast compression immediately.

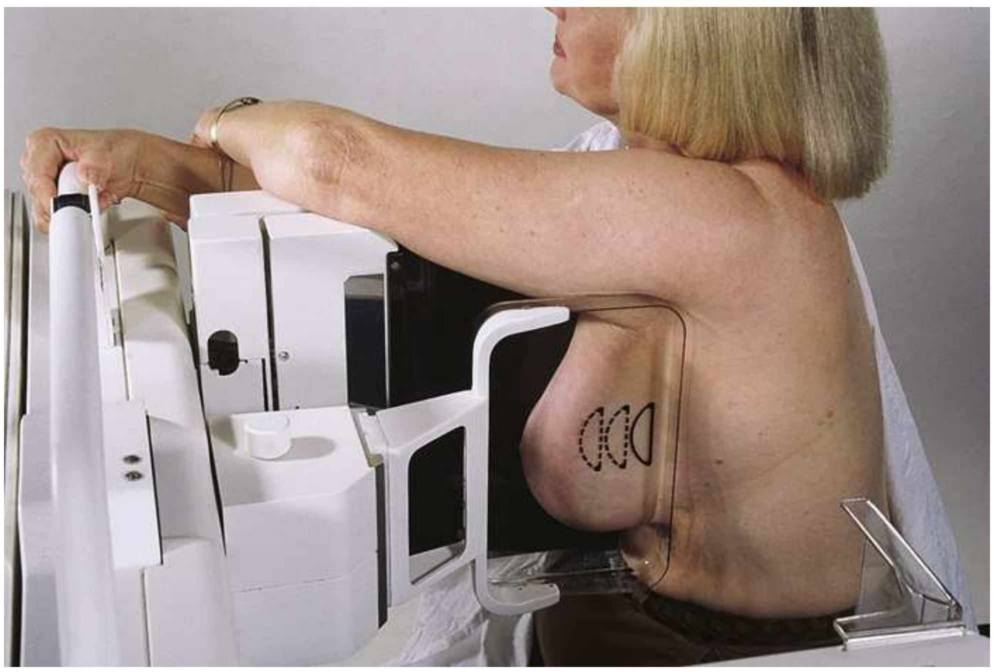


FIG. 18.48 Lateromedial projection.

A female patient is standing against the mammography unit with the neck slightly forwards. Both the arms are resting on the unit at the level of her shoulder. The breast is placed between the film holder and the compression paddle.

Central ray

- Perpendicular to the base of the breast

Structures shown

This projection shows lesions on the medial aspect of the breast in the superior or inferior aspects (Fig. 18.49). It resolves superimposed structures seen on the MLO projection, localizes a lesion seen on one (or both) of the initial projections, and shows air-fluid and fat-fluid levels in breast structures (e.g., milk of calcium, galactoceles) and in pneumocystography (a rarely performed procedure involving injection of air into an aspirated cyst to image the cyst lining for intracystic lesions). The LM view is an orthogonal view to the CC and is often used to localize the depth of breast lesions.

Evaluation Criteria

The following should be clearly shown:

- Nipple in profile
- Open inframammary fold
- Deep and superficial breast tissues well separated when breast is adequately maneuvered up and out from chest wall
- Retroglandular fat well visualized to ensure inclusion of deep fibroglandular breast tissue
- Uniform tissue exposure if compression is adequate

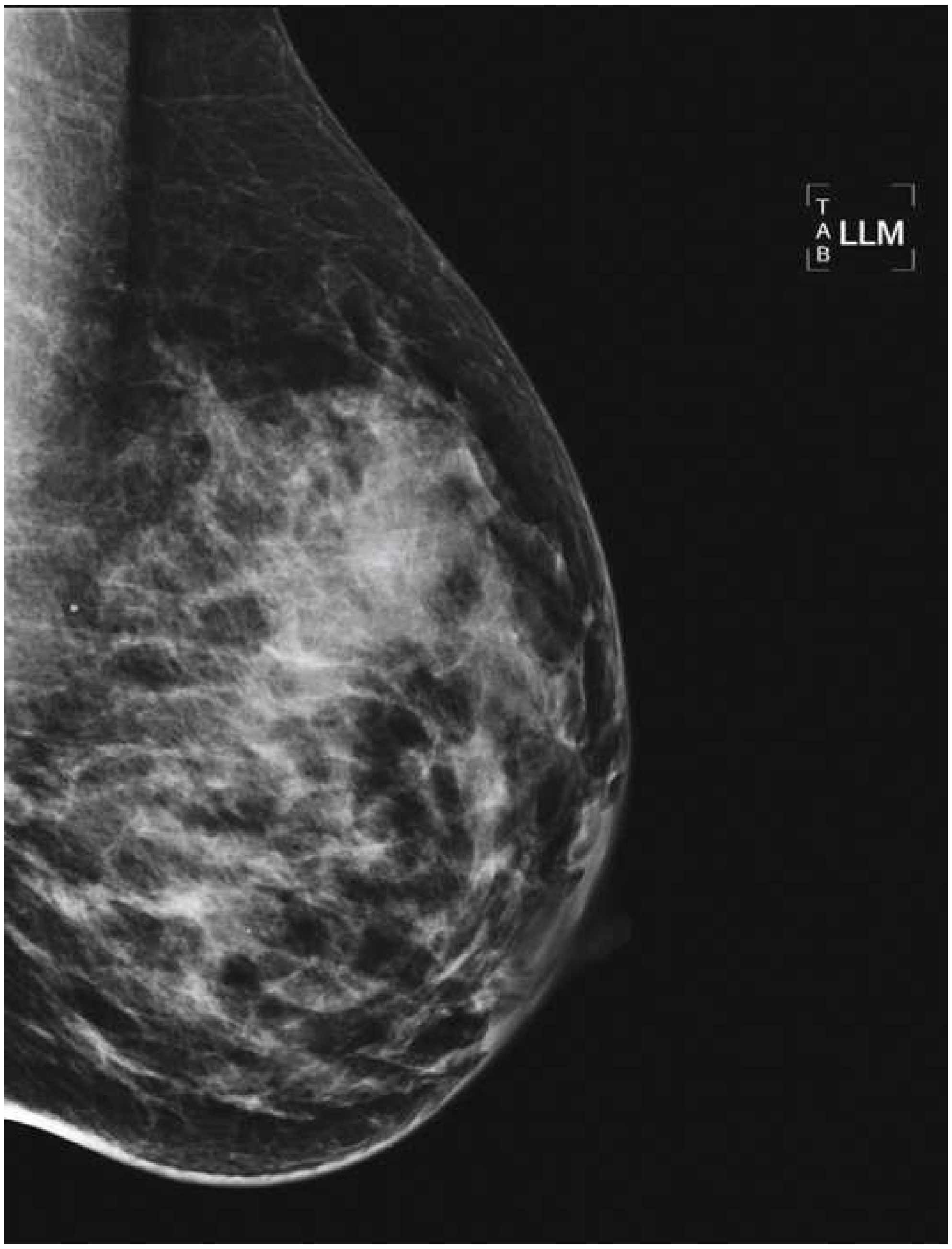


FIG. 18.49 LM projection.

Exaggerated Craniocaudal (XCCL) Projection

Paddle:

8 × 10 inches (18 × 24 cm) or 10 × 12 inches (24 × 30 cm).

Position of patient

• Have the patient stand facing the IR or seat the patient on an adjustable stool facing the unit.

Position of part

• The contralateral side should be turned away from the image receptor.
• The lateral aspect of the ipsilateral breast should be closest to the image receptor.
• Elevate the inframammary fold to its maximal height.
• Adjust the height of the C-arm accordingly.
• Use one hand to scoop the inferior and posterior breast tissue up from the inframammary fold and place the breast onto the IR.
• This should be done with the technologist's right hand when the left breast is positioned, and with the left hand when the right breast is positioned.
• Use both hands to pull the breast gently onto the IR while instructing the patient to press the thorax against the breast tray.

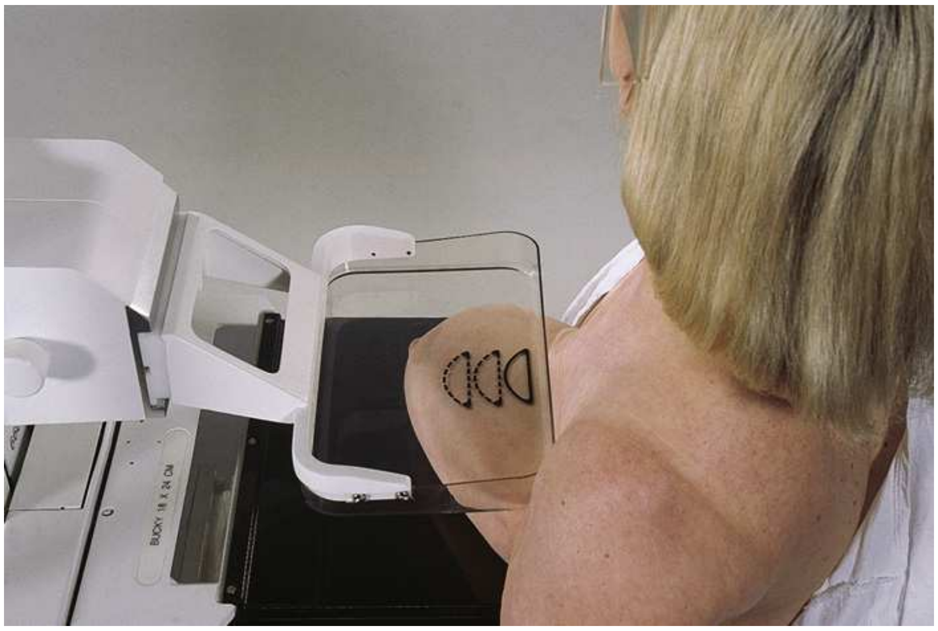


FIG. 18.50 XCCL projection.

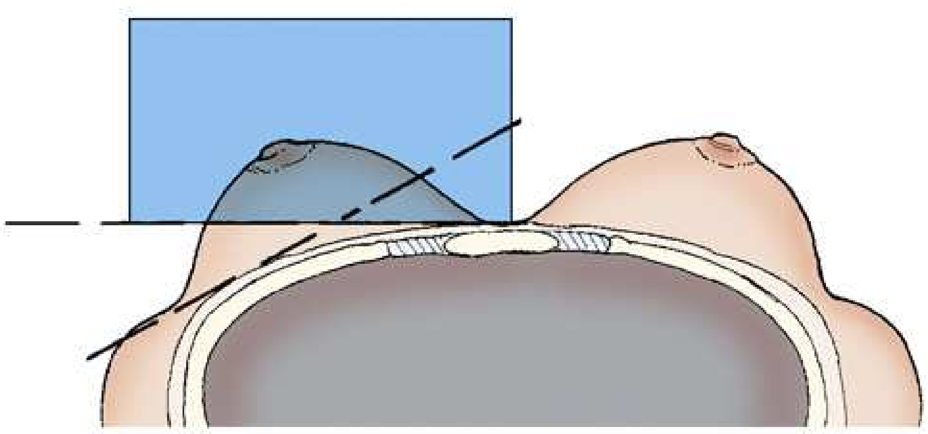


FIG. 18.51 Superior profile illustrates how placement of flat edge of IR against curved chest wall excludes a portion of breast tissue *(shaded area)*. *Dashed line* indicates placement of IR for exaggerated position.

• Slightly rotate the patient medially to place the lateral aspect of the breast on the IR.
• Place an arm against the patient's back with the hand on the shoulder of the affected side, ensuring that the shoulder is relaxed in external rotation.
• Slightly rotate the patient's head away from the affected side.
• Have the patient lean toward the machine and rest the head against the face guard.
• Rotate the C-arm assembly mediolaterally approximately 5 degrees, if necessary, to eliminate overlapping of the humeral head.
• Inform the patient that compression of the breast will be used. Smooth and flatten the breast tissue toward the nipple while bringing the compression paddle into contact with the breast.
• Slowly apply compression until the breast feels taut.
• Instruct the patient to indicate if the compression becomes uncomfortable.
• When full compression is achieved, move the AEC detector to the appropriate position if necessary, and instruct the patient to stop breathing (Figs. 18.50 and 18.51).

- Make the exposure.
- Release breast compression immediately.

Central ray

- Angled 5 degrees mediolaterally to the base of the breast, if necessary

Structures shown

This projection shows a superoinferior projection of the lateral fibroglandular breast tissue and posterior aspect of the pectoral muscle. It also shows a sagittal orientation of a lateral lesion located in the AT of the breast.

Evaluation Criteria

The following should be clearly shown:

- Retroglandular fat well visualized to ensure inclusion of deep fibroglandular breast tissue on lateral aspect of breast and lower axillary region
- Pectoral muscle visualized over lateral chest wall (Fig. 18.52)
- Humeral head projected clear of image with use of a 5-degree ML angle
- Uniform tissue exposure if compression is adequate

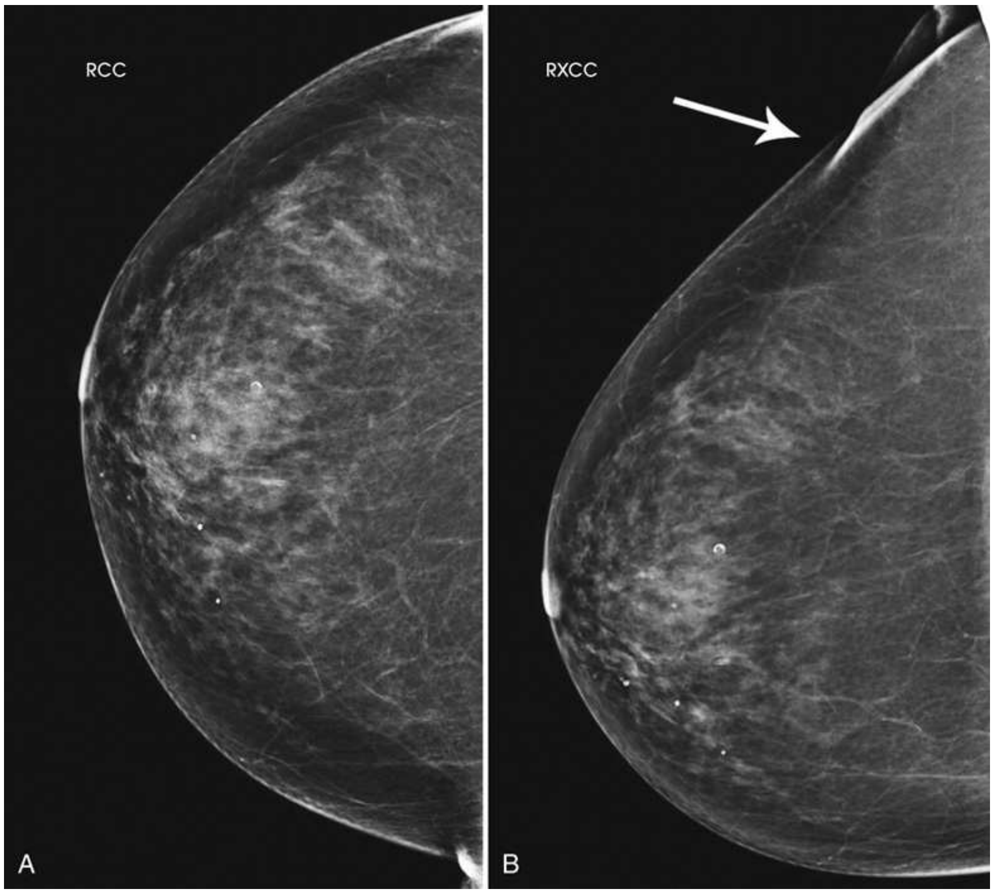


FIG. 18.52 (A) CC projection of right breast. (B) XCCL projection of right breast. This projection is exaggerated laterally to show AT *(arrow)*. Note also some visualization of pectoral muscle.

Craniocaudal Projection for Cleavage (CV)

Paddle:

8 × 10 inches (18 × 24 cm) or 10 × 12 inches (24 × 30 cm).

Position of patient

- Have the patient stand facing the IR or seat the patient on an adjustable stool facing the unit

Position of part

• Turn the AEC *off*, and preselect a *manual* technique. The radiographer may use AEC only if enough breast tissue is positioned over the AEC detector. The cleavage may be intentionally offset for this purpose.
• Determine the proper height of the breast tray by elevating the inframammary fold to its maximal height.
• Adjust the height of the C-arm accordingly.

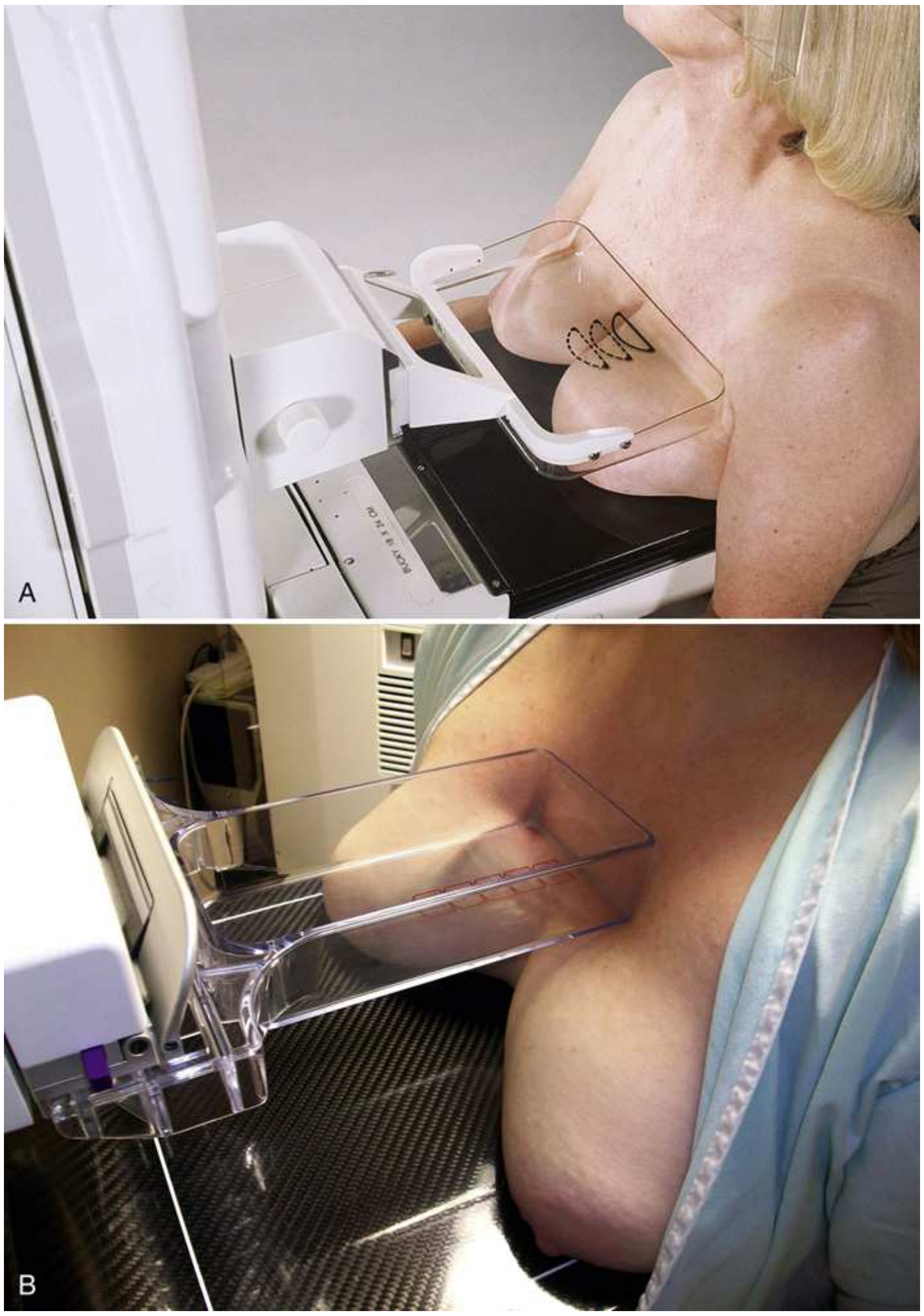


FIG. 18.53 (A) Craniocaudal projection for cleavage. Cleavage is slightly off-center, so that AEC is under breast tissue. (B) Craniocaudal projection for cleavage using a smaller-quadrant paddle for maximum posterior visualization.

(A) A female patient is standing against the mammography unit. Both the breasts are placed between the film holder and the compression paddle. The arms are holding the grip bars. (B) One of the breasts and the cleavage is placed between the film holder and the compression paddle.

• Lift and pull both breasts gently forward onto the IR while instructing the patient to press the thorax against the IR.
• Pull as much medial breast tissue as possible onto the IR.
• Slightly rotate the patient's head away from the affected side.
• Have the patient lean toward the machine and rest the head against the face guard.
• Ask the patient to hold the grip bars with both hands to keep in position on the IR.
• Raise the height of the IR slightly to loosen the superior tissue.
• Place one hand at the level of the patient's jugular notch, and then slide the hand down the patient's chest while pulling forward as much deep medial tissue as possible.
• Inform the patient that compression of the breast will be used. Bring the compression paddle into contact with the breasts, and slowly apply compression until the medial tissue feels taut. Using a quadrant compression paddle allows better compression of the cleavage

area and allows more of the area of interest to be pulled into the imaging area. If a quadrant paddle is used, collimate to the area of compression to better visualize the detail of the tissue.

- Instruct the patient to indicate if the compression becomes uncomfortable.
- When full compression is achieved, move the AEC detector to the appropriate position if AEC is used, and instruct the patient to stop breathing (Fig. 18.53).
- Make the exposure.
- Release breast compression immediately.

Central ray

- Perpendicular to the area of interest or the centered cleavage

Structures shown

This projection shows lesions located in the deep posteromedial aspect of the breast.

Evaluation Criteria

The following should be clearly shown:

- Area of interest over the central portion of the IR (over the AEC detector if possible) with cleavage slightly off-centered or with cleavage centered to the IR and manual technique selected (Fig. 18.54)
- Deep medial tissue of affected breast
- All medial tissue included, as shown by visualization of medial retroglandular fat and the absence of any fibroglandular tissue extending to the posteromedial edge of imaged breasts
- Uniform tissue exposure. It is not necessary to image all of the breast tissue on this projection.

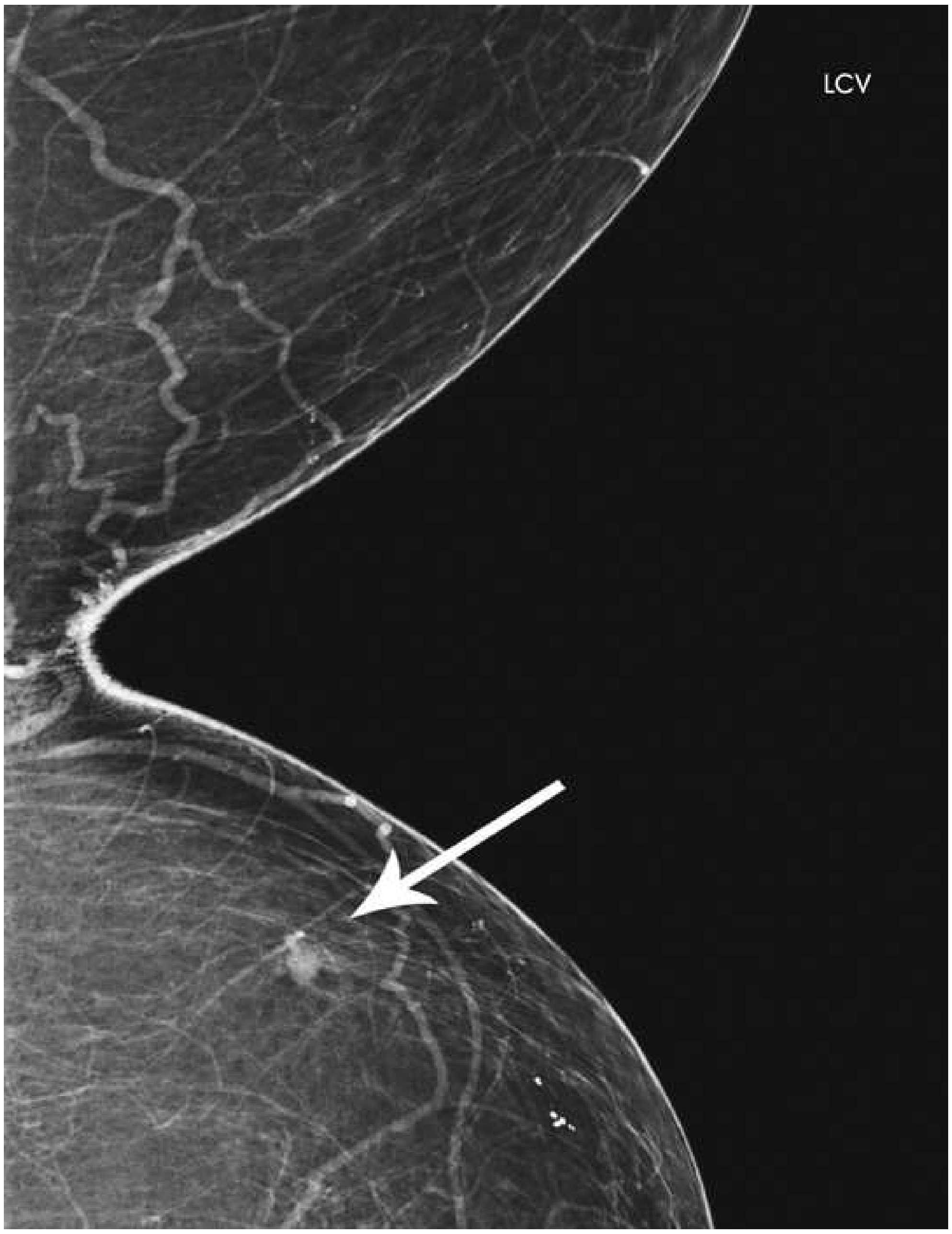


FIG. 18.54 This cleavage view was off-center to the left (LCV) but was performed to view the medial aspect of the right breast. A mass was seen on the right MLO but was not visualized on the standard RCC view. This extremely medial mass *(arrow)* proved to be invasive carcinoma on biopsy.

Craniocaudal Projection With Roll Lateral or Roll Medial (RL or RM Used as Suffix)

Paddle:

8 × 10 inches (18 × 24 cm) or 10 × 12 inches (24 × 30 cm).

Position of patient

- Have the patient stand facing the IR or seat the patient on an adjustable stool facing the unit.

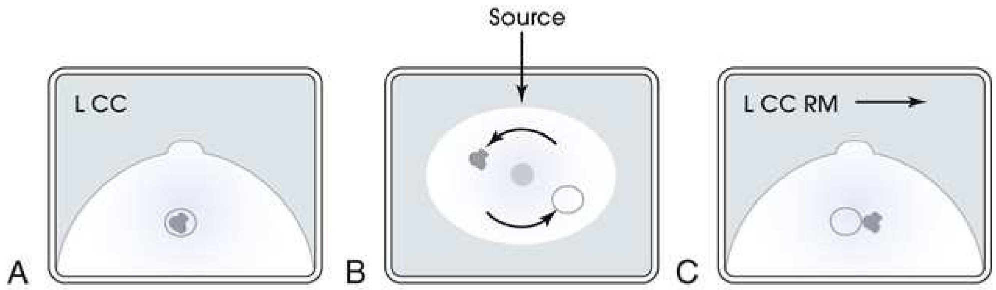


FIG. 18.55 (A) CC projection showing lesion that may represent superimposition of two structures. If spot compression fails to resolve these structures, CC projection with the roll position may be performed. (B) Anterior view of CC projection, with *arrows* indicating rolling of superior and inferior breast surfaces in opposite directions to separate superimposed structures. (C) CC projection with RM, showing resolution of two lesions. *Arrow* indicates direction of roll of superior surface of breast.

Diagram (A) shows a part of the breast in a box. It is labeled as L C C. A grey-colored spot is inside a circle on the breast. Diagram (B) shows a grey circular area in the middle surrounded by an irregular grey patch and a circle. They are connected by arrows. It is labeled as the source. Diagram (C) shows a part of the breast in a box. A grey-colored spot is next to a circle. An arrow pointing right is labeled as L C C R M.

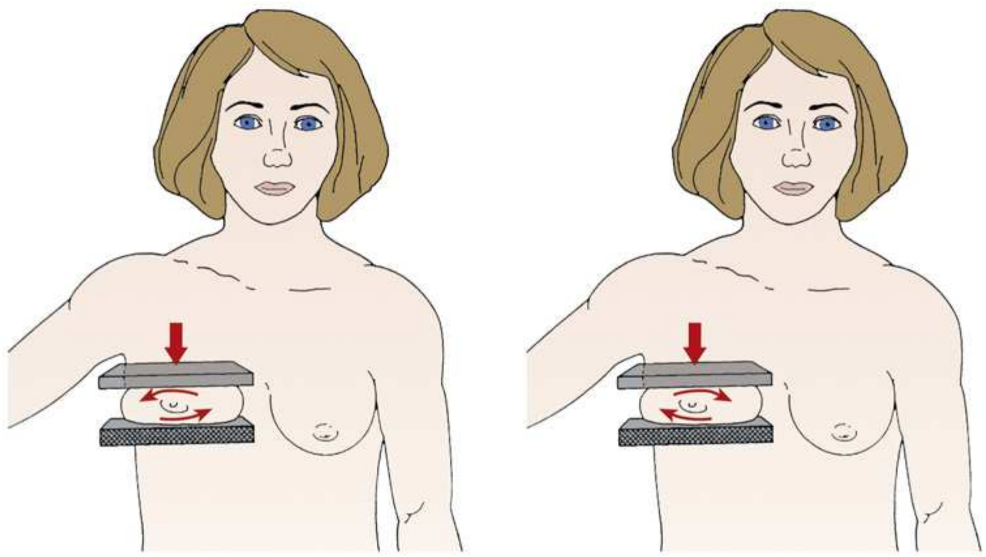


FIG. 18.56 CC projection with lateral and medial roll.

Diagram on the left shows the craniocaudal region of the patient's right breast is placed between the image receptor and the compression paddle. The breast is rolled towards the medial side. The right arm is abducted. An arrow is drawn perpendicular to the compression paddle. Diagram on the right shows the craniocaudal region of the patient's right breast is placed between the image receptor and the compression paddle. The breast is rolled towards the lateral side. The right arm is abducted. An arrow is drawn perpendicular to the compression paddle.

Position of part

- Reposition the patient's breast in the CC projection.
- Place the hands on opposite surfaces of the patient's breast (superior/inferior), and roll the surfaces in opposite directions. The direction of the roll is not important as long as the mammographer rolls the superior surface in one direction and the inferior surface in the other direction. In a sense, the mammographer is very gently rotating the breast approximately 10 to 15 degrees (Fig. 18.55).
- Place the patient's breast onto the IR surface with the lower hand while holding the rolled position with the upper hand.
- Note the direction of the superior surface roll (lateral [RL] or medial [RM]) and label the image accordingly. If the superior aspect of the breast is rolled medially, the image should be labeled RM.
- Inform the patient that compression of the breast will be used. Bring the compression paddle into contact with the breast, and slide the hand out while rolling the breast tissue.
- Slowly apply compression until the breast feels taut.
- Instruct the patient to indicate if the compression becomes uncomfortable.
- When full compression is achieved, move the AEC detector to the appropriate position if necessary and instruct the patient to stop breathing (Fig. 18.56).
- Make the exposure.
- Release breast compression immediately.

Central ray

- Perpendicular to the base of the breast

Structures shown

This position shows separation of superimposed breast tissues (also known as *summation shadow*), particularly those seen only on the CC projection. The position also helps determine whether a lesion is located in the superior or inferior aspect of the breast (Fig. 18.57). Alternatively, the standard CC projection may be performed using the spot compression technique, or with the C-arm assembly rotated 10 to 15 degrees mediolaterally or lateromedially to eliminate superimposition of breast tissue. These methods are often preferred because they allow for easier duplication of the projection during subsequent examinations.

Evaluation Criteria

The following should be clearly shown:

- Suspected superimposition adequately resolved
- Suspected lesion in superior or inferior aspect of breast
- All medial tissue included, as shown by visualization of medial retroglandular fat and the absence of fibroglandular tissue extending to posteromedial edge of image

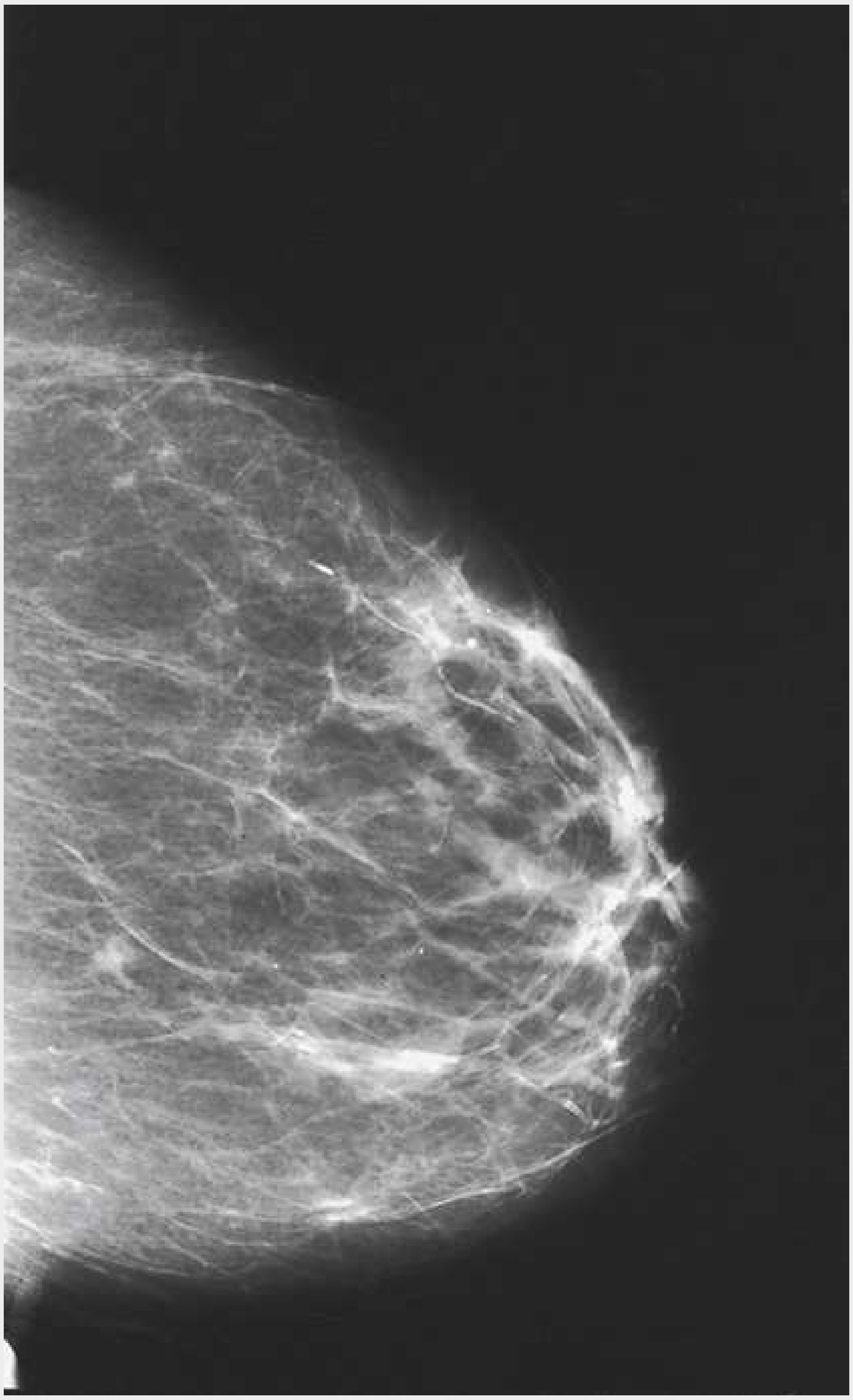


FIG. 18.57 CC projection with RL.

- Nipple in profile and at midline, indicating no exaggeration of positioning. The nipple is used as a point of reference to distinguish the location of the suspected lesion, if it exists.
- Some lateral tissue possibly excluded to emphasize medial tissue visualized
- Slight medial skin reflection at cleavage, ensuring that posterior medial tissue is adequately included
- Uniform tissue exposure if compression is adequate

Tangential (TAN) Projection

Paddle:

8 × 10 inches (18 × 24 cm).

Position of patient

- Have the patient stand facing the IR or seat the patient on an adjustable stool facing the unit.

Position of part

For a palpable mass

The TAN projection is most often performed with use of the magnification technique.

- Select a standard, quadrant, or spot compression paddle, as appropriate.
- Place the AEC detector at the chest wall.
- Locate the area of interest by palpating the patient's breast.
- Place a radiopaque marker or BB on the mass, or have the patient place the BB on the area of concern.
- Using the imaginary line between the nipple and the BB as the angle reference (Fig. 18.58), rotate the C-arm apparatus parallel to this line. The central ray is directed tangential to the breast at the point identified by the BB marker.
- Place the breast on the IR or magnification stand with the area of interest marked by the BB on the edge of the skin.
- The "shadow" of the BB will be projected onto the IR surface.
- Using the appropriate compression paddle, compress the breast while ensuring that enough breast tissue covers the AEC detector area.
- Slowly apply compression until the breast feels taut.
- Instruct the patient to indicate if the compression becomes uncomfortable.
- When full compression is achieved, instruct the patient to stop breathing (Figs. 18.59 and 18.60).
- Make the exposure.
- Release breast compression immediately.

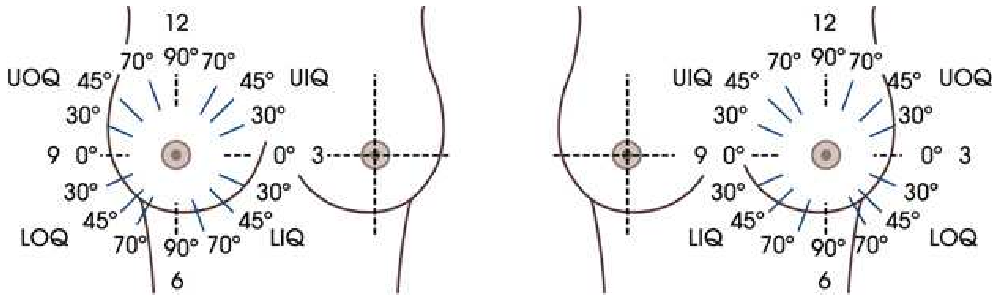


FIG. 18.58 Degree of angle for TAN projection. Correlation of location of abnormality with degree of rotation of C-arm; an angle of the C-arm shows upper quadrant and lower quadrant abnormality tangentially.

Two diagrams show the correlation of the location of abnormality with the degree of rotation of the C-arm. The right breast is viewed as a clock and is divided into four quadrants. Right side: They are the upper outer quadrant (U O Q), upper inner quadrant (U I Q), lower outer quadrant (L O Q), and lower inner quadrant (L I Q). From 12:00 position the degrees marked in a clockwise direction are 90 degrees, 70 degrees, 45 degrees, 30 degrees, 0 degrees, 30 degrees, 45 degrees, 70 degrees, 90 degrees, 70 degrees, 45 degrees, 30 degrees, 0 degrees, 30 degrees, 45 degrees, 70 degrees. The left breast is viewed as a clock and is divided into four quadrants. They are the upper inner quadrant (U I Q), upper outer quadrant (U O Q), lower inner quadrant (L I Q), and lower outer quadrant (L O Q). From 12:00 position the degrees marked in a clockwise direction are 90 degrees, 70 degrees, 45 degrees, 30 degrees, 0 degrees, 30 degrees, 45 degrees, 70 degrees, 90 degrees, 70 degrees, 45 degrees, 30 degrees, 0 degrees, 30 degrees, 45 degrees, 70 degrees.

Central ray

- Perpendicular to the area of interest

Structures shown

This projection shows superficial lesions close to the skin surface with minimal parenchymal overlapping. It also shows skin calcifications or palpable lesions projected over subcutaneous fat (Fig. 18.61).

Evaluation Criteria

The following should be clearly shown:

- Palpable lesion visualized over subcutaneous fat
- TAN radiopaque marker or BB marker accurately correlated with palpable lesion
- Minimal overlapping of adjacent parenchyma
- Calcification in parenchyma or skin
- Uniform tissue exposure if compression is adequate

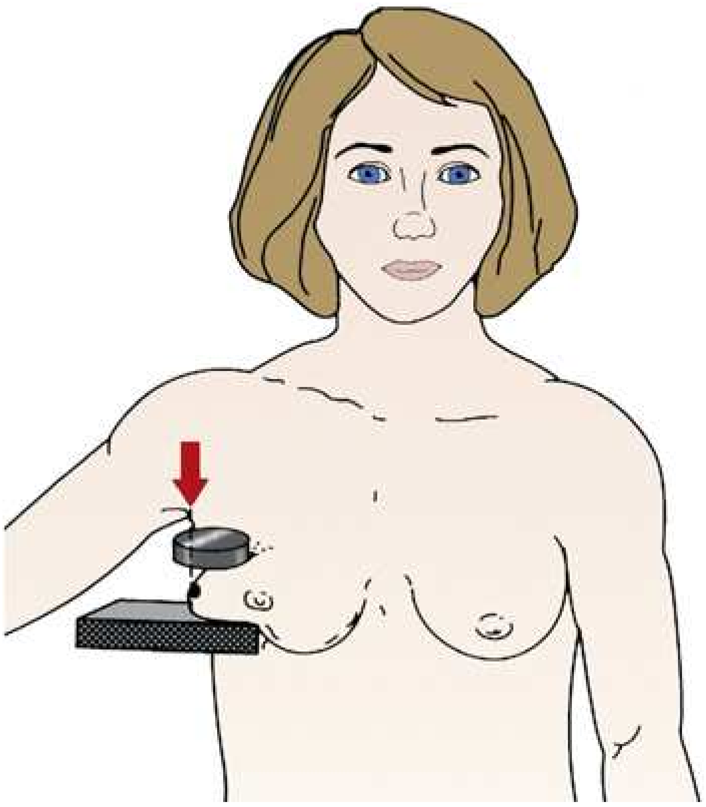


FIG. 18.59 TAN projection.

Diagram shows the tangential projection of the patient’s right breast is placed between the image receptor and a circular compression paddle. The right arm is abducted. An arrow is drawn perpendicular to the image receptor.

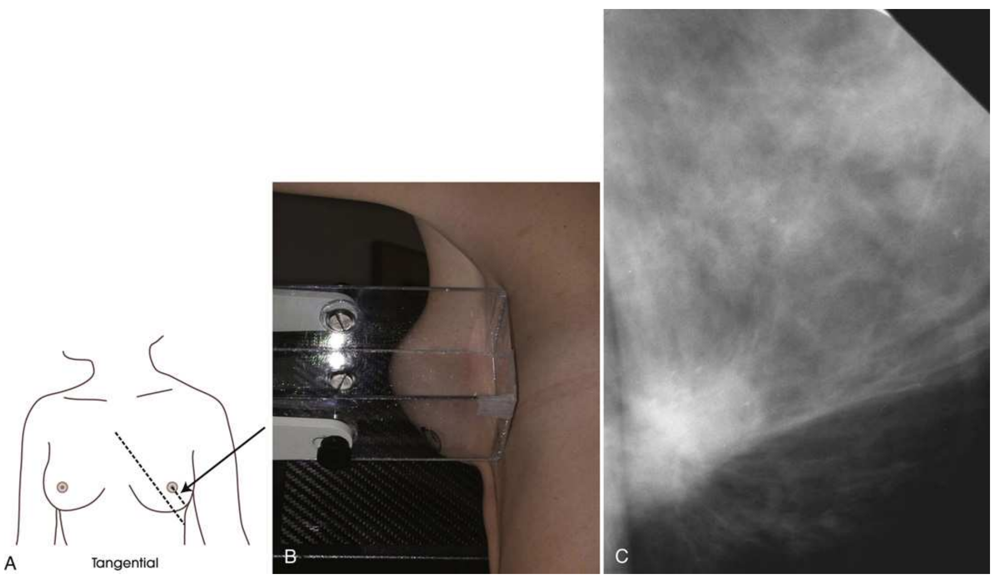


FIG. 18.60 TAN projection of palpable mass in LOQ. (A) IR is angled parallel to nipple-to-mass line. (B) The mass, marked by *BB*, is positioned on edge of skin line. (C) Radiograph of mass imaged in tangent using the magnification technique. Spiculated borders indicate cancer.

Diagram (A) shows the anterior view of the breasts. The I R is angled parallel to the nipple-to-mass line. (B) shows the breast positioned on edge of the skin line. (C) A mammogram shows speculated bright and white borders on the left.

FIG. 18.61 Left magnified tangential view of a palpable mass with a BB placed on it shows the area of interest in the subdermal fatty tissue. The magnified view showed an area of architectural distortion with scattered clusters of coarse calcifications. This proved to be a cancer on biopsy.

Captured Lesion or Coat-Hanger Projection (CL)

This specialized positioning is seldom used but is very useful when a palpable lesion located in the extreme posterior or lateral breast tissue is imaged. Sometimes lesions in these areas tether themselves to the chest wall and resist being pulled forward to be visualized on a routine projection. This procedure is a variation of the TAN projection and should be labeled as such. It is generally performed using magnification and tight collimation. The captured lesion (CL) or coat-hanger projection captures and isolates the palpable lump for imaging (Figs. 18.62 and 18.63).

Paddle:

8 × 10 inches (18 × 24 cm).

Position of patient

- Have the patient stand facing the IR or seat the patient on an adjustable stool facing the unit.

Position of part

- Place the magnification platform designed for use with the dedicated mammography unit on the equipment.
- Place a lead BB over the palpable mass.
- Using your hands, determine the projection most likely to image the lump with no superimposition of other tissue. Place the area of clinical concern at the edge of the breast in a tangent plane to the imaging plate.
- The palpable area of clinical concern is captured with a corner of a wire coat-hanger or an inverted spot compression device. No additional compression is needed.

- It may be necessary to use a manual technique if the amount of tissue captured within the coat-hanger or inverted compression device does not cover the AEC detector.

Central ray

- Perpendicular to the imaging plate.

Structures shown

The area of clinical concern is positively identified and visualized with the advantages of magnification mammography.

Evaluation Criteria

The following should be clearly shown:

- Area of interest within collimated and self-compressed margins

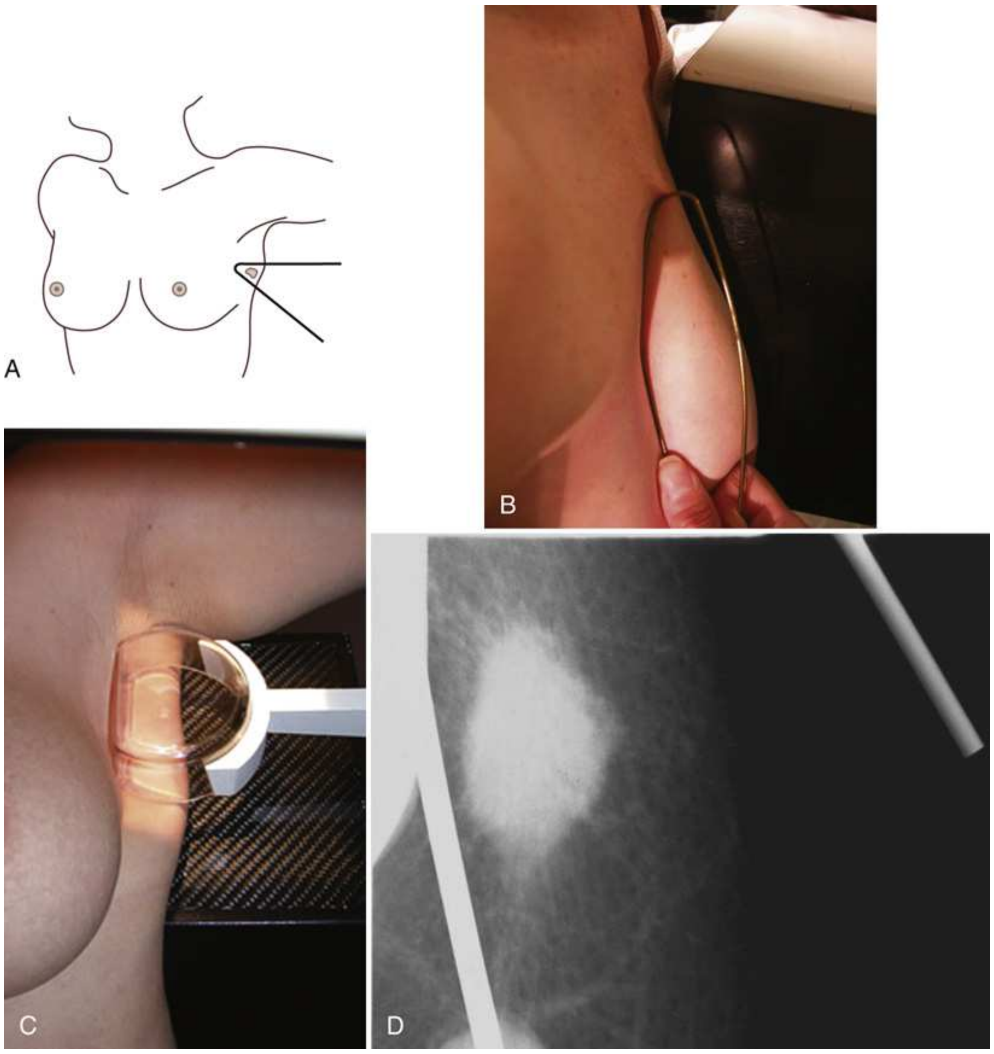


FIG. 18.62 Coat-hanger projection. (A and B) A slippery lesion is captured for imaging by the angle of a wire coat-hanger. (C) Inverted spot compression device can sometimes achieve the same results. (D) Radiograph of lesion imaged using coat-hanger projection. This lesion could not be viewed on routine projections because of its position within the breast and the elastic nature of the lesion, which was determined to be a cancer on biopsy.

Diagram (A) shows the anterior view of the breasts. The I R is at an angle of a wire coat-hanger. (B) shows a slippery lesion. (C) shows a coat hanger projection device held against the side of the breast. (D) A mammogram shows a white region on the left side.

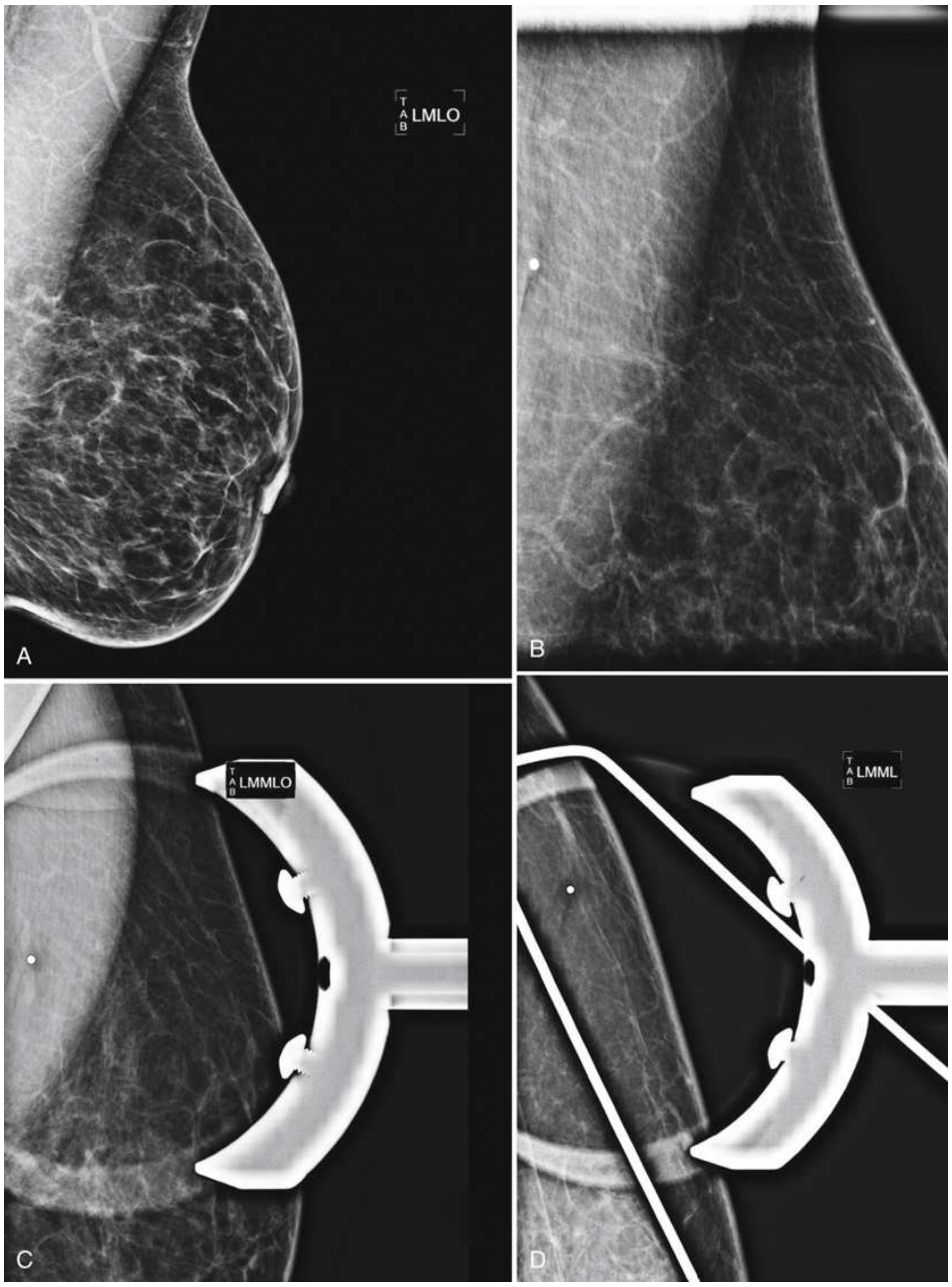


FIG. 18.63 This 40-year-old patient presented with a palpable lump on the left breast extremely posterior at 1:00. A BB was placed on the lump before imaging. The area was not visualized on the standard MLO view (A). Subsequent tangential imaging was unsuccessful because of the proximity of the pectoral muscle (B and C). A CL view was performed (D) to stabilize the lump within the imaged area. This proved to be a lipoma.

(A) A mammogram shows the left breast. It has a network of white regions. (B) A mammogram shows an enlarged image of the left breast. The pectoralis muscle appears white and blurry. (C) A mammogram shows the coat hanger device causing a shadow on the breast tissue. It appears radiopaque. (D) A mammogram shows a white spot on the breast tissue.

Caudocranial Projection (FB, or From Below)

Paddle:

8 × 10 inches (18 × 24 cm) or 10 × 12 inches (24 × 30 cm).

Position of patient

- Have the patient stand facing the IR.

Position of part

- Rotate the C-arm apparatus 180 degrees from the rotation used for a routine CC projection. The tube head will be near the floor and the IR will be above the patient's breast.

- Standing on the medial side of the breast to be imaged, elevate the inframammary fold to its maximal height.

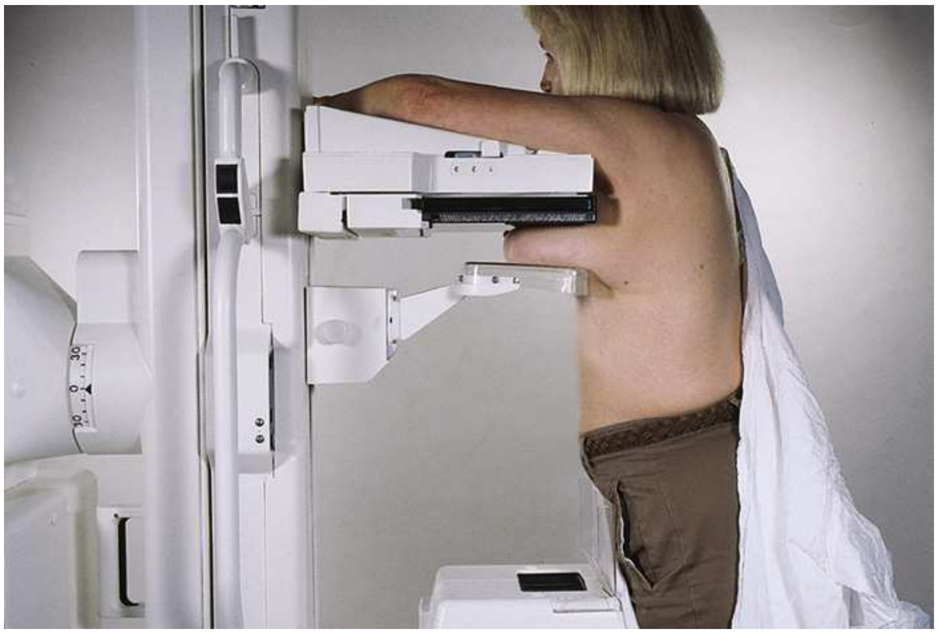


FIG. 18.64 FB projection.

- Adjust the height of the C-arm so that the IR is in contact with the superior breast tissue.
- Lean the patient slightly forward while gently pulling the elevated breast out and perpendicular to the chest wall. Hold the breast in position.
- Have the patient rest the affected arm over the top of the IR.
- Inform the patient that compression of the breast will be used. Bring the compression paddle from below into contact with the patient's breast while sliding the hand toward the nipple.
- Slowly apply compression until the breast feels taut.
- Instruct the patient to indicate if the compression becomes uncomfortable.
- To ensure that the patient's abdomen is not superimposed over the path of the beam, have the patient pull in the abdomen or move the hips back slightly.
- When full compression is achieved, move the AEC detector to the appropriate position, and instruct the patient to stop breathing (Fig. 18.64).
- Make the exposure.
- Release breast compression immediately.

Central ray

- Perpendicular to the base of the breast

Structures shown

This projection shows an inferosuperior projection of the breast for improved visualization of lesions located in the superior aspect as a result of reduced object–to–IR distance. The FB projection may facilitate a shorter route for needle-wire insertion to localize an inferior lesion (Fig. 18.65) or during prone stereotactic core biopsy. The projection may also be used as a replacement for the standard CC projection in patients with prominent pectoral muscles or kyphosis.

Evaluation Criteria

The following should be clearly shown:

- Superior breast tissue and lesions clearly visualized
- For needle localization images, inferior lesion visualized within specialized fenestrated compression plate
- Patient's abdomen projected clear of image
- Inclusion of fixed posterior tissue of superior aspect of breast
- PNL extending posteriorly to edge of image, measuring within ⅓ inch (1 cm) of depth of PNL on MLO projection

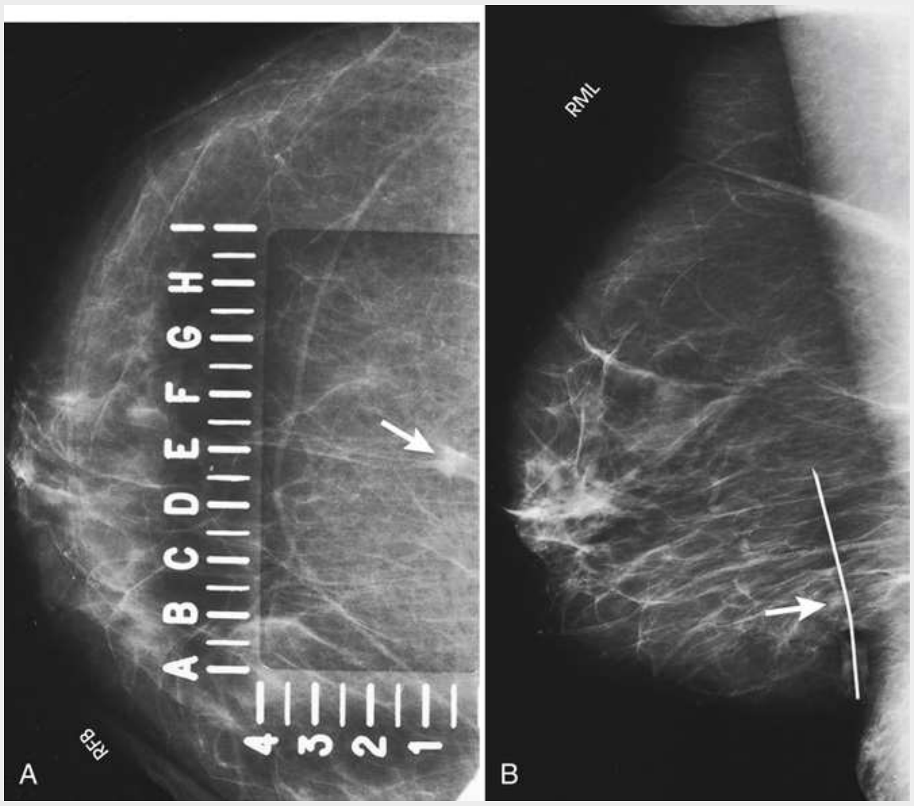


FIG. 18.65 (A) FB projection performed in a 57-year-old woman to access the shortest route for localizing lesions identified in the inferior aspect of the breast *(arrow)*. (B) Orthogonal 90-degree ML projection of the same patient, showing successful placement of needle-wire system within lesion *(arrow)*. The lesion was found to be a 9-mm infiltrating ductal carcinoma.

(A) A mammogram shows vertical calibrations ranging from A to I and horizontal calibrations ranging from 1 to 4 on the breast tissue. A white spot is marked at (1, E) and it is indicated by a white arrow. (B) A mammogram shows a white vertical line on the breast tissue. It is indicated by a white arrow.

- All medial tissue included as shown by visualization of medial retroglandular fat and absence of fibroglandular tissue extending to posteromedial edge of image
- Nipple in profile, if possible, and at midline, indicating no exaggeration of positioning
- Some lateral tissue possibly excluded to emphasize medial tissue
- Slight medial skin reflection at cleavage, ensuring that posterior medial tissue is adequately included
- Uniform tissue exposure if compression is adequate

Mediolateral Oblique Projection for Axillary Tail (AT)

Paddle:

8 × 10 inches (18 × 24 cm) or 10 × 12 inches (24 × 30 cm).

Position of patient

- Have the patient stand facing the IR or seat the patient on an adjustable stool facing the unit.

Position of part

- Determine the degree of obliquity of the C-arm apparatus by rotating the tube until the long edge of the IR is parallel with the AT of the affected side. The degree of obliquity varies between 10 and 35 degrees.
- Adjust the height of the C-arm so that the superior border of the IR is just under the axilla.
- Instruct the patient to elevate the arm of the affected side over the corner of the IR and to rest the hand on the adjacent handgrip. The patient's elbow should be flexed.
- Have the patient relax the affected shoulder and lean it slightly anterior. Using the flat surface of the hand, gently pull the tail of the breast anteriorly and medially onto the IR, keeping the skin and tissue smooth and free of wrinkles.
- Ask the patient to turn the head away from the side being examined and to rest the head against the face guard.
- Inform the patient that compression of the breast will be used. Continue to hold the breast in position while sliding the hand toward the nipple as the compression paddle is brought into contact with the AT (Fig. 18.66).
- Slowly apply compression until the breast feels taut. The corner of the compression paddle should be inferior to the clavicle. To avoid patient discomfort caused by the corner of the paddle and to facilitate even compression, remind the patient to keep the shoulder relaxed.
- Instruct the patient to indicate if the compression becomes uncomfortable.

- When full compression is achieved, move the AEC detector to the appropriate position, and instruct the patient to stop breathing. It may be necessary to increase exposure factors if compression is not as taut as in the routine projections.
- Make the exposure.
- Release breast compression immediately.

FIG. 18.66 MLO projection for AT.

Central ray

- Perpendicular to the IR
- The angle of the C-arm apparatus is determined by the slope of the patient's AT.

Structures shown

This projection shows the AT of the breast, with emphasis on its lateral aspect.

Evaluation Criteria

The following should be clearly shown:

- AT with inclusion of axillary lymph nodes under focal compression (Fig. 18.67)
- Uniform tissue exposure if compression is adequate
- Slight skin reflection of affected arm on superior border of image

FIG. 18.67 Right AT projection.

Axilla Projection for Axillary Tail (AT)

Paddle:

8 × 10 inches (18 × 24 cm).

Position of patient

- Have the patient stand facing the IR or seat the patient on an adjustable stool facing the unit.

Position of part

- Rotate the C-arm to approximately 70 degrees.
- Adjust the height of the C-arm so that the superior edge of the IR is even with the top of the patient's shoulder.
- Select the appropriate compression device. A quadrant paddle will capture more deep axillary tissue; a standard 18 × 24 cm compression paddle will capture additional lateral tissue and AT.

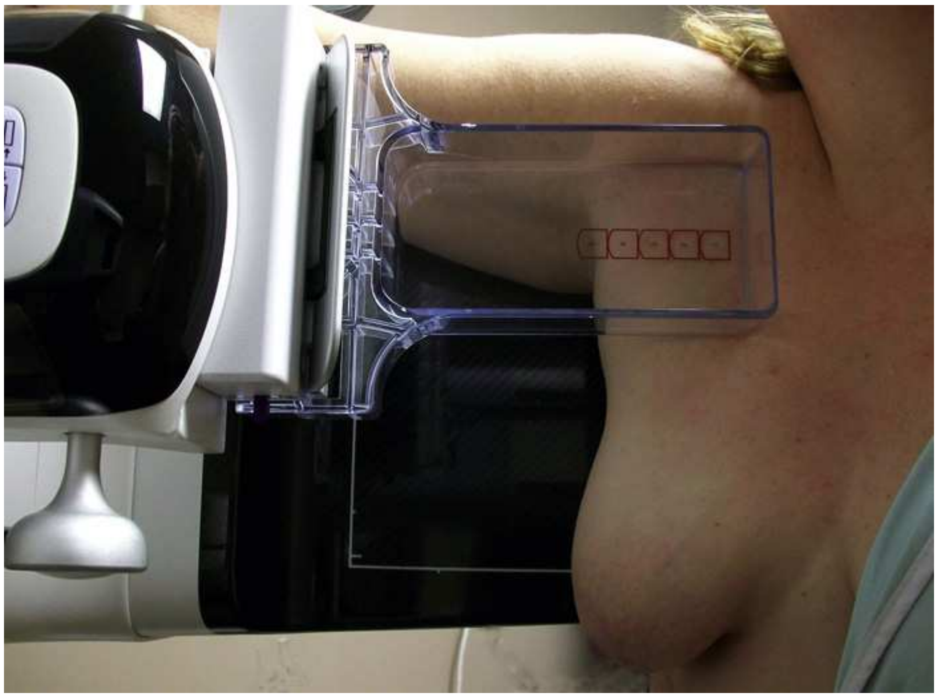


FIG. 18.68 Axilla projection for AT.

A female patient is sitting with her right arm against the IR so that the posterior aspect of the shoulder is resting against the IR. The patient's arm is draped across the I R. The compression pabble is over the ribs.

- Instruct the patient to elevate the arm of the affected side so that it is perpendicular to the body.
- Place the arm against the IR so that the posterior aspect of the shoulder is resting against the IR. The patient's arm is draped across the IR with the forearm resting on the grip bar.
- Have the patient relax the affected shoulder and lean slightly anterior. Using the flat surface of the hand placed under the axillary region, gently pull the tail of the breast anteriorly and medially onto the IR, keeping the skin and tissue smooth and free of wrinkles.
- Inform the patient that compression of the breast will be used. Slowly bring compression down along the patient's ribs, with the top edge of the compression paddle skimming the lower edge of the patient's upper arm.
- Slowly apply compression until the axillary tissue feels taut. The corner of the compression paddle should be inferior to the clavicle. To avoid patient discomfort caused by the corner of the paddle and to facilitate even compression, remind the patient to keep the shoulder relaxed.
- Instruct the patient to indicate if the compression becomes uncomfortable. Vigorous compression is not necessary for this view (Fig. 18.68).
- When full compression is achieved, move the AEC detector to the appropriate position, and instruct the patient to stop breathing. It may be necessary to increase exposure factors if compression is not as taut as in the routine projections.
- Make the exposure.
- Release breast compression immediately.

Structures shown

This projection shows the axilla and the AT of the breast, with emphasis on its lateral aspect.

Evaluation Criteria

The following should be clearly shown:

- AT with inclusion of axillary lymph nodes under focal compression (Fig. 18.69)
- Uniform tissue exposure if compression is adequate
- Slight skin reflection of affected arm on superior border of image

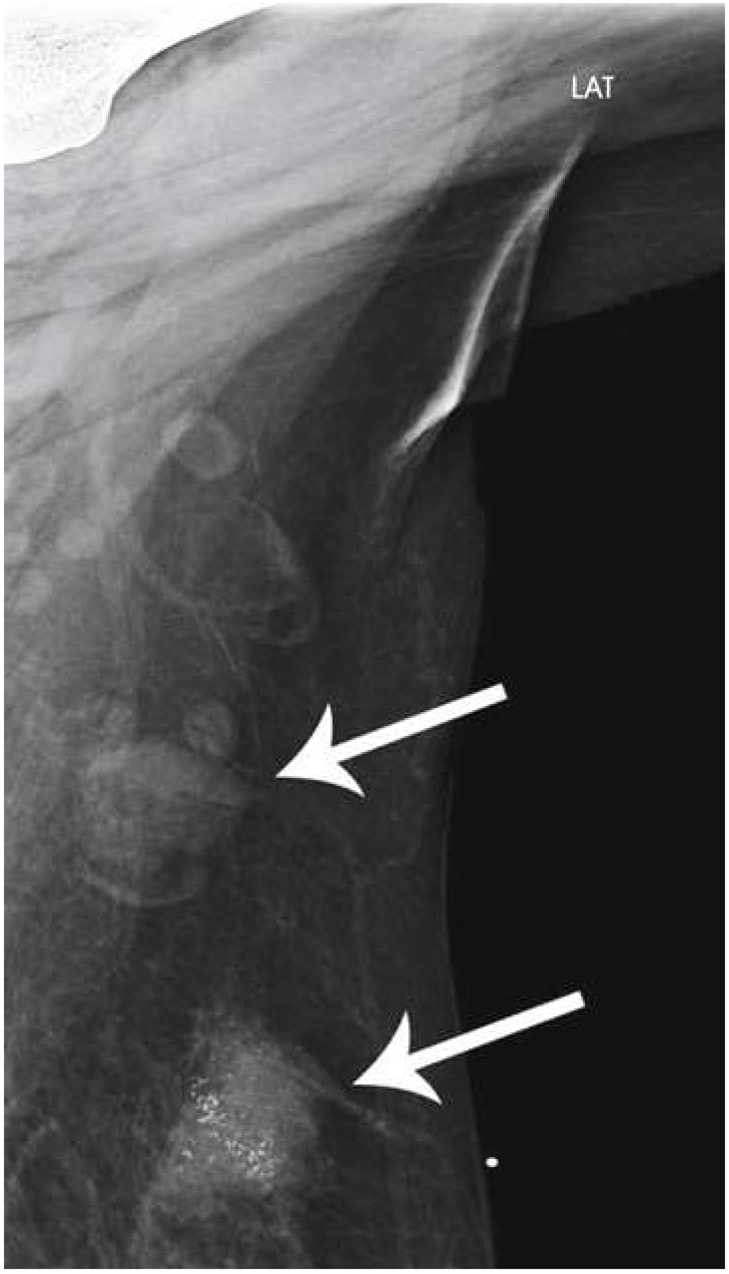


FIG. 18.69 Left AT projection demonstrating the axilla and its contents. Note ductal carcinoma and metastasized lymph nodes *(arrows)*.

Lateromedial Oblique (LMO) Projection

Paddle:

8 × 10 inches (18 × 24 cm) or 10 × 12 inches (24 × 30 cm).

Position of patient

- Have the patient stand facing the IR or seat the patient on an adjustable stool facing the unit.

Position of part

- Determine the degree of obliquity of the C-arm apparatus by rotating the assembly until the long edge of the IR is parallel with the upper third of the pectoral muscle of the affected side. The central ray enters the inferior aspect of the breast from the lateral side. The degree of obliquity should be between 30 and 60 degrees, depending on the body habitus of the patient.
- Adjust the height of the C-arm so that the superior border of the IR is level with the jugular notch.
- Ask the patient to place the opposite hand on the C-arm. The patient's elbow should be flexed.
- Lean the patient toward the C-arm apparatus and press the sternum against the edge of the IR, which is slightly off-center toward the opposite breast.
- Have the patient relax the affected shoulder and lean it slightly anterior. Gently pull the patient's breast and pectoral muscle anteriorly and medially, with the flat surface of the hand positioned along the lateral aspect of the breast.
- Scoop breast tissue up with the hand, gently grasping the breast between fingers and thumb.
- Center the breast with the nipple in profile, if possible, and hold the breast in position.
- Inform the patient that compression of the breast will be used. Continue to hold the patient's breast up and out while sliding the hand toward the nipple as the compression paddle is brought into contact with the LOQ of the breast.

- Slowly apply compression until the breast feels taut.
- Instruct the patient to indicate if the compression becomes uncomfortable.
- Pull down on the patient's abdominal tissue to open the inframammary fold.
- Ask the patient to rest the affected elbow on the top edge of the IR.
- When full compression is achieved, move the AEC detector to the appropriate position, and instruct the patient to stop breathing (Fig. 18.70).
- Make the exposure.
- Release breast compression immediately.

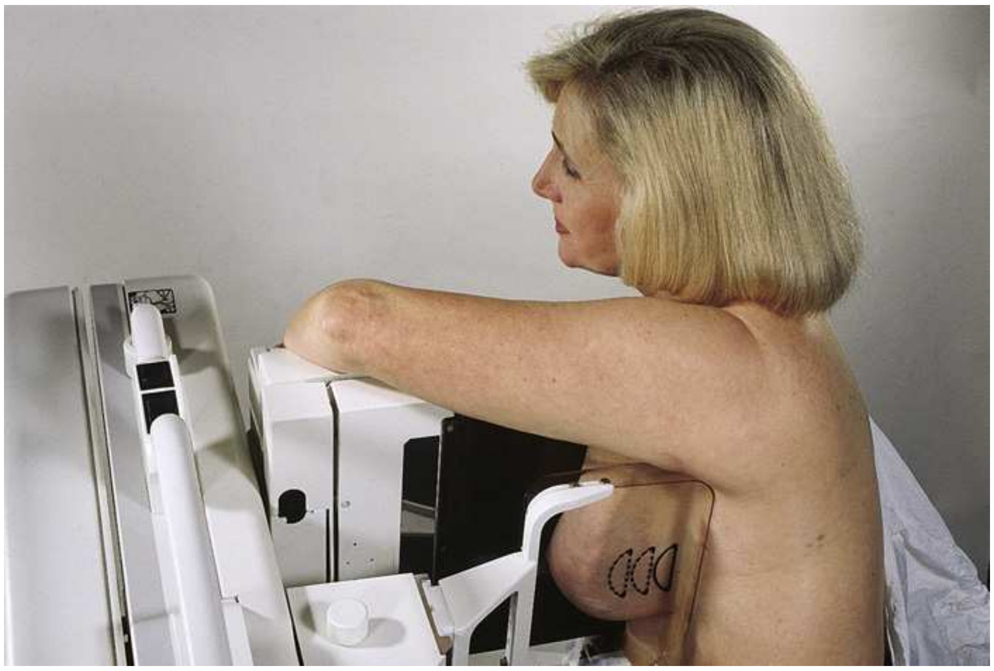


FIG. 18.70 LMO projection.

A female patient is standing against the mammography unit. Her left arm is flexed and the forearm is resting handgrip adjacent to the I R holder. The left breast is placed between the film holder and the compression paddle.

Central ray

- Perpendicular to the IR
- The C-arm apparatus is positioned at an angle determined by the slope of the patient's pectoral muscle (30 to 60 degrees). The actual angle is determined by the patient's body habitus: Tall, thin patients require steep angulation, whereas short, stout patients require shallow angulation.

Structures shown

This projection shows a true reverse projection of the routine MLO projection and is typically performed to better show the medial breast tissue. It is also performed if the routine MLO cannot be completed because of one or more of the following conditions: pectus excavatum, extreme kyphosis, post open-heart surgery, prominent pacemaker, men or women with prominent pectoralis muscles, or Port-A-Cath/MediPort (Hickman catheters).

Evaluation Criteria

The following should be clearly shown:

- Medial breast tissue clearly visualized (Fig. 18.71)
- PNL measuring within ⅓ inch (1 cm) of the depth of the PNL on the CC projection. (While drawing the PNL obliquely, following the orientation of the breast tissue toward the pectoral muscle, measure its depth from nipple to pectoral muscle or to the edge of the image, whichever comes first.)
- Inferior aspect of the pectoral muscle extending to nipple line or below it if possible
- Pectoral muscle with anterior convexity to ensure a relaxed shoulder and axilla
- Nipple in profile if possible
- Open inframammary fold
- Deep and superficial breast tissues well separated when breast is adequately maneuvered up and out from chest wall
- Retroglandular fat well visualized to ensure inclusion of deep fibroglandular breast tissue
- Uniform tissue exposure if compression is adequate

FIG. 18.71 LMO projection. From Svane G: *Screening mammography*, St Louis, 1993, Mosby.

Superolateral to Inferomedial Oblique (SIO) Projection

Paddle:

8 × 10 inches (18 × 24 cm) or 10 × 12 inches (24 × 30 cm).

Position of patient

- Have the patient stand facing the IR or seat the patient on an adjustable stool facing the unit.

Position of part

- Rotate the C-arm apparatus so that the central ray is directed at an angle to enter the superior and lateral aspect of the affected breast. The LIQ is adjacent to the IR.
- Adjust the degree of C-arm obliquity according to the body habitus of the patient, or, when the superolateral to inferomedial oblique (SIO) projection is being used as an additional projection to image an area of the tissue more clearly without superimposition of surrounding tissue, adjust the C-arm to the degree of angulation required by the radiologist, generally a 20- to 30-degree angle.

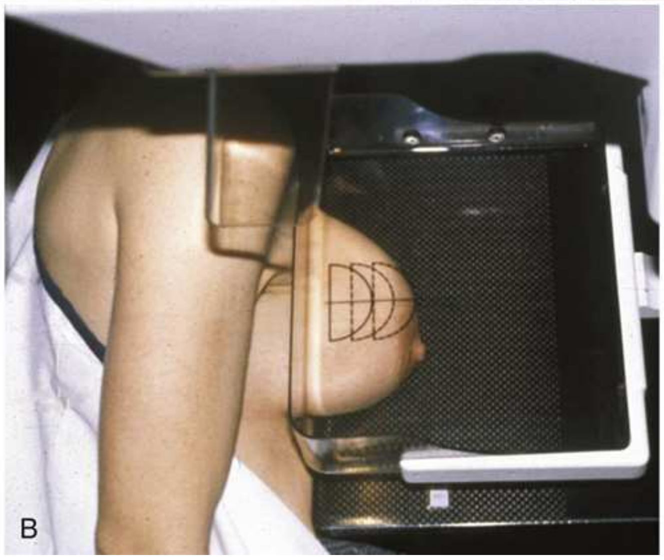


FIG. 18.72 (A) SIO projection. (B) Shallow-angled SIO with arm down.

A female patient is standing against the mammography unit and is leaning forward. Her left arm is flexed and the forearm is resting handgrip adjacent to the I R holder. Her breasts are placed between the film holder and the compression paddle. A female patient is standing against the mammography unit Her breasts are placed between the film holder and the compression paddle.

- Adjust the height of the C-arm to position the patient's breast over the center of the IR.
- Instruct the patient to rest the hand of the affected side on the handgrip adjacent to the IR holder. The patient's elbow should be flexed. For shallow-angled SIO projections, the arm on the affected side should lie straight against the patient's side. The handgrip is held by the hand on the contralateral side.
- Place the upper corner of the IR along the sternal edge adjacent to the upper inner aspect of the patient's breast.
- With the patient leaning slightly forward, gently pull as much medial tissue as possible away from the sternal edge while holding the breast up and out. The breast should not droop. Ensure that the patient's back remains straight during positioning, and that the patient does not lean to the side or toward the IR.
- Inform the patient that compression of the breast will be used. Continue to hold the breast up and out.
- Bring the compression paddle under the affected arm and into contact with the patient's breast while sliding the hand toward the patient's nipple. For shallow-angled SIO, the affected arm at the patient's side should be bent at the elbow to avoid superimposition of the humeral head over the breast tissue.
- Slowly apply compression until the breast feels taut. The upper corner of the compression paddle should be in the axilla for the standard SIO projection.
- Instruct the patient to indicate if the compression becomes uncomfortable.
- When full compression is achieved on the standard SIO, help the patient bring the arm up and over with the flexed elbow resting on top of the IR.
- Gently pull down on the patient's abdominal tissue to smooth out any skin folds.
- Move the AEC detector to the appropriate position and instruct the patient to stop breathing (Fig. 18.72).
- Make the exposure.
- Release breast compression immediately.

Central ray

- Perpendicular to the IR
- The C-arm apparatus is positioned at an angle determined by the patient's body habitus or tissue composition.

Structures shown

This projection shows the UIQ and LOQ of the breast free of superimposition. In addition, lesions located in the lower inner aspect of the breast are shown with better recorded detail. This projection may also be used to replace the MLO ID projection in patients with encapsulated implants (Fig. 18.73).

Evaluation Criteria

The following should be clearly shown:

- UIQ and LOQ free of superimposition (these quadrants are superimposed on MLO and LMO projections)
- Lower inner aspect of breast visualized with greater detail
- Nipple in profile if possible
- Deep and superficial breast tissues well separated when breast is adequately maneuvered up and out from chest wall
- Retroglandular fat well visualized to ensure inclusion of deep fibroglandular breast tissue
- Uniform tissue exposure if compression is adequate.

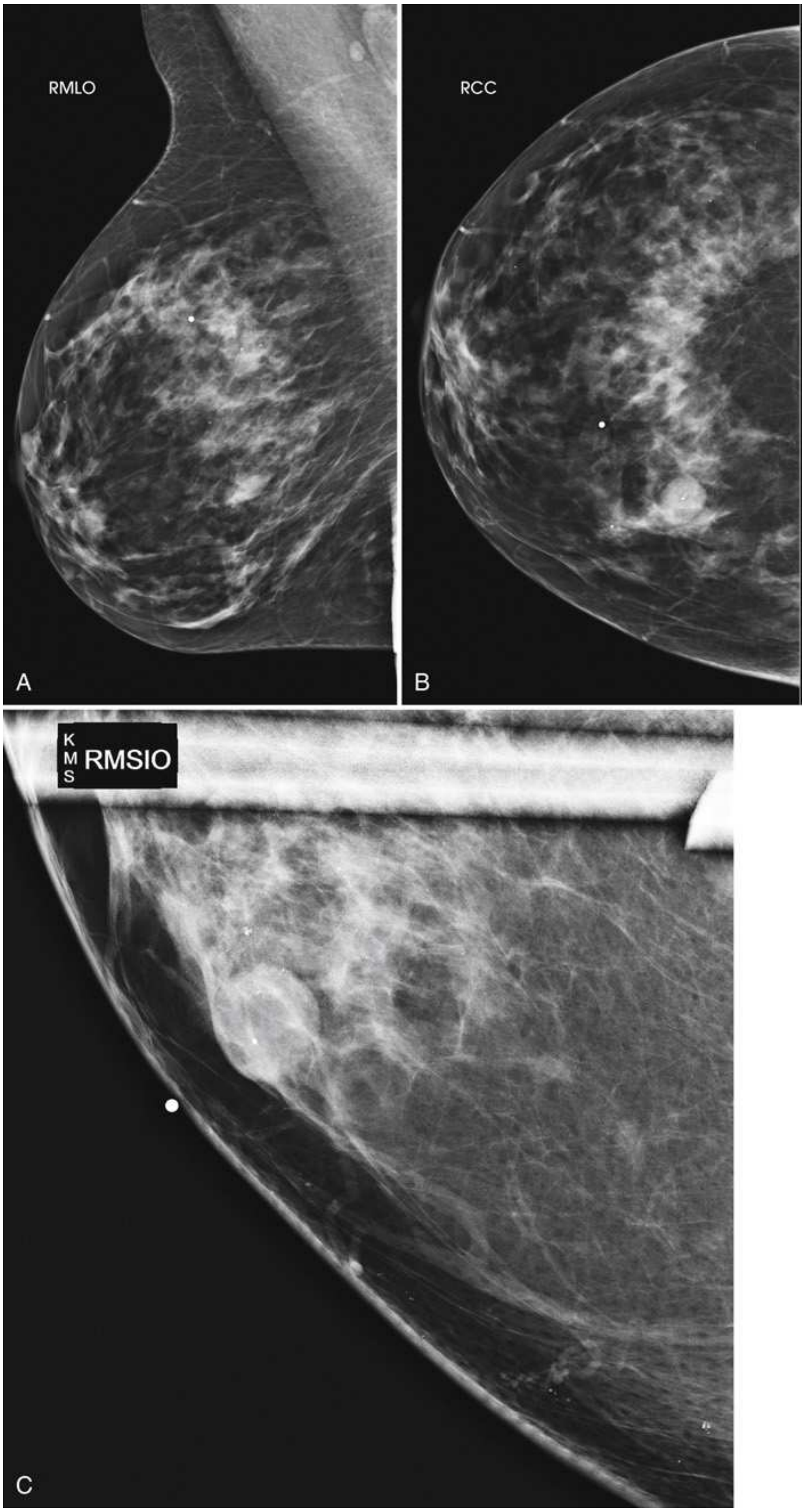


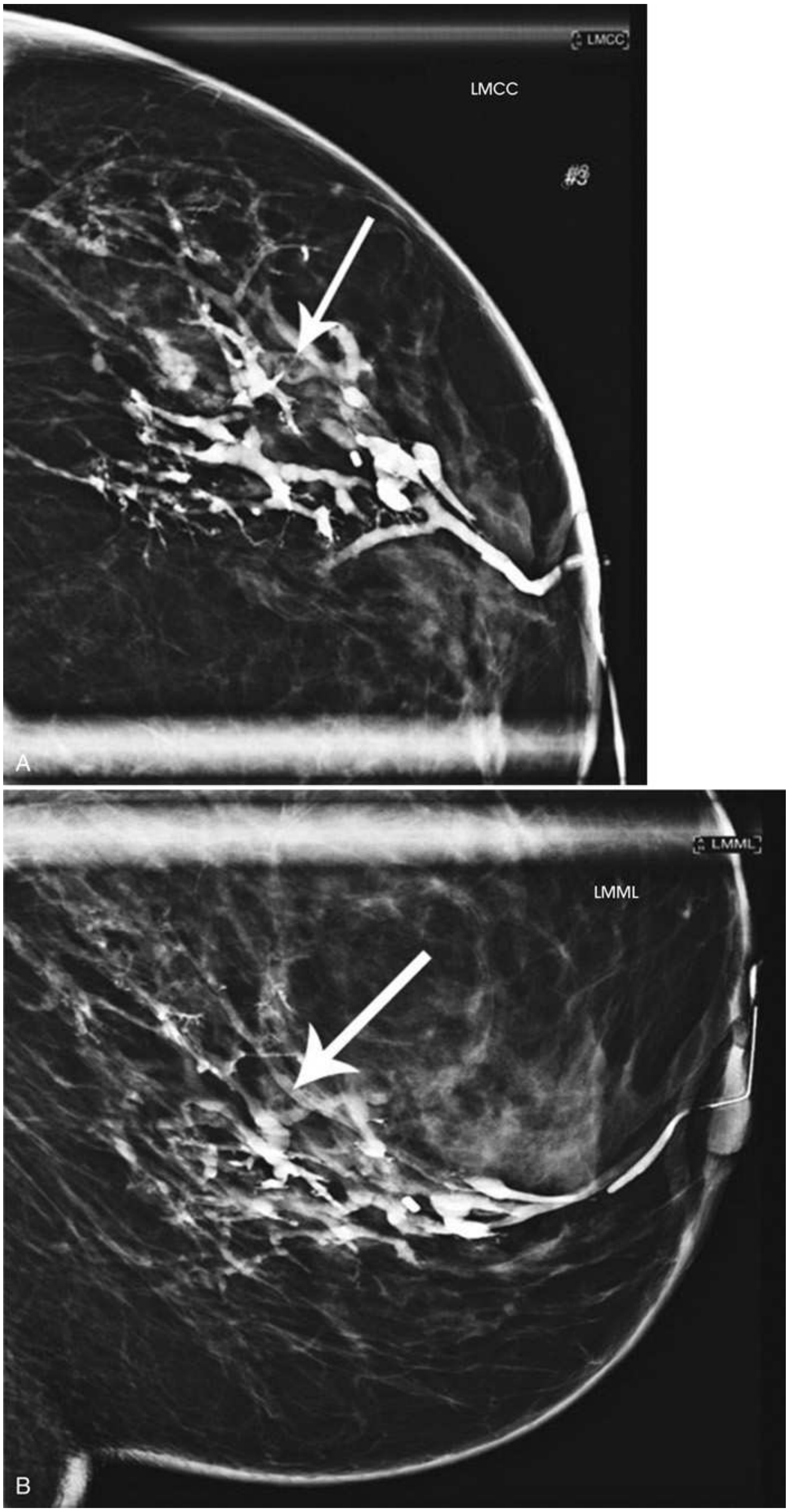
FIG. 18.73 Patient presented with a palpable mass at 1:00 in the right breast. A BB was placed on the skin over the lump, and standard MLO and CC projections were taken (A and B). A tangential view taken in an SIO projection (C) places the palpable lump within the dermis for best visualization. This proved to be invasive ductal carcinoma on biopsy.

(A) A mammogram shows lesions located in the lower inner aspect of the breast. (B) A mammogram shows a curved white hazy region in the middle. (C) A mammogram shows a white circular lump surrounded by a white cloudy region.

Ductography (Examination of Milk Ducts)

Ductography is indicated in a patient who presents with a unilateral spontaneous discharge from the nipple that is either bloody or clear and watery. This type of discharge can be associated with a ductal carcinoma that is mammographically occult. More often, nipple discharge is the product of a papilloma within the duct. The ductogram can help the radiologist determine the cause and location of the origin of the discharge by injecting an opaque contrast medium into the duct. These patients can often be biopsied immediately using stereotactic methods with contrast-enhanced ducts (Fig. 18.74).

Equipment and supplies for the examination include a sterile hypodermic syringe (usually 1 to 3 mL); a 30-gauge ductography cannula with a smooth, round tip; a skin cleansing agent; sterile gauze sponges or cotton balls; paper tape; a waste basin; and an organic, water-soluble, iodinated contrast medium.


LMCC
LMCC
#3
A
LMML
LMML
B

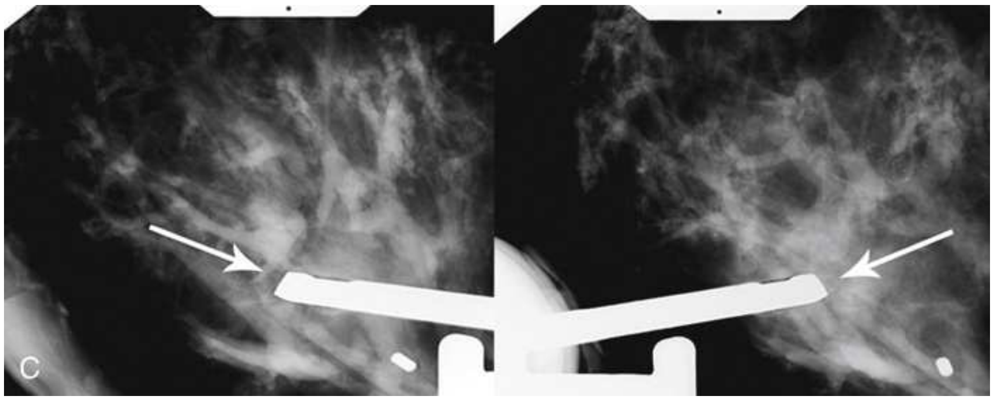


FIG. 18.74 This 55-year-old patient presented with a spontaneous brown discharge from the left nipple. Ductography was performed for visualization of the ducts. A probable papilloma was noted as an area of lucency *(arrows)* on CC (A) and ML (B) views. This patient was sent for stereotactic core biopsy (C, pre-fire images) where the area was excised. It proved to be a papilloma.

(A) A mammogram shows a radiolucent white streak of tissues. It is indicated by a white arrow. (B) A mammogram shows a radiolucent white streak of tissues. It is indicated by a white arrow. (A) A mammogram shows a radiolucent white line on the right. It is indicated by a white arrow. (B) A mammogram shows a radiolucent white line on the left. It is indicated by a white arrow.

After the nipple is cleaned, a small amount of discharge is expressed to identify the correct ductal opening. The cannula is inserted into the orifice of the duct, and undiluted iothalamate meglumine or iopamidol is gently injected. So that the patient does not experience unnecessary discomfort and extravasation does not occur, the injection is terminated as soon as the patient experiences a sense of fullness, pressure, or pain. The cannula is taped in place before the patient is positioned for the radiographs. If cannulation is unsuccessful, a sterile local anesthetic gel or warm compress may be applied to the nipple and areola, and the procedure is reattempted. If ductography is unsuccessful after several attempts, the procedure may be rescheduled in 7 to 14 days. On successful injection, the following guidelines are observed:

- Immediately obtain radiographs with the patient positioned for the CC and lateral projections of the subareolar region using the magnification technique (see Fig. 18.74A and B). If needed, MLO or rolled CC and rolled MLO magnification projections may be obtained to resolve superimposed ducts.
- Employ the exposure techniques used in general mammography.
- Leave the cannula in the duct to minimize leakage of contrast material during compression and to facilitate reinjection of the contrast medium without the need for recannulation.
- If the cannula is removed for the images, do not apply vigorous compression because this would cause the contrast medium to be expelled.

Localization and Biopsy of Suspicious Lesions

Approximately 80% of nonpalpable lesions identified by mammography are not malignant. Nonetheless, a breast lesion cannot be definitively judged benign until it has been microscopically evaluated. When mammography identifies a nonpalpable lesion that warrants biopsy, the abnormality must be accurately located so that the smallest amount of breast tissue is removed for microscopic evaluation, minimizing trauma to the breast. This technique conserves the maximal amount of normal breast tissue unless extensive surgery is indicated by pathologic findings.

Suspicious breast lesions can be biopsied using three techniques: (1) FNAB, (2) large-core needle biopsy (LCNB), and (3) open surgical biopsy. FNAB uses a hollow small-gauge needle to extract tissue cells from a suspicious lesion. The location of the lesion is identified by the doctor using palpation, ultrasonography, or mammographic or stereotactic guidance. FNAB can potentially decrease the need for surgical excisional biopsy by identifying benign lesions and by diagnosing malignant lesions that require extensive surgery rather than excisional biopsy.

LCNB obtains small samples of breast tissue by means of a larger-gauge (generally sized between 9-gauge and 14-gauge) hollow needle with a trough adjacent to the tip of the needle, using the same localizing techniques. A vacuum suction system is frequently employed during this procedure to pull the target tissue through the trough into a collecting chamber. Once the tissue sample has been obtained, a titanium clip is often placed in the breast through the needle to mark the exact location of the biopsy. This clip can be used by the surgeon to locate the area of concern during an open surgical excision, or to indicate the area of a prior LCNB during subsequent mammography. Because larger tissue samples are obtained with LCNB, and because results are very accurate, clinical support is available for use of this technique instead of surgical excisional biopsy to diagnose pathology of a lesion. LCNB may be used with clinical, ultrasound, stereotactic, and MRI guidance. The method used depends on the preference of the radiologist and the surgeon and is typically determined by the modality with which the lesion is most visible.

When a patient is a candidate for an open surgical biopsy, preoperative localization is used to locate and guide the surgeon to a nonpalpable lesion. Several types of preoperative localization methods are in use today, but all require imaging assistance to tag the nonpalpable area of concern.

The most common method of preoperative localization is needle-wire localization. A long needle containing a hooked guidewire is inserted into the breast to lead the surgeon directly to the lesion. The four most common needle-wire localization systems are the Kopans, Homer (18-gauge), Frank (21-gauge), and Hawkins (20-gauge) biopsy guides. A small incision (1 to 2 mm) at the entry site may be necessary to facilitate insertion of a larger-gauge needle. With each system, a long needle containing a hooked wire is inserted into the breast until the needle's tip is adjacent to the lesion. When the needle and wire are in place, the needle is withdrawn over the wire. The hook on the end of the wire anchors the wire within the breast tissue. Some radiologists also inject a small amount of methylene blue dye to label the proper biopsy site visually. After needle-wire localization, the patient is bandaged and taken to the surgical area for excisional biopsy (Fig. 18.75). The surgeon then cuts along the guidewire and removes the breast tissue around the wire's hooked end. Alternatively, the surgeon may choose an incision site that intercepts the anchored wire distant from the point of wire entry. Ideally, the radiologist and the surgeon should review the localization images together before the excisional biopsy is performed.

Newer methods of preoperative localization that utilize breast imaging include radioguided occult lesion localization (ROLL), radioactive iodine seed localization (RSL), and SAVI Scout (Cianna Medical) radar localization. The ROLL method involves the injection of a radioisotope into the tissue in the area to be excised. With RSL, a radioactive seed is placed in the tissue through a localizing needle. Both of these methods require the surgeon to locate the tissue to be excised using a gamma probe. Surgical outcomes with this method have been found to be similar to those of wire-guided localizations.[35, 36] The SAVI Scout method utilizes radar technology. A reflector is placed into the target tissue by the radiologist up to 30 days prior to surgery using mammographic or ultrasound guidance. The surgeon uses the SCOUT guide, which emits the radar signal, to detect the location of the reflector and target tissue. Real-time audible and visual indicators from the radar console assist the surgeon in accurately locating the reflector and target tissue.[37] This is a newer and nonradioactive method of localization.[38]

FIG. 18.75 Material for breast localization using specialized compression plate: alphanumeric localization compression plate, sterile gloves, topical antiseptic, alcohol wipe, local anesthetic, 5-mL syringe, 25-gauge needle, scalpel blade, sterile gauze, tape, and needle-wire localization system.

A breast compression plate sterile gloves, topical antiseptic, alcohol wipe, local anesthetic, 5-milliliter syringe, 25-gauge needle, scalpel blade, sterile gauze, tape, and needle-wire localization system are next to each other.

Breast Lesion Localization With A Specialized Compression Plate

Most breast cancers that are surgically removed are nonpalpable lesions that have been found during mammography. Preoperative localization of these lesions is often performed to aid the surgeon in locating the area of concern to ensure excision of the lesion. Most mammography units are adaptable with specialized compression plates with openings that can be positioned over a breast lesion. Through the opening, a specialized localizing needle-wire set can be introduced into the breast. The initial mammogram and a 90-degree lateral projection are usually reviewed together to determine the shortest distance from the skin to the breast lesion. A lesion in the inferior aspect of the breast may be best approached from the medial, lateral, or inferior surface of the breast but not from the superior surface.

Two styles of fenestrated localization compression paddles are currently in use: a rectangular cutout with radiopaque alphanumeric grid markings along at least two adjacent sides, and a device in which the plate may be fenestrated with several rows of holes, each large enough to accommodate insertion of a localization needle (Fig. 18.76). There are proponents for each of the paddles, and the radiologist performing the localization procedure usually decides which one to use. The device with fenestrated holes allows the breast tissue to be more firmly fixed and compressed; this in turn allows the area to be localized, making it more discernible from the surrounding tissue.

FIG. 18.76 Compression plates specifically designed for breast localization procedure.

Needle-localization procedures vary from radiologist to radiologist. As a result, no standardized procedure is known. The following steps are typically taken:

- Perform preliminary routine full-breast projections to confirm the existence of the lesion (Figs. 18.77 and 18.78). Orthogonal views will be more helpful in visualizing the exact location of the lesion; therefore, the MLO projection may be replaced by a 90-degree lateral projection.
- Obtain informed consent after discussing the following topics with the patient:
    1. Full explanation of the procedure
    2. Full description of potential problems per facility policy: These may include vasovagal reaction, excessive bleeding, allergic reaction to lidocaine, and possible failure of the procedure (failure rate of 0% to 20%).[39–41]
    3. Answers to patient's preliminary questions

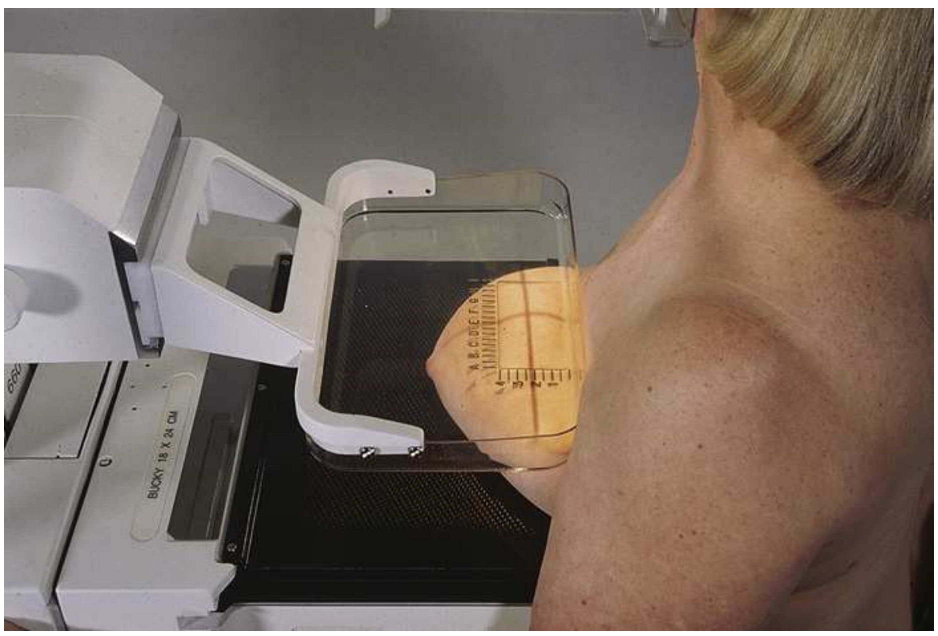


FIG. 18.77 CC projection shown with specialized open-hole compression plate.

A female patient is standing against the mammography unit with her face turned away. Her left breast is placed between the film holder and the compression paddle. The compression plate has an open hole with calibrations on the sides of the hole.

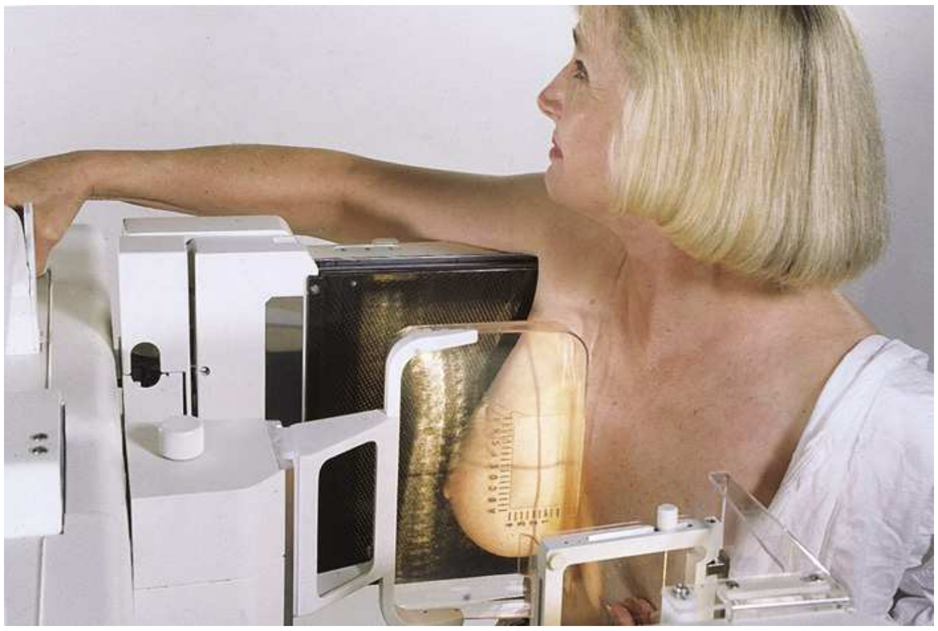


FIG. 18.78 ML projection shown with specialized open-hole compression plate.

A female patient is standing against the mammography unit with her face turned away. Her right arm is holding the grip bar. Her right breast is placed between the film holder and the compression paddle. The compression plate has an open hole with calibrations on the sides of the hole.

- Position the patient so that the compression plate is against the skin surface closest to the lesion as determined from preliminary images.
- Tell the patient that compression will not be released until the needle has been successfully placed and that the patient is to hold as still as possible.
- Disable the automatic release of the compression paddle.
- Make a preliminary exposure using compression. Ink marks may be placed at the corners of the paddle window or in several of the concentric holes away from the area to be localized to determine whether the patient moves during the procedure.
- Process the image without removing compression. The resultant image shows where the lesion lies in relation to the compression plate openings (Fig. 18.79). If using the circularly fenestrated paddle, count the holes visible on the image to determine the correct entry point of the needle. If using the rectangular hole, use the alphanumeric marker system supplied with the paddle to determine the location of the lesion and the needle entry point.
- Clean the skin of the breast over the entry site with a topical antiseptic. Some radiologists may prefer to do this before compression.
- Apply a topical anesthetic if necessary.

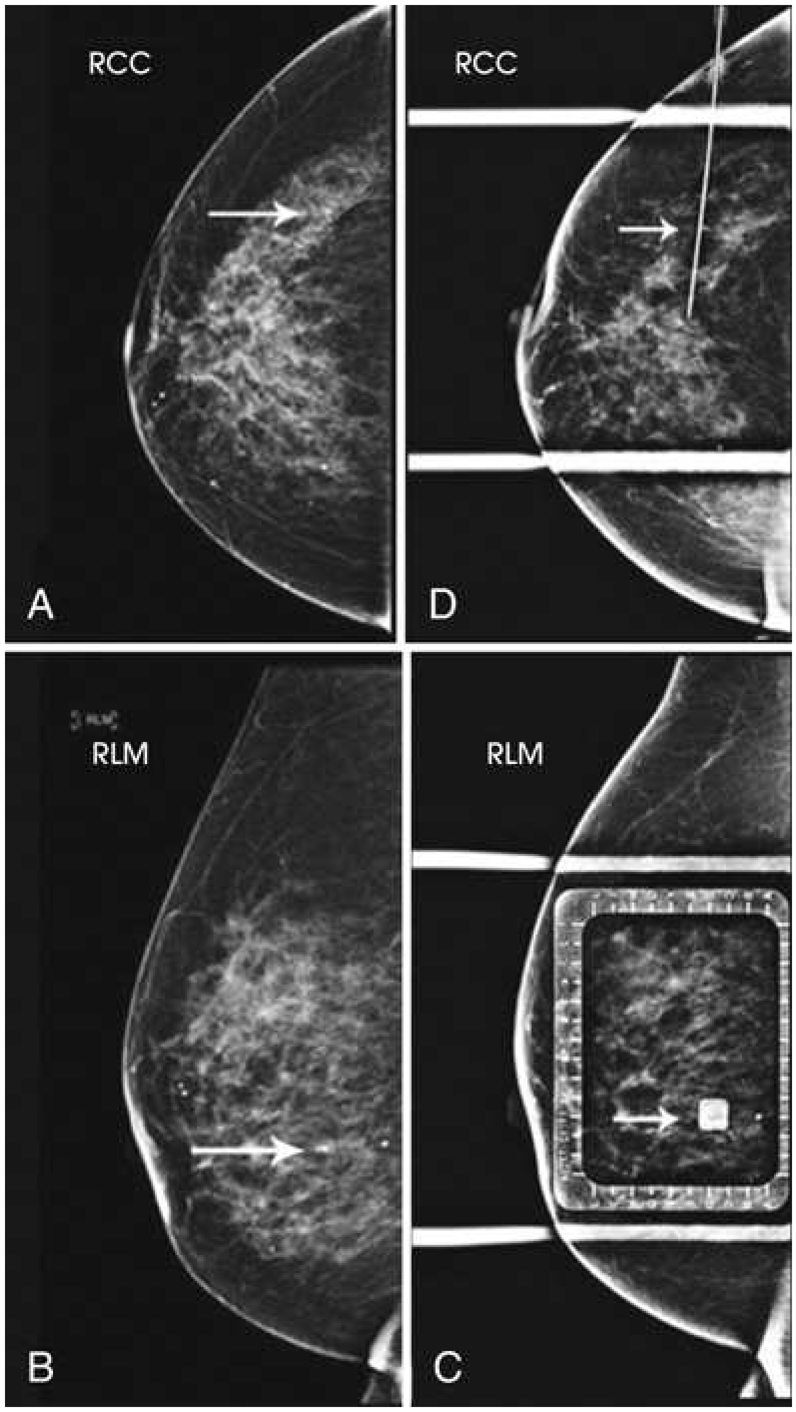


FIG. 18.79 CC and ML projections (A and B) taken to verify area to be excised. Clips from prior core biopsy *(arrows)* indicate correct area for wire localization. These images show that inserting the localization needle from the lateral aspect of the breast uses the closest route, thereby minimizing trauma and scarring from surgery. The breast is positioned in the LM projection using the alphanumeric fenestrated paddle. The needle is inserted, and an image is taken to verify that it has been inserted over the lesion (C). The arrow indicates the hub of the needle. A final image (D) is taken in the CC projection to affirm that the needle passes through the area to be biopsied.

(A) A mammogram shows a white arrow to indicate the correct area for wire localization. (B) A mammogram shows the lateral aspect of the breast. A white arrow indicates the scarring from surgery. (C) A mammogram shows a white vertical line. It is indicated by a white arrow. (D) A mammogram shows a rectangular region in which a white bo=x shaped white region is visible. It is indicated by a white arrow.

- Insert the localizing needle and guidewire into the breast perpendicular to the compression plate and parallel to the chest wall, moving the needle directly toward the underlying lesion. Advance the needle to the estimated depth of the lesion. Because the breast is compressed in the direction of the needle's insertion, it is better to pass beyond the lesion than to be short of the lesion. Do not advance the guidewire into the tissue until the depth of the lesion has been determined by the orthogonal view.
- With the needle in position, make an exposure. Be sure that the shadow of the hub of the needle projects directly over the insertion point of the needle during the exposure to precisely indicate the location of the tip. Slowly release the compression plate, leaving the needle-wire system in place. Obtain an additional projection after the C-arm apparatus has been shifted 90 degrees. (These two orthogonal radiographs are used to determine the position of the end of the needle-wire relative to the depth of the lesion.)
- If the needle is not located adjacent to or within the area of interest, reposition the needle-wire, and repeat the exposures.
- When the needle is accurately placed within the lesion, withdraw the needle, but leave the hooked guidewire in place.

- Place a gauze bandage over the breast.
- Transport the patient to surgery along with the final localization images.

Localization of dermal calcifications

For localization of nonpalpable dermal calcifications, two projections are necessary: (1) a localization projection (which depends on the area of interest) and (2) a TAN projection.

- From the routine CC and MLO projections, determine the quadrant in which the area of interest is located.
- Determine which projection would best localize the area of interest—the CC or 90-degree lateral projection.
- Turn off the automatic compression release, and inform the patient that compression will be continued while the first image is processed.
- Using a localization compression paddle, position the C-arm and breast so that the paddle opening is positioned over the quadrant of interest.
- Slowly apply compression until the breast feels taut.
- Instruct the patient to indicate if the compression becomes uncomfortable.
- When full compression is achieved, move the AEC detector to the appropriate position, and instruct the patient to stop breathing.
- Make the exposure.
- *Do not release compression.* Keep the breast compressed while the initial image is processed.

Tangential projection

- Check the initial image, and locate the area of interest using the alphanumeric identifiers.
- With the patient's breast still under compression, locate the corresponding area on the breast and place a radiopaque marker or BB over the area.
- Release breast compression, and replace the localization compression paddle with a regular or spot compression paddle.
- Rotate the C-arm apparatus until the central ray is directed TAN to the breast at the point identified by the BB marker (the "shadow" of the BB is projected onto the IR surface).
- Compress the area while ensuring that enough breast tissue covers the AEC detector area.
- Slowly apply compression until the breast feels taut.
- Instruct the patient to indicate whether the compression becomes uncomfortable.
- When full compression is achieved, move the AEC detector to the appropriate position, and instruct the patient to stop breathing.
- Make the exposure.
- Release breast compression immediately.

Central ray

- Perpendicular to the area of interest

Structures shown

This projection shows superficial lesions close to the skin surface with minimal parenchymal overlapping. It also shows skin calcifications or palpable lesions projected over subcutaneous fat (see Fig. 18.61).

Evaluation Criteria

The following should be clearly shown:

- Palpable lesion visualized over subcutaneous fat
- TAN radiopaque marker or BB marker accurately correlated with palpable lesion
- Minimal overlapping of adjacent parenchyma
- Calcification in parenchyma or skin
- Uniform tissue exposure if compression is adequate

Stereotactic Imaging and Biopsy Procedures

Stereotactic imaging, or *stereotaxis*, is a method of calculating the exact location of a specific lesion in the breast using mammographic imaging. Stereotaxis uses three-dimensional triangulation to identify the exact location of a breast lesion by taking two *stereo images* 30 degrees apart (Fig. 18.80). Once the lesion has been identified in a perpendicular *scout image*, the x-ray tube is rotated +15 degrees for the first stereo exposure, then −15 for the second. At a computer workstation, the lesion is marked in each stereo image, and a digitizer calculates *X*, *Y*, and *Z* coordinates (Fig. 18.81).

The *X*, *Y*, and *Z* coordinates allow the physician to calculate the exact location of the breast lesion in three dimensions. The *X* coordinate identifies the transverse location, right to left, or the inferior breast versus the lateral breast. The *Y* coordinate designates depth, front to back, or anterior versus posterior breast. The *Z* coordinate identifies the height of the lesion, top to bottom, or superficial to the skin versus the center of the breast (Fig. 18.82). Different stereotactic systems have different methods for calculating a *Z* value depending on the location of the center reference point. The operator should be familiar with the system in use so that accurate adjustments of the localization device can be made.

Imaging with stereotactic units is available as digital imaging, or DBT. DBT units have the capacity to image two-dimensionally, tomographically, or with a combination of images if needed. The operator can select the type of views within each case that best suits each biopsy. With DBT biopsies, one scout image is taken with tomosynthesis. The multiple tomographic images at varying angles eliminate the need for two additional stereotactic images. The operator finds the slice where the area of interest is best visualized, and that allows the computer to calculate the *Z* coordinate. DBT biopsies reduce the overall images and the time spent on the biopsy table. This is important as the breast is held in compression throughout the procedure. Any slight movement changes the *X*, *Y*, and *Z* values.

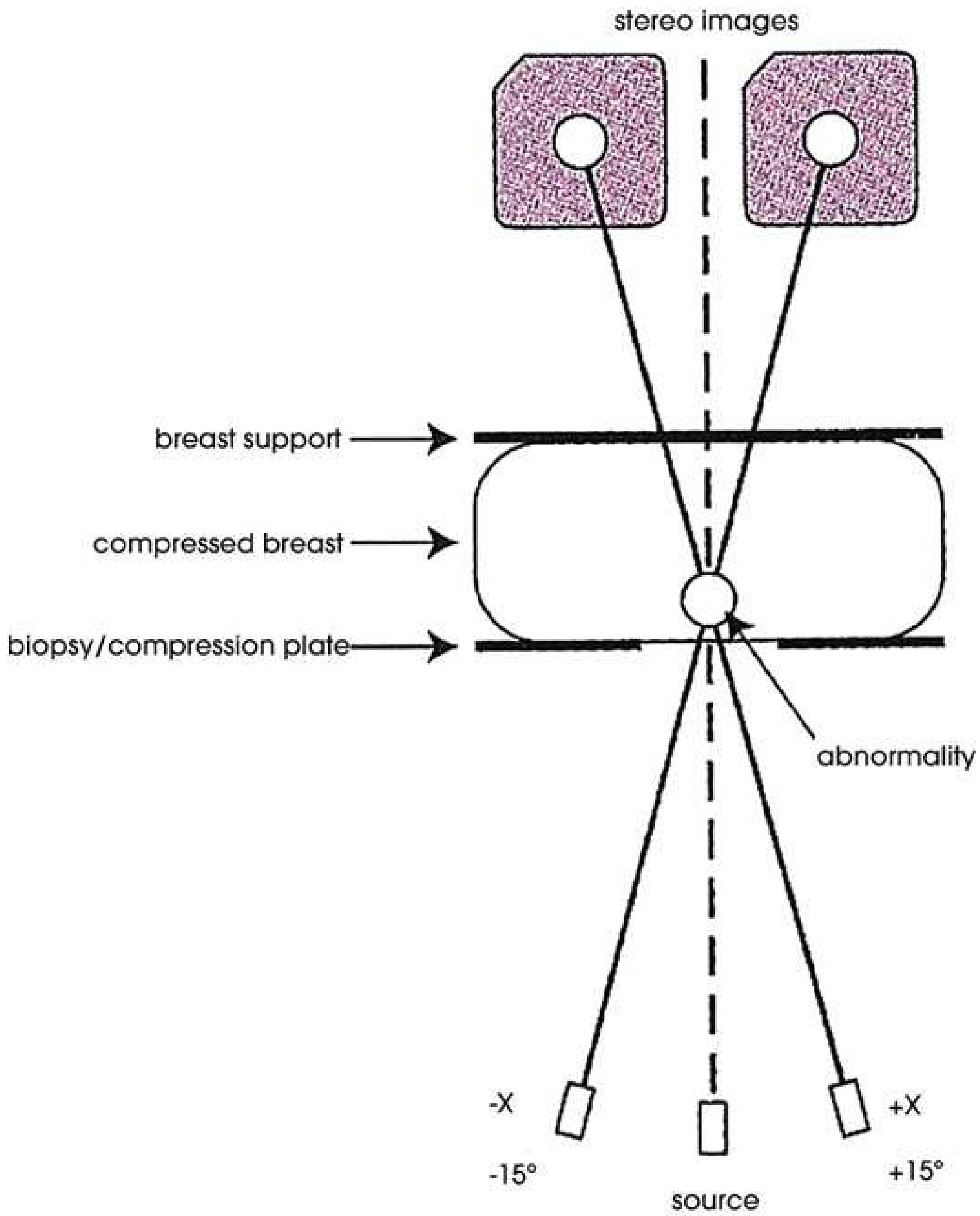


FIG. 18.80 Three-dimensional localization. Acquisition of two planar images from different source positions provides the means for 3D localization. Reprinted with permission from Willison KM: Fundamentals of stereotactic breast biopsy. In Fajardo LL, Willison KM, Pizzutello RJ, editors: *A comprehensive approach to stereotactic breast biopsy*, Cambridge, 1996, Blackwell Science, p 14.

Diagram shows the Stereotaxis uses three-dimensional triangulation to identify the exact location of a breast lesion by taking two stereo images 30 degrees apart. The x-ray is the tube is rotated plus 15 degrees for the first stereo exposure, then negative 15 for the second. The parts labeled are stereo images, breast support, compressed breast, biopsy or compression plate, and abnormality.

FIG. 18.81 Digitizer calculates and transmits *X*, *Y*, and *Z* coordinates to stage, or "brain," of biopsy system, where biopsy gun is attached. This information is used to determine placement of biopsy needle. Courtesy Hologic, Bedford, MA.

Once the lesion is localized using stereotaxis, three general methods can be used to biopsy a breast lesion. The physician's preference generally determines the procedure that is performed. The lesion can be mapped with hooked guidewire in needle-wire localization for subsequent surgery, or it can be biopsied through FNAB or LCNB. In FNAB, cells are extracted from a suspicious lesion with a thin needle. For LCNBs, core samples of tissue are obtained by means of a larger needle with a trough adjacent to its tip. Samples are then evaluated to determine the benign or malignant nature of the suspicious breast lesion. Given that LCNB using stereotactic imaging is a minor outpatient procedure and the preferred biopsy method, it is discussed in depth in this chapter.

The benefits of *stereotactic core needle biopsy* over open surgical biopsy include less pain, less scarring, shorter recovery time, less patient anxiety, and lower cost. Most women with a mammographic or clinical breast abnormality are candidates for stereotactic core needle biopsy. The only exceptions are patients who cannot cooperate for the procedure, patients with physical limitations prohibiting use of the equipment, patients who have mammographic findings at the limits of perception, and patients with lesions of potentially ambiguous histology.

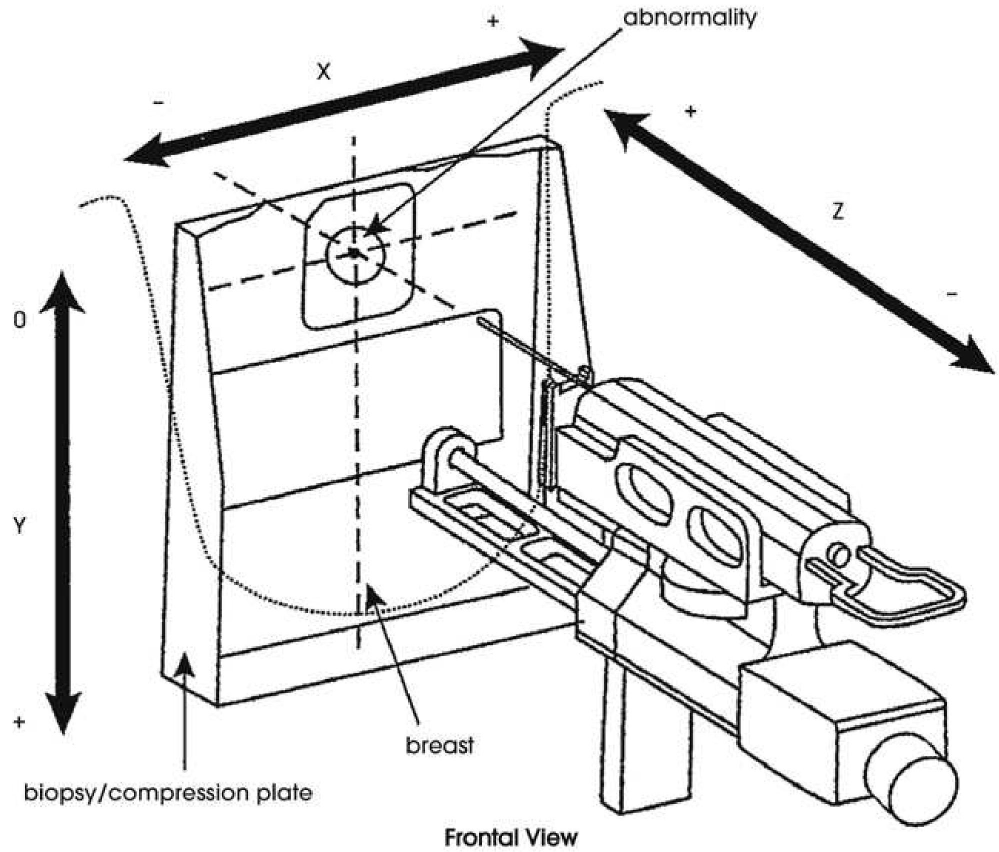


FIG. 18.82 Cartesian coordinates. A Cartesian system identifies the location of a unique point by three axes intersecting at right angles. Reprinted with permission from Willison KM: Fundamentals of stereotactic breast biopsy. In Fajardo LL, Willison KM, Pizzutello RJ, editors: A comprehensive approach to stereotactic breast biopsy, Cambridge, 1996, Blackwell Science, p 16.

Diagram shows the frontal view of the Cartesian coordinate system. A Cartesian system identifies the location of a unique point by three axes intersecting at right angles. The X coordinate identifies the transverse location, right to left, or the inferior breast versus the lateral breast. The Y coordinate designates depth, front to back, or anterior versus posterior breast. The Z coordinate identifies the height of the lesion, top to bottom, or superficial to the skin versus the center of the breast.

Stereotactic biopsies are generally quicker and easier to schedule than conventional surgery. This can expedite pathology results, so potential surgical decisions regarding lumpectomy or mastectomy can be made with minimal delay. When operating on the basis of a core biopsy diagnosis of cancer, surgeons are more likely to obtain clean (negative) lumpectomy margins with the first excision. Axillary lymph nodes, which are evaluated to ascertain metastases, are also sampled at the time of the initial surgery. A woman with a known diagnosis of breast cancer may avoid a second operation.

Two types of mammographic equipment are commercially available for stereotactic biopsy procedures: prone biopsy tables and upright add-on devices. Disadvantages of the upright add-on system include a limited working space, increased potential for patient motion, and greater potential for vasovagal reactions as the patient can watch the biopsy procedure (Fig. 18.83). The dedicated prone system allows the patient to lie face down with the breast hanging pendulous through a hole in the table (Figs. 18.84 and 18.85). This gives the technologists and doctors more work space underneath the raised table, and the procedure is out of sight of the patient. The prone table is more expensive than the add-on system, requires a larger space, and should not be used for conventional mammography. It can be more difficult to locate suspicious lesions close to the chest wall with the prone table versus the upright add-on system. But the success or failure of core needle breast biopsy ultimately depends more on the experience and interest of the diagnostic team, including a radiologist, a mammographer, a pathologist, and a specially trained nurse or technologist, than on the particulars of the system that is used.

FIG. 18.83 Upright stereotactic system attached to dedicated mammography unit. Courtesy Hologic, Bedford, MA.

FIG. 18.84 Prone stereotactic biopsy system with digital imaging. Courtesy Hologic, Bedford, MA.

Before beginning the procedure, the physician reviews the initial mammographic images to determine the best approach and projection of the breast to allow for the shortest distance from the surface of the skin to the breast lesion. The biopsy needle should be inserted through the least amount of tissue, limiting the amount of trauma to the breast. A lesion located in the lateral aspect of the UOQ is approached from the lateral aspect, whereas a lesion located in the medial and superior portion of the breast is approached from above. After the best approach to the lesion has been determined, the affected breast is positioned and compressed with an open compression paddle for a scout image to localize the breast lesion. Once the breast lesion has been localized, stereo images are taken to triangulate the lesion and measure its *X*, *Y*, and *Z* coordinates (Fig. 18.86).

FIG. 18.85 Open aperture in table for prone biopsy system allows breast to be positioned beneath table.
Courtesy Trex Medical Corp., LORAD Division, Danbury, CT.

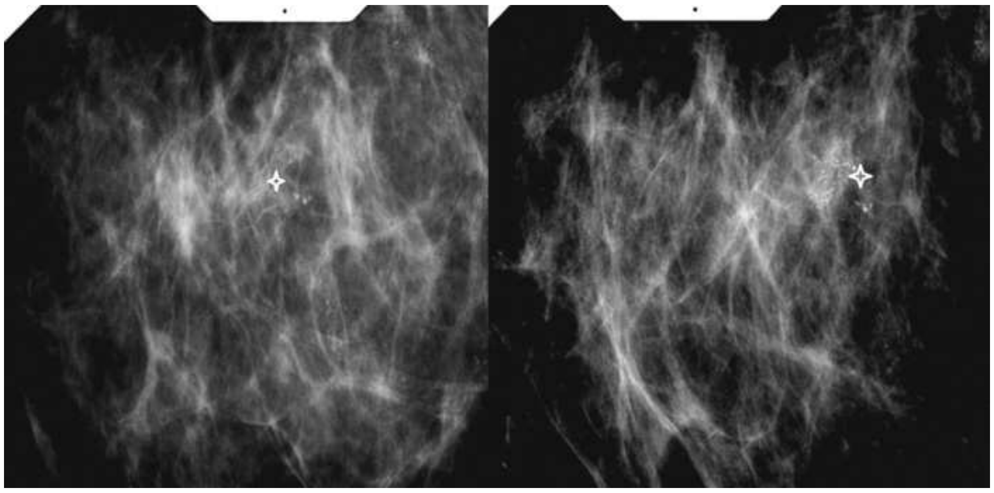


FIG. 18.86 Stereo images showing three-dimensional view of breast lesion before intervention.

At the computer workstation, the physician reads the two side-by-side stereotactic images and identifies the center of the lesion on each image. Or with a DBT biopsy, the physician uses the one scout image to locate and mark the lesion. The computer is then used to calculate the exact *X*, *Y*, and *Z* coordinates. At this point the physician must determine whether the *Z* value, or depth of the lesion, is within range for the biopsy. If the lesion is very deep within the breast with a high *Z* value, it may be appropriate to change the approach and positioning of the breast to minimize trauma. If the *Z* value is too low, the lesion is very shallow and close to the surface of the skin; there may not be enough breast tissue to cover the trough and tip of the biopsy needle. In this case, another approach would be justified. Once an appropriate *Z* value is found, the physician transmits the coordinates from the computer workstation to the biopsy table stage (Fig. 18.87).

At the biopsy table, the breast is aseptically cleansed to minimize infection, and the skin is anesthetized at the area where the biopsy needle enters. The physician can effectively manage the pain associated with the procedure by anesthetizing the tissue within the breast at the biopsy site. The biopsy needle is then placed on the *stage*, which holds it in place and interprets the coordinates sent by the computer. Next, the tip of the needle must be *zeroed* by aligning it with the center reference point. The needle is then moved into position within the opening of the compression plate based on the appropriate *X* and *Y* values sent from the workstation. A small incision is made with a scalpel to facilitate entry of the needle into the breast and proper positioning of the *Z* axis. Before the needle enters the lesion at the exact *Z* axis, the needle is "dialed back," and "pre-fire" images are obtained with stereotaxis to ensure proper positioning (Fig. 18.88).

After the pre-fire images verify the needle's tip adjacent to the lesion, the needle is fired into the lesion quickly to penetrate the tissue without pushing it deeper within the breast. With vacuum-assisted core biopsies, the probe is fired with the use of air pressure. Or the physician may use a spring-loaded biopsy device to power the needle back and forth through the target. Once the first pass is made, stereotactic "post-fire" images confirm correct needle placement. These images determine the course of subsequent passes. Redigitization (use of a digitizer to repeat the steps needed to calculate the new triangulation coordinates) can be performed to obtain additional samples. Alternatively, the physician can estimate where to move the biopsy needle based on the initial needle location within the breast.

After post-fire images are acquired, vacuum-assisted biopsies gently aspirate the tissue through a trough in a rotating cutter into the probe's aperture and collected in a basket. With the probe in the center of the lesion, the cutter can be spun in a circle to move the trough and collect samples from every direction without multiple insertions. When the biopsy is complete, the cutter is removed, and a radiopaque clip can be deployed through the probe and into the biopsy site to mark the area for future reference.

FIG. 18.87 Stage of biopsy system supports biopsy gun. X, Y, and Z coordinates are displayed.

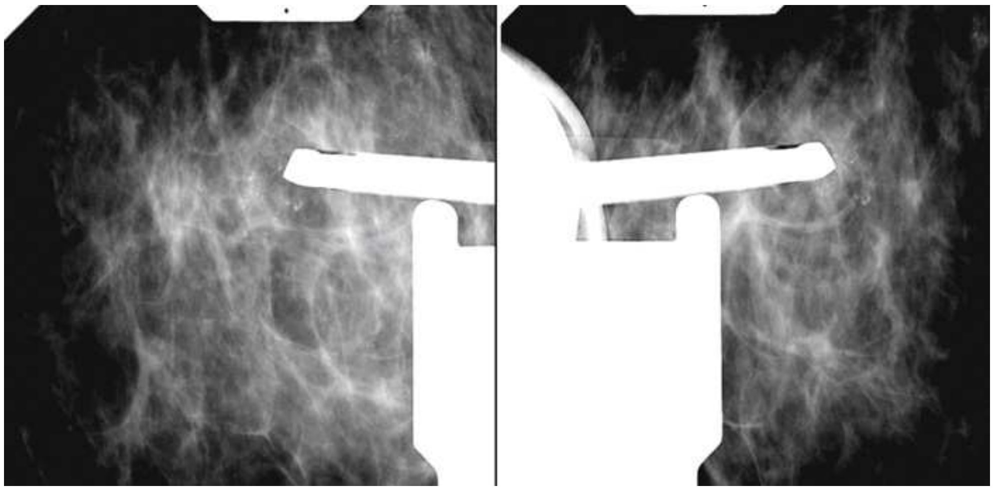


FIG. 18.88 Pre-fire stereo images showing placement of the biopsy needle adjacent to calcium to be biopsied.

If a multi-fire, spring-loaded biopsy device is used, the sheath, or needle cover, slides over the trough of the needle. The sheath cuts the tissue sample within the trough and holds the sample in place while the needle is removed from the breast. The sheath is then pulled back exposing the tissue for collection. Subsequent passes can then be made for additional sampling. This method requires the clip marker to be placed within the breast separately.

Radiopaque clips are placed following most LCNBs. The titanium clip serves as a marker, allowing radiologists to know the location of past biopsies for subsequent mammograms or for surgical guidance. Immediately after the clip is seeded, "post-clip" images are obtained to ensure proper deployment and placement (Fig. 18.89). After this is done, the patient is released from compression and is given follow-up care.

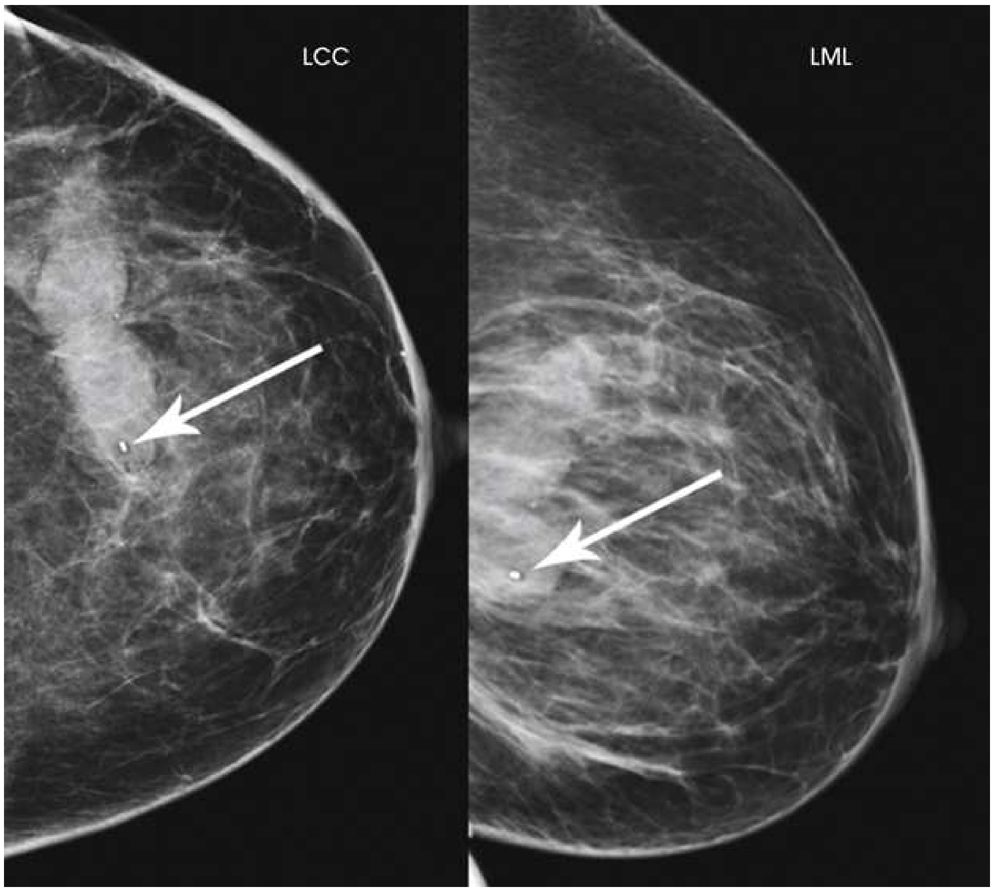


FIG. 18.89 Post-biopsy images in standard CC and lateral projections to document accuracy of biopsy site and marker clip placement.

The mammogram on the left shows a segment white region of the left side. It is indicated by a white arrow. The mammogram on the right shows a white hazy region on the left side. It is indicated by a white arrow.

With each technique, a minimum of 5 to a maximum of 20 tissue samples are obtained to ensure proper sampling of the abnormality. For vacuum-assisted biopsies, a larger amount of tissue sample is obtained; this has been reported to improve accuracy in diagnosing atypical ductal hyperplasia (ADH) and DCIS lesions. [42] If the abnormality contains radiopaque calcium, the radiologist may choose to x-ray the sample to guarantee the presence of calcium for accurate diagnosis. Following this image, the tissue samples are transferred into a formalin specimen container for transportation to the pathology laboratory.

After the LCNB procedure is completed, the breast is cleaned and bandaged using sterile technique. Compression to the biopsy site is necessary to prevent excessive bleeding, and a cold compress is applied to minimize discomfort and swelling of related tissues. The patient should limit strenuous activity and keep the affected breast immobilized for at least 8 hours to prevent future bleeding or excessive bruising. The patient may be asked to return within 24 to 48 hours, so the breast can be examined to ensure that no bleeding or infection has occurred. The physician who performed the biopsy discusses the biopsy results and subsequent treatment options, if applicable, with the patient.

Breast Specimen Radiography

When open surgical biopsy is performed, the suspected lesion must be contained in its entirety in the tissue removed during the biopsy. Very small lesions that are characterized by tissue irregularity or microcalcifications on a mammographic image and that are nonpalpable in the excised specimen may be undetectable on visual inspection; a radiographic image of the biopsied tissue may be necessary to determine that the entire lesion has been removed. Compression of the specimen is necessary to identify lesions, especially lesions that do not contain calcifications. Magnification imaging is used to better visualize microcalcifications. Specimen radiography is often performed as an immediate postexcision procedure while the patient is still under anesthesia. Speed is essential.

The procedure for handling the specimen must be established before the procedure is started. Cooperation among radiologist, mammographer, surgeon, and pathologist is imperative. Together, a system of identifying the orientation of the tissue sample to the patient's breast (anterior, posterior, medial, or lateral aspect of the sample) can be applied to help the clinician confirm that the lesion has been completely removed. [43]

The specimen may be imaged using the magnification technique, with or without compression, as ordained by the policy of the facility. As patient radiation exposure and patient motion are no longer factors, imaging for high resolution, regardless of dose, is appropriate. Exposure factors depend on the thickness of the specimen and the imaging modality that is used (Fig. 18.90). Alternatively, radiographic equipment is manufactured specifically for imaging tissue specimens. These units are self-contained, are often portable, and allow specimens to be imaged directly in the operating suite. Digital technology allows the image to be seen by the surgeon and the radiologist and the pathologist in remote locations, almost immediately and simultaneously. [44, 45]

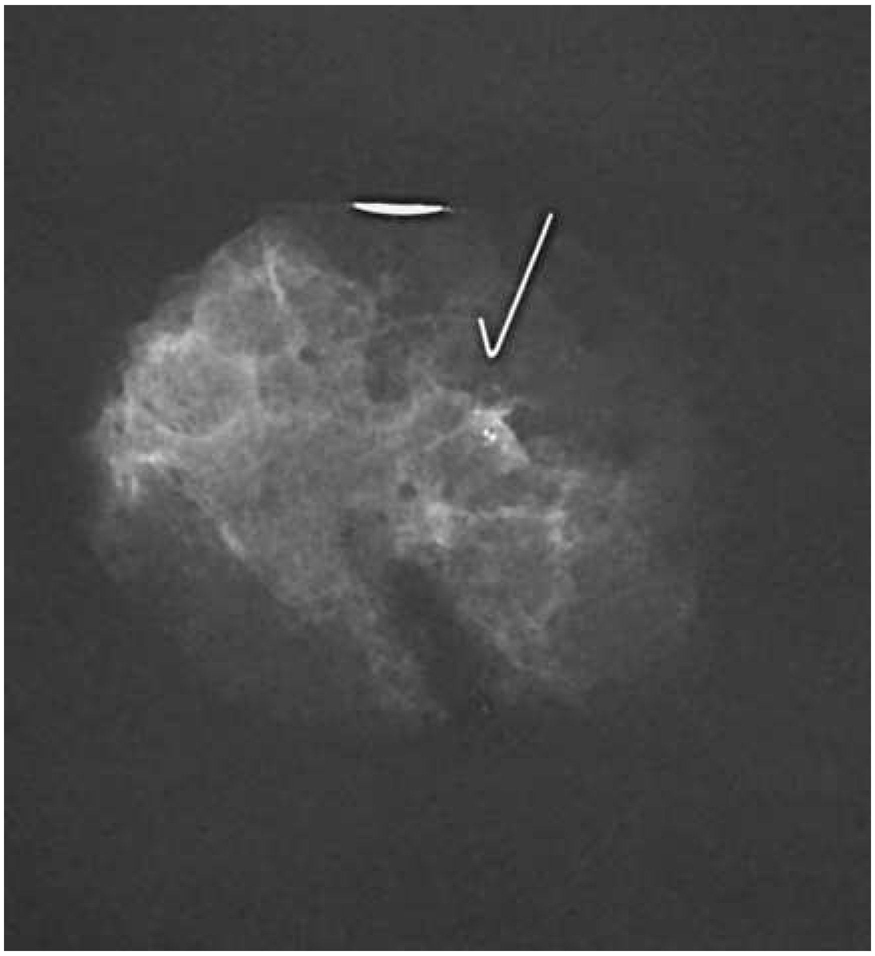


FIG. 18.90 Radiograph of surgical specimen containing suspicious microcalcifications.

The pathologist often uses the specimen radiograph to precisely locate the area of concern, so a copy of the image should be sent with the specimen. The next step is to match the actual specimen to the specimen radiograph before the specimen is dissected. Marking the area of concern within the specimen by placing a radiopaque object, such as a 1- or 2-inch (2.5- or 5-cm) needle, directly at the area of concern helps the pathologist locate the abnormality more accurately.

Specimens of tissue from LCNBs are frequently radiographed, particularly when the biopsy is performed for calcifications. Radiographing tissue specimens can confirm that the area of interest has been sampled and is included within the tissue sent for examination by the pathologist (Fig. 18.91).

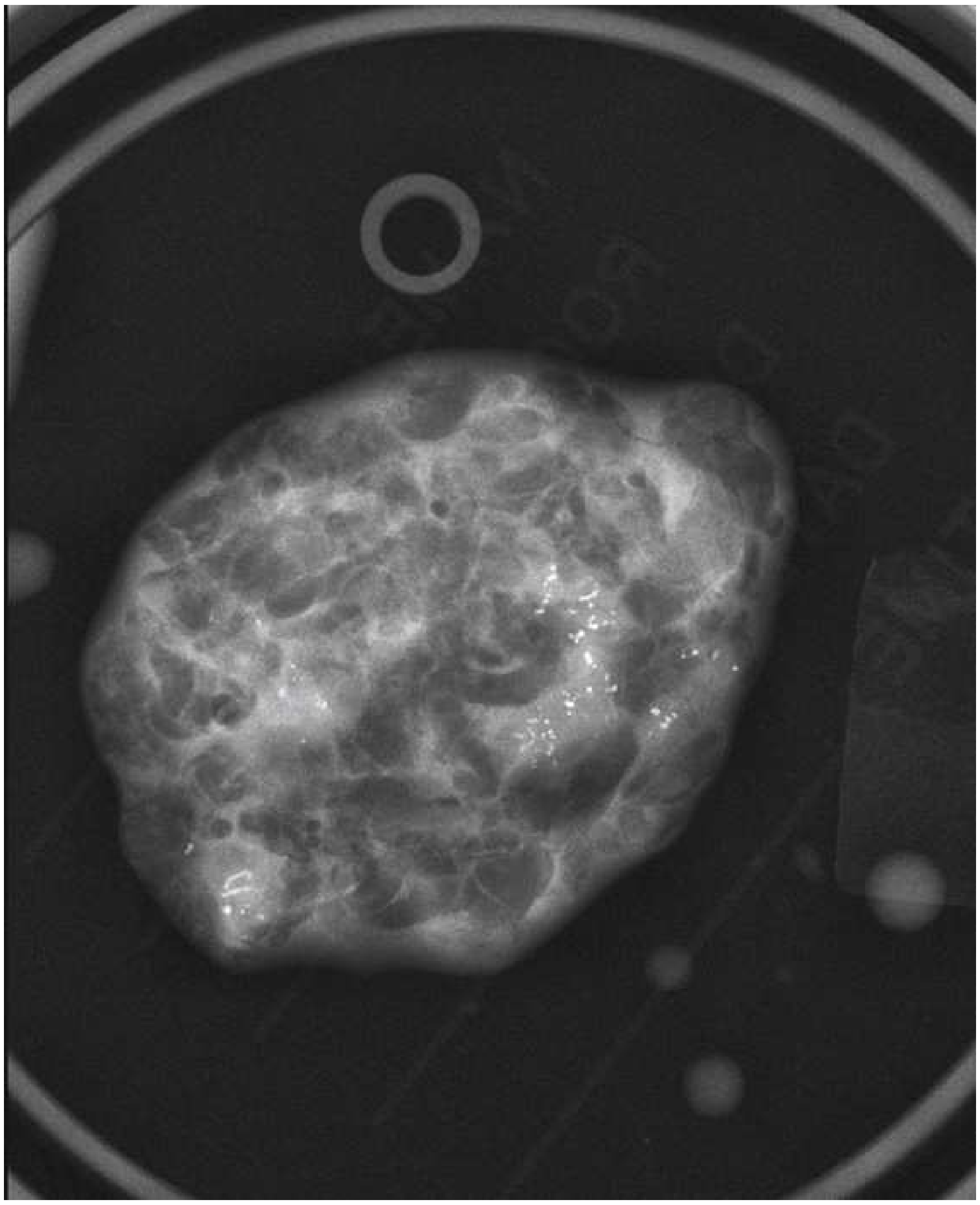


FIG. 18.91 Magnified radiograph of specimen obtained from core biopsy shown in Figs. 18.86–18.89. Note calcium indicating successful biopsy.

Breast Magnetic Resonance Imaging

Breast MRI has proved most useful in patients with proven breast cancer or at high risk for breast cancer, to assess for multifocal or multicentric disease, chest wall involvement, chemotherapy response, or tumor recurrence, or to identify the primary site in patients with occult breast disease. [46]

Indications

Assessment of extent of disease and residual disease

MRI can be helpful for patients who have had a lumpectomy and have positive margins and no evidence of residual disease on conventional imaging (mammography, ultrasound). Postoperative mammography can help detect residual calcifications but is limited for residual mass. MRI is very sensitive for detection of residual mass and identifies other potentially suspicious sites seen only on MRI.

Assessment of tumor recurrence

Assessment of tumor recurrence on MRI can be very complicated because scars can become enhanced for 1 to 2 years after surgery. Suggestion of recurrence can be made by MRI, yet the cost of the procedure should be weighed against a less expensive needle biopsy of the area.

Occult primary breast cancer

Patients with axillary metastases suspicious for primary breast cancer with a negative physical examination, mammogram, and ultrasound are good candidates for MRI because of its high sensitivity for invasive cancers. MRI has been shown to detect 90% to 100% of cancers if tumor is present in the breast. If the primary site is detected, the patient may be spared a mastectomy, and MRI can influence patient surgical management.

Neoadjuvant chemotherapy response

In patients with advanced breast cancer, MRI may be used to predict earlier which patients are responding to chemotherapy. Mammography and physical examination can sometimes be limited by fibrosis. Studies suggest that MRI may be better for assessing patients' response to treatment. [47–49]

High-risk screening

Breast MRI is recommended as an annual screening examination for patients at high risk for developing breast cancer. [18] These include women

1. Who have a first-degree relative (parent, sibling, child) with a *BRCA1* or *BRCA2* mutation, even if they have yet to be tested themselves.
2. Whose lifetime risk of breast cancer has been scored at 20% to 25% or greater, based on one of several accepted risk assessment tools that look at family history and other factors.
3. Who have received radiation to the chest between 10 and 30 years of age.
4. Who have Li-Fraumeni syndrome, Cowden syndrome, or Bannayan-Riley-Ruvalcaba syndrome, or who may have one of these syndromes based on history in a first-degree relative.

A study published in the *New England Journal of Medicine* concluded that MRI is "more sensitive than mammography in detecting tumors in women with an inherited susceptibility of breast cancer." [50]

Breast MRI is recommended for women at high risk to be used as an adjunct to mammography. The most beneficial method for screening is to schedule 6-month intervals alternating MRI with mammography. Women who are found to have MRI-detected foci suspicious of cancer need to have these verified by biopsy. Often these areas are reexamined with mammography and directed ultrasound for potential biopsy. If these lesions are not found by conventional imaging, confirmation with MRI-guided biopsy would be necessary before the patient is committed to potential lumpectomy or mastectomy or both.

Thermography and Diaphanography

Beginning in the 1950s, thermography and diaphanography were actively investigated in the hope that breast cancer and other abnormalities could be diagnosed using nonionizing forms of radiation. These two diagnostic tools are seldom used today.

Thermography is the photographic recording of the infrared radiation emanating from a patient's body surface. The resulting thermogram shows areas of increased temperature, with a temperature increase often suggesting increased metabolism. (More complete information on this technique is provided in the fourth through eighth editions of this atlas.)

Diaphanography is an examination in which a body part is transilluminated using selected light wavelengths and special imaging equipment. With this technique, the interior of the breast is inspected using light directed through its exterior wall. The light exiting the patient's body is recorded and interpreted. Rapid advances in mammography have essentially eliminated the use of this technique for evaluating breast disease. (More complete information on diaphanography is given in this chapter in the fourth through eighth editions of this atlas.)

Conclusion

Radiographic examination of the breast is a technically demanding procedure. Success depends in large part on the skills of the mammographer—more so than in most other areas of radiology. In addition to skill, the mammographer must have a strong desire to perform high-quality mammography and must be willing to work with the patient to allay qualms and to obtain cooperation. In the course of taking the patient's history and physically assessing and radiographing the breasts, the mammographer may be asked questions about breast disease, BSE, screening guidelines, and breast radiography that the patient has been reluctant to ask other health care professionals. The knowledge, skill, and attitude of the mammographer may be lifesaving for the patient. Although most patients do not have significant breast disease when first examined, statistics show that approximately 12% of patients develop breast cancer at some time during their lifetime. An early positive mammography encounter may make the patient more willing to undergo mammography in the future. When properly performed, breast radiography is safe, and presently, it offers the best hope for significantly reducing the mortality of breast cancer.

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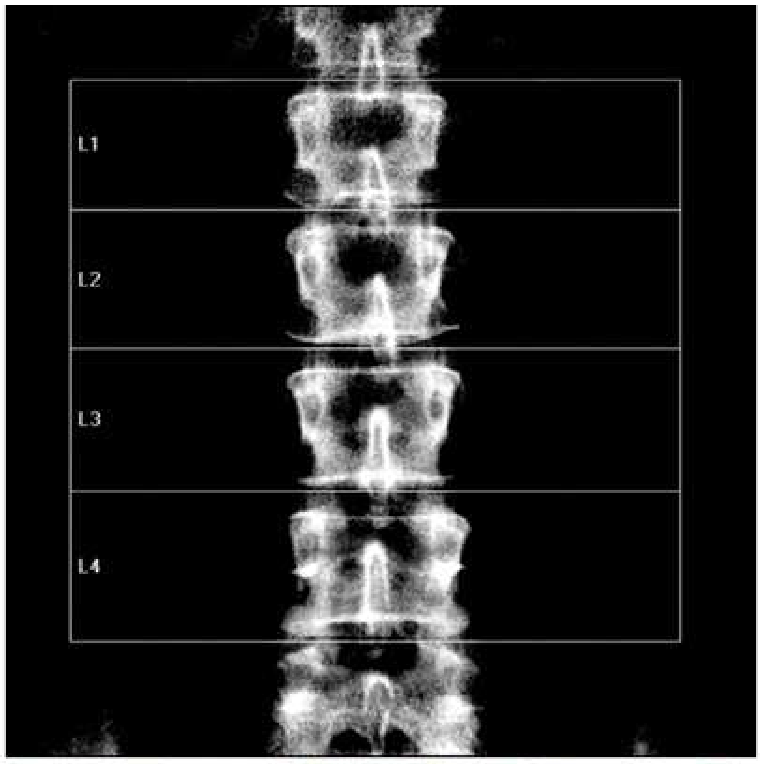
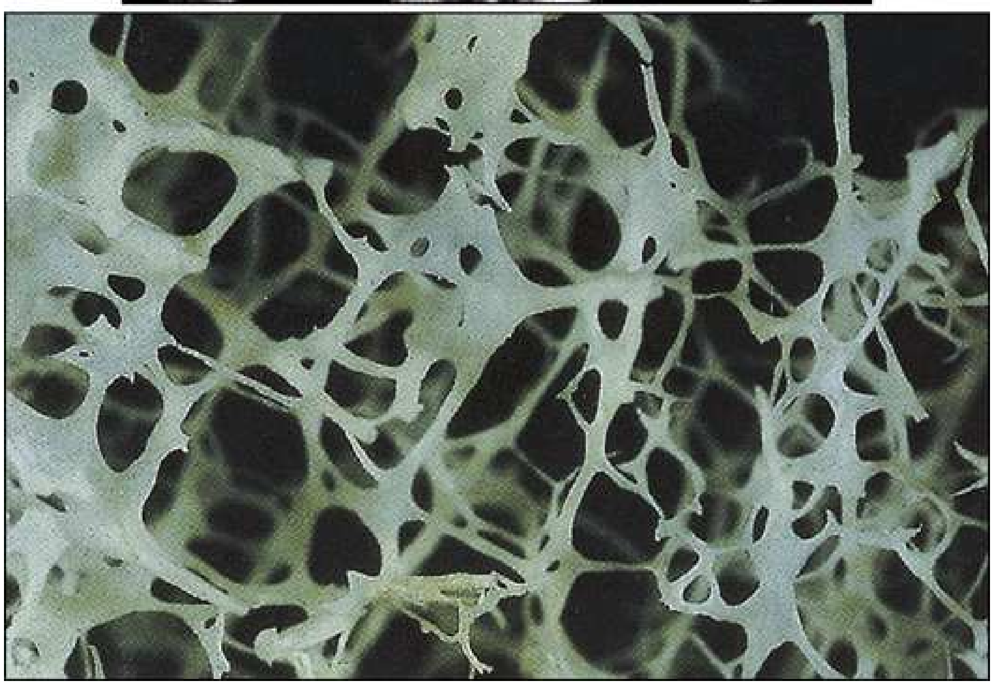
19: Bone Densitometry





Sharon R. Wartenbee

OUTLINE

Principles of Bone Densitometry

Bone densitometry [a] is a general term that encompasses the art and science of measuring the *bone mineral content* (BMC) and *bone mineral density* (BMD) of specific skeletal sites or the whole body. The bone measurement values are used to assess bone strength, diagnose diseases associated with low bone density (especially *osteoporosis*), monitor the effects of therapy for such diseases, and predict risk of future fractures.

Several techniques are available to perform bone densitometry using ionizing radiation or ultrasound. The most versatile and widely used is *dual energy x-ray absorptiometry* (DXA) (Fig. 19.1). [1] This procedure has the advantages of low radiation dose, wide availability, ease of use, short scan time, high-resolution images, good *precision,* and stable calibration. DXA is the focus of this chapter, but summaries of other procedures are also presented.

FIG. 19.1 (A) Hologic model, Horizon. (B) GE Lunar model, Prodigy. (C) Norland model, XR-46. A, Courtesy Hologic, Inc, Bedford, MA; B, courtesy GE Lunar Corp, Madison, WI; C, courtesy Norland/Swissray Inc, Ft. Atkinson, WI.

(A) shows a machine with a blue colored bed and a stand on the side. (B) shows a black bed with curved ends on either side. A vertical stand is on the side. (C) shows a bed and a vertical stand with a horizontal end. A computer screen is on a table on the side.

Dual Energy X-Ray Absorptiometry and Conventional Radiography

The differences between DXA and conventional radiography are as follows:

1. DXA can be conceptualized as a *subtraction technique.* To quantitate BMD, it is necessary to eliminate the contributions of soft tissue and measure the x-ray attenuation of bone alone. This is achieved by scanning two x-rays at different photon energies (hence the term *dual energy x-ray*) and mathematically manipulating the recorded signal to take advantage of the differing attenuation properties of soft tissue and bone at the two energies. The density of the isolated bone is calculated on the basis of the principle that dense, more mineralized bone attenuates (absorbs) more x-ray. Adequate amounts of artifact-free soft tissue are essential to help ensure the reliability of the bone density results.
2. The bone density results are computed by proprietary software from the x-ray attenuation pattern striking the detector, not from the scan image. Scanned images are only for the purpose of confirming correct positioning of the patient and correct placement of the *regions of interest* (ROI). The images may not be used for diagnosis, and any apparent medical conditions must be followed up by appropriate diagnostic tests.
3. In conventional radiography, x-ray machines from different manufacturers are operated in essentially the same manner and produce identical images. This is not the case with DXA. Three DXA manufacturers are in the United States (see Fig. 19.1), and technologists must be educated about the specific scanner model in their facility. The numeric bone density results cannot be compared among manufacturers. This chapter presents general scan positioning and analysis information, but the manufacturers' specific procedures must be used when actual scans are performed and analyzed.

4. The effective radiation dose for DXA is considerably lower than the effective radiation dose for conventional radiography. The specific personnel requirements vary among states and countries. All bone density technologists should be instructed in core competencies, including radiation protection, patient care, history taking, basic computer operations, knowledge of scanner quality control, patient positioning, scan acquisition and analysis, and proper record keeping and documentation.

History of Bone Densitometry

Osteoporosis was an undetected and overlooked disease until the 1920s, when the advent of x-ray film methods allowed the detection of markedly decreased bone densities. The first publications indicating an interest in *bone mass* quantification methods appeared in the 1930s, and much of the pioneering work was performed in the field of dentistry. *Radiographic absorptiometry* involved taking a radiograph of bone with a known standard, placing it in the ROI, and optically comparing the densities.

Radiogrammetry was introduced in the 1960s, partly in response to the measurements of bone loss performed in astronauts. As bone loss progresses, the thickness of the outer shell of phalanges and metacarpals decreases while the inner cavity enlarges. Indices of bone loss are established by measuring and comparing the inner and outer diameters.

In the late 1970s the emerging technique of computed tomography (CT) (see Chapter 25) was adapted, through the use of specialized software and reference phantoms, enabling quantitative measurement of the central area of the vertebral body, where early bone loss occurs. This technique, called *quantitative computed tomography* (QCT), is still used.

The first scanners dedicated to bone densitometry appeared in the 1970s and early 1980s. *Single photon absorptiometry* (SPA) (Fig. 19.2) and *dual photon absorptiometry* (DPA) are based on physical principles similar to those for DXA. The SPA approach was not a subtraction technique but relied on a water bath or other medium to eliminate the effects of soft tissue. SPA found application only in the peripheral skeleton. DPA used photons of two energies and was used to assess sites in the central skeleton (lumbar spine and proximal femur). The radiation source was a highly collimated beam from a radioisotope (iodine-125 [^{125}I] for SPA and gadolinium-153 [^{153}Gd] for DPA). The intensity of the attenuated beam was measured by a collimated *scintillation counter,* and the bone mineral was quantified.

The first commercial DXA scanner was introduced in 1987. In this scanner, the expensive, rare, and short-lived radioisotope source was replaced with an x-ray tube. Improvements over time have included the choice of *pencil-beam* or *array-beam collimation*; a rotating C-arm to allow supine lateral spine imaging; shorter scan time; improved detection of low bone density; improved image quality; and enhanced computer power, multimedia, and networking capabilities.

Since the late 1990s, renewed attention has been given to smaller, more portable, less complex techniques for measuring the peripheral skeleton. This trend has been driven by the introduction of new therapies for osteoporosis and the resultant need for simple, inexpensive screening tests to identify persons with osteoporosis who are at increased risk for fracture. However, DXA of the hip and spine is still the most widely accepted method for measuring bone density, and it remains a superior procedure for monitoring the effects of therapy.

FIG. 19.2 SPA wrist scan being performed on a Lunar model, SP2. This form of bone densitometry is obsolete. Courtesy GE Lunar Corp, Madison, WI.

Bone Biology and Remodeling

The skeleton serves the following purposes:

- Supports the body and protects vital organs
- Manufactures red blood cells
- Stores minerals that are necessary for life, including calcium and phosphate

The two basic types of bone are *cortical* (or compact) and *trabecular* (or cancellous). Cortical bone forms the dense, compact outer shell of all bones, and the shafts of the long bones. It supports weight, resists bending and twisting, and accounts for approximately 80% of the skeletal mass. Trabecular bone is the delicate, latticework structure within bones that adds strength without excessive weight. It supports compressive loading in the spine, hip, and calcaneus, and it is also found at the ends of long bones, such as the distal radius. The relative amounts of trabecular and cortical bone differ by bone densitometric technique used and anatomic site measured (Table 19.1).

Bone is constantly going through a remodeling process in which old bone is replaced with new bone. With this *bone remodeling* process (Fig. 19.3), the equivalent of a new skeleton is formed approximately every 7 years. Bone-destroying cells called *osteoclasts* break down and remove old bone, leaving pits. This part of the process is called *resorption,* whereas bone-building cells called *osteoblasts* fill the pits with new bone. This process is called *formation*. The comparative rates of resorption and formation determine whether bone mass increases (more formation than resorption), remains stable (equal resorption and formation), or decreases (more resorption than formation).

Osteoclasts and osteoblasts operate as a bone-remodeling unit. A properly functioning bone remodeling cycle is a tightly coupled physiologic process in which resorption equals formation, and the net bone mass is maintained. The length of the resorption process is approximately 1 week compared with a longer formation process of approximately 3 months. At any point in time, millions of remodeling sites within the body are in different phases of the remodeling cycle or at rest.

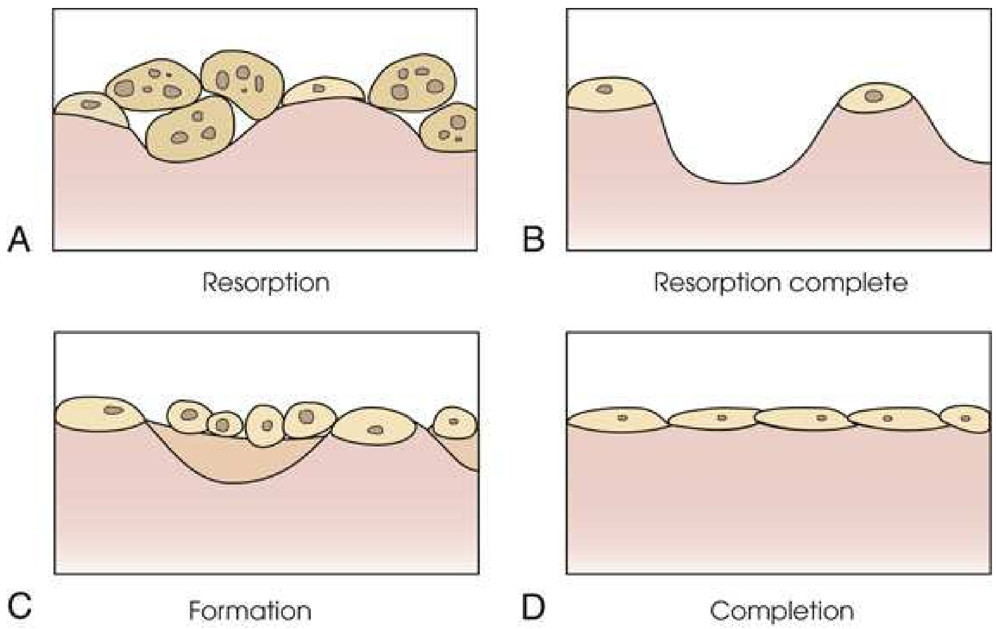


FIG. 19.3 Bone remodeling process. (A) Osteoclasts break down bone in the process of resorption. (B) Pits in the bone. (C) Osteoblasts form new bone. (D) With equal amounts of resorption and formation, the bone mass is stable. From National Osteoporosis Foundation. *Boning up on osteoporosis*. Washington, DC: National Osteoporosis Foundation; 1997.

(A) shows few oval shaped yellow colored osteoclasts on a surface with many pits. There are a few circular spots on it. (B) shows two oval shaped yellow colored osteoclasts on top of the elevated portion of the pits. (C) shows the pits filled with a brown colored substance. The oval shaped yellow colored osteoclasts are on top of it. (D) shows a few oval shaped yellow colored osteoclasts lined up without a gap on the surface.

TABLE 19.1

Region of interest	Trabecular bone (%)	Cortical bone (%)	Preferred measurement site
PA spine (by DXA)	66	34	Cushing disease, corticosteroid use
PA spine (by QCT)	100		
Femoral neck	25	75	Type II osteoporosis
			Second choice for hyperparathyroidism
Trochanteric region	50	50	
Calcaneus	95	5	
33% radius	1	99	First choice for hyperparathyroidism
Ultradistal radius	66	34	
Phalanges	40	60	
Whole body	20	80	Pediatrics

Data from Bonnick SL. *Bone Densitometry in Clinical Practice: Application and Interpretation*. Totowa, NJ: Humana Press; 1998.

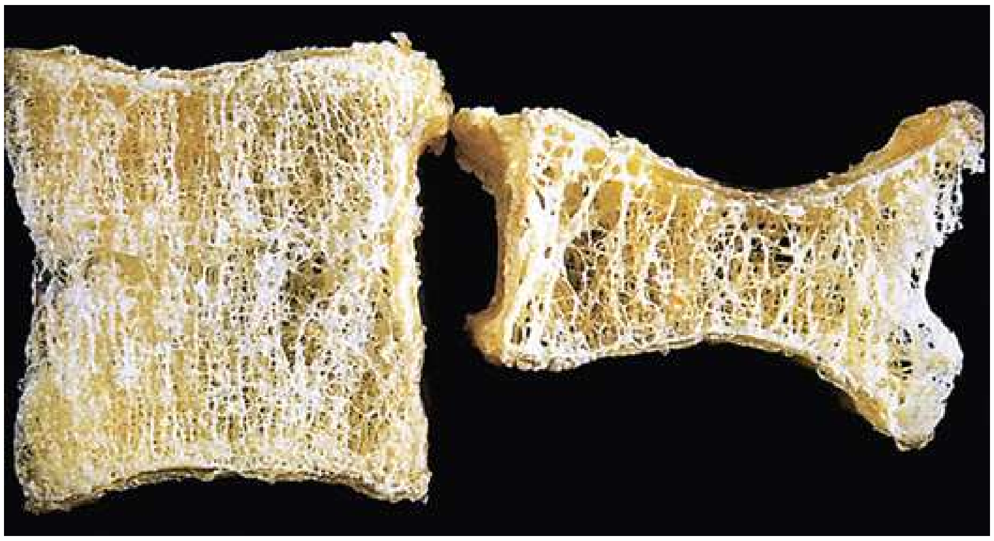


FIG. 19.4 Osteoporotic vertebral body *(right)* shortened by compression fractures, compared with a normal vertebral body. The osteoporotic vertebra exhibits a characteristic loss of horizontal trabeculae and thickened vertical trabeculae. From Kumar V, Abbas AK, Aster JC, Cotran RS, Robbins SL. *Robbins and Cotran pathologic basis of disease*. 8th ed. Philadelphia: Saunders/Elsevier; 2010.

When the cycle becomes uncoupled, the result is a net loss of bone mass. Some reasons for uncoupling include enhanced osteoclastic recruitment, impaired osteoblastic activity, and increased number of cycles which results in a shorter time for each cycle. The increased number of cycles favors the shorter resorption phase over the longer formation phase.

Bone mass increases in youths until *peak bone mass* is reached at approximately 20 to 30 years of age. This is followed by a stable period in middle age. A period of decreasing bone mass starts at approximately age 50 in women and approximately age 65 in men. The decrease in bone mass becomes pronounced in women at menopause because of the loss of bone-preserving estrogen. If the peak bone mass is low or the resorption rate is excessive, or both, at menopause, osteoporosis may result (Fig. 19.4).

Osteoporosis

Osteoporosis is a disease characterized by low bone mass and structural deterioration of bone tissue. This decrease in bone mass and degradation of bone architecture may not support the mechanical stress and loading of normal activity. As a result, the bones are at increased risk for *fragility fractures.* In 2014, the National Osteoporosis Foundation (NOF) released an estimate that stated 54 million adults over the age of 50 were affected by osteoporosis or low bone mass. With current trends, the NOF expects this number to grow to 71.2 million by the year 2030. Persons with osteoporosis may experience decreased life quality due to the pain, deformity, and disability of fragility fractures. An increased risk of morbidity and mortality exists, especially from hip fractures.

Many risk factors for osteoporosis have been identified and studied. The following are considered primary risk factors:

- Female gender
- Increased age
- Estrogen deficiency
- Caucasian race
- Low body weight (<127 lb [<58 kg]), low body mass index (BMI) (weight in kilograms divided by height in meters squared), or both
- Family history of osteoporosis or fracture
- History of prior fracture as an adult
- Smoking tobacco

Osteoporosis is often overlooked in older men because it is considered a woman's disease. However, the NOF found that 2 million American men have osteoporosis, and another 12 million are at risk. Of Americans diagnosed with osteoporosis, 20% are men.

The exact cause of osteoporosis is unknown, but it is clearly a multifactorial disorder. Major contributors are genetics, metabolic factors regulating internal calcium equilibrium, lifestyle, aging, and menopause. Peak bone mass attained in young adulthood, coupled with the rate of bone loss in older age, will determine whether an individual's bone mass becomes low enough to be diagnosed as osteoporosis. Genetic factors are estimated to account for 70% of the peak bone mass attained, which is why family history is an important risk factor for osteoporosis and fracture. Calcium equilibrium is maintained by a complex mechanism involving hormones (parathyroid, calcitonin, and vitamin D) controlling key ions (calcium, magnesium, and phosphate) within target tissues (blood, intestine, and bone). Calcium and phosphate enter the blood from the intestine and are stored in bone. The process also occurs in reverse, moving calcium out of the bones for other uses within the body. Nutritional and lifestyle factors can upset the balance and cause too much calcium to move out of bone. In the course of normal aging, the loss of estrogen at menopause tends to increase the rate of bone turnover, which increases the number of remodeling cycles and shortens the length of each cycle. Enough time is allowed for the shorter resorption process, but the longer formation process is cut short. Various combinations of these factors can result in a net loss of bone mass and increase the risk of osteoporosis and fracture.

Two points are important to note about osteoporosis. First, an older person with a normal bone loss rate may still develop osteoporosis if their peak bone mass is low. Second, a common misconception is that proper exercise and diet at menopause prevents bone loss associated with a decrease in estrogen. Persons concerned about their risk of osteoporosis should consult their physician.

Osteoporosis can be classified as primary or secondary. A DXA scan result does not automatically lead to a diagnosis of primary osteoporosis. Secondary causes of systemic or localized disturbances in bone mass must be ruled out before a final diagnosis can be made. Proper choice of treatment should be based on the type of osteoporosis and the underlying cause, if secondary osteoporosis is present (see Table 19.1).

Primary osteoporosis can be *type I* (postmenopausal), *type II* (senile or age related), or both. Type I osteoporosis is caused by bone resorption exceeding bone formation owing to estrogen deprivation in women. Type II osteoporosis occurs in aging men and women and results from a decreased ability to build bone.

Secondary osteoporosis is osteoporosis caused by a heterogeneous group of skeletal disorders resulting in an imbalance of bone turnover. Disorder categories include genetic, endocrine and metabolic, hypogonadal, connective tissue, nutritional and gastrointestinal, hematologic, malignancy, and use of certain prescription drugs. Common causes of secondary osteoporosis include the following:

- Hyperparathyroidism
- Gonadal insufficiency (including estrogen deficiency in women and hypogonadism in men)
- Osteomalacia (rickets in children)
- Rheumatoid arthritis
- Anorexia nervosa
- Gastrectomy
- Celiac disease (hypersensitivity to gluten [wheat protein])
- Multiple myeloma
- Use of corticosteroids, heparin, anticonvulsants, or excessive thyroid hormone treatment

Several prescription medications arrest bone loss and may increase bone mass, including traditional estrogen or hormone replacement therapies, bisphosphonates, selective estrogen receptor modulators, parathyroid hormone, receptor activator of nuclear factor kappa-B ligand (RANKL) inhibitors, and calcitonin (Table 19.2). The availability of therapies beyond the traditional estrogens has led to the widespread use of DXA to diagnose osteoporosis.

Laboratory tests for *biochemical markers* of bone turnover may be used in conjunction with DXA to determine the need for or the effectiveness of the therapy. Problems of poor precision and individual variability have limited their use. Some markers of bone formation found in blood are alkaline phosphatase, osteocalcin, and C- and N-propeptides of type I collagen. Some markers of bone resorption excreted in urine are pyridinium cross-links of collagen, C- and N-telopeptides of collagen, galactosyl hydroxylysine, and hydroxyproline.

TABLE 19.2

FDA approved for:	Postmenopausal women	Men	Prevents osteoporosis	Treats osteoporosis	Prevents osteoporosis caused by steroid medicines	Treats osteoporosis caused by steroid medicines
Bisphosphonates						
Alendronate (Fosamax, Fosamax Plus D)	■	■[a]	■	■		■
Ibandronate (Boniva)	■		■	■[b]		
Risedronate (Actonel, Actonel with Calcium)	■	■[a]	■	■	■	■
Zoledronic Acid (Reclast)	■	■		■	■	■
Calcitonins						
Calcitonin (Fortical)	■			■		
Calcitonin (Miacalcin)	■			■		
Estrogen agonists/antagonists						
Raloxifene (Evista)	■		■	■		
Estrogen therapy (ET) and hormone therapy (HT)						
Many brands	■		■			
Parathyroid hormone						
Tomosozumab (Evenity)	■			■		
Teriparatide (Forteo)	■	■		■		
Abaloparatide (Tymlos)	■			■		
RANK ligand (RANKL)						
Denosumab (Prolia)	■			■		

[a] For men, alendronate and risedronate are approved for treatment only.

[b] Ibandronate as an intravenous (IV) injection is approved for treatment only.

Fractures and Falls

Fractures occur when bones encounter an outside force that exceeds their strength. Fragility fractures occur with minimal trauma from a standing height or less. A small percentage of fragility fractures are spontaneous, meaning that they occur with no apparent force being applied. The most common sites for fractures associated with osteoporosis are the hip, spinal vertebrae, wrist (Colles fracture), ribs, and proximal humerus, but other bones can be affected. Current estimates of fracture in the United States are that approximately 1.5 million osteoporotic fractures occur each year; these include 700,000 vertebral (only one-third are clinically diagnosed), 300,000 hip, 250,000 wrist, and 300,000 other fractures.

One in two women and one in four men above 50 years of age, have an osteoporotic fracture in their remaining lifetime. Risk factors for fracture include being female, low bone mass, personal history of fracture as an adult, history of fracture in a first-degree relative, current cigarette smoking, and low body weight (<127 lb [<58 kg]).

Hip fractures account for 20% of osteoporotic fractures and are the most devastating for the patient in terms of health costs. Important points about hip fracture include the following:

- The overall 1-year mortality rate after hip fracture is one in five. [2]
- Two to three times as many women as men sustain hip fractures, but the 1-year mortality rate for men is twice as high.
- Two-thirds of patients with hip fracture never regain their preoperative activity status. One-fourth requires long-term care.
- A woman's risk of hip fracture is equal to her combined risk of breast, uterine, and ovarian cancer.
- Protective undergarments with side padding, called *hip pads,* have proven effective in preventing hip fractures from falling in elderly adults. Resistance to wearing the garment is the only limitation.

Vertebral fractures are the most common osteoporotic fracture, but only approximately one-third are clinically diagnosed. The effects of vertebral fractures have traditionally been underestimated but are beginning to be recognized and quantified. These fractures cause pain, disfigurement, and dysfunction and decrease the quality of life. More recent studies link them to an increased risk of mortality. Vertebroplasty is a minimally invasive procedure for managing acute painful vertebral fractures. This procedure involves injecting bone cement into the fractured vertebra under fluoroscopic guidance (see Fig. 14.16). Balloon kyphoplasty is a minimally invasive procedure that can reduce back pain and restore vertebral body height and spinal alignment. This procedure involves reducing the vertebral compression and injecting the cement into this space created within the vertebral body (Fig. 19.5). Fluoroscopic guidance is used for this procedure.

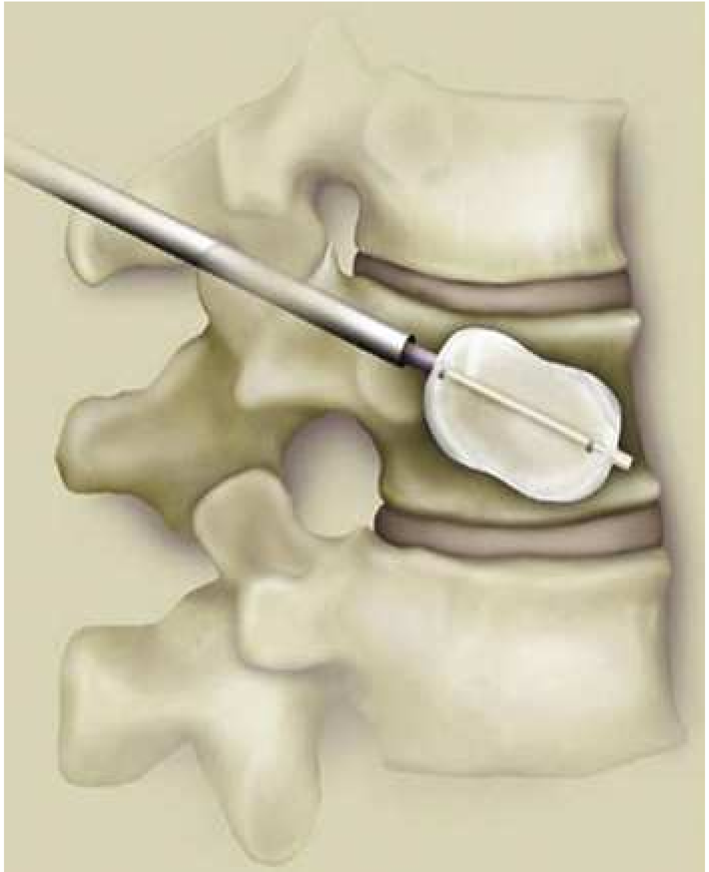


FIG. 19.5 Diagram of balloon kyphoplasty.

The presence of one osteoporotic vertebral fracture significantly increases the risk of future vertebral fractures and progressive curvature of the spine. Most osteoporotic fractures are caused by falls. Identifying elderly persons at increased risk for falls and instituting fall prevention strategies are important goals. Some risk factors for falling are the use of some medications including sedatives, sleep aids, and antidepressants; impaired muscle strength, range of motion, balance, and gait; impaired psychological functioning, including dementia and depression; and environmental hazards, including lighting, rugs, furniture, bathroom, and stairs. Fall prevention strategies through a physical therapy program include balance, gait, and strengthening exercises. Addressing psychological issues, reviewing medication regimens, and counseling patients on correct dosing are other prevention methods. Homes and living areas should be inspected for hazards, and safety measures should be implemented.

Bone Health Recommendations

The NOF's Bone Health and Prevention Recommendations are as follows:

- Obtain daily recommended amounts of calcium and vitamin D.
- Engage in regular weight-bearing and resistance exercise.
- Avoid smoking and excessive alcohol.
- Talk to a health care provider about bone health.
- Have a bone density test and take medication when appropriate.

Surgeon General’s Report on Bone Health and Osteoporosis

The Surgeon General’s Report on Bone Health and Osteoporosis includes an extensive review of the factors affecting bone health, including the health consequences associated with poor bone health. The report provides the following list of recommendations to promote better bone health and health status in general:

- Getting adequate levels of calcium and vitamin D
- Engaging in physical activity
- Reducing hazards in the home that can lead to fractures and falls

TABLE 19.3

Your body needs calcium	
If this is your age	**then you need this much calcium each day (mg)**
0–6 months	200
6–12 months	260
1–3 years	700
4–8 years	1000
9–18 years	1300
19–50 years	1000
51–70-year-old males	1000
51–70-year-old females	1200
>70 years old	1200

A cup of milk or fortified orange juice has approximately 300 mg of calcium.

From the Office of the Surgeon General’s Report.

- Talking with a physician about preventive strategies to promote bone health
- Maintaining a healthy weight
- Not smoking
- Limiting alcohol use

Many Americans fail to meet currently recommended guidelines for optimal calcium intake. The Surgeon General’s Report on Bone Health and Osteoporosis recommends the following calcium intake: 1000 mg/daily for women 19 to 50 years of age and 1200 mg/daily for females over the age of 50; 1000 mg/daily is recommended for males 51 to 70 years of age. Dietary calcium is the best source, including yogurt, milk, and some cheeses. Dietary shortfall should be met with calcium supplements with the United States Pharmacopeia (USP) designation that supply the appropriate amount of elemental calcium. The individual needs to check the number of pills to meet the serving size and whether or not to take with food (Table 19.3).

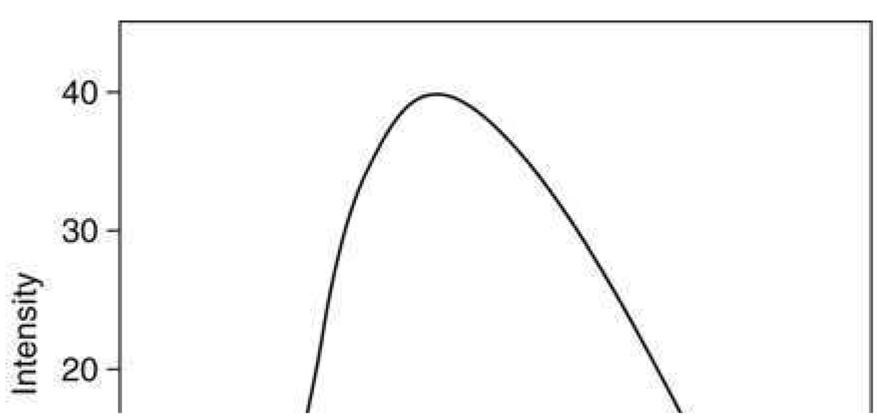
Adequate intake of vitamin D is essential for calcium absorption and bone health. Some calcium supplements and most multivitamins contain vitamin D. The Surgeon General’s Report on Bone Health and Osteoporosis recommends at least 800 IU/day for adults older than 50 years. Dietary sources are vitamin D–fortified milk and cereals, egg yolks, saltwater fish, and liver.

Weight-bearing exercise occurs when bones and muscles work against gravity as the feet and legs bear the body’s weight. Some examples are weightlifting to improve muscle mass and bone strength, low-impact aerobics, walking or jogging, tennis, dancing, stair climbing, gardening, and household chores.

Physical and Mathematic Principles of Dual Energy X-Ray Absorptiometry

The measurement of bone density requires separation of the x-ray attenuating effects of soft tissue and bone. The mass attenuation coefficients of soft tissue and bone differ and depend on the energy of the x-ray photons. The use of two different photon energies (dual energy x-ray) optimizes the differentiation of soft tissue and bone. GE Lunar model Advance (GE Lunar Corp, Madison, WI) and Norland model XR-46 (Norland/Swissray, Inc, Ft. Atkinson, WI) use a different method of producing the two energies than Hologic model Horizon (Hologic, Inc, Bedford, MA).

GE Lunar and Norland Swissray use a rare-earth, filtered x-ray source. The primary x-ray beam is passed through selected rare-earth filters to produce a spectrum with peaks near 40 kiloelectron volts (keV) and 70 keV compared with the usual continuous spectrum with one peak near 50 keV (Fig. 19.6A and B). Sophisticated pulse-counting detectors are used to separate and measure the low-energy and high-energy photons (Fig. 19.7). Calibration must be performed externally by scanning a calibration phantom on a regular basis.


40
30
20
Intensity

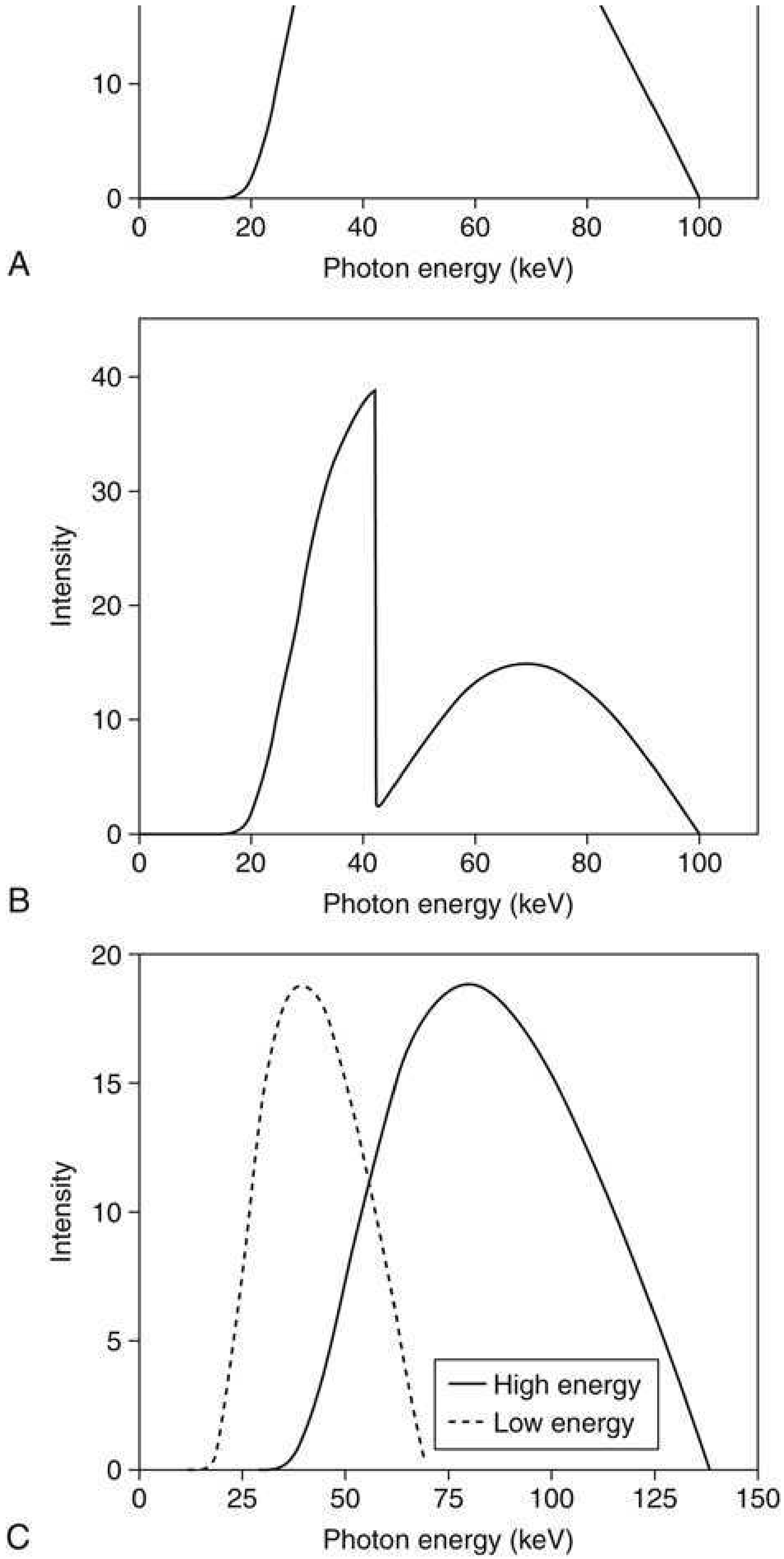


FIG. 19.6 Energy spectra (keV) for x-ray sources used in bone densitometry instruments. (A) Continuous spectrum from x-ray tube. (B) Continuous x-ray spectrum modified by K-edge filter. (C) High-energy and low-energy spectra from kV-switching system. From Blake G et al. *The evaluation of osteoporosis: DXA and ultrasound in clinical practice*. London: Martin Dunitz; 1998.

Graph (A) plots intensity versus photon energy in kilo electron volt. The horizontal axis plots photon energy from 0 to 100 with an interval of 20. The vertical axis plots intensity from 0 to 40 with an interval of 10. The curve starts from (0, 18) and rises to a peak of (44, 40) and then falls back to (100, 0). Graph (B) plots intensity versus photon energy in kilo electron volt. The horizontal axis plots photon energy from 0 to 100 with an interval of 20. The vertical axis plots intensity from 0 to 40 with an interval of 10. The curve starts from (0, 18) and rises to a peak of (44, 40) and then falls straight down to (44, 2), then rises to (65, 15) and then falls to (100, 0). Graph (C) plots intensity versus photon energy in kilo electron volt. The horizontal axis plots photon energy from 0 to 150 with an interval of 25. The vertical axis plots intensity from 0 to 20 with an interval of 5. A dashed curve labeled as low energy starts from (20, 0), rises to a peak at (37, 18) and then falls to (70, 0). Another curve labeled high energy rises from (35, 0), rises to a peak at (80, 18) and then falls to (137, 0).

Hologic scanners use an energy-switching system that synchronously switches the x-ray potential between 100 and 140 kVp. This system produces a primary beam with two photon energies with peaks near 40 and 80 keV (see Fig. 19.6C). The energy-switching system continuously calibrates the beam by passing it through a calibration wheel or drum (Fig. 19.8) containing three sectors for an open-air gap, a soft tissue equivalent, and a bone equivalent. Each sector is divided so that it can differentiate and measure the low-energy and high-energy photons. This permits the use of a relatively simple current-integrating detector that does not have to separate the photons.

Common physics problems of DXA are as follows:

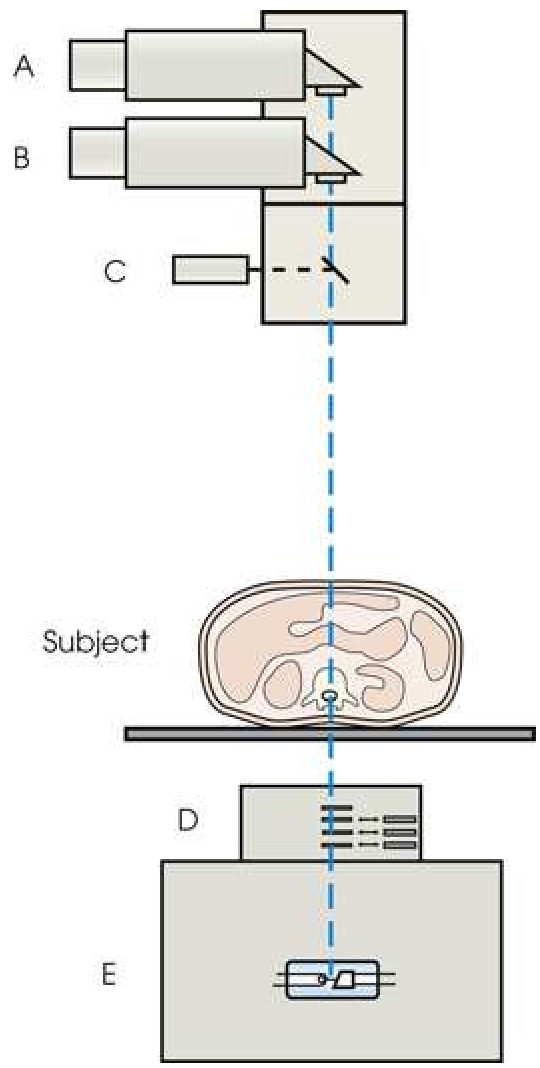


FIG. 19.7 Schematic drawing of a Norland model XR-35 illustrating the principle of operation of a rare-earth filtered system. (A) High-energy detector. (B) Low-energy detector. (C) Laser indicator. (D) Samarium filter module (one fixed, three selectable). (E) Ultrastable 100-kV x-ray source.

A schematic drawing of a Norland model X R-35 shows two detectors (A) and (B) inserted into a rectangle. (C) is smaller than the above and is inserted into it at the bottom. Below it, a section of a body part is on a tray placed above (D) fixed on top of a square (E). A dotted line from (A) passes through (b), (C), the body part, (D), and falls on a blue region in the middle of the square in (E).

- *Beam hardening in energy-switching systems.* With increasing body thickness, a higher proportion of low-energy photons are absorbed within the body, shifting the spectral distribution toward high-energy photons.
- *Scintillating detector pileup in K-edge filtration systems.* A detector can process only one photon at a time and assign it to the high-energy or low-energy channel. An incoming photon may be missed if the preceding photon has not yet been processed. Digital detectors do not have this problem.

• *Crossover in K-edge filtration systems.* Some high-energy photons lose energy passing through the body and are counted as low-energy photons by the detector. This problem is solved by subtracting a fraction of the high-energy counts from the low-energy channel, depending on body thickness.

The low-energy and high-energy x-rays are attenuated differently within each patient, producing a unique attenuation pattern at the detector, which is transmitted electronically to the computer. Mathematic computations are then performed to subtract the soft tissue signals, producing a profile of the bone (Fig. 19.9). Proprietary bone edge detection algorithms are next applied, and a two-dimensional area is calculated. The average BMD is calculated for all areas, and finally the *BMD* is calculated as BMD = BMC/Area. The three bone densitometry parameters reported on the DXA printouts are area in centimeters squared (cm^2), BMC in grams (g), and BMD in g/cm^2. BMD is the most widely used parameter because it reduces the effect of body size.

FIG. 19.8 Calibration drum used as internal reference standard in Hologic energy-switching instruments. Different segments represent bone standard, soft tissue standard, and empty segment for air value.

BMD can be calculated if BMC and the area is known by the equation BMD = BMC/Area. This equation can be used to determine if a change in BMD is due to a change in BMC, area, or both. A decrease in BMC results in a decrease in BMD; conversely, a decrease in area results in an increase in BMD. If BMC and area move proportionally in the same direction, BMD remains unchanged. In general, a change in a patient's BMD over time should be from a change in BMC, not area. A change in area could be from the technologist not reproducing the baseline positioning or from a change in the software's bone edge detection. Changes in area over time should be investigated and corrected, if possible.

BMD is based on a two-dimensional area, not a three-dimensional volume, making DXA a *projectional,* or *areal, technique.* Techniques to estimate *volumetric density* from DXA scans have been developed but have not been shown to have any improved diagnostic sensitivity over traditional areal density. Fig. 19.10 shows the lateral spine areal and estimated volumetric BMDs.

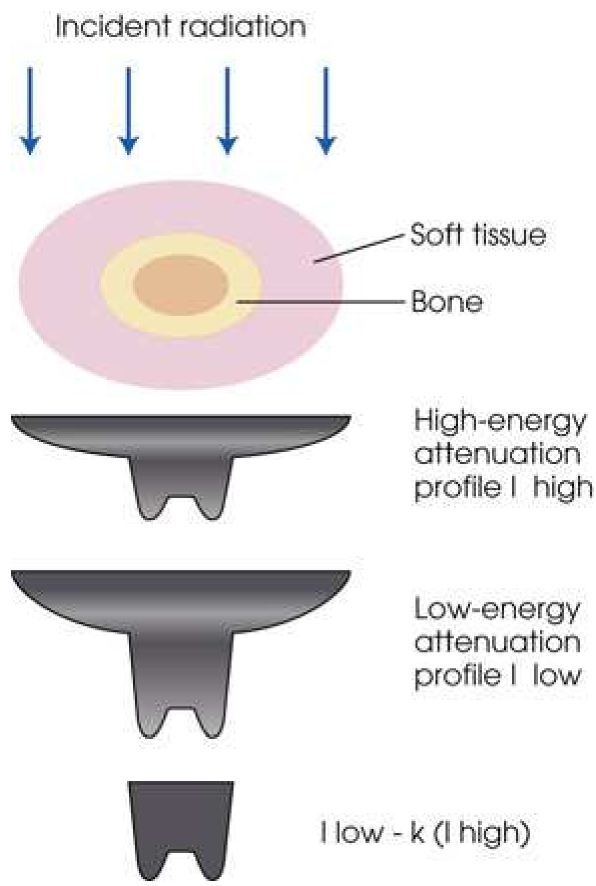


FIG. 19.9 Soft tissue compensation using DXA. By obtaining data at two energies, the soft tissue attenuation can be mathematically eliminated. The remaining attenuation is due to the amount of bone present. From Faulkner KG. *DXA Basic science, radiation use and safety, quality assurance, unpublished certification report*. Madison, WI: Personal Communication; 1996.

Four vertical arrows labeled as incident radiation is pointed at a pick circle with a yellow and a orange circle in the middle. The yellow area is labeled as bone and the pink area is labeled as soft tissue. A grey bowl shaped object with a tooth shaped bottom below it is labeled high-energy attenuation profile high. Another grey bowl shaped object with a tooth shaped below it is labeled low-energy attenuation profile low. A tooth shaped object at the bottom is labeled I low - k (I high).

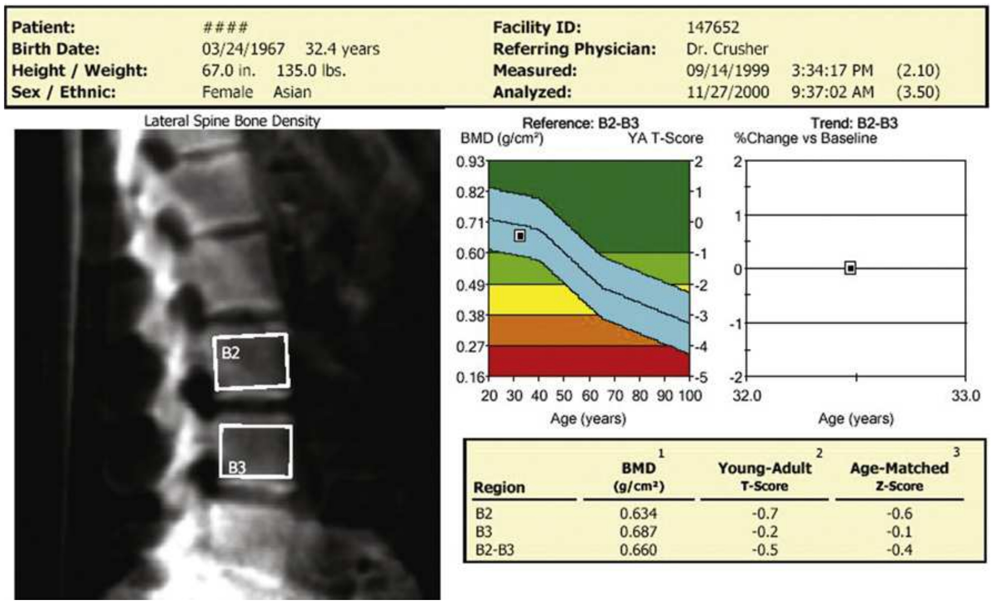


FIG. 19.10 Lateral spine BMD scan.

A box on top has the following text on it. Patient, birth date, height or weight, sex or ethnic, facility I D, referring physician, measured, analyzed. An x-ray on the left shows the lateral view of the spine, Two boxes with labels B 2 and B 3 respectively are on the spine. A graph on the left shows the age in years labeled on the horizontal axis and B M D (gram over centimeter squared) labeled on the vertical axis. Another graph next to it has age in years labeled on the horizontal axis and percent change versus baseline labeled on the vertical axis. A table at the bottom has four columns and three rows. From left to the right, the columns are labeled as region, B M D (gram over centimeter squared), young adult t-score, age matched z-score. The row-wise entries of the table are as follows: Row 1. B 2, 0.634, negative 0.7, negative 0.6. Row 2. B 3, 0.687, negative 0.2, negative 0.1. Row 3. B 2 to B 3, 0.660, negative 0.5, negative 0.4.

Pencil-Beam and Array-Beam Techniques

The original DXA scanners used a pencil-beam system. With this system, a circular pinhole x-ray collimator produces a narrow (or pencil-beam) stream of x-ray photons that are received by a single detector. The pencil-beam of x-ray moves in a serpentine (also called *rectilinear* or *raster*) fashion across or along the length of the body (Fig. 19.11). This system has a good resolution and it is reproducible, but the early scanners had relatively long scanning periods of 5 to 7 minutes.

The array-beam (also called fan-beam) system has a wide "slit" x-ray collimator and a multielement detector (Fig. 19.12). The scanning motion is reduced to only one direction, which greatly reduces scan time and permits supine lateral lumbar spine scans to be performed. The array-beam system introduces geometric magnification and a slight geometric distortion at the outer edges. Consequently, careful centering of the object of interest is necessary to avoid parallax (Fig. 19.13). The software takes into account the known degree of magnification and produces an *estimated* BMC and an estimated area.

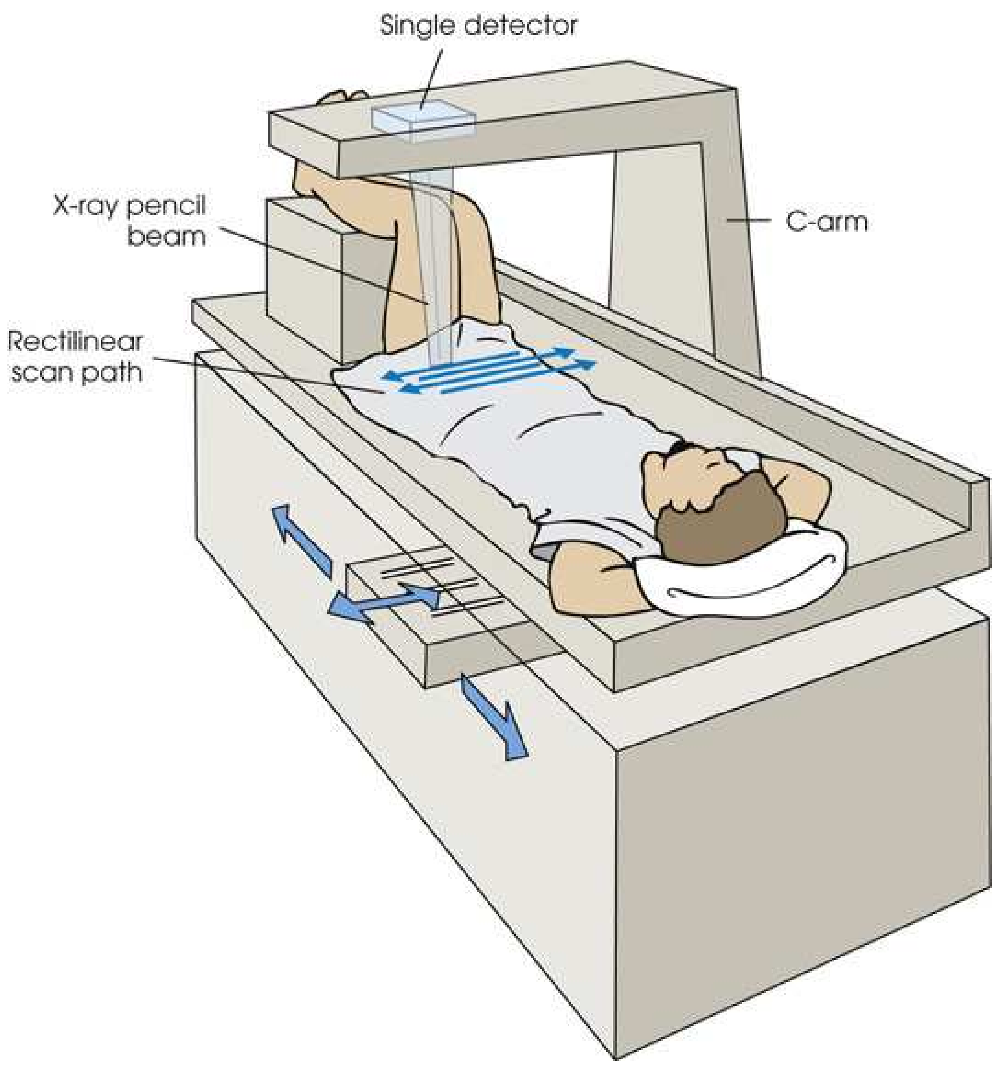


FIG. 19.11 DXA system using pencil-beam single detector.

A patient is in supine position on the radiographic table with both is hands under the pillow supporting the head. Both his legs are elevated and is resting on a block in front of him. The pencil-beam of x-ray moves in a serpentine fashion across or along the length of the body. The parts labeled are as follows: rectilinear scan path, x-ray pencil beam, single detector, and C-arm.

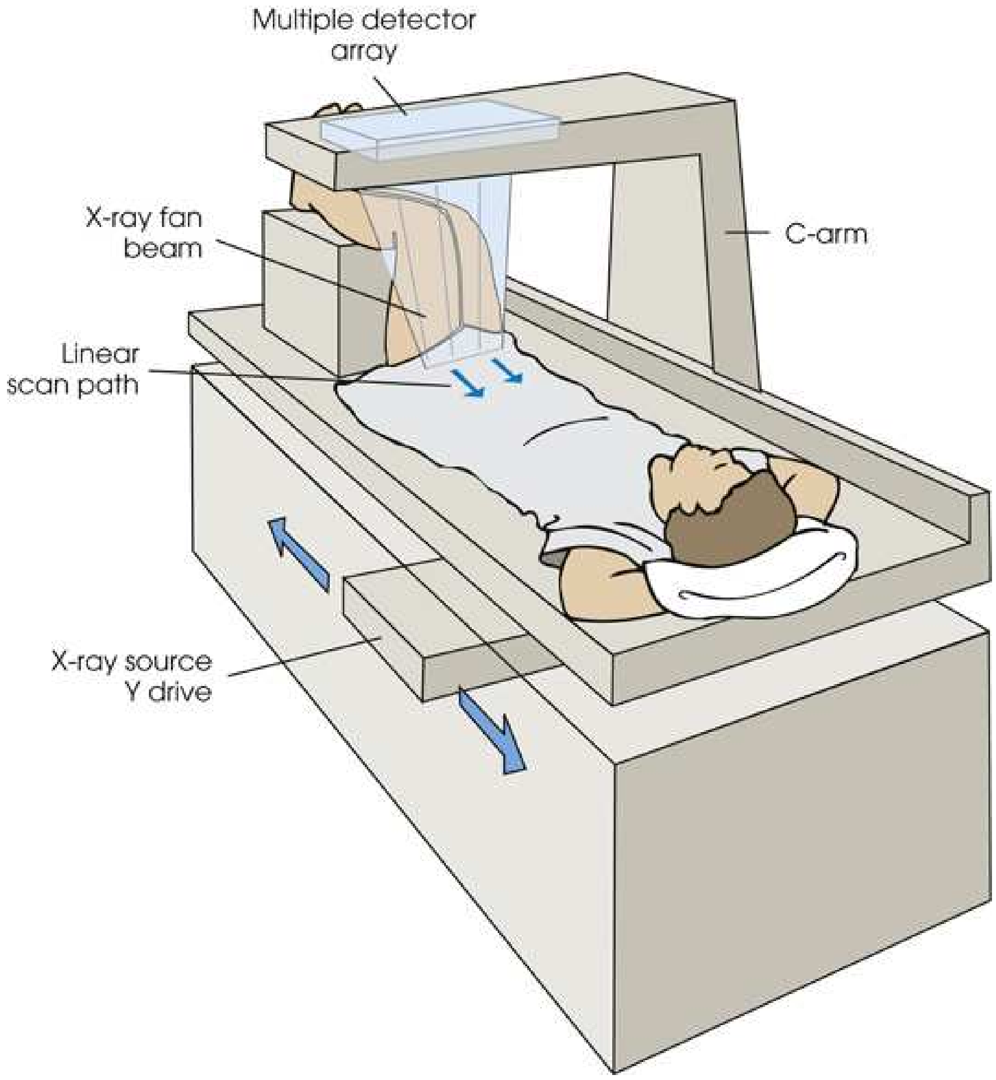


FIG. 19.12 DXA system using an array-beam multiple detector.

A patient is in supine position on the radiographic table with both is hands under the pillow supporting the head. Both his legs are elevated and is resting on a block in front of him. The array-beam system has a wide “slit” x-ray collimator and a multielement detector. The parts labeled are as follows: x-ray source Y drive, linear scan path, x-ray fan beam, multiple detector array, and C-arm.

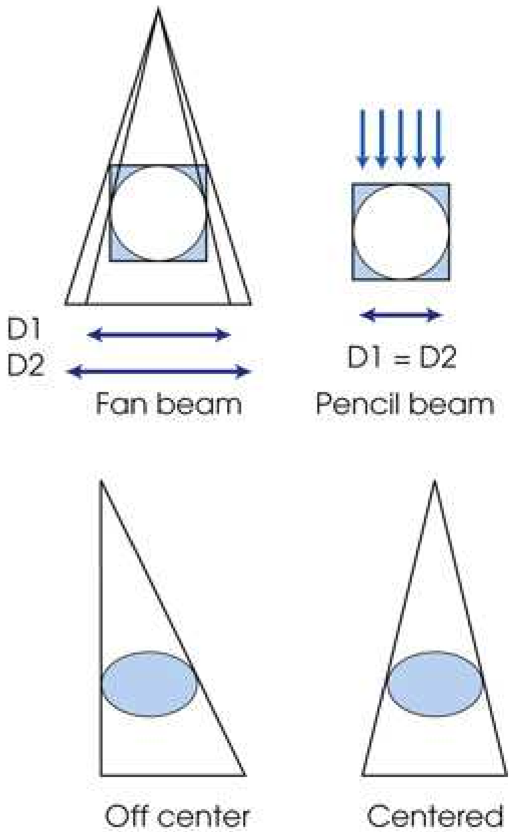


FIG. 19.13 Potential array-beam errors including magnification *(top)* and parallax *(bottom)*. Area and BMC are influenced by magnification to the same degree, such that BMD is not significantly affected. Parallax errors can cause changes in BMD by altering the beam path through the object being measured. From Faulkner KG. *DXA Basic science, radiation use and safety, quality assurance, unpublished certification report*. Madison, WI: Personal Communication; 1996.

Diagram on the top left side shows a triangle with a square in it. The square has a circle in it. The space between the square and the circle is shaded in blue. Two horizontal lines are below it. The short line is labeled D 1 and the long one is labeled D 2. The text fan beam is at the bottom. Diagram on the top right shows a square with a circle in it. The space between the square and the circle is shaded in blue. Five vertical lines are pointing at the square at the top. A horizontal line below the square is labeled D 1 equals D 2. The text below reads, pencil beam. Diagram at the bottom left shows a right angled triangle with a blue circle in the middle. A text below it reads, off center. Diagram at the bottom right shows a triangle with a blue circle in the middle. A text below reads, centered.

Accuracy and Precision

Three statistics are particularly important in bone densitometry: mean, standard deviation (SD), and percent coefficient of variation (%CV).

1. The mean is commonly called the average. It is the sum of the data values divided by the number of values.
2. The SD is a measure of variability that measures the spread of the data values around their mean. It takes into account the average distance of the data values from the mean. The smaller the average distance or the spread, the smaller the SD. This is the goal in bone densitometry—a smaller SD is better. Fig. 19.14 plots two sets of phantom BMD data measured over 6 months. The means are the same (1.005 g/cm^2), but the red data set has an SD that is twice as large as that of the green data set (0.008 g/cm^2 versus 0.004 g/cm^2). It is better to have phantom BMD data that looks like the green data set.
3. The %CV is a statistic that allows the comparison of variability between different data sets, whether or not they have the same mean. A smaller %CV means less variability and is preferred in bone densitometry. The %CV is calculated using the following equation:

$$\%\,CV = \left(\frac{SD}{Mean}\right) \times 100$$

In Fig. 19.14, the green data set has a %CV of 0.35 and the red data set has a %CV of 0.81. This is the %CV that must be checked on a Hologic spine phantom plot (Fig. 19.15). The red data set would not pass the criteria that the %CV should be less than or equal to 0.6. The %CV is also used to express precision.

Bone densitometry differs from diagnostic radiology in that, it has a good image quality, which can tolerate variability in technique though it is not the ultimate goal, but it is very important. With bone densitometry, the goal is accurate and precise quantitative measurement by the scanner software, which requires stable equipment and careful, consistent work from the technologist. Two important performance measures in bone densitometry are *accuracy* and *precision*. Accuracy relates to the ability of the system to measure the true value of an object. Precision relates to the ability of the system to reproduce the same (but not necessarily accurate) results in repeat measurements of the same object. A target may be used to illustrate this point. In Fig. 19.16A, the archer is precise but not accurate. In Fig. 19.16B, the archer is accurate but not precise. Finally, in Fig. 19.16C, the archer is precise and accurate.

In bone densitometry practice, accuracy is most important at baseline when the original diagnosis of osteoporosis is made. Accuracy is determined primarily by the calibration of the scanner, which is set and maintained by the manufacturer. Preventive maintenance once or twice a year is recommended. Precision is followed closely because it is easy to determine and is the most important performance measure in following a patient's BMD over time. Precision can be measured in vitro (in an inanimate object, e.g., phantom) or in vivo (in a live body). Precision is commonly expressed as %CV, and a smaller value indicates better precision.

In vitro precision is the cornerstone of the quality control systems built into the scanners to detect drifts or shifts (variations) in calibration. Each manufacturer provides a unique phantom for this purpose.

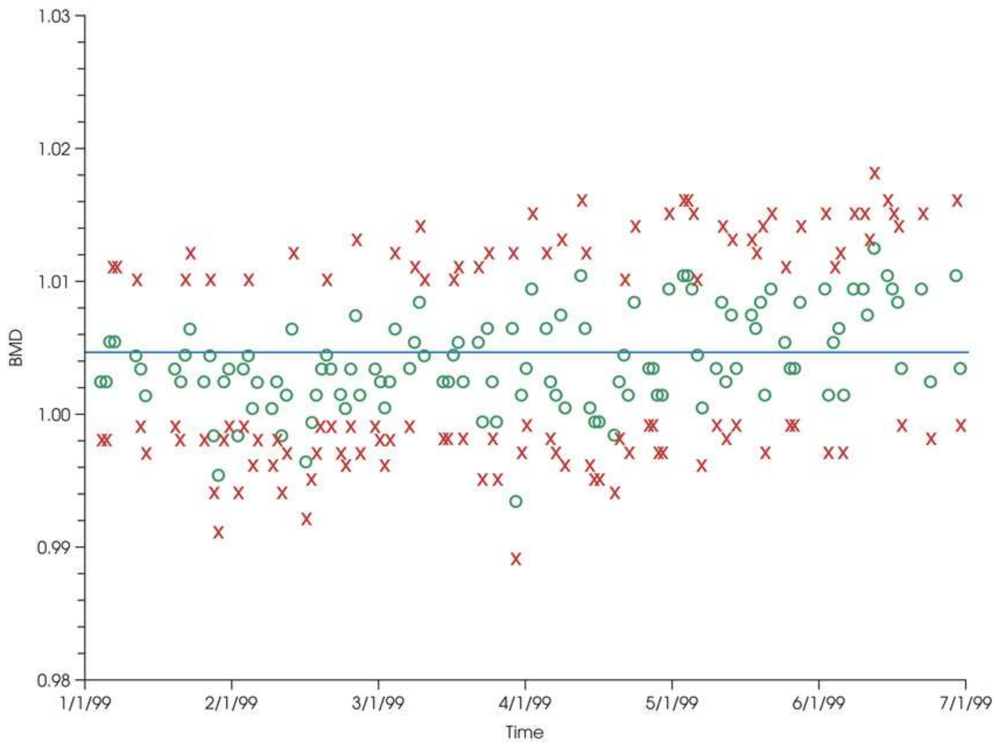


FIG. 19.14 Two data sets of longitudinal phantom BMD (*blue line* is the mean). *Green data set* has mean = 1.005 g/cm^2, SD = 0.004 g/cm^2, and %CV = 0.35. *Red data set* has mean = 1.005 g/cm^2, SD = 0.008 g/cm^2, and %CV = 0.81.

A scatterplot plots B M D versus time. The plots for red data are scarcely distributed between 0.99 and 1 B M D and between 1.01 and 1.02 B M D through out the time. The plots for green data are scarcely distributed between 1 and 1.01 B M D through out the time. A horizontal line is drawn at mean equals 1.005.

In vivo precision has two main aspects in bone densitometry:

1. The variability within a patient makes it easy or difficult to obtain similar BMD results from several scans on the same patient, on the same day, with repositioning between scans. (Patients with abnormal anatomy, very low bone mass, or thick or thin bodies are known to reflect a larger precision error.)
2. The variability is related to the technologist's skill and how attentive he or she is to obtaining the best possible baseline scan and then reproducing the positioning, scanning parameters, and placement of ROI on all *follow-up scans*.

The primary factors affecting precision are as follows:

- Reproduction of positioning, acquisition parameters (e.g., mode, speed, current), and ROI placement. It is important to note that with a faster scan mode, there is less precision.
- Anatomic variations and pathology and their degeneration over time.

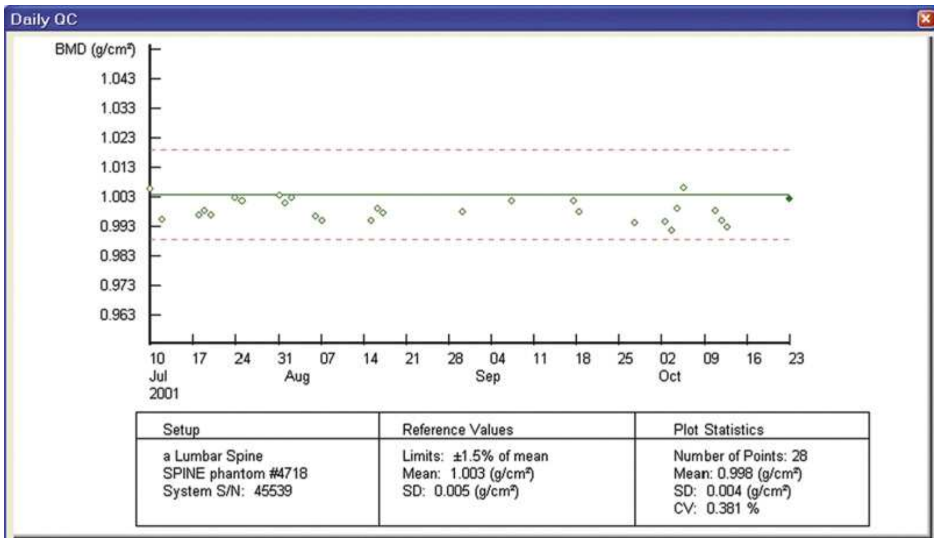


FIG. 19.15 Hologic spine phantom quality control plot. All plotted BMD points are within the control limits *(dotted lines),* which indicate 1.5% of the mean. The coefficient of variation (CV) (under *Plot Statistics*) is within acceptable limits at 0.43%.

A scatterplot plots B M D versus months from July to October. The plots are scarcely distributed between 0.99 and 1.05 B M D from the months July to October. A table below the graph has three columns and one rows. From left to right, the columns are labeled as setup, reference values, plot statistics. The contents of the table row wise are as follows. 1. setup: a lumbar spine, spine phantom number 4718, system serial number: 45539. reference values: Limits, plus or minus 1.5 percent of mean, mean: 1.003 gram per centimeter cube, standard deviation: 0.005 gram per centimeter squared. Plot statistics: Number of points: 28, Mean: 0.998 gram per centimeter squared, standard deviation: 0.004 gram per centimeter squared, coefficient of variation: 0.381 percent.

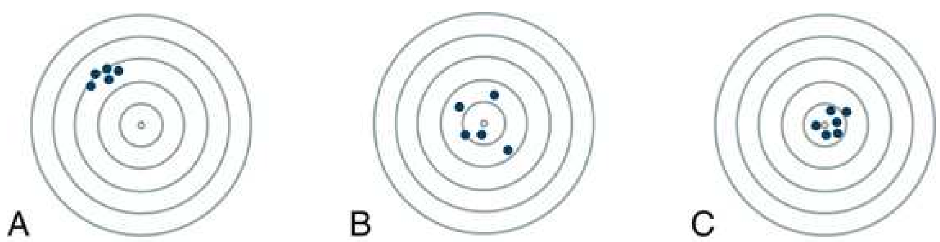


FIG. 19.16 Illustration of accuracy versus precision, assuming an archer is shooting for the center of the target. (A) Precise but not accurate. (B) Accurate but not precise. (C) Accurate and precise.

(A) shows a shooting target with 5 shots that are grouped together but far away from the center. (B) shows a shooting target with 5 shots that are all around the center but far from each other. (C) shows a shooting target with 5 shots that are grouped together and at center of the target.

- Body habitus (e.g., excessive thickness or thinness).
- Large weight changes over time.
- Geometric factors on array scanners.
- Stability of scanner calibration and bone edge detection.

Performing precision assessment

Each DXA laboratory should determine its precision error and calculate the *least significant change* (LSC). This precision is used to determine the magnitude of change in BMD that must occur over time to ensure the change is due to a change in the patient's BMD and not to the precision error of the technologist and scanner. The precision error supplied by the manufacturer should not be used because it is the error rate for the machine and not the technologist. If a DXA laboratory has more than one technologist, an average precision error that combines the data from all technologists should be used to establish the precision error and LSC for the facility. Every technologist should perform an in vivo precision assessment using patients who are representative of the patient population of the facility. Each technologist should do one complete precision assessment after basic scanning skills have been learned, and after having performed at least 100 patient scans. If a new DXA system is installed, a repeat precision assessment should be done. A repeat assessment should also be done if a technologist's skill level has changed (International Society for Clinical Densitometry [ISCD] 2019 Position Statements).

Procedure to determine precision error for each technologist

Measure 15 patients three times or 30 patients two times, repositioning the patient after each scan. Use the ISCD Precision Assessment tool (http://www.iscd.org) to calculate precision. Calculate LSC for the group at 95% confidence interval. The clinician uses this information to interpret all serial scans. The minimum acceptable precision values for an individual technologist are as follows:

- Lumbar spine: 1.9% (LSC = 5.3%)
- Total hip: 1.8% (LSC = 5.0%)
- Femoral neck: 2.5% (LSC = 6.9%)

Retraining is required if a technologist's precision is worse than these values.

Precision assessment should be standard clinical practice. This research should not require approval from an institutional review board and may potentially benefit patients. Adherence to local or state radiologic safety regulations is necessary. A precision assessment requires the consent of participating patients (ISCD 2019 Position Statements).

Cross-Calibration of Dual Energy X-Ray Absorptiometry Machines

- It is impossible to quantitatively compare BMD or to calculate LSC between facilities/scanners without cross-calibration of the machines.
- DXA facilities should always cross-calibrate machines when changing hardware, replacing a system with the same technology, changing the entire system, or changing to a system by a different manufacturer.
- Scan patients as suggested in ISCD position statements. Calculate the average BMD relationship and LSC between the initial machine and new machine using the ISCD Machine Cross-Calibration tool (http://www.iscd.org).
- If a cross-calibration assessment is not performed, no quantitative comparison to the prior machine can be made. Consequently, a new baseline BMD and intrasystem LSC should be established (ISCD 2019 Position Statements).

Z-Scores and T-Scores

A BMD measurement from a patient is most useful when it is compared statistically with an appropriate sex-matched *reference population*. The three DXA manufacturers have separately collected reference population databases, which vary because different populations, entrance criteria, and statistical methods were used. To correct this problem, the Third National Health and Nutrition Examination Survey (NHANES III) DXA total hip database was adapted to provide a *standardized hip* reference database for all manufacturers. This database is currently widely used. All reference databases are separated by gender and provide the BMD mean and SD at each age; however, the lumbar spine database is manufacturer specific.

To compare a patient's BMD with the reference population BMD, two standardized scores have been developed, called the *Z-score* and *T-score* (see Fig. 19.10). In older adults, the Z-score is greater than the T-score.

The Z-score indicates the number of SDs the patient's BMD is from the average BMD for the patient's respective age and sex group. The Z-score is used to determine if the measured BMD is reasonable, and if an evaluation for secondary osteoporosis is warranted.

The T-score indicates the number of SDs the patient's BMD is from the average BMD of young, normal, sex-matched individuals with peak bone mass. The T-score is used to assess fracture risk, diagnose osteoporosis, and low bone mass *(osteopenia),* when determining if therapy is recommended.

The Z-score, T-score, or both may be adjusted for ethnicity, weight, or both. It is incorrect to assume that because ethnicity and weight have been entered into the scan biographic information, the standardized scores have been adjusted. Some manufacturers allow an ethnicity to be entered for which there is no reference database; these patients are compared with whites. Some manufacturers adjust for weight and ethnicity on the Z-score but not the T-score. To determine what adjustments have been made, first carefully check the information on the scan printout, including footnotes. If a question remains, call the manufacturer's customer service line and ask.

The ISCD recommends the use of a uniform white (non–race adjusted) female and male normative database for women and men of all ethnic groups. All manufacturers' defaults may not be adjusted to this recommendation. The technologist needs to be familiar with the defaults of the specific equipment and know how to make adjustments.

Bone mass is normally distributed (i.e., has a bell-shaped curve) in the population, and no one exact cut point exists below which a person has osteoporosis. However, with the widespread availability of DXA and T-scores, there was pressure to declare such a cut point. The World Health Organization (WHO) recommended that the classifications presented in Table 19.4 be used in DXA studies of postmenopausal Caucasian women.

Discordance occurs when there exist different T-scores at anatomic sites within a patient, within populations, and between modalities. It makes the diagnosis of osteoporosis more complicated than simply applying T-score criteria, and the problems are being researched to find more standardized diagnostic criteria. A patient may be found to have a low T-score at the hip but not at the spine, and a QCT scan of the spine is likely to produce a lower T score than is a DXA scan of the spine in the same patient.

Applying the T-score criteria designed for DXA to other modalities (e.g., quantitative ultrasound [QUS], QCT) has proven problematic. The best practice is to apply the T-score criteria only to DXA. The T-score is one important risk factor for osteoporosis, but the patient's medical history, lifestyle, medications, and other risk factors must also be considered in a complete clinical evaluation. Physicians who interpret bone density scans need to be educated in the complexities of the task.

Large epidemiologic studies have investigated the clinical value of BMD in elderly women and have yielded information on the relationship of BMD and T-scores to fracture risk. A gradient of risk has been observed between BMD and fracture incidence, with lower BMD or T-score conferring increased risk of fracture. For each 1 SD decrease in T-score, the risk for fracture increases 1.5-fold to 2.5-fold. A woman with a T-score of −2 has approximately twice the risk of fracture compared with a woman with a T-score of −1, all other factors being equal. This information helps clinicians to explain the meaning of a bone density test to patients. Patients can then make informed decisions about the level of fracture risk they are willing to accept and whether to begin or continue therapy.

Dual Energy X-Ray Absorptiometry Scanning

Radiation Protection

Radiologic technologists receive extensive instruction in radiation physics, biology, and protection during their professional education. Practicing proper radiation protection and achieving the goal of *ALARA* (as low as reasonably achievable) is relatively simple for DXA. The effective radiation dose in micro*sieverts* (μSv) for DXA scans is low compared with conventional radiography doses and similar to natural background radiation (Table 19.5). If the positioning or acquisition parameters of a scan are questionable, the scan should be repeated because the risk from the additional radiation dose is negligible compared with the risk of an incorrect medical diagnosis.

Time, distance, and shielding relate to DXA in the following ways:

1. The manufacturer sets the time for the scan based on the array or scan mode appropriate for the thickness of the body part being scanned.
2. The manufacturer sets the distance from the x-ray tube to the patient. This is a fixed distance.
3. Distance is the best form of protection for the technologist. The technologist's console should be at least 3 ft (1 m) from the x-ray source (x-ray tube) scanner for pencil-beam scanners and up to 9 ft (3 m) from heavily used array-beam scanners (array-beam produces higher dose than pencil-beam). If these distances cannot be accommodated, a mobile radiation shield can be used.

Shielding is built into the scanner via collimation. Additional lead shielding should not be used on DXA patients.

Other important radiation safety points include the following:

- The technologist should wear an individual dosimetry device (radiation badge, thermoluminescent dosimeter, or optically stimulated luminescence device) at the collar on the side adjacent to the scanner. Another monitor can be placed outside the scan room. A staff member should be charged with understanding and monitoring the dosimetry records and performing any necessary follow-up. A radiation warning sign should be posted and highly visible.
- The technologist should always remain in the room during the scan and monitor the acquisition image, allowing the scan to be aborted as soon as the need for repositioning and rescanning is obvious.
- The technologist should have adequate education and be clinically competent with DXA experience in order to minimize repositioning and repeated scans. It is important to know how to prepare the patient to eliminate artifacts. Any questionable scan should be repeated.
- The technologist should follow proper procedures to avoid scanning a pregnant patient and place documentation in the permanent record. If a woman of childbearing age will not sign that she is not pregnant, the "10-day rule" allows scanning during the first 10 days after the first day of her last menstrual period.
- Patients should be screened at scheduling for problems that require postponement of scanning, such as pregnancy and recent barium, contrast, or nuclear medicine examinations.

The most effective radiation safety practice is a knowledgeable, well-educated, clinically competent, and conscientious DXA technologist. It is essential for DXA technologists to receive instructions from the manufacturer of a specific model of scanner. This might consist of reviewing digital information and reviewing performed scans with a field application specialist. When experience is obtained, a technologist can become certified by the ISCD. Another certification is available through the American Registry of Radiologic Technologists (ARRT). Both of these credentials can be obtained by technologists who are educationally prepared and clinically competent. Technologists must obtain continuing education in bone densitometry to meet the qualifications of maintaining current practice status for both ISCD and ARRT.

TABLE 19.4

World Health Organization classifications of bone density by T-score

Classification	Criteria
Normal	BMD or BMC T-score of ≥−1
Low bone mass (osteopenia)	BMD or BMC T-score between −1 and −2.5
Osteoporosis	BMD or BMC T-score of ≤2.5
Severe osteoporosis	BMD or BMC T-score of ≤2.5 and ≥1 fragility fractures

Data from Kanis JA. World Health Organization (WHO) Study Group: assessment of fracture risk and its application to screening for postmenopausal osteoporosis: a synopsis of the WHO report. *Osteoporos Int*. 1994;4:358.

TABLE 19.5

Bone densitometry radiation doses compared with other commonly acquired doses

Type of radiation exposure	Effective dose (mSv)
Daily natural background radiation	5–8
Round-trip air flight across the United States	60
Lateral lumbar spine radiograph	700
PA chest radiograph	50
QCT with localizer scan (from scanner offering low kV and mAs; may be 10 times higher for other scanners)	60
DXA scan (range allows for different anatomic sites; Lunar EXPERT-XL may be higher)	1–5
SXA scan	≤1
QUS	0

Data from Kalender WA. Effective dose values in bone mineral measurements by photon absorptiometry and computed tomography. *Osteoporos Int*. 1992;2:82.

Patient Care and Education

Typical DXA patients are ambulatory outpatients; however, many are frail and at increased risk for fragility fractures. Patient care and safety require attention to the following points of courtesy and common sense:

- All areas of the laboratory, including the front entrance, waiting room, and scan room, should be monitored daily and modified for patient safety. The location of floor-level cables in the scan room should be checked.
- The technologist should maintain professionalism at all times by introducing himself or herself and other staff members to the patient and explaining the procedure. Ethical conduct and professionalism in the workplace are requirements of all health care professionals. The technologist should adhere to the Code of Ethics for Radiologic Technologists (Chapter 1) and the American Society of Radiologic Technologists (ASRT) Bone Density Practice Standards.
- The technologist needs to remove all external artifacts. Some DXA laboratories have all patients gowned for consistency. However, it is possible to scan a patient who is wearing loose cotton clothing with no buttons, snaps, or zippers (i.e., "sweats"). If clothing is not removed, the bra must be undone, and all hooks and underwires must be removed from the scan field. Considering that shoes must be removed for proper height measurement, a long-handled shoehorn would be a practical aid.
- The technologist should provide a simple explanation of the expected action of the scan-arm, the proximity of the scan-arm to the patient's face and head, the noise of the motor, and the length of time for the scan. This information may reduce the patient's anxiety.
- The technologist must listen to any concerns the patient may have about the procedure and be ready to answer questions about radiation exposure, the length of the examination, and the reporting protocol used by the laboratory.
- Although the scan tables are not more than 3 ft (approximately 1 m) in height, a steady footstool with a long handle is recommended. All patients should be assisted on and off the table.
- On completion of the examination, the technologist should ensure the scan-arm has returned to the home position, clearing the patient's head. The patient should sit upright for several seconds to regain stability before descending from the scanner.

In some institutions, it is the responsibility of the DXA technologist to provide education to the patient and the family. Topics may include osteoporosis prevention, proper nutrition, calcium and vitamin D supplementation, weight-bearing exercise, and creating a hazard-free living environment. Many technologists give community educational programs, in-service staff seminars, and participate in health fairs.

Patient History

Each bone density laboratory should develop a patient questionnaire customized for the types of patients who are referred to undergo the exam. Before scanning is performed, any information that could postpone or cancel the scan should be identified. The questionnaire should be directed at obtaining information in four basic categories. Sample questions include the following:

1. Scanning criteria:
   - Is there a possibility of pregnancy?
   - Is it impossible for you to lie flat on your back for several minutes?
   - Have you had a nuclear medicine, barium, or contrast x-ray examination performed in the last week?
   - Have you had any previous fractures or surgeries in the hip, spine, abdomen, or forearm areas?
   - Do you have any other medical conditions affecting the bones, such as osteoporosis, curvature of the spine, or arthritis?
2. *Patient information*: This includes identifying information, referring physician, current standing height without shoes along with current weight, and medical history including medications.
3. *Insurance information*: Because DXA scans are not universally covered by insurance, it is important to obtain information on the insurance carrier, the need for prior approval, and the information necessary for insurance coding. In 1998, the US Congress passed the Bone Mass Measurement Act (BMMA) dealing with reimbursement for Medicare patients. Central and peripheral technologies are covered. Medicare does not cover screening, so a qualified individual must meet at least one of the following requirements:
   - Estrogen-deficient woman at clinical risk of osteoporosis

- Individuals with hyperparathyroidism
- Individuals receiving long-term glucocorticoid (steroid) therapy
- Individuals with vertebral abnormalities by radiograph
- Individuals being monitored on osteoporosis therapy and have been approved by the US Food and Drug Administration (FDA)

4. *Reporting information*: The type and scope of the report that is provided determine how much information is necessary about the patient's risk factors for, and history of, low bone mass, fragility fractures, and bone diseases.

Reporting, Confidentiality, Record Keeping, and Scan Storage

When the scan has been completed, the following guidelines should be observed:

- The technologist should end the examination by telling the patient when the scan results will be available to the referring physician. If a patient asks for immediate results, the technologist should explain that it is the ordering physician's responsibility to give the results to the patient after the scan has been interpreted by an educationally prepared and clinically competent DXA clinician.
- DXA scan results are confidential medical records and should be handled according to the institution's rules for such records. Results should not be discussed with other staff members or patients, and digital results should be shielded from inappropriate viewing. As of April 2005 the guidelines of the American Health Insurance Portability and Accountability Act of 1996 (HIPAA) must be integrated into the DXA laboratory. Manufacturers use privacy tools or HIPAA-secure tools to ensure patient confidentiality.
- Complete records must be kept for each patient. If a patient returns for *follow-up* scans, the positioning, acquisition parameters, and placement of the ROI must be reproduced as closely as possible to the original scans. The technologist must keep electronic records with the patient's identifying information and date, the file name, and the archive location of each scan. The electronic record should also identify any special information about why particular scans were or were not performed (e.g., the right hip was scanned because the left hip was fractured, or the forearm was not scanned because of the patient's severe arthritis) and any special procedures done for positioning (e.g., the femur was not fully rotated because of pain) or scan analysis (e.g., the bone edge was manually placed for the radial ultradistal region). The patient questionnaire, log sheet, and complete scan information must also be kept electronically.
- The general consensus is that DXA scan results should continually be kept electronically because all serial studies are compared with the baseline.

Computer Competency

DXA scan acquisition, analysis, and archiving is controlled with a personal computer (PC). DXA technologists must be familiar with the basic PC components and how they work. Digital networking allows a scan to be performed at one location and be sent electronically to a remote location for reading or review by an interpreting or referring physician. A technologist must be able to back up, archive, locate, and restore patient scan files. Daily backup and archival are recommended to preserve patient scan files and data. A third copy of data should be stored offsite to ensure retrieval of patient data and to be able to rebuild databases if there is a computer failure, fire, flood, or theft. Most facilities have access to *picture archiving communications systems (PACS)* where all scans are stored electronically and can be retrieved when needed.

Manufacturers frequently upgrade software versions, and the technologist is responsible for performing this task. Records of upgrades and software installation should be maintained. Current software media should be accessible to service engineers at the time of preventive maintenance and repairs.

Computers consist of software and hardware. Software consists of programs written in code that instruct the computer how to perform tasks. The DXA manufacturer's software controls many aspects of DXA scanning from starting the scan to calculating and reporting the results. Hardware comprises the physical components for central processing, input, output, and storage.

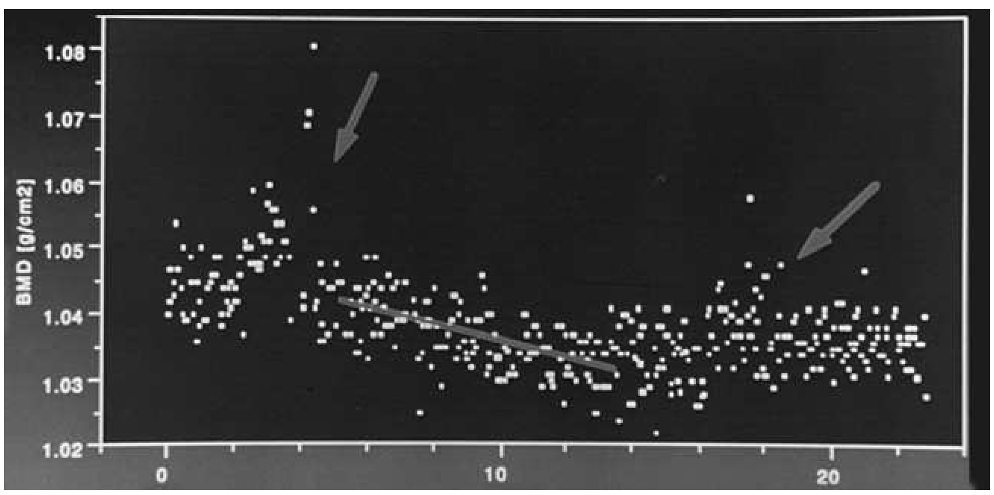


FIG. 19.17 Plot of spine phantom BMD and time (in months). Two *arrows* show abrupt shifts in BMD. *Straight line* shows a slow drift downward in BMD. These indicate changes in scanner calibration.

A scatterplot plots B M D versus time in months from 0 to 20. The plots are tightly distributed between 1.02 and 1.05 B M D for 0 to 10 months. A decreasing line is drawn from the months 5 to 14. Two arrows are pointing at plots that are far from the group.

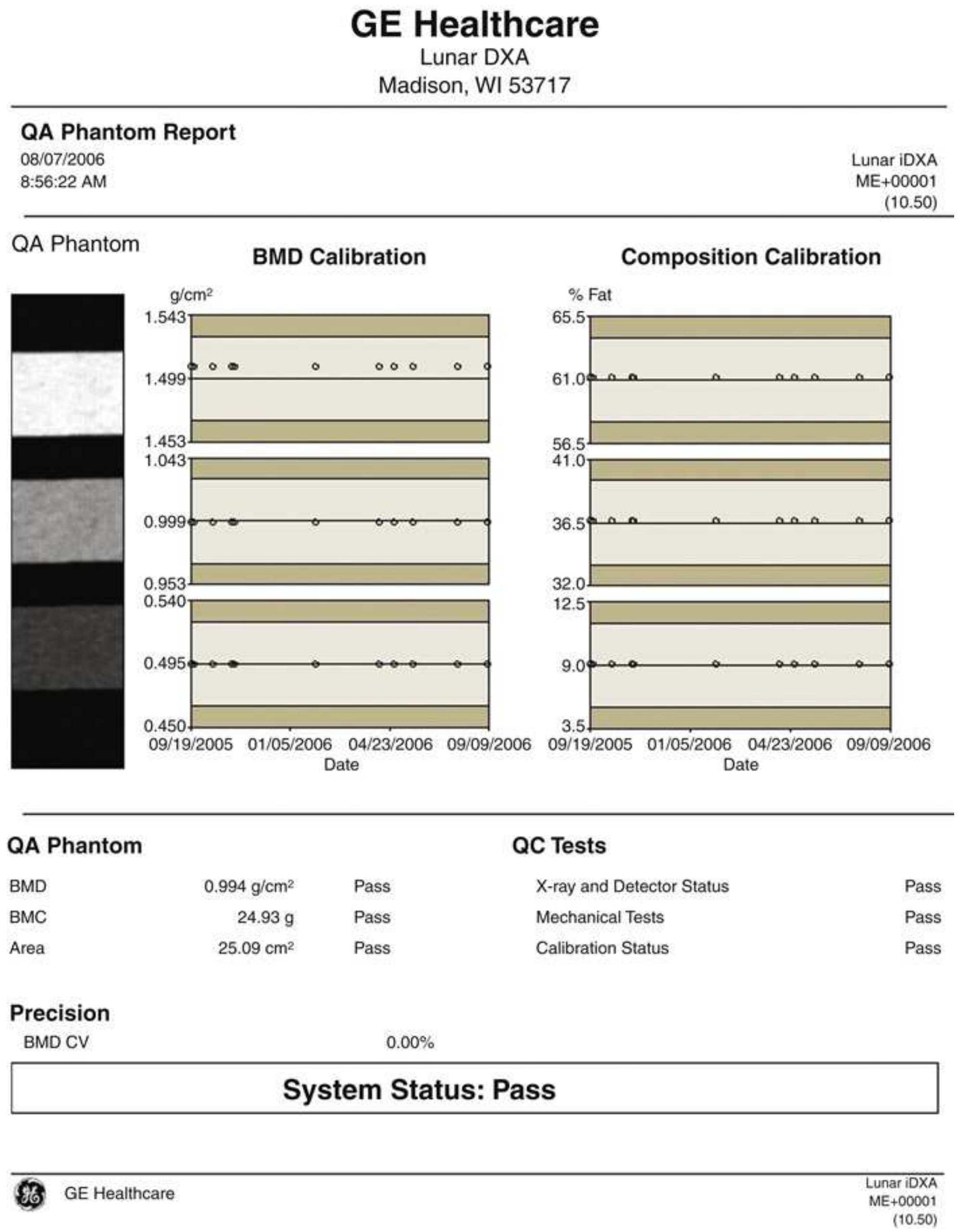


FIG. 19.18 GE Lunar quality assurance results printout. The technologist must perform and review the data before performing clinical patient scans. Courtesy GE Lunar, Madison, WI.

A printout is titled G E healthcare, Lunar D X A, Madison, W I 53717. The contents are as follows. Q A phantom report. A rectangular box titled Q A Phantom shows black color on top followed by white, black, light grey, black, grey, and black. Three rectangular box graph titled B M D calibration is next to it. The date is scaled on the horizontal axis and grams in centimeter squared is scaled on the vertical axis. Next to it is another three rectangular box graph titled composition calibration. The date is scaled on the horizontal axis and fat in percent is scaled on the vertical axis. Below it on the left is the Q A phantom. Under it B M D, B M C, and area values are listed. On the right is the Q C tests. Under it x-ray and detector status, mechanical tests, and calibration status values are listed. Under precision B M D C V value is listed. At the bottom is the text system status: pass is in a rectangular box.

Dual Energy X-Ray Absorptiometry Scanner Longitudinal Quality Control

Longitudinal quality control procedures are performed in accordance with the manufacturer's recommendations. Manufacturers' instructions in operator manuals must be followed exactly. These procedures have the common goal of ensuring that patients are scanned on properly functioning equipment with stable calibration. Unstable calibration can take the form of abrupt shifts or slow drifts in BMD, as seen on plots of phantom scan results (Fig. 19.17). These problems make the patient's BMD values too high or too low and prohibit a valid comparison between baseline and follow-up scans. Calibration "shift" may occur if there has been a relocation, maintenance, or change of x-ray tube or detector on the scanner. Calibration "drift" may occur if there is a change in room conditions (temperature, humidity) or change in power supply or with aging of the x-ray tube or detector. It is important to monitor the plots regularly.

The procedures use either external or internal instruments to track the calibration of the DXA scanner over time. GE Lunar and Norland Swissray systems necessitate scanning an external calibration block to perform a calibration check. The technologist must observe the procedure; he or she should review the report and note whether the system passed all tests of internal parameters (Fig. 19.18). Hologic systems perform an automatic internal calibration check when the system is turned on.

Manufacturers also provide semianthropomorphic and aluminum phantoms for tracking calibration over time. Hologic systems require that daily QC be performed before patient scanning (Fig. 19.19).

When not recommended by the manufacturer, the ISCD advises the following procedures; Periodic (at least once per week) phantom scans should be performed for any DXA system as an independent assessment of system calibration. The BMD is plotted, monitored, and checked with statistical and quality control rules. The quality control rule used to check DXA scanners is modified from Shewhart Control Chart rules. Shewhart rules are a classic method of checking that a quality parameter is stable and within acceptable limits of 3 SDs. For DXA, the value of the control limits is modified to *1.5%* of the mean to provide more uniformity across scanners.

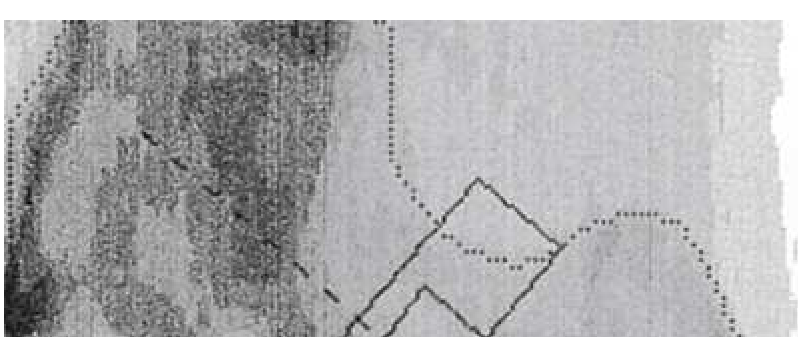
The mean and SD are calculated from the first 25 measurements of the parameter. A graph is created displaying the mean and the control limits 1.5 SDs above and below the mean. The parameter measurements are plotted over time and checked for violation of rules, such as one measurement more than 1.5 SDs from the mean. DXA control charts display the mean as the center line with control limits (1.5% of the mean) above and below. The Hologic software produces this graph automatically (see Fig. 19.15). For other manufacturers, the graph and plotting must be done by hand. The technologist must verify the phantom BMD after any service is performed on the scanner. When the phantom BMD value falls outside the control limits, the scan should be repeated once; if it fails, service should be called and patient scans should be canceled. If the BMD remains outside the control limits, the manufacturer must be contacted. No patients should be scanned until the equipment has been repaired and is operating within the known values.

Ten phantom scans should be performed and plotted before and after scanner preventive maintenance, repair, relocation, and software or hardware upgrades. This practice is to ensure that the calibration has not been altered and proper adjustments can be made. These phantoms and values should be reviewed before the service engineer leaves the DXA laboratory. Recalibration adjustments should be made before scanning any patients. The technologist is required to oversee this operation.

Inconsistent phantom scanning, analysis, or interpretation of the results may lead to false precision and patient outcomes. The DXA technologist must understand the quality control procedures and follow them consistently. DXA laboratories should have written standard operating procedures (SOPs) and documented instructions to ensure consistency among technologists. The technologist is required to maintain service logs and compliance with government inspections, radiation surveys, and regulatory requirements.

FIG. 19.19 Hologic phantom.

A white block with a grey irregular region at the top in the middle. The text on it reads, hologic D X A quality control phantom serial number 20621. Area: 95.2 centimeter squared, B M C: 35.6 gram, B M D: 0.01 gram per centimeter squared. A label is below it.



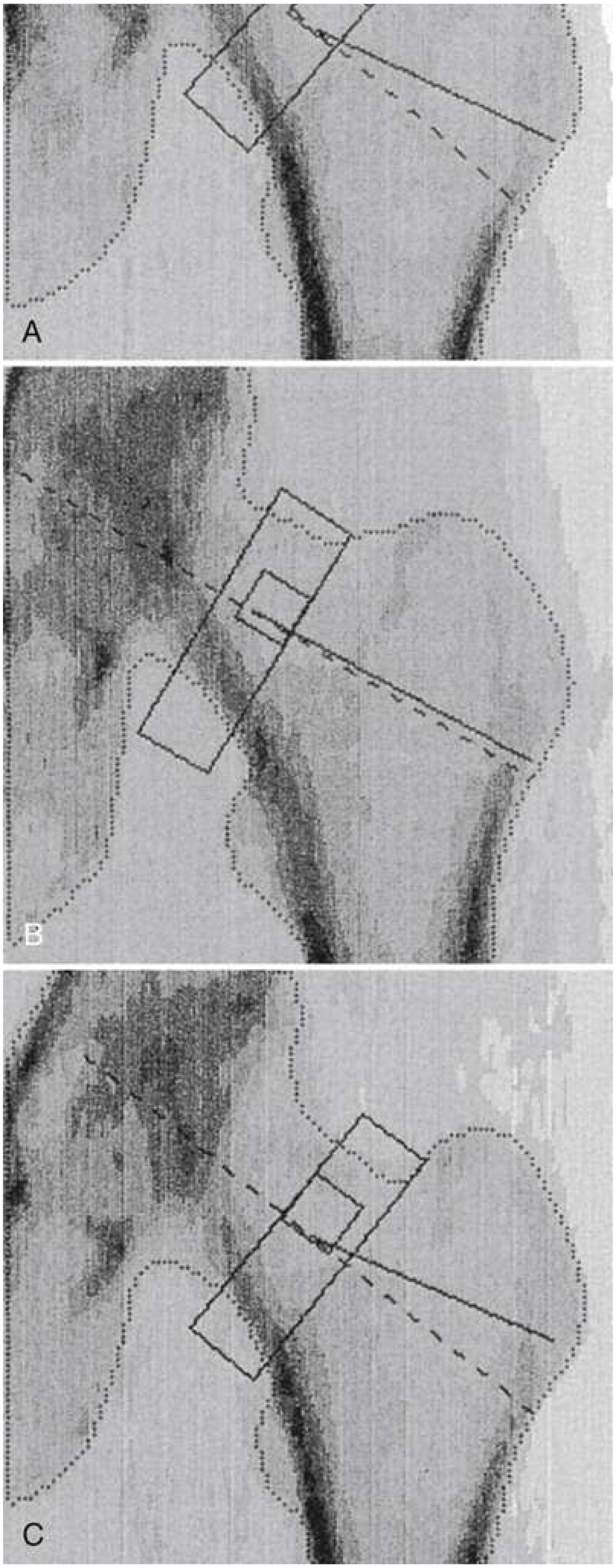


FIG. 19.20 Examples of incorrect and correct follow-up scan positioning. Note difference in BMD between the scans. (A) Baseline hip scan. (B) Incorrectly positioned follow-up scan. Size and shape of

lesser trochanter and angle of femoral body do not match baseline. (C) Correctly positioned follow-up scan.

(A) shows the baseline hip scan. A rectangular box is drawn at the femur head. A dotted line and a line intersects at the center of the box. (B) shows the baseline hip scan. A rectangular box is drawn at the femur head. The size and shape of lesser trochanter and angle of femoral body are aligned to each other. (C) shows the baseline hip scan. A rectangular box is drawn at the femur head. A dotted line and a line intersects at the center of the box.

Anatomy, Positioning, and Analysis

Radiologic technologists receive extensive instruction in anatomy during their radiology training. DXA scanning requires knowledge of DXA-specific anatomy. This anatomy relates to positioning the patient properly for scan acquisition. The points presented in this section generally apply to all DXA scanners; however, instruction from the specific manufacturer is required before operating the scanner.

Similar to all technologies, DXA has operating limits. Accuracy and precision may be impaired if the bone mass is low, the patient is too thick or thin, the anatomy is abnormal, or there have been significant changes in soft tissue between serial scans. The added value of an experienced DXA technologist is recognition and adaptation to abnormal situations. Any anomaly or protocol variation that may compromise the scan results must be noted by the technologist and taken into consideration by the interpreting physician.

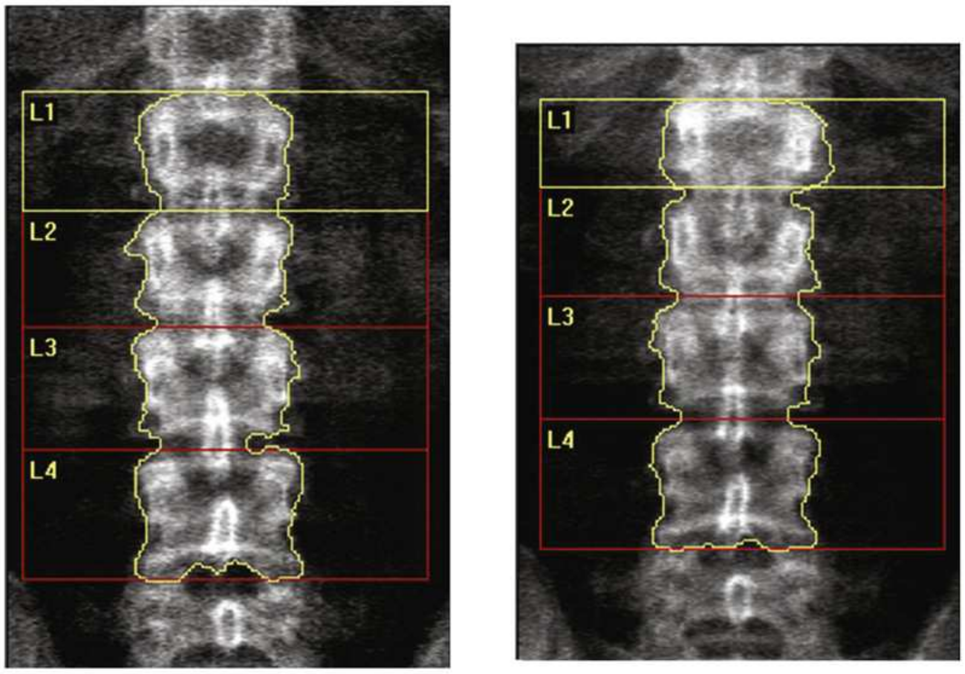
DXA calculations are based on soft tissue and bone. Adequate amounts of soft tissue are essential for valid results.

Serial scans

DXA is a qualitative instrument used to monitor BMD change over time. True comparison of BMD results requires that serial scans be performed on the same scanner that was used for the baseline scans.

Scan results are more precise with less intervention from the technologist and the DXA equipment, reflecting a true biologic change. It is imperative that the patient positioning be exactly the same for baseline and serial scans. The same scan settings (e.g., field size, mode, or speed and current) and ROI should be placed identically on the images. These steps ensure that scan results are comparable over time. The software's *compare feature or copy* should be used. The baseline scans should be available at the time of the patient's appointment. Documentation of any procedures out of the range of the laboratory's SOP needs to be available when performing serial scans. ISCD recommends comparing any serial scan to the baseline scan. If the baseline scan has been previously analyzed incorrectly, always reanalyze correctly and then compare. Note this information for the interpreting clinician.

Fig. 19.20 shows the comparison of a patient's baseline hip scan (see Fig. 19.20A) and a follow-up scan done 6 years later. It is an example to demonstrate why follow-up positioning must match baseline if the BMD measurements are to be compared. The first follow-up scan (see Fig. 19.20B) did not reproduce the baseline positioning. The rotation of the femoral neck was different, as indicated by the larger lesser trochanter and the femoral shaft being more abducted, and resulted in the midline being placed differently by the software and a different angle for the neck ROI. The scan was repeated (see Fig. 19.20C) to reproduce the baseline positioning correctly. The difference in total hip BMD between scans *A* and *B* is −13% compared with a difference of −10% between scans *A* and *C*.



A

Region	Area(cm²)	BMC(g)	BMD(g/cm²)
L1	13.56	10.07	0.743
L2	13.75	11.63	0.846
L3	14.56	11.83	0.812
L4	16.44	14.34	0.872
TOTAL	58.31	47.87	0.821

B

Region	Area(cm²)	BMC(g)	BMD(g/cm²)
L1	11.45	10.88	0.951
L2	12.97	11.72	0.903
L3	14.95	11.80	0.789
L4	16.50	14.35	0.870
TOTAL	55.87	48.75	0.873

FIG. 19.21 Use of Hologic compare feature indicates that L1 bone map and ROI from baseline scan (A) no longer fit the follow-up scan (B) because of a compression fracture of L1. Both scans should be analyzed to exclude L1 before comparing total BMD. Note differences in BMD and area measurements.

(A) shows a radiographic image of the spine. The border is outlined in yellow. A rectangular box is split into four sections and is labeled as L 1, L 2, L 3, and L 4 respectively. All are of the same size. A table below it has four columns and five rows. From left to the right, the columns are listed as region, area in centimeter squared, B M C in gram, B M D (gram over centimeter squared). The row-wise entries of the table are as follows: Row 1. L 1, 13.56, 10.07, 0.743. Row 2. L 2, 13.75, 11.63, 0.846. Row 3. L 3, 14.56, 11.83, 0.812. Row 4. L 4, 16.44, 14.34, 0.872. Row 5. Total, 58.31, 47.87, 0.821. (B) shows a radiographic image of the spine. The border is outlined in yellow. A rectangular box is split into four sections and is labeled as L 1, L 2, L 3, and L 4 respectively. They are of different sizes. L 1 is small and L 4 is bigger than the rest. A table below it has four columns and five rows. From left to the right, the columns are listed as region, area in centimeter squared, B M C in gram, B M D (gram over centimeter squared). The row-wise entries of the table are as follows: Row 1. L 1, 11.45, 10.88, 0.952. Row 2. L 2, 12.97, 11.72, 0.903. Row 3. L 3, 14.95, 11.80, 0.789. Row 4. L 4, 16.50, 14.35, 0.870. Row 5. Total, 55.87, 48.75, 0.873.

PA lumbar spine

Spine scans are most appropriate for predicting vertebral fracture risk. It is noted that vertebral fractures are the most common osteoporotic fracture. Underestimation of fracture risk occurs in patients older than 65 years who present with degenerative changes that can artificially elevate spinal BMD. The following points can help with positioning patients for PA lumbar spine DXA scans, analyzing the scan results, and evaluating the validity of the scans:

1. Degenerative changes in the spine, such as *osteophytosis*, overlying calcification, compression fractures (Fig. 19.21), or scoliosis greater than 15 degrees (Fig. 19.22), can falsely elevate the BMD. Artifacts in the vertebral bodies or very dense artifacts in the soft tissue may also affect the BMD, depending on the model of the scanner and version of the software. The interpreting clinician should develop policies and protocols for the technologist in these circumstances (e.g., do not include the spine but include another site, such as forearm). These are considered SOPs and should be followed by all technologists for consistency.
2. The lumbar spine is centered in the scan field. In a patient with scoliosis, L5 may need to be off center so that adequate and relatively equal amounts of soft tissue are on either side of the spine throughout the scan.
3. Some visualization of iliac crests should be acquired in the scan region. This ensures the inclusion of all of L4. The iliac crest is an excellent landmark for consistent placement of the intervertebral markers at baseline and follow-up scanning.

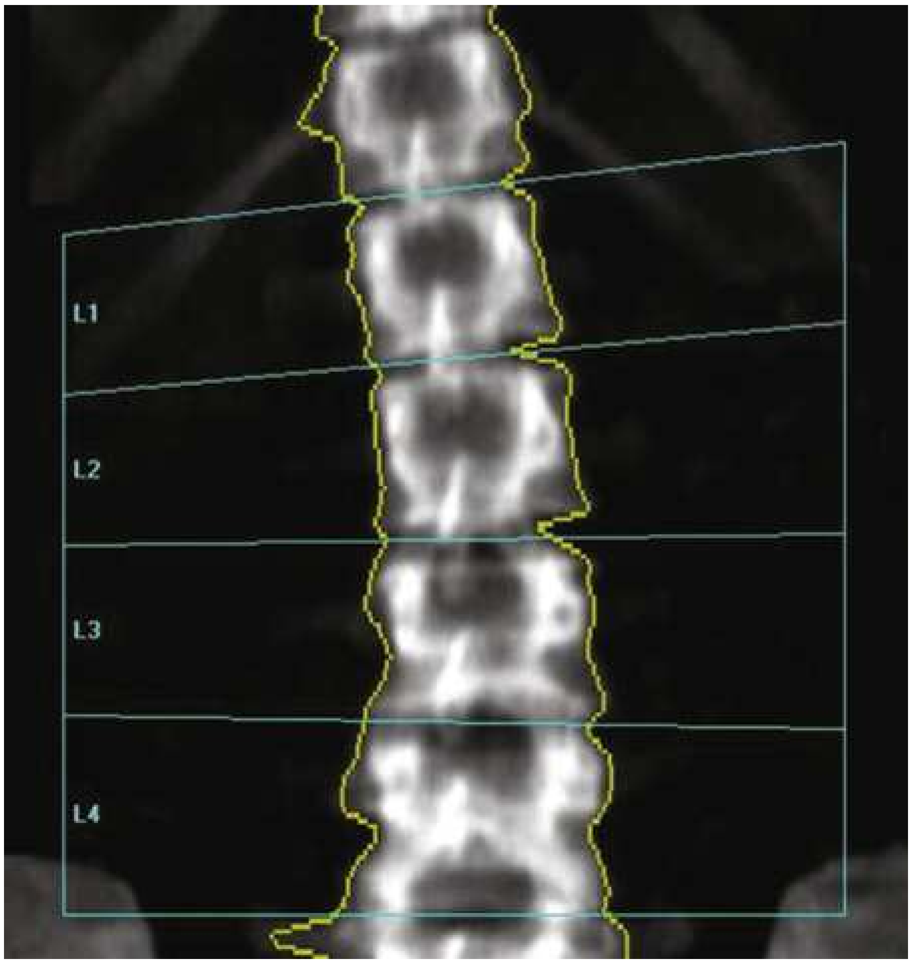


FIG. 19.22 DXA PA spine scan with scoliosis and scoliosis analysis technique.

A D X A P A scan shows the spine. The lumbar spine is centered in the scan field. The border is outlined in yellow. A rectangular box is split into four sections and is labeled as L 1, L 2, L 3, and L 4 respectively. They are of different sizes. The left side of the box is short and the right side of the box is long.

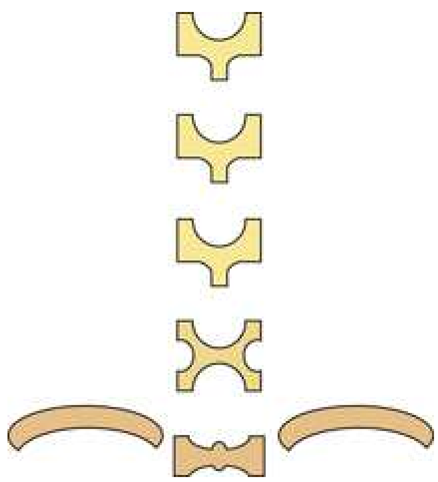


FIG. 19.23 Characteristic shapes of L1-5 and their relationship to the iliac crests as seen on DXA PA spine scan.

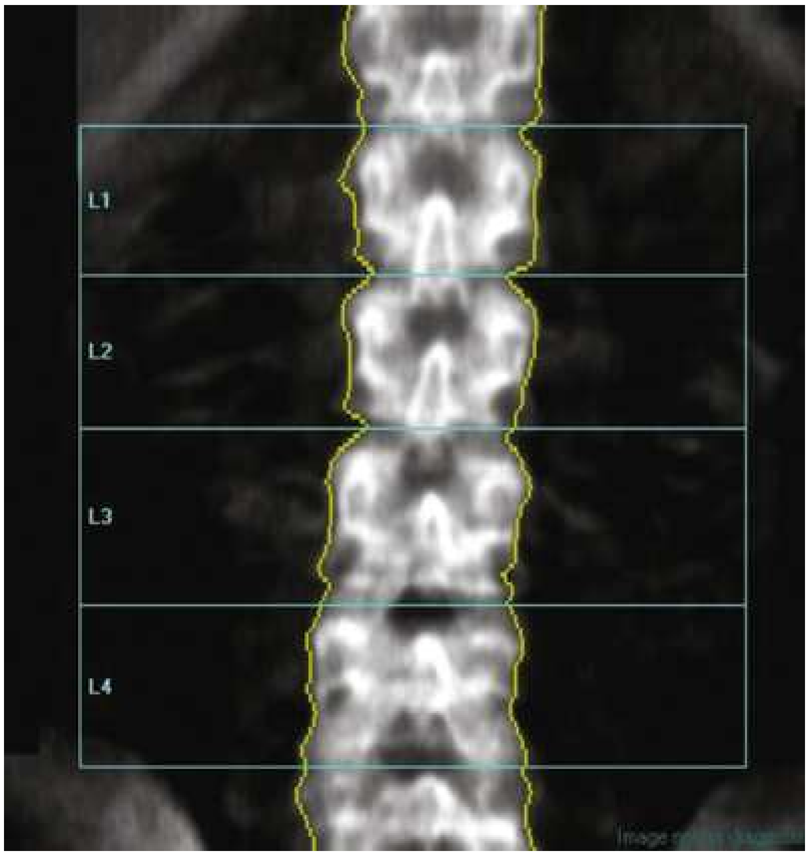


FIG. 19.24 Six lumbar vertebrae. Vertebral labeling is done from the bottom to the top according to the shape of the vertebrae.

A D X A P A scan shows the six lumbar vertebrae. The lumbar spine is centered in the scan field. The border is outlined in yellow. A rectangular box is split into four sections and is labeled as L 1, L 2, L 3, and L 4 respectively. They are of different sizes.

4. The PA spine scan image displays the posterior vertebral elements, which have unique characteristic shapes, in contrast to a general lumbar radiograph. These shapes can be used to differentiate placement of the intervertebral markers. When degenerative disease has obscured the intervertebral spaces, these shapes can aid in determining proper labeling of the vertebral levels. L1, L2, and L3 have a U shape; L4 has an H or X shape and appears to have "feet," and L5 looks like a sideways I or "dog bone" (Fig. 19.23). Another aid is that L3 typically has the widest transverse processes. L1, L2, and L3 are approximately the same height. L4 is a bit taller than the others, whereas L5 is the shortest in height. The iliac crest usually lies at the level of L4-5 intervertebral space.
5. A small percentage of patients appear to have four or six lumbar vertebrae rather than five, which is most commonly seen. The vertebrae can be labeled by locating L5 and L4 on the basis of their characteristic shapes and then counting upward (Fig. 19.24). The procedure of counting from the bottom greatly biases toward a higher BMD and avoids including T12 without a rib, which significantly lowers the BMD. This procedure ensures a conservative diagnosis of low BMD. If necessary, the technologist can adjust the scan parameters manually to accommodate the six lumbar vertebrae.
6. Do not adjust the bone edges or angle or move the intervertebral markers unless absolutely necessary. These techniques should be performed in a fashion that is easy to reproduce for serial scans. Variations to protocol should be documented.
7. Check that the patient is lying straight by observing from the head or foot end of the table. If a patient is lying straight on the table, but the spine is not straight on the scan, do not attempt to twist the patient to get the image straight. This unusual positioning would not be reproducible at follow-up. Make a note in the record that the patient was positioned straight on the table.
8. The purpose of the leg-positioning block is to reduce the lordotic curve, open up the intervertebral spaces, and reduce the part-image distance. Consistency in using the same height of the leg-positioning block when a patient returns for serial scans is important. Document the block height.
9. A checklist for a good PA spine scan (see Fig. 19.21A) includes the following:
   - The spine is straight and centered in the scan field. Patients with scoliosis should have equal amounts of soft tissue on either side of the spine if possible.
   - The scan contains a portion of the iliac crest and half of T12; the last set of ribs is shown, when applicable.
   - The entire scan field is free of external artifacts.
   - The intervertebral markers are properly placed.
   - The vertebral levels are properly labeled.
   - The bone edges are correct.

Proximal femur

The hip scan is perhaps the most important because it is the best predictor of future hip fracture, which is the most devastating of fragility fractures. Compared with the spine scan, the hip scan is more difficult to perform properly and precisely because of variations in anatomy and the small ROI. The following points can help in positioning patients for hip DXA scans, analyzing the results, and evaluating the validity of the scans:

1. With the patient in a supine position, rotate the entire leg 15 to 25 degrees internally to place the femoral neck parallel with the tabletop and perpendicular to the x-ray beam. Successful rotation is achieved when the lesser trochanter is diminished in size and only slightly visible (or not visible). A large, pointed lesser trochanter may indicate a low degree of rotation (see Fig. 19.20B and C). However, patient anatomy is not always as shown in textbooks. Patients can have a prominent lesser trochanter, and proper rotation is achieved when the femoral neck region is free of overlapping ischium, and appropriate pelvis separation is visualized. This positioning allows proper placement of the femoral neck ROI. All scanners come with positioning aids that should be used according to the manufacturer's instructions.
2. The shaft of the femur must be straight and parallel to the long axis of the table.
3. A few patients have little or no space between the ischium and femoral neck. In some cases, part of the ischium lies under the femoral neck, elevating the BMC and falsely elevating the femoral neck BMD (Fig. 19.25). This could be caused by the rotation of the ischium (pelvis). The patient should be removed from the table and repositioned. If the problem persists, slightly adjust the leg until the ischium and neck are separated. Variations in positioning should be noted and reproduced at the time of the serial scan.

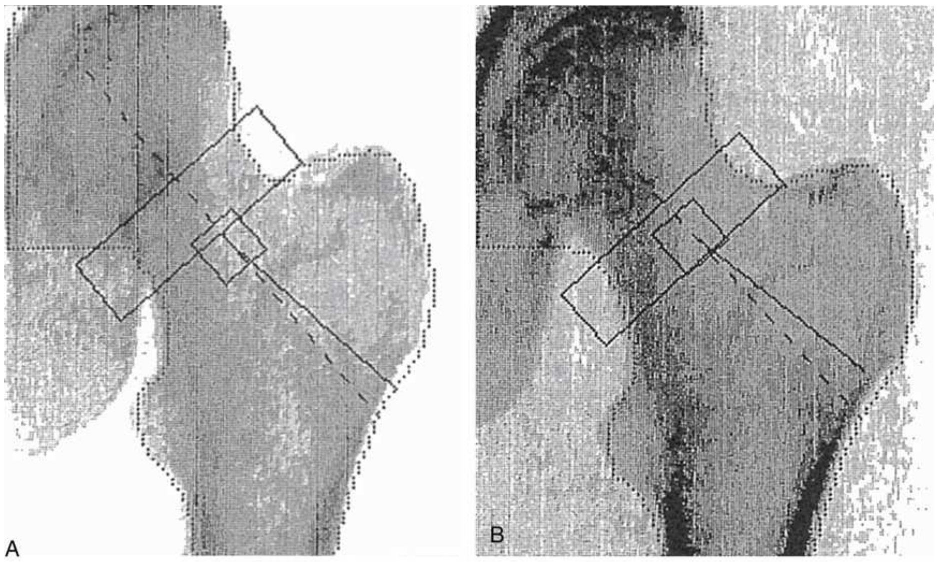


FIG. 19.25 (A) Despite use of the software tool to "cut out the ischium," bone from the ischium underlies the femoral neck ROI. The BMC is increased, increasing the BMD. (B) The same patient was positioned for a follow-up scan 1 year later. The pelvis is no longer rotated, as indicated by the narrower width of the ischium. Adequate space exists between the neck and ischium, and there is no ischium beneath the neck ROI. This is an example of poor pelvis positioning in A; the patient must be lying flat on the pelvis as in B. These two scans *cannot* be compared for rate of bone loss. The scan in B should be considered a new baseline and compared with a properly performed follow-up scan in the future.

(A) shows the baseline hip scan. A rectangular box is drawn at the femur head. A dotted line and a line intersects at the center of the box. The background appears white and the bones appear grainy. (A) shows the baseline hip scan. A rectangular box is drawn at the femur head. A dotted line and a line intersects at the center of the box. The background appears grey and the bones appear dark and grainy.

4. To compare proximal femur BMD over time, the positioning must be exactly reproduced and the angle of the neck box ROI must be the same (see Fig. 19.20). Check these points on the baseline and serial scan images:
   - The lesser trochanter must be of same size and shape. If not, change the hip rotation. More rotation would make the lesser trochanter appear smaller.
   - The femoral shaft must be abducted the same amount. Adjust the abduction or adduction accordingly.
   - The neck box ROI is automatically placed perpendicular to the midline, so the midline must be at the same angle in each scan. If it is not, reposition as required. If positioning is not the problem, proper software adjustments must be made according to the manufacturer's guidelines.
5. A fractured hip with orthopedic hardware should not be scanned. If arthritis is present in the scan, it can cause an increase in the density of the medial hip with shortening of the femoral neck (Fig. 19.26). The less affected hip should, therefore, be scanned for an accurate diagnosis. The DXA diagnosis should always be based on the lowest BMD value. The limits of the technology are taxed by patients who are very thin or thick or have very low bone mass. These problems are revealed by poor bone edge detection, a mottled appearance of the image, or both. Some images show the bone edges, and it is obvious when the proper edge cannot be detected. For images that do not show the bone edges, the area values must be checked and compared. The operator's manual may not adequately cover these problems. The technologist is responsible for recognizing problems and querying the manufacturer's application department about the best ways to handle such difficulties. If a patient is deemed unsuitable for a DXA hip scan, another site, such as a forearm, may prove to be valuable.
6. A basic checklist for a good DXA hip scan (see Fig. 19.20A) includes the following:
   - The lesser trochanter is small or barely visible.
   - The midline of the femoral shaft is parallel to the lateral edge of the scan.
   - Adequate space is present between the ischium and femoral neck.

- The midline through the femoral neck is reasonably placed, resulting in a reasonable angle for the femoral neck box.
- The proximal, distal, and lateral edges of the scan field are properly located.
- No air is present in the scan field on GE Lunar scans.

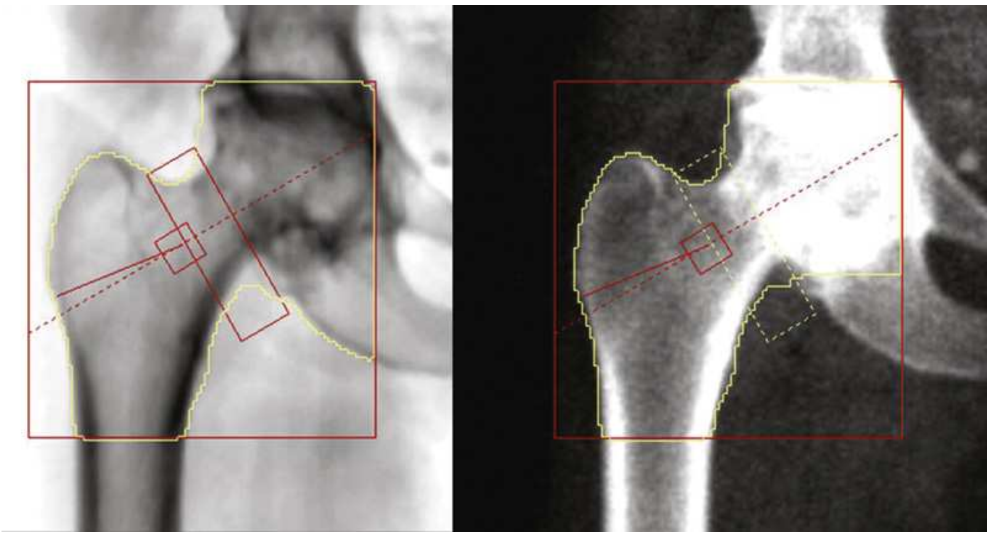


FIG. 19.26 Hip arthritis. Note increased density in medial hip and foreshortened femoral neck. The technologist may be required to intervene in this situation. Notation of difficulty with positioning and known arthritis should be mentioned on the patient's history form.

(A) shows the baseline hip scan. A rectangular box is drawn inside a square at the femur head. A dotted line and a line intersects at the center of the box. The border of the bone is outlined in yellow. The background appears grey and the bones appear grainy. (A) shows the baseline hip scan. A rectangular box is drawn inside a square at the femur head. A dotted line and a line intersects at the center of the box. The border of the bone is outlined in yellow. The background appears black and the bones appear grey and grainy. The region above the femur head is radiopaque.

Forearm

Two important ROIs are present on the DXA forearm scan: the ultradistal region, which is the site of the common Colles fracture, and the one-third (33%) region, which measures an area that is primarily cortical bone near the mid-forearm (see Table 19.1). Although the ulna is used for forearm length measurement and available for analysis, only the one-third (33%) region of the radius is reported. The following guidelines can aid in positioning, acquisition, and analysis of forearm DXA scans and evaluating the validity of the scans:

1. The nondominant forearm is scanned because it is expected to have slightly lower BMD than the dominant arm. A forearm should not be scanned in patients with a history of wrist fracture, internal hardware, or severe deformity resulting from arthritis. An indication for scanning the forearm would be documented hyperparathyroidism.
2. The same chair should be used for all patients to ensure consistency over time. The chair should have a back but no wheels or arms.
3. At the time of the baseline scan, the forearm should be measured according to the manufacturer's instructions. The ulna is measured from the ulnar styloid to the olecranon process. The distal one-third of this measurement is used to place the one-third, or 33%, ROI. A manufacturer estimates the forearm length based on the height. The directions for determining the starting and ending locations of the scan must be followed exactly (Fig. 19.27A).
4. The forearm must be straight and centered in the scan field (see Fig. 19.27A). Correct use of the appropriate positioning aids must be applied. For Hologic models, the forearm scan requires adequate amounts of air in the scan field. Soft tissue must surround the ulna and radius, and several lines of air must be present on the ulnar side. If the forearm is wide, the scan must be manually set for a wider scan region so that adequate air is included.
5. Motion is a common problem in forearm scan acquisition (see Fig. 19.27A). The patient should be in a comfortable position so that the arm does not move during the scan. The hand and proximal forearm can be secured with straps or tapes placed outside the scan field. Avoid unnecessary conversation during the scan to minimize movements.

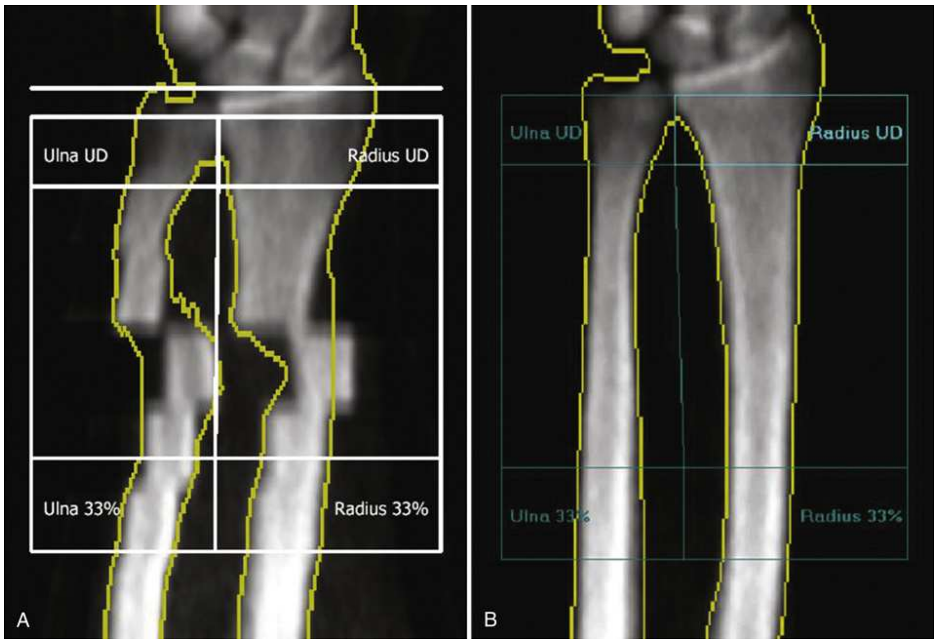


FIG. 19.27 DXA forearm scans. (A) DXA forearm scan shows several positioning and acquisition mistakes: The forearm is not straight or centered in the scan field, and motion has occurred in the radius and ulna. (B) Scan shows good patient positioning, scan acquisition, and scan analysis.

(A) shows a scan of the forearm which is not straight. The border of the bone is outlined in yellow. The background appears black. There is an irregularly shaped blurred region at the center. A box over the scan is split into two parts on either side. They are labeled on the top as ulna U D and radius U D. At the bottom they are labeled as ulna 33 percent and radius 33 percent. (B) shows a scan of the forearm that is straight and centered in the scan field. The background appears black. The border of the bone is outlined in yellow. A box over the scan is split into two parts on either side. They are labeled on the top as ulna U D and radius U D. At the bottom they are labeled as ulna 33 percent and radius 33 percent.

6. The placement of the ultradistal ROI should be just below the radial end plate. This placement is easy to reproduce on serial scans. The ultradistal ROI is subject to low BMD, which could create bone edge detection problems. The bone edge should be adjusted if necessary. Baseline and serial scan bone edges must match for proper analysis, comparison, and report of percent change over time.
7. A basic checklist for a good DXA forearm scan (see Fig. 19.27B) includes the following:
    - The forearm is straight and centered in the scan field.
    - Adequate amounts of soft tissue and air are included.
    - No motion is present.
    - The proximal and distal ends of the scan field are properly placed.
    - Bone edges are properly and consistently placed.
    - No artifacts or clothing are present in the scan field.

Other Bone Densitometry Techniques

Central (or Axial) Skeletal Measurements

QCT is an established method using cross-sectional CT images from commercial scanners equipped with QCT software and a bone mineral reference standard. QCT has the unique ability to provide separate BMD measurements of trabecular and cortical bone and true volumetric density measurements in grams per cubic centimeter (g/cm^3). QCT of the spine is used to measure the trabecular bone within the vertebral bodies to estimate vertebral fracture risk and age-related bone loss; it is also used for follow-up of osteoporosis and other metabolic bone diseases and their therapies (Fig. 19.28). Other current uses of QCT involve measuring BMD at the hip and producing high-resolution three-dimensional images to analyze trabecular bone architecture.

Lateral lumbar spine DXA scans can be performed with the patient in the decubitus lateral position using fan-beam technology. Decubitus lateral scans are obtained with fixed-arm scanners. Lateral spine DXA allows partial removal of the outer cortical bone and gives a truer measurement of the inner trabecular bone, which experiences earlier bone loss and is more responsive to therapy (see Fig. 19.10). However, lateral spine DXA is often confounded by superimposition of the ribs and iliac crest with the vertebral bodies and has poorer precision than does PA spine DXA. Lateral DXA is more widely used in clinical practice for early detection of vertebral fractures and abdominal aortic calcifications.

The term *vertebral fracture assessment (VFA)* encompasses looking at the spine “morphometrically” in the lateral projection, which means visualizing the shapes of the vertebral bodies of the lumbar and thoracic spine to determine if there has been some deformity with resultant compression of the vertebral bodies. Dual energy vertebral assessment (DVA), lateral vertebral assessment (LVA), instant vertebral analysis (IVA), and radiologic vertebral assessment (RVA) are synonymous for this process. The manufacturers of bone densitometers have devised their own way of either enhancing the image or improving the scan acquisition and analysis. Images are obtained in dual energy acquisition and the single energy method. Both methods are comparable. VFA is used for the sole purpose of detecting vertebral fractures.

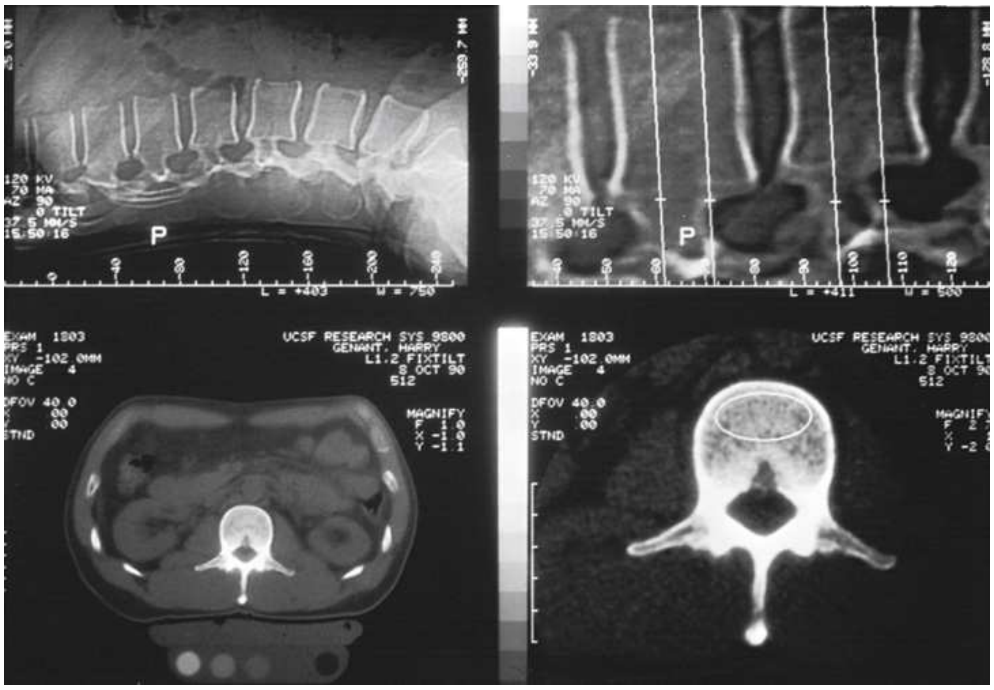


FIG. 19.28 Examples of various elements of QCT examination. *Upper left,* Lateral scout image of lumbar spine. *Upper right,* Localizer lines for midvertebral slices through L1 and L2. *Lower left,* CT slice showing calibration phantom below the patient. *Lower right,* Elliptic ROI positioned in the trabecular bone of the vertebral body.

A radiographic image on the top left shows lateral scout image of lumbar spine. The calibrations at the bottom range from 0 to 240. A radiographic image on the top right shows four vertical lines for midvertebral slices through L 1 and L 2. The calibrations at the bottom range from 40 to 120.A radiographic image on the bottom left shows a C T slice of the vertebra. A radiopaque region with three pointed ends is on the image. A radiographic image on the bottom right shows the trabecular bone of the vertebral body. It appears radiopaque with three pointed ends. A oval is drawn at the head.

In contrast to traditional lateral spine x-rays, VFA has the capability of visualizing the lumbar and the thoracic spine as one continuous image. This capability aids the interpreting physician in identifying the vertebral level where abnormalities are present. PA views can also be incorporated into a VFA study. For an accurate representation of the vertebral bodies, the patient's spine must be as straight as possible.

The PA view can help identify artifacts and deformities, such as scoliosis. Scoliosis is a condition that can cause the greatest challenge in VFA and could possibly make a study "unreadable." VFA also exposes the patient to approximately 1⁄100 the radiation dose of just a single lateral x-ray image. VFA is an adjunct to DXA scanning in cases where a patient might not have been x-rayed for vertebral fracture beforehand. General spine x-ray is still the "gold standard" for visualizing abnormalities in the spine.

VFA uses single energy x-ray absorptiometry (for image only) or DXA (for image and BMD) lateral scans of the thoracic and lumbar spines from the level of approximately T4 to L5 (Fig. 19.29). The images are used to determine abnormalities in vertebral shape that may indicate vertebral fragility fractures, which are a strong risk factor for future vertebral fractures. The upper right corner of Fig. 19.29 shows the Genant grading system. The three columns on the right show the types of fracture, and the rows show the grades of severity. Seeing a severe fracture is easy, and seeing a moderate fracture is relatively easy, but it is difficult to determine if a mild deformity is normal for the patient or the beginning of a problem. VFA should be interpreted by a trained physician who is viewing the images on the scan monitor (Fig. 19.30).

FIG. 19.29 Morphometric x-ray absorptiometry scan to detect vertebral shape abnormalities. Genant grading system is in the *upper right corner.* Courtesy Hologic, Inc, Bedford, MA.

A screen is titled hologic view print utility. The options on the left are single, single with data, compare. Single with data is selected. Below it is a box labeled markers. Under it, deformity I D, W 128, L 128, revert, invert, flip, zoom in, zoom out, print report, print image, exit. A radiographic image in the middle shows the lateral view of the spine. It is labeled as L 2 wedge (severe). On the right, a black and white image is under normal grade D. Nine black and white images are next to it. The labels reads, wedge deformity, biconcave deformity, crush deformity, milk grade 1, moderate grade 2, severe grade 3. Below it is the deformity identification. A horizontal line is under it. The labels above the line are vertebral label, deformity, grade. The labels below the line are L 2, wedge, severe.

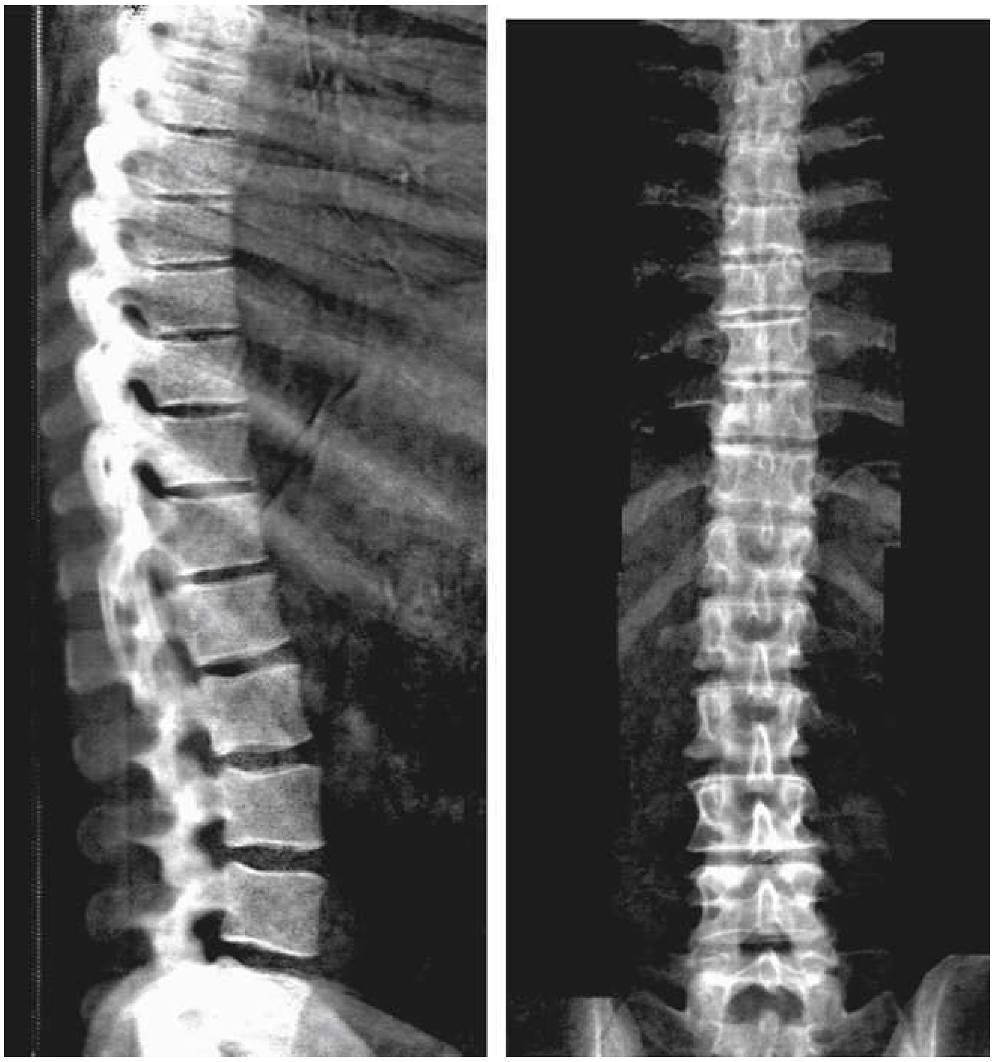


FIG. 19.30 Dual VFA.

A radiographic image on the left shows the lateral view of the spine. It appears radiopaque. The intervertebral spaces are well defined. A radiographic image on the right shows the anterior view of the spine.

Total body and body composition

Whole-body DXA measures bone mass (i.e., area, BMC, BMD) and *body composition* for the total body and subregions of the body (e.g., arms, legs, trunk). Body composition can be measured as fat and fat-free mass (with or without BMC) in grams or percent body fat (Fig. 19.31). Careful positioning is required to separate the bones of the forearm and lower leg. Obese patients present a problem when not all of the body fits in the scan field. The ROI must be carefully placed according to the manufacturer's instructions. Having internal or external artifacts that cannot be removed is not unusual; the effect of such artifacts depends on size, density, and location. Hip joint replacement hardware would have more effect than a woman's thin wedding band. Each DXA laboratory should have written SOPs so that all patients are scanned and analyzed consistently. All deviations from normal and artifacts should be noted for the interpreting physician. Whole-body DXA data are useful for studying energy expenditure, energy stores, protein mass, skeletal mineral status, and relative hydration. These measurements have been used in research studies and clinical trials of osteoporosis therapies, obesity, and weight change, fat and lean distribution, and diabetes. Clinically, whole-body scans are used routinely in pediatrics and body fat analysis in athletes and patients with underweight disorders (e.g., anorexia nervosa).

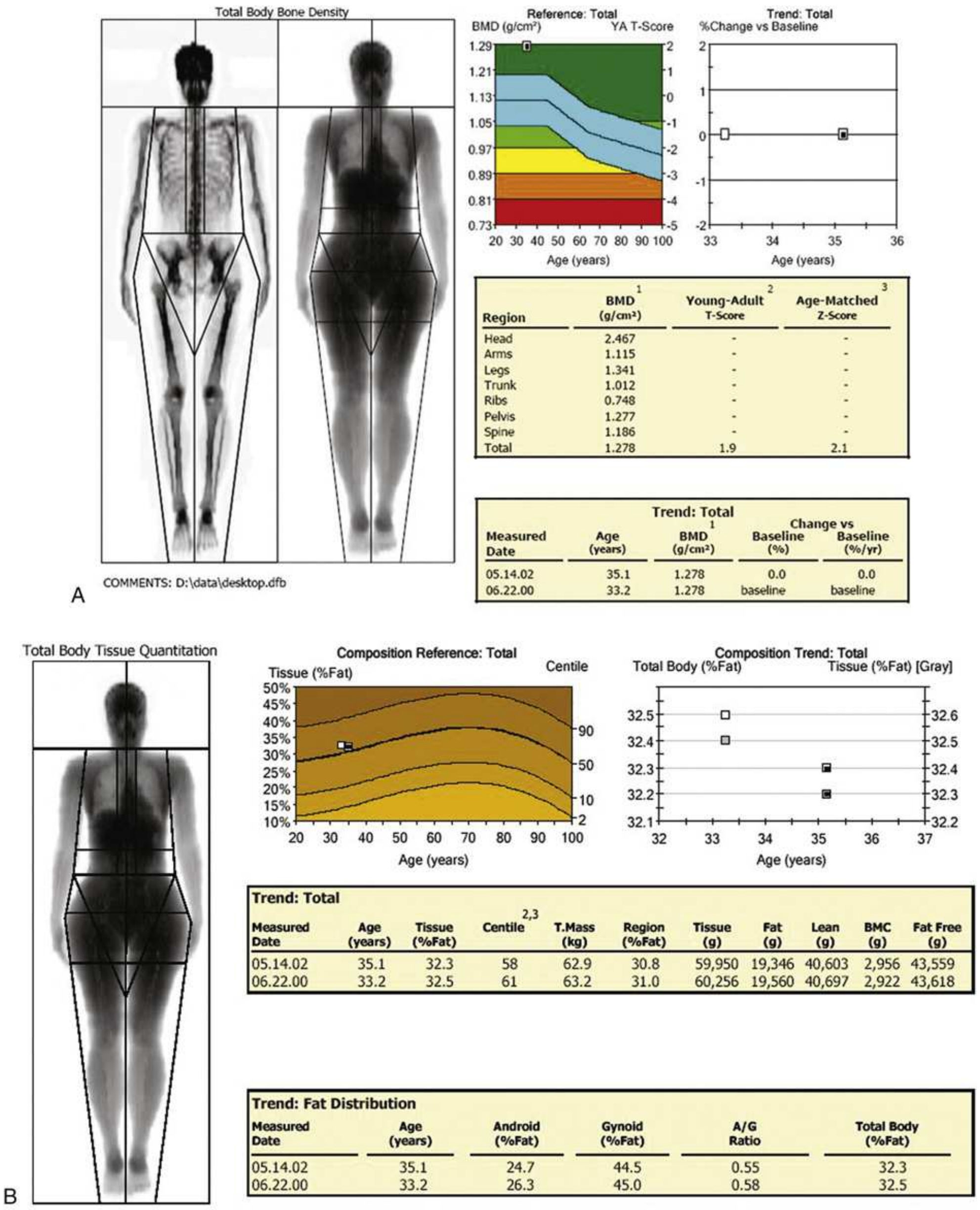


FIG. 19.31 (A) Hologic DXA whole-body scan with printout of total body composition results. (B) Percent body fat (*% Fat*) is reported. *YA*, Young adult.

(A) shows two whole-body scan. The scan on the left has more white areas compared with the scan on the right. A graph next to it is titled reference total. Age in years is scaled on the horizontal axis and B M D (grams over centimeter squared) is scaled on the vertical axis. The values in the horizontal axis range from 20 to 100 with an interval of 10. The values in the vertical axis range from 0.73 to 1.29. Another graph next to it has age in years labeled on the horizontal axis and percent change versus baseline labeled on the vertical axis. Age in years is scaled on the horizontal axis and percent change versus baseline is scaled on the vertical axis. The values in the horizontal axis range from 33 to 36. The values in the vertical axis range from negative 2 to 2. A table at the below has four columns and eight rows. From left to the right, the columns are labeled as region, B M D (gram over centimeter squared), young adult t-score, age matched z-score. Another table below is titled trend: total. It has five columns and two rows. From left to the right, the columns are labeled as measured date, age (years) B M D (years), B M D (grams over centimeter squared), change versus baseline in percent, change versus baseline in percent over years. (B) shows a whole-body scan. A graph next to it is titled reference total. Age in years is scaled on the horizontal axis and tissue in percent fat is scaled on the vertical axis. The values in the horizontal axis range from 20 to 100 with an interval of 10. The values in the vertical axis range from 10 percent to 50 percent. Another graph next to it has age in years labeled on the horizontal axis and total boy fat percent is scaled on the vertical axis. The values in the horizontal axis range from 23 to 37. The values in the vertical axis range from 32.1 to 32.5. There are two tables below.

Skeletal Health Assessment in Children From Infancy to Adolescence

Fracture prediction and definition of osteoporosis

- Evaluation of bone health should identify children and adolescents who may benefit from interventions to decrease their elevated risk of a clinically significant fracture.
- The finding of one or more vertebral compression (crush) fractures is indicative of osteoporosis in the absence of local disease or high-energy trauma. In such children and adolescents, measuring BMD adds to the overall assessment of bone health.
- The diagnosis of osteoporosis in children and adolescents should not be made on the basis of densitometric criteria alone.
- In the absence of vertebral compression (crush) fractures, the diagnosis of osteoporosis is indicated by the presence of both a clinically significant history of fracture and BMD Z-score less than or equal to −2.0. A clinically significant fracture history is one or more of the following: (1) two or more long bone fractures by age 10 years; (2) three or more long bone fractures at any age up to 19 years of age. A BMC/BMD Z-score greater than −2.0 does not preclude the possibility of skeletal fragility and increased fracture risk.

DXA assessment in children and adolescents with disease that may affect the skeleton

- DXA measurement is part of a comprehensive skeletal health assessment in patients with increased risk of fracture.
- In patients with primary bone disease or at risk for a secondary bone disease, a DXA should be performed when the patient may benefit from interventions to decrease their elevated risk of a clinically significant fracture, and the DXA results will influence that management.
- DXA should not be performed if safe and appropriate positioning of the child cannot be ensured.

QCT in children and adolescents

There is no preferred method for QCT for clinical application in children and adolescents. QCT, pQCT peripheral quantitative computed tomography (pQCT), and high-resolution-peripheral quantitative computed tomography (HR-pQCT) are primarily research techniques used to characterize bone deficits in children. They can be used clinically in children when appropriate reference data and expertise are available. It is imperative that QCT protocols in children using general CT scanners implement appropriate exposure factors, calibration phantoms, and software to optimize results and minimize radiation exposure.

Densitometry in infants and young children

DXA is an appropriate method for clinical densitometry of infants and young children. DXA lumbar spine measurements are feasible and can provide reproducible measures of BMC and areal bone mineral density (aBMD) for infants and young children 0 to 5 years of age. DXA whole-body measurements are feasible and can provide reproducible measures of BMC and aBMD for children 3 years or older. DXA whole-body BMC measurements for children younger than 3 years are of limited clinical utility due to feasibility and lack of normative data. Areal BMD should not be used routinely due to difficulty in appropriate positioning. Forearm and femur measurements are technically feasible in infants and young children, but there is insufficient information regarding methodology, reproducibility, and reference data for these measurement sites to be clinically useful at this time. In infants and children younger than 5 years, the impact of growth delay on the interpretation of the DXA results should be considered, but it is not currently quantifiable (Fig. 19.32) (ISCD 2019 Position Statements).

DXA interpretation and reporting in children and adolescents

- DXA is the preferred method for assessing BMC and areal BMD.
- The PA spine and total body less head (TBLH) are the preferred skeletal sites for performing BMC and areal BMD measurements in most pediatric subjects. Soft tissue measures in conjunction with whole-body scans may be helpful in evaluating patients with chronic conditions associated with malnutrition or with muscular and skeletal deficits.
- The hip is not a preferred measurement site in growing children due to variability in skeletal development.
- If a follow-up DXA scan is indicated, the minimum interval between scans is 6 to 12 months.
- In children with short stature or growth delay, spine and TBLH BMC and areal BMD results should be adjusted. For the spine, adjustment should be done using either bone mineral apparent density (BMAD) or the height Z-score. For TBLH, adjust using the height Z-score.
- An appropriate reference data set must include a sample of healthy representatives of the general population sufficiently large to capture variability in bone measures that takes into consideration gender, age, and race/ethnicity.
- When upgrading densitometer instrumentation or software, it is essential to use reference data valid for the hardware and software technologic updates.

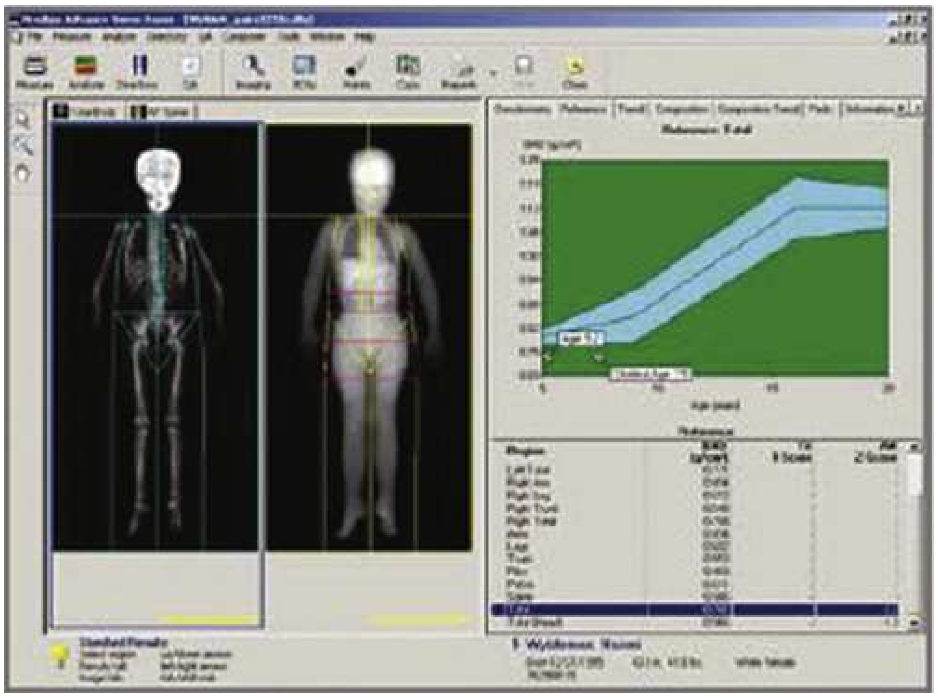


FIG. 19.32 Pediatric BMD and soft tissue assessment.

A screen shows two separate radiographic images. The image on the left shows the anterior view of the human body. The bones appear radiopaque. The image on the right shows the anterior view of the human body. The soft tissues appear white and blurry. A graph is on the right side and a table is below it.

- Baseline DXA reports should contain the following information:
  - DXA manufacturer, model, and software version
  - Referring physician
  - Patient age, gender, race-ethnicity, weight, and height
  - Relevant medical history including previous fractures
  - Indication for study
  - Tanner stage or bone age results, if available
  - Technical quality
  - BMC and areal BMD
  - BMC and/or areal BMD Z-score
  - Source of reference data for Z-score calculation
  - Adjustments made for growth and interpretation
  - Recommendations for the necessity and timing of the next DXA study are optional
- Serial DXA reports should include the same information as for baseline testing. In addition, indications for follow-up scan, technical comparability of studies, changes in height and weight, and changes in BMC and areal BMD Z-scores should be reported.
- Terminology
  - T-scores should not appear in pediatric DXA reports.
  - The term “osteopenia” should not appear in pediatric DXA reports.
  - The term “osteoporosis” should not appear in pediatric DXA reports without a clinically significant fracture history.
  - “Low bone mineral mass or BMD” is the preferred term for pediatric DXA reports when BMC or areal BMD Z-scores are less than or equal to −2.0 SD. (ISCD 2019 Position Statements)

Peripheral Skeletal Measurements

Peripheral bone density measurements include scans of the hand, forearm, heel, and tibia. The scanners are smaller (some are portable), making the scans more available to the public and less expensive than conventional DXA. Peripheral measurements can predict *overall risk of fragility fracture* to the same degree as measurements at central skeletal sites but are not generally accepted for following skeletal response to therapy.

Radiographic absorptiometry is a modern adaptation of the early bone density technique. Digital radiographic absorptiometry uses a hand radiograph that is scanned (digitized) into a computer (Fig. 19.33A). ROI is placed on the digital image of the metacarpals, and estimated BMD is reported (see Fig. 19.33B).

Single energy x-ray absorptiometry, peripheral DXA, and peripheral QCT are adaptations of DXA or QCT for measuring the thinner, easier to penetrate, peripheral skeletal sites. Most scanners measure the wrist (Fig. 19.34) or the heel.

With *QUS* of the heel, ultrasound waves are transmitted laterally through the calcaneus using water, gel, or alcohol (dry system) as a coupling medium (Fig. 19.35). Attenuation increases as the velocity of the ultrasound waves increases, and normal bone attenuates more than osteoporotic bone. These properties of bone and ultrasound signals permit the assessment of the QUS parameters of broadband ultrasound attenuation (BUA) and speed of sound (SOS). BUA, SOS, and proprietary combinations of the two (e.g., stiffness) characterize the mechanical properties of bone relating to elasticity, strength, and consequently fracture risk.

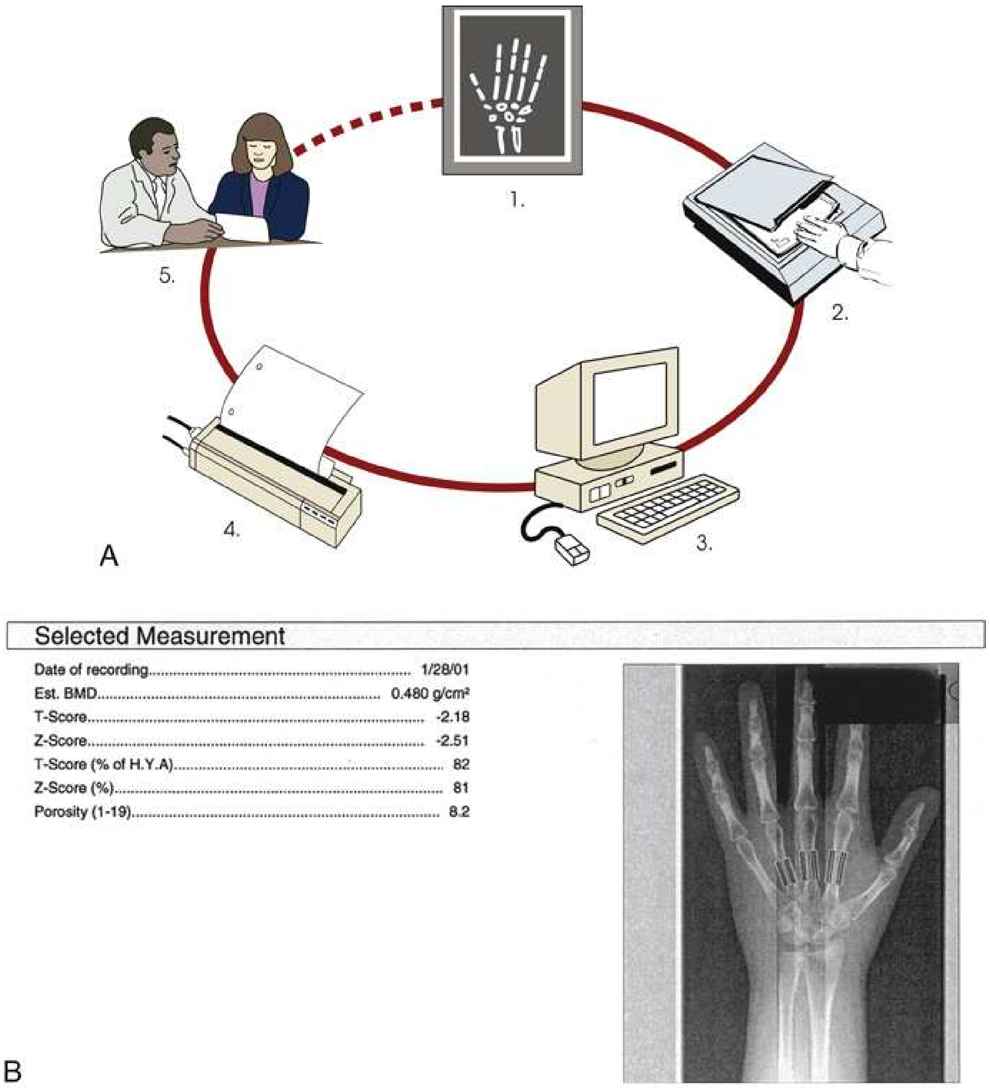


FIG. 19.33 Pronosco X-posure System for digital BMD estimates. (A) Five steps of acquiring and digitizing a standard hand x-ray, keying in patient data, receiving a printout, and discussing results with the patient. (B) Partial report showing automatically placed ROI on the metacarpals, estimated BMD, T-score and Z-score, and a unique porosity measurement. Courtesy Pronosco A/S, Vedbaek, Denmark.

(A) shows five steps. 1 shows an x-ray view of the hand. It is connected to 2 which shows a hand placed on a sheet on top of a machine. 2 is connected to 3 which shows a computer, keyboard, and a mouse. 3 is connected to 4 which shows a printer printing out a paper. 4 is connected to 5 which shows a man wearing a white coat sitting next to a woman holding a paper. 5 is connect to 1 by a dashed line. (B) shows a report titled selected measurement. Below it the values of Date of recording, estimated B M D, t-score, z-score, t-score (percent of H Y A), z-score (percent), porosity (1 to 19) are given. Next to it is an x-ray image of a hand. It appears grainy. The carpals, metacarpals, phalanges appear grey.

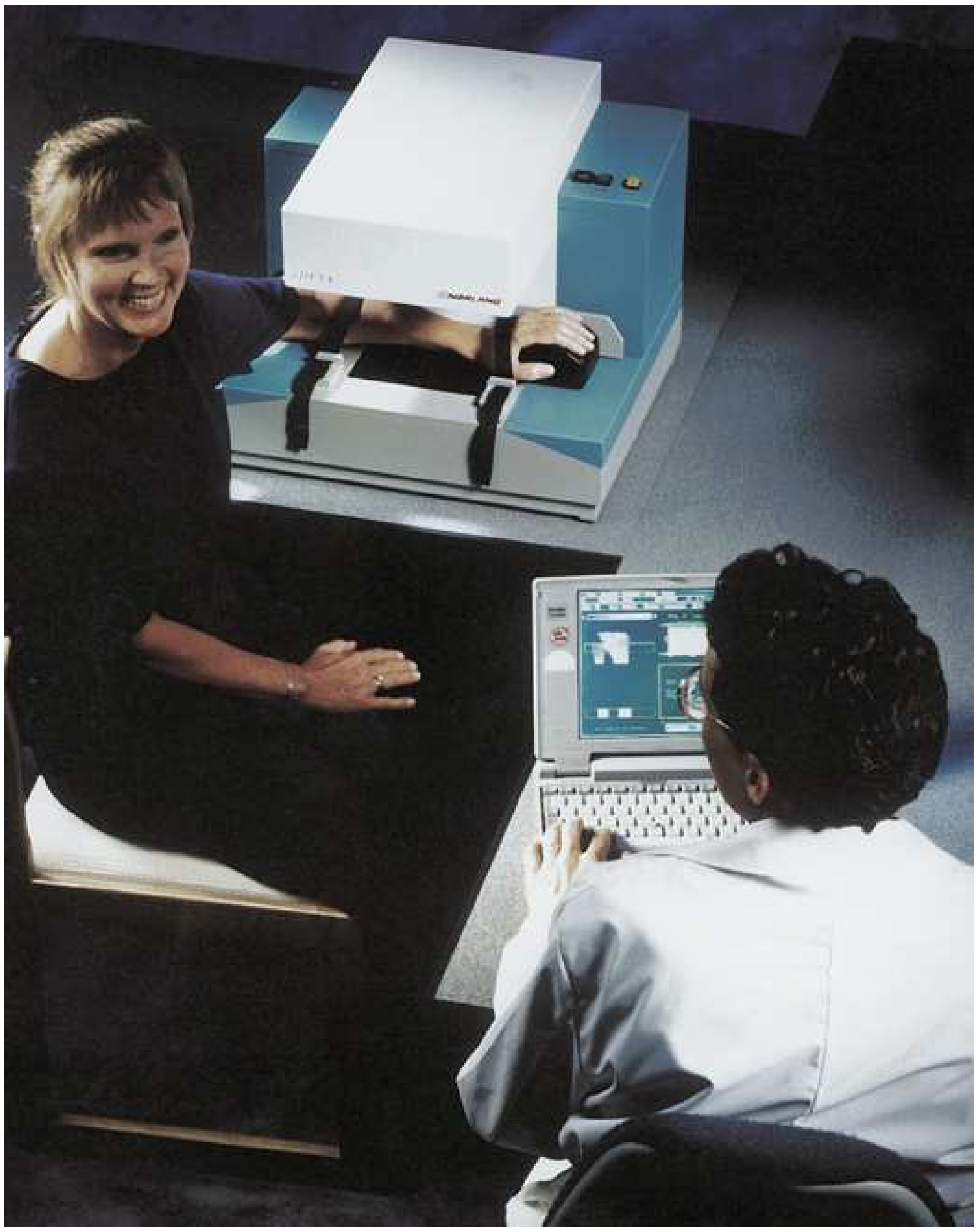


FIG. 19.34 Norland model peripheral DXA performs peripheral DXA bone mineral analysis of the wrist.
Courtesy Norland/Swissray, Ft. Atkinson, WI.

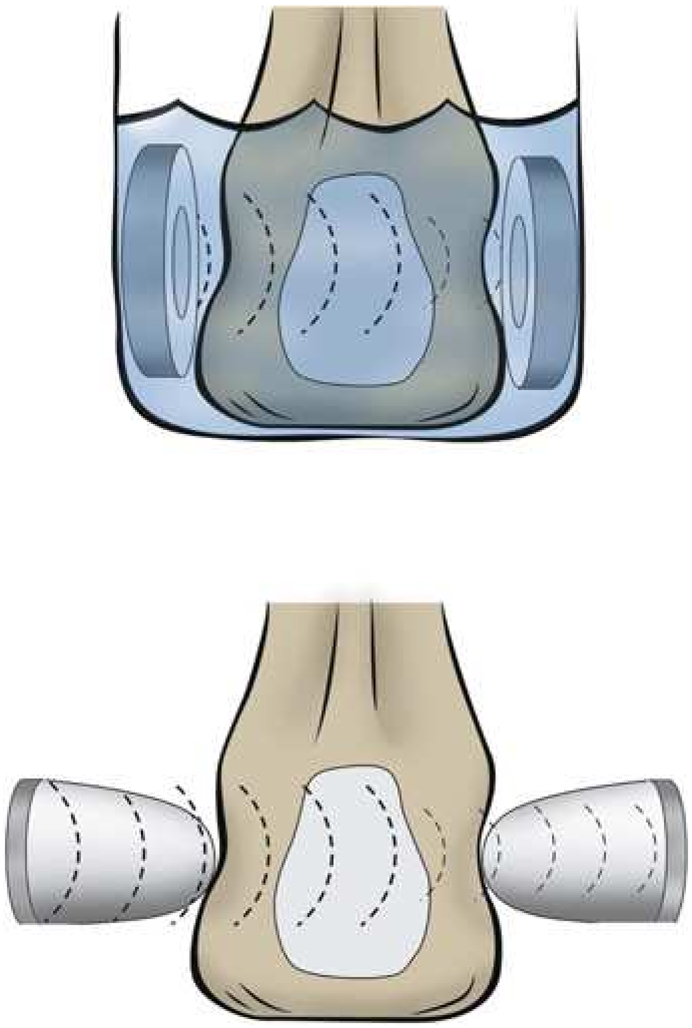


FIG. 19.35 QUS of the heel uses either water as a coupling mechanism *(top)* or a dry system using a gel on the transducers *(bottom)*. Courtesy GE Lunar, Madison, WI.

Diagram on top shows the heel placed in a container containing water. The calcaneus is highlighted. Two circular objects are placed on either side. Diagram at the bottom shows a heel placed in the middle of two bullet shaped transducers. The calcaneus is highlighted.

Fracture Risk Models

The University of Sheffield, UK has developed the *FRAX* tool to evaluate the fracture risk of patients. It is based on individual patient models that integrate the risks associated with clinical risk factors and BMD at the femoral neck. It uses clinical risk factors with the femoral BMD to estimate the 10-year probability risk of a major osteoporotic fracture. FRAX is intended to assess fracture risk only and assist the physician in treatment decisions for patients between the ages of 40 and 90 years. It cannot be used if the patient is on pharmacologic treatment for osteoporosis. The FRAX tool and other fracture risk models may assist physicians in making decisions about who to treat, especially patients with low bone mass. Fracture prediction models should be used judiciously in managing individual patients and are not meant to replace clinical judgment (http://www.shef.ac.uk/FRAX).

Trabecular bone score

Trabecular bone score (TBS) is an analytic tool developed in 2008 that performs measurements on lumbar spine DXA images that capture information relating to trabecular microarchitecture. TBS is not a direct measurement of bone microarchitecture but is related to three-dimensional bone characteristics. These include the trabecular number, the trabecular separation, and the connectivity density. ISCD 2019 Position Statements state that TBS is associated with vertebral, hip, and major osteoporotic fracture risk in postmenopausal women and in postmenopausal women with type II diabetes. However, it is associated only with hip and major osteoporotic fracture risk in men over the age of 50 years. TBS is not useful for monitoring bisphosphonate treatment in postmenopausal women with osteoporosis and should not be used alone to determine treatment recommendations in clinical practice. ISCD also states that TBS can be used in association with FRAX and BMD to adjust FRAX probability of fracture in postmenopausal women and older men.

Best Practices for Dual-Energy X-Ray Absorptiometry (DXA)

DXA is a technology used worldwide to diagnose osteoporosis, monitor changes in BMD, and assess fracture risk. The clinical results of the DXA scan are highly dependent on the quality of the scan acquisition, analysis and interpretation. The following best practices describe quality standards for BMD testing that have been derived from the International Society for Clinical Densitometry (ISCD.org). These practices will aid patients, health care providers, and payers in facilitating recognition of high-quality DXA services.

1. ***Qualifications:*** All bone densitometry technologists should be educated and competent in the areas of anatomy, radiation protection, patient care, history taking, basic computer operation, scanner quality control, patient positioning, scan acquisition and analysis, and proper record keeping and documentation. At least one practicing DXA technologist and preferably all technologists practicing in the DXA department should have a valid certification in bone densitometry. This includes keeping up to date on continuing education. Each DXA technologist should have performed an in vivo precision assessment according to standard methods and calculation of the facility's LSC. Precision Assessment should be standard clinical practice and completed by all technologists. Adherence to state and local safety regulations is necessary.
2. ***Radiation safety:*** The DXA facility must comply with all applicable radiation safety requirements for both the patient and the technologist. A DXA scan should not be performed unless there is a net benefit to the patient. Radiation exposure should be as low as reasonably achievable (ALARA). Pregnant patients should never be scanned and, if in doubt, follow the "10 day" rule. The technologist should wear an individual dosimetry device to monitor any radiation that might be received. Adhere to all safety regulations that are required by the facility, city, state, and country to minimize radiation exposure.
3. ***Standard operating procedures:*** Each DXA facility should have a detailed SOP for DXA procedures that is updated routinely and available for all personnel to follow. Examples of three different categories of SOPs include pre-testing, testing, and post-testing. *Pre-testing* consists of patient scheduling, patient preparation, patient education, instrument calibration, and maintenance. *Testing* should include the selection of accurate skeletal sites, scan mode, acquisition, and patient positioning. *Post-testing* should be accurate analysis, interpretation, and reporting. Individuals who are involved in all aspects of bone density should participate in the development of the document. This will help reduce errors, improve patient and technologist safety, and produce consistent quality scans. Failure to follow SOPs may result in invalid data, which can lead to potentially harmful patient care.
4. ***Professionalism:*** Ethical conduct and professionalism in the workplace is a requirement of all health care professionals. The technologist should adhere to the Code of Ethics for Radiologic Technologists (Chapter 1) and the ASRT Bone Density Practice Standards. The HIPAA of 1996 must also be followed to ensure the privacy of the patient's health information.
5. ***Scan acquisition and analysis:*** There are important manufacturer-specific differences in DXA hardware, software, instrument operation, and requirements for patient positioning, acquisition, and analysis. Each technologist must be knowledgeable in their specific DXA manufacturer as it is the primary source for quality control standards, instrument maintenance, patient scanning, and data analysis. Deviation from the recommended procedures may adversely affect the validity of the BMD measurements. The accuracy and precision of BMD measurements by DXA can be directly affected by changes in instrument performance that may occur as a calibration "shift" or "drift." Phantom scanning on a regular basis can determine when a DXA system is out of calibration and requires service. If the phantom falls outside acceptable ranges, then patient scanning should be postponed until machine service occurs.
6. ***Interpretation and reporting:*** It is recommended that at least one practicing DXA interpreter/clinician, and preferably all interpreters, have a valid certification in bone densitometry. This includes keeping up to date on continuing education. DXA reports must provide correct and meaningful information for the referring health care provider to provide quality bone health care. By passing an examination and receiving a certification in Bone Densitometry, an interpreter provides evidence that this skill set has been met.

Conclusion

The main purpose of bone densitometry is to assist the diagnosis of osteoporosis by detecting low bone mass before fractures occur. Osteoporosis is a preventable and treatable disease. Patients concerned about their risk of this disease should consult their physicians for a complete evaluation.

DXA scans of the hip and spine are the most widely performed techniques and considered the gold standard, but simpler, less expensive peripheral scans of the extremities are also available for screening purposes. Radiographers using bone densitometry equipment must be properly trained in scanner quality control, anatomy, patient scan positioning, acquisition, and analysis. This training ensures accurate and precise bone density results.

Knowledge of current treatments and expected changes is important for complete technical evaluation of the scan results. History taking and data input are valuable tools for completion of this examination. Technologists are frontline educators to patients, and knowledge in the field is ever changing. The technologist must keep informed about the treatment options and their effects on bone density.

Quality assurance is a key factor in accurate and precise DXA acquisition and analysis. Technology changes frequently, so it is important for the technologist to understand the changes within the industry. The technologist must be able to oversee these applications to maintain and update equipment properly.

Definition of Terms

ALARA (as low as reasonably achievable): Principle of reducing patient radiation exposure and dose to lowest reasonable amounts.

anthropomorphic: Simulating human form.

areal technique: See *projectional technique.*

array-beam collimation: Dual-energy x-ray absorptiometry system that uses a narrow "slit" x-ray collimator and a multielement detector. The motion is in one direction only, which greatly reduces scan time and permits supine lateral spine scans. It introduces a slight geometric distortion at the outer edges, which necessitates careful centering of the object of interest.

biochemical markers: Laboratory tests on blood and urine to detect levels of bone formation or resorption.

body composition: Results from whole-body scans obtained by dual energy x-ray absorptiometry; reported as lean mass in grams, percent body fat, and bone mineral density of the total body and selected regions of interest.

bone densitometry: Art and science of measuring bone mineral content and density of specific anatomic sites or the whole body.

bone mass: General term for amount of mineral in a bone.

bone mineral content (BMC): Measure of bone mineral in the total area of a region of interest.

bone mineral density (BMD): Measure of bone mineral per unit area of a region of interest.

bone remodeling: Process of bone resorption by osteoclasts, followed by bone formation by osteoblasts. The relative rates of resorption and formation determine whether bone mass increases, remains stable, or decreases.

celiac disease: Disease characterized by hypersensitivity to gluten (wheat protein).
compare feature: Software feature of dual energy x-ray absorptiometry that replicates the size and placement of regions of interest from the reference scan to the follow-up scan.
cortical bone: Dense, compact outer shell of all bones and the shafts of the long bones; supports weight, resists bending and twisting, and accounts for approximately 80% of the skeletal mass.
cross-calibration: Cross-calibration of numbers is needed to calculate the average BMD relationship and least significant change between the initial machine and new machine of a DXA facility. It is not possible to quantitatively compare BMD or to calculate LSC between facilities without cross-calibration.
discordance: Patient may have T-score indicating osteoporosis at one anatomic site but not at another site or by one modality but not by another.
dual energy x-ray absorptiometry (DXA): Bone density measurement technique using an x-ray source separated into two energies. It has good accuracy and precision and can scan essentially any anatomic site, making it the most versatile of the bone density techniques.
dual photon absorptiometry (DPA): Obsolete method of measuring bone density at the hip or spine using a radioisotope source that produces two sources of photons; replaced by dual energy x-ray absorptiometry.
fragility fractures: Nontraumatic fractures resulting from low bone mass, usually at the hip, spinal vertebrae, wrist, proximal humerus, or ribs.
FRAX: Fracture risk assessment tool developed by the World Health Organization.
HIPAA: The American Health Insurance Portability and Accountability Act of 1996 (HIPAA) is a set of rules to be followed by health plans, physicians, hospitals, and other health care providers. HIPAA took effect on April 14, 2003. In the health care and medical profession, the great challenge that HIPAA has created is the assurance that all patient account handling, billing, and medical records are HIPAA compliant.
hyperparathyroidism: Disease caused by excessive secretion of parathyroid hormone (PTH) from one or more parathyroid glands, resulting in excessive calcium in the blood; affects cortical bone more than trabecular bone.
kyphosis: Exaggerated outward curvature of the thoracic spine, also called *dowager's hump*.
least significant change (LSC): Amount of change in bone density needed to be statistically confident that a real change has occurred.
longitudinal quality control: Manufacturer-defined procedures performed on a regular basis to ensure that patients are scanned on properly functioning equipment with stable calibration. Scanning must be postponed until identified problems are corrected.
mean: Statistic commonly called the average; sum of the data values divided by the number of data values.
morphometric x-ray absorptiometry (MXA): Lateral scans of the thoracic and lumbar spine using single energy or dual energy x-ray absorptiometry to determine vertebral abnormalities or fractures from the shapes of the vertebrae.
osteoblasts: Bone-building cells that fill the pits left by resorption with new bone.
osteoclasts: Bone-destroying cells that break down and remove old bone, leaving pits.
osteomalacia: Bone disorder characterized by variable amounts of uncalcified osteoid matrix.
osteopenia/low bone mass: Reduction in bone mass, putting a person at increased risk of developing osteoporosis. By World Health Organization criteria, it is a bone mineral density or bone mineral content T-score between −1 and −2.5. *Low bone mass* or *low bone density* is the preferred term.
osteophytosis: Form of degenerative joint disease resulting from mechanical stress that increases measured spinal bone mineral density.
osteoporosis: Systemic skeletal disease characterized by low bone mass and deterioration of bone structure, resulting in decreased mechanical competence of bone and an increase in susceptibility to fracture. By World Health Organization criteria, it is a bone mineral density or bone mineral content T-score of less than −2.5.
overall risk of fragility fracture: Risk of sustaining an unspecified fragility fracture. The risk for hip fracture specifically is best measured at the hip.
peak bone mass: Maximum bone mass, usually achieved between 20 and 30 years of age. Population mean peak bone mass is used as a reference point for the T-score.
pencil-beam collimation: Dual energy x-ray absorptiometry system using a circular pinhole x-ray collimator that produces a narrow x-ray stream, which is received by a single detector. Its motion is serpentine (or raster) across or along the length of the body. Modern systems have improved scan time and image quality. Off-centering of the object does not cause geometric distortion.
percent coefficient of variation (%CV): Statistic used to compare standard deviations from different data sets, which may have different means; also a measure of precision; calculated as SD ÷ mean × 100. A smaller %CV indicates better precision.
peripheral dual energy x-ray absorptiometry (pDXA): Dual energy x-ray absorptiometry system designed to scan only the peripheral skeleton; smaller and simpler to operate than DXA scanners.
peripheral quantitative computed tomography (pQCT): Dedicated QCT system designed to measure bone density on the peripheral skeleton, usually the forearm.
picture archiving communication system (PACS): Medical imaging technology that provides economical storage and convenient access to images from multiple modalities.
primary osteoporosis: Osteoporosis not caused by an underlying disease, classified as type I or type II.
projectional (or areal) technique: Two-dimensional representation of a three-dimensional object.
quantitative computed tomography (QCT): System for quantitative CT measurements of bone density, allowing true measurement of volume and separation of trabecular and cortical bone; usually measured at the spine or forearm, sometimes at the hip.
quantitative ultrasound (QUS): Quantitative measurement of bone properties related to mechanical competence using ultrasound. The results are reported in terms of broadband ultrasound attenuation (BUA); speed of sound (SOS); and a non-standardized proprietary mathematic combination of the two, called the *stiffness* or *quantitative ultrasound index* (QUI). It predicts overall or spine fracture risk without using ionizing radiation and is usually measured at the calcaneus.
radiogrammetry: Older method of measuring bone loss by comparing the outer diameter and inner medullary diameter of small tubular bones, usually the finger phalanges, or metacarpals.
radiographic absorptiometry (RA): Visual comparison of hand x-ray density with a known standard in the exposure field.

reference population: Large, sex-matched, community-based population used to determine the average bone mineral density and standard deviation at each age; used as reference base for T-scores and Z-scores; may also be matched on ethnicity and weight.
regions of interest (ROI): Defined portion of bone density scans where the bone mineral density is calculated; may be placed manually or automatically by computer software.
scintillation counter: Counter using a photomultiplier tube for detection of radiation.
secondary osteoporosis: Osteoporosis caused by an underlying disease.
serial scans: Sequential scans, usually performed 12, 18, or 24 months apart, to measure changes in bone density. Scans are best done on the same scanner or on a new scanner cross-calibrated to the original scanner.
Shewhart Control Chart rules: Classic quality control rules based on comparing a data value with the mean and standard deviation of a set of similar values.
sieverts (Sv): Measurement of effective radiation dose to a patient. Bone density doses are measured in microsieverts (μSv), which are one millionth of 1 sievert.
single energy x-ray absorptiometry (SXA): Bone density technique for the peripheral skeleton, making use of a single energy x-ray source and an external medium, such as water, to correct for the effects of soft tissue attenuation. Scanners are smaller and simpler to operate than dual energy x-ray absorptiometry scanners.
single photon absorptiometry (SPA): Obsolete method of measuring bone density at the forearm using a single radioisotope source; replaced by single energy x-ray absorptiometry.
standard deviation (SD): Measure of the variability of data values around the mean value.
subtraction technique: Removal of the density attributable to soft tissue so that the remaining density belongs to bone only
total body less head (TBLH): Total body scanning less head analysis.
trabecular bone: Delicate, lattice-work structure within bones that adds strength without excessive weight; supports compressive loading at the spine, hip, and calcaneus and is found in the ends of long bones, such as the distal radius.
trabecular bone score (TBS): Analytic tool that performs measurements on lumbar spine DXA images to capture information relating to trabecular microarchitecture.
T-score: Number of standard deviations an individual's bone mineral density (BMD) is from the average BMD for sex-matched, young normal peak bone masses.
type I osteoporosis: Primary osteoporosis related to postmenopausal status.
type II osteoporosis: Primary osteoporosis related to aging.
vertebral fracture assessment (VFA): Encompasses looking at the spine "morphometrically" in the lateral projection. Common synonymous terms are *dual energy vertebral assessment (DVA), lateral vertebral assessment (LVA), instant vertebral assessment (IVA),* and *radiologic vertebral assessment (RVA).*
volumetric density: Bone mineral density calculated by dividing by the true three-dimensional volume.
Ward triangle: Region on proximal femur lying on the border of the femoral neck and greater trochanter; has low bone mineral density. Cannot be used in diagnosis.
Z-score: Number of standard deviations the individual's bone mineral density (BMD) is from the average BMD for a sex-matched and age-matched reference group.

Resources for information and instruction

American College of Radiology: ACR standard for the performance of adult dual or single x-ray absorptiometry (DXA/pDXA/SXA). Contact the Standards & Accreditation Department, Preston White Drive, Reston, VA, 1891, American College of Radiology. 22091.

American Registry of Radiologic Technologists: Provides a postprimary examination leading to a certificate of added qualifications in bone densitometry. For details, see the Examinee handbook for bone densitometry. Contact the American Registry of Radiologic Technologists, 1255 Northland Drive, St Paul, MN 55120-1155. Web site: www.arrt.org.

American Society of Radiologic Technologists: Approved elective curriculum in bone densitometry for radiography programs. Contact the American Society of Radiologic Technologists, 15000 Central Avenue SE, Albuquerque, NM 87123. Web site: www.asrt.org.

Best Practices for Dual-Energy X-ray Absorptiometry Measurement and Reporting: International Society for Clinical Densitometry Guidance. Journal of Clinical Densitometry Assessment & Management of Musculoskeletal Health. Contact International Society for Clinical Densitometry 955 South Main St. Building C Middletown, CT 06457. Web site: www.iscd.org.

International Society for Clinical Densitometry: Certification courses, annual and regional meetings, continuing education, newsletter, Journal of Clinical Densitometry, and web site with links to Official Positions and Pediatric Official Positions. Contact International Society for Clinical Densitometry 955 South Main St. Building C Middletown, CT 06457. Web site: www.iscd.org.

National Osteoporosis Foundation: Excellent source of osteoporosis information and educational materials for technologists, physicians, and patients. Contact the National Osteoporosis Foundation, 1232 22nd Street NW, Washington, DC 20037-1292. Web site: www.nof.org.

Scanner manufacturers: source for technologist instruction and answers to scanner-specific application questions. Refer to the operator's manual for contact information.

StrongerBones.org

Surgeon General's Report. Web site: www.surgeongeneral.gov.

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11. National Osteoporosis Foundation. Available at: www.nof.org. (Accessed August 17, 2020.)

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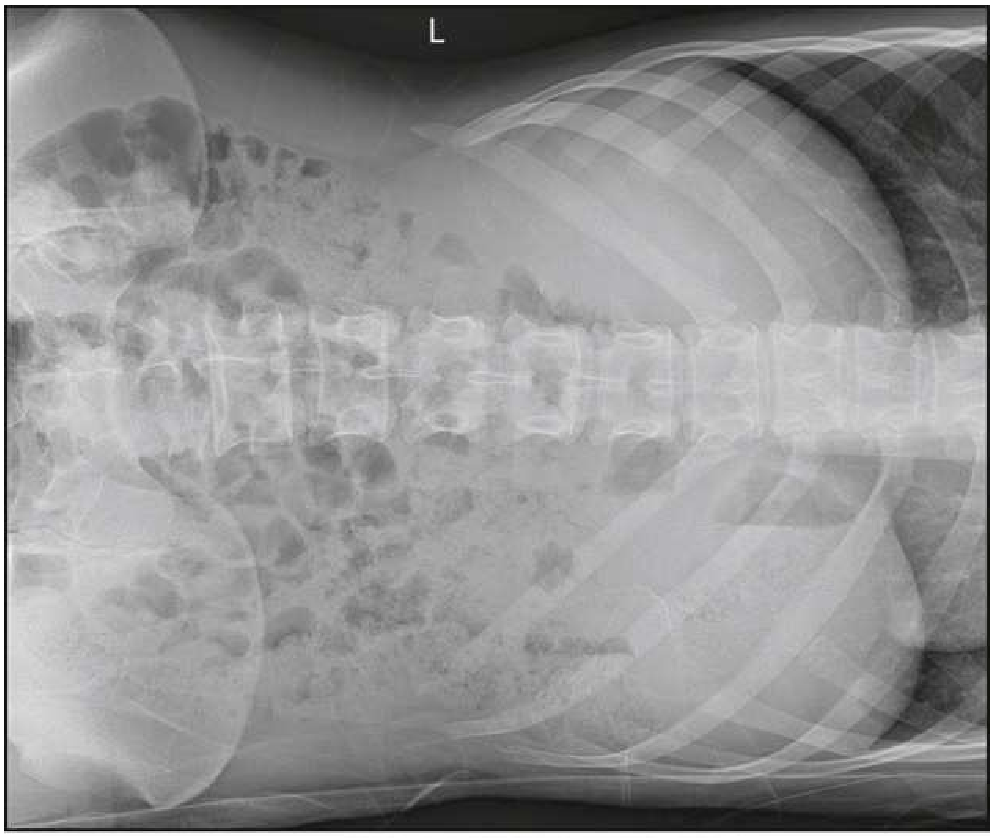
13. National Osteoporosis Foundation. Available at: https://www.nof.org/2014/06/02/54-million-americans-affected-by-osteoporosis-and-low-bone-mass/. (Accessed August 17, 2020.)

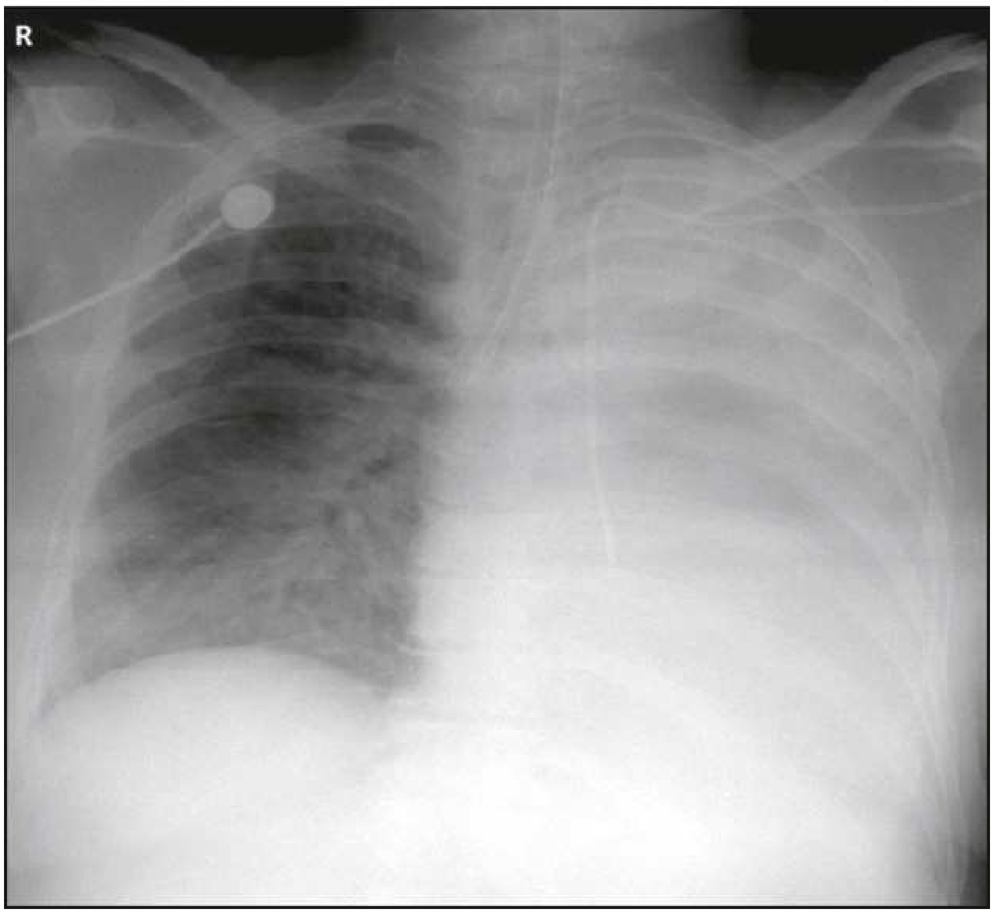
[a] Almost all italicized words on the succeeding pages are defined at the end of this chapter.

Volume Three

OUTLINE

20: Mobile Radiography





Steven G. Hayes Jr.

OUTLINE

Principles of Mobile Radiography

Mobile radiography using transportable radiographic equipment allows imaging services to be brought to the patient. In contrast to the large stationary machines found in radiography rooms, compact mobile radiography units can produce diagnostic images in virtually any location (Fig. 20.1). Mobile radiography is commonly performed in patients' rooms, emergency departments, intensive care units, surgery, recovery rooms, and nursery and neonatal units. Some machines are designed for transport by automobile or van to extended-care facilities or other off-site locations requiring radiographic imaging services.

Mobile radiography was first used by the military for treating battlefield injuries during World War I. Small portable units were designed to be carried by soldiers and set up in field locations. Although mobile equipment is no longer "carried" to the patient, the term *portable* has persisted and is often used in reference to mobile procedures.

This chapter focuses on the most common projections performed with mobile radiography machines. The basic principles of mobile radiography are described and helpful hints are provided for successful completion of examinations. An understanding of common projections enables the radiographer to perform most mobile examinations ordered by the physician.

FIG. 20.1 Radiographer moving a battery-operated mobile radiography machine to a patient's room.

Mobile X-Ray Machines

Mobile x-ray machines are not as sophisticated as the larger stationary machines in the radiology department; although mobile units are capable of producing images of most body parts, they vary in their exposure controls and power sources (generators).

A typical mobile x-ray machine has controls for setting kilovolt (peak) (kVp) and milliampere-seconds (mAs). The mAs control automatically adjusts milliamperage (mA) and time to preset values. Maximum settings differ among manufacturers, but mAs typically range from 0.04 to 320 and kVp from 40 to 130. The total power of the unit ranges from 15 to 25 kilowatts (kW), which is adequate for most mobile projections. By comparison, the power of a stationary radiography unit can reach 150 kW (150 kVp, 1000 mA) or more.

Some mobile x-ray machines have preset anatomic programs (APRs) similar to stationary units. The APRs use exposure techniques with predetermined values based on the selected examination; the radiographer can adjust these settings as needed to compensate for differences in the size or condition of a patient. The much wider dynamic range available with CR or digital radiography (DR) and the ability to manipulate the final image with computer software can provide images of proper density.

Digital Radiography Mobile Units

The advancement in digital imaging has evolved in both fixed x-ray rooms and bedside mobile units. Some mobile units have direct digital capability, wherein the image is acquired immediately on the unit. These machines have a flat-panel detector, similar to those found in a DR table bucky. The detector is either connected to the portable unit by a tethered cord or communicates through wireless technology (Fig. 20.2). The bedside DR mobile unit converts digital data in real time, allowing images to display on the mobile monitor within seconds after exposure. This practice enables the technologist to review the image before removing the wireless or tethered flat-panel IR from behind the patient or part. One of the benefits of using DR mobile units is improving workflow efficiency by displaying images after capture without having to process the IR in a separate reader housed in a different location. The images are sent wirelessly to the facility's picture archiving and communication system (PACS). Earlier DR mobile unit models used a physical cable to transfer images from the portable to PACS at designated wired ethernet network workstations. With current secure wireless systems, technologists can perform bedside imaging for one patient after another and evaluate the images before leaving each patient's area. Another benefit when comparing CR to DR mobile units is lower radiation doses, made possible with digital post-processing software inherent to DR systems while maintaining high image quality.

Technical Considerations

Mobile radiography presents the radiographer with challenges different from those associated with performing examinations with stationary equipment in the radiology department. Although the positioning of the patient and placement of the central ray are essentially the same, three important technical matters must be clearly understood to perform optimal mobile examinations: the *grid,* the *anode heel effect*, and the *source-to-image receptor distance (SID).* In addition, exposure technique charts must be available (Fig. 20.3).

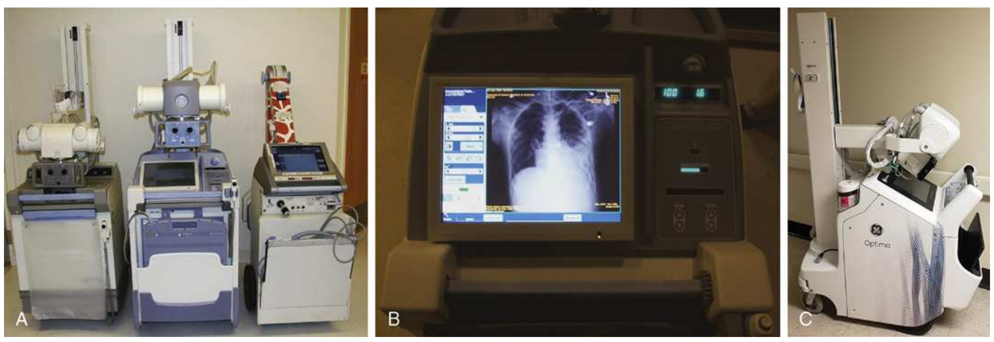


FIG. 20.2 (A) The machine on the left is an analog mobile unit, and the other two are digital units. Notice that the two digital mobile units have computer screens. (B) Mobile digital screen with a chest image. (C) DR mobile unit with wireless IR.

(A) shows three machines next to each other. The machine on the left does not have a screen. The other two machines have a screen on them. (B) shows a screen with a chest image on it. (C) shows a mobile unit with a screen.

MOBILE RADIOGRAPHIC TECHNIQUE CHART

AMX—4 40-inch SID CR IP 8:1 grid

Part	*Projection*	*Position*	*cm—kVp*	*mAs*	*Grid*
Chest	AP	Supine/upright	21—120	3.2	Yes
	AP	Lateral decubitus	21—85	6.25	Yes
Abdomen	AP	Supine	23—74	25	Yes
	AP	Lateral decubitus	23—74	32	Yes
Pelvis	AP	Supine	23—74	32	Yes
Femur (distal)	AP	Supine	15—70	10	Yes
	Lateral	Dorsal decubitus	15—70	10	Yes
C-spine	Lateral	Dorsal decubitus	10—62	20	Yes
NEONATAL					
Chest/abdomen	AP	Supine	7—64	0.8	No
	Lateral	Dorsal decubitus	10—72	1	No

FIG. 20.3 Sample radiographic technique chart showing manual technical factors used for the 10 common mobile projections described in this chapter. The kVp and mAs factors are for the specific centimeter measurements indicated. Factors vary depending on the actual centimeter measurement.

A table titled mobile radiograph technique chart is shown. The table has six columns and 10 rows. From left to right, the columns are labeled as follows: part, projection position, centimeter - kilovoltage peak, milliampere-seconds, and grid. The contents pf the table row wise are as follows. 1. part: Chest. Projection: A P. Position: supine or upright. centimeter - kilovoltage peak: 21 to 120. milliampere-seconds: 3.2. Grid: yes. 2. part: chest. Projection: A P. Position: lateral decubitus. centimeter - kilovoltage peak: 21 to 85. milliampere-seconds: 6.25. Grid: Yes. 3. part: abdomen. Projection: A P. Position: supine. centimeter - kilovoltage peak: 23 to 74. milliampere-seconds: 25. Grid: Yes. 4. part: abdomen. Projection: A P. Position: lateral decubitus. centimeter - kilovoltage peak: 23 to 74. milliampere-seconds: 32. Grid: Yes. 5. part: pelvis. Projection: A P. Position: supine. centimeter - kilovoltage peak: 23 to 74. milliampere-seconds: 32. Grid: Yes. 6. part: Femur (distal). Projection: A P. Position: supine. centimeter - kilovoltage peak: 15 to 70. milliampere-seconds: 10. Grid: Yes. 7. part: Femur (distal). Projection: lateral. Position: dorsal decubitus. centimeter - kilovoltage peak: 150 to 70. milliampere-seconds: 10. Grid: Yes. 8. part: c-spine. Projection: lateral. Position: dorsal decubitus. centimeter - kilovoltage peak: 10 to 62. milliampere-seconds: 20. Grid: Yes. 9. part: Neonatal chest or abdomen. Projection: A P. Position: supine. centimeter - kilovoltage peak: 7 to 64. milliampere-seconds: 0.8. Grid: No. 10. part: Neonatal chest or abdomen. Projection: lateral. Position: dorsal decubitus. centimeter - kilovoltage peak: 10 to 72. milliampere-seconds: 1. Grid: No.

Standard Grid

The phosphor used in CR imaging plates is very sensitive to the image degradation effects of scattered radiation, so in performing portable radiography with CR imaging plates, it is important to use a grid.

For optimal imaging, a grid must be level, centered to the central ray, and correctly used at the recommended focal distance (radius). When a grid is placed on an unstable surface such as the mattress of a bed, the weight of the patient can cause the grid to tilt "off level." If a longitudinal grid tilts transversely, the central ray forms an angle across the long axis. Image density is then lost as a result of grid "cutoff " (Fig. 20.4). If the grid tilts longitudinally, the central ray angles through the long axis. In this case, grid cutoff is avoided, but the image may be distorted or elongated.

A grid positioned under a patient can be difficult to center. If the central ray is directed to a point transversely off the midline of a grid more than 1 to 1½ inches (2.5 to 3.8 cm), it causes a cutoff effect similar to that produced by off-level grid results. The central ray can be centered longitudinally to any point along the midline of a grid without cutoff. Depending on the procedure, beam-restriction problems may occur; if this happens, a portion of the image is "collimated off," or patient exposure is excessive because of an oversized exposure field.

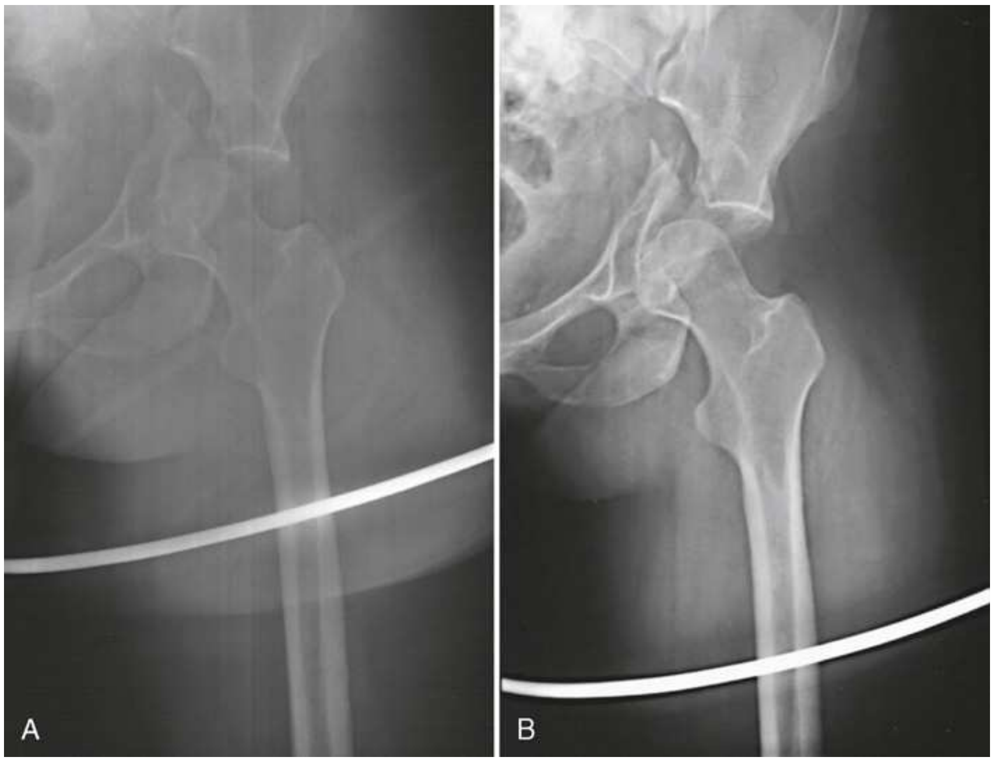


FIG. 20.4 Mobile radiograph of proximal femur and hip, showing comminuted fracture of left acetabulum. (A) Poor-quality radiograph resulted when grid was transversely tilted far enough to produce significant grid cutoff. (B) Excellent-quality repeat radiograph on the same patient, performed with grid accurately positioned perpendicular to central ray.

(A) An x-ray of the proximal femur shows a white horizontal curved line across the radiograph. (B) An x-ray shows well-defined outlines of the bones. A white horizontal curved line is across the radiograph.

FIG. 20.5 The directions of the grid lines are marked on the front of the grid as either transverse *(short dimension)* or longitudinal *(long dimension)*. Focal ranges are clearly identified for proper use.

Grids used for mobile radiography are often of the focused type. However, some radiology departments continue to use the older, parallel-type grids. All focused grids have a recommended focal range, or radius, that varies with the grid ratio. Projections taken at distances greater or less than the recommended focal range can produce cutoff in which image density is reduced on lateral margins. Grids with a lower ratio have a greater focal range, but they are less efficient for cleaning up scatter radiation. The radiographer must be aware of the *exact* focal range for the grid used. Most focused grids used for mobile radiography have a ratio of 6:1 or 8:1 and a focal range of about 36 to 44 inches (91 to 112 cm). This focal range allows mobile examinations to be performed efficiently. Inverting a focused grid causes a pronounced cutoff effect similar to that produced by improper distance. Most grids are mounted on a protective frame, and the IR is easily inserted behind the grid (Fig. 20.5). The direction of the grid lines is usually marked to indicate if it is transverse (short dimension) or longitudinal (long dimension).

Grid-Less Imaging

With the evolution of DR mobile units, standard anti-scatter grids and grid covers have been replaced with an alternate approach developed to compensate for image degradation through digital image processing. Vendors have developed new software that estimates the scattered radiation and provides scatter correction without the usage of standard grids. The technology enables the estimation of the scatter signal and calculation of the grid effect and improves image contrast reduction resulting from scatter by subtracting the estimated scatter from the raw image during postprocessing. The grid-less imaging software eliminates artifacts caused by standard anti-scatter grids and the absorption of primary radiation, which negatively impacts image quality.

The examinations described in this chapter present methods of ensuring proper grid and IR placement for projections that require a grid.

Anode Heel Effect

Another consideration in mobile radiography is the *anode heel effect*. The heel effect causes a decrease of image density under the anode side of the x-ray tube, and is more pronounced with the following:

- Short SID
- Larger field sizes
- Small anode angles

Short SIDs and large field sizes are common in mobile radiography. The radiographer has control of the anode-cathode axis of the x-ray tube relative to the body part; correct placement of the anode-cathode axis with regard to the anatomy is essential. In performing a mobile examination, the radiographer may not always be able to orient the anode-cathode axis of the tube to the desired position due to limited space and maneuverability in the room. For optimal mobile radiography, the anode and cathode sides of the x-ray tube should be clearly marked to indicate where the high-tension cables enter the x-ray tube, and the radiographer should use the heel effect maximally (Table 20.1).

Source-to-Image Receptor Distance

The SID should be maintained at 40 inches (102 cm) for most mobile examinations. A standardized distance for all patients and projections helps to ensure consistency in imaging. Longer SIDs—40 to 48 inches (102 to 122 cm)—require increased mAs to compensate for the additional distance; the mA limitations of a mobile unit necessitate longer exposure times when the SID exceeds 40 inches (102 cm). Despite the longer exposure time, a radiograph with motion artifacts may result if the SID is greater than 40 inches (102 cm). In addition, motion artifacts may occur in the radiographs of critically ill adult patients and infants or small children who require chest and abdominal examinations but are unable to hold their breath.

Radiographic Technique Charts

A radiographic technique chart should be available for use with every mobile machine. The chart should display, in an organized manner, the standardized technical factors for all the radiographic projections done with the machine (see Fig. 20.3). A caliper should also be available; this device is used to measure the thickness of body parts to ensure that accurate and consistent exposure factors are used. Measuring the patient also allows the radiographer to determine the optimal kVp level for all exposures (Fig. 20.6).

FIG. 20.6 Radiographer measuring the thickest portion of the femur to determine the exact technical factors needed for the examination.

TABLE 20.1

Note: The cathode side of the beam has the greatest intensity.

[a] Not necessary because of small field size of the collimator.

Radiation Safety

Radiation protection for the radiographer, others in the immediate area, and the patient is of paramount importance when mobile examinations are performed. *Mobile radiography produces some of the highest occupational radiation exposures for radiographers.* The radiographer should wear a lead apron and stand as far away from the patient, x-ray tube, and useful beam as the room and the exposure cable allow. The recommended *minimal* distance is 6 ft (2 m). For a horizontal (cross-table) x-ray beam or for an upright AP chest projection, the radiographer should stand at a right angle (90 degrees) to the primary beam and the object being radiographed. The least amount of scatter radiation occurs at this position (Fig. 20.7). Shielding and distance have a greater effect on exposure reduction and should always be considered first.

The most effective means of radiation protection is *distance*. The radiographer should inform all persons in the immediate area that an x-ray exposure is about to occur so that they may leave to avoid exposure. Lead protection should be provided for any individuals who are unable to leave the room and for individuals who may have to hold a patient or IR.

Patients should be shielded as necessary with appropriate radiation protection devices for any of the following situations:

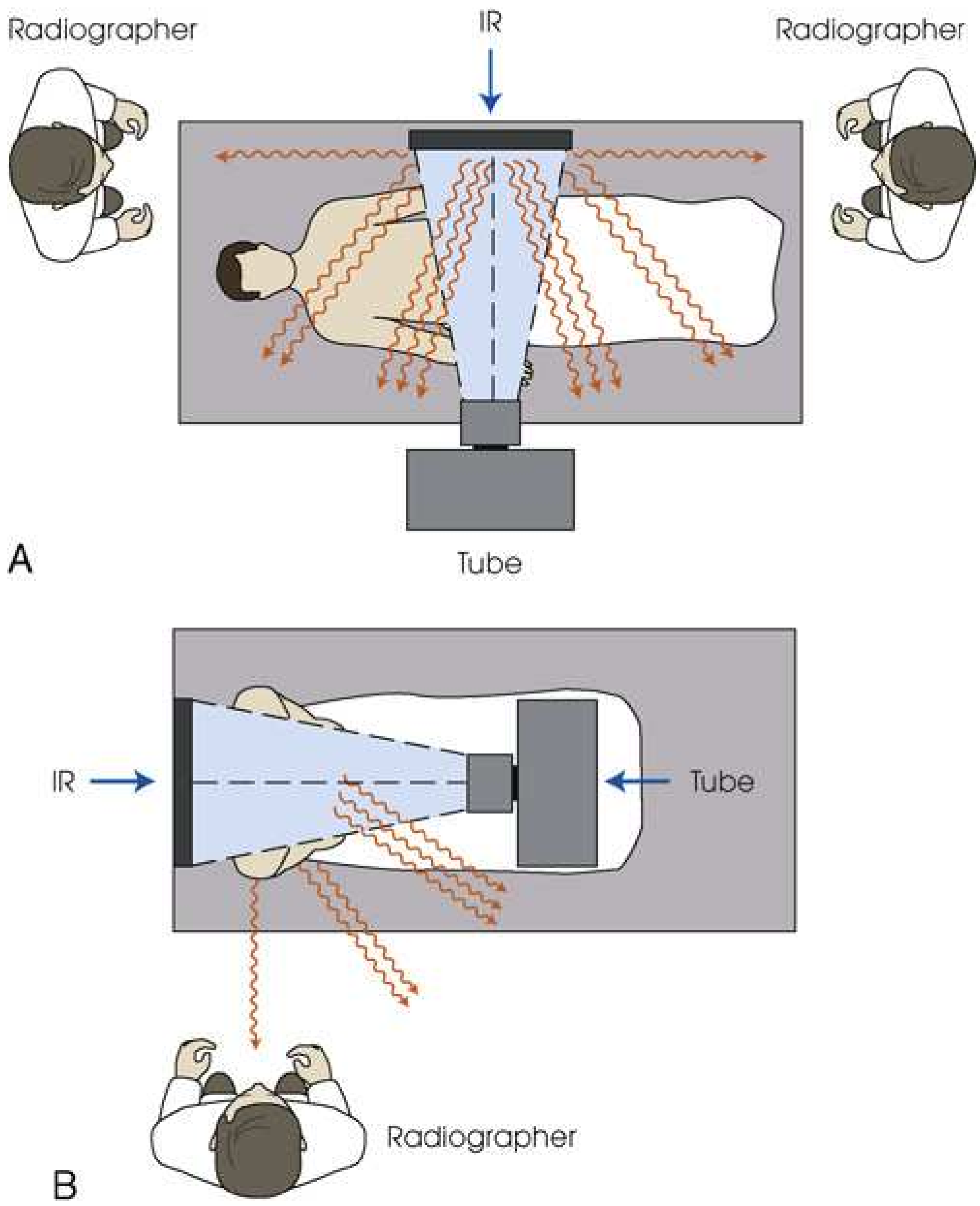


FIG. 20.7 Whenever possible, the radiographer should stand at least 6 feet (2 m) from the patient and useful beam. The lowest amount of scatter radiation occurs at a right angle (90 degrees) from the primary x-ray beam. (A) Note radiographer standing at either the head or the foot of the patient at a right angle to the x-ray beam for dorsal decubitus position lateral projection of the abdomen. (B) Radiographer standing at right angle to the x-ray beam for AP projection of the chest. *IR,* Image receptor.

(A) A patient is lying on the radiographic table below the x-ray tube emitting x-ray beams. The I R is placed on the lateral side of the patient. A radiographer is standing at either the head or the foot of the patient at a right angle to the x-ray beam for dorsal decubitus position lateral projection of the abdomen. (B) A patient is standing against the I R. The x-ray tube behind him is emitting x-ray beams. A radiographer is standing at a right angle to the x-ray beam.

- X-ray examinations performed on children
- X-ray examinations performed on patients of reproductive age
- Any examination for which the patient requests protection
- Examinations in which the gonads lie in or near the useful beam
- Examinations in which shielding would not interfere with imaging of the anatomy that must be shown (Fig. 20.8)

In addition, the source-to-skin distance (SSD) cannot be less than 12 inches (30 cm), in accordance with federal safety regulations. [1]

Isolation Considerations

Two types of patients are often cared for in isolation units: (1) patients who have infectious microorganisms that could be spread to health care workers and visitors, and (2) patients who need protection from potentially lethal microorganisms that may be carried by healthcare workers and visitors. Optimally, a radiographer entering an isolation room should have full knowledge of the patient's disease, the way in which the disease is transmitted, and the proper way to clean and disinfect equipment before and after use in the isolation unit. All patients must be treated with universal precautions.

If isolation is used to protect the patient from receiving microorganisms (reverse isolation), a different protocol may be required. Institutional policy regarding isolation procedures should be available and strictly followed.

FIG. 20.8 Patient ready for mobile chest examination. Note lead shield placed over the patient's pelvis. This shield does not interfere with the examination.

In performing mobile procedures in an isolation unit, the radiographer should wear the required protective apparel for the specific situation: gown, cap, mask, shoe covers, eye shield, and gloves. Not all of this apparel is necessary for every isolation patient. All persons entering a strict isolation unit must wear a mask, a gown, and gloves, but only gloves are worn for drainage secretion precautions. Radiographers should always wash their hands with warm soapy water before putting on gloves. The x-ray machine is taken into the room and moved into position. The IR is placed into a clean protective cover. Pillowcases would not protect the IR or the patient if body fluids soaked through them. A clean, impermeable cover should be used in situations in which body fluids may come into contact with the IR. For examinations of patients in strict isolation, two radiographers may be required to maintain a safe barrier (see Chapter 1).

After finishing the examination, the radiographer should remove and dispose of the mask, cap, gown, shoe covers, and gloves according to institutional policies. All equipment that touched the patient or the patient's bed must be wiped with a disinfectant according to the appropriate aseptic technique. If necessary, the radiographer should wear new gloves while cleaning equipment. Handwashing is repeated before the radiographer leaves the room.

Performing Mobile Examinations

Initial Procedures

The radiographer should plan for the trip out of the radiology department. Ensuring that all of the necessary devices (e.g., IR, IR protective covers, grid, tape, caliper, markers, and positioning blocks) are transported with the mobile x-ray machine provides greater efficiency in performing examinations. Many mobile x-ray machines are equipped with storage areas for transporting IRs and supplies. If a battery-operated machine is used, the radiographer should check the machine to ensure that it is acceptably charged. An inadequately charged machine can interfere with performance and affect the quality of the radiograph.

Before entering the patient's room with the machine, the radiographer should follow several important steps (Box 20.1). The radiographer begins by checking that the correct patient is going to be examined. After confirming the identity of the patient, the radiographer enters, makes an introduction as a radiographer, and informs the patient about the x-ray examinations to be performed. While in the room, the radiographer observes any medical appliances (such as chest tube boxes, catheter bags, and intravenous [IV] poles) that may be positioned next to or hanging on the sides of the patient's bed. The radiographer should ask family members or visitors to step out of the room until the examination is finished. If necessary, the nursing staff should be alerted that assistance is required.

BOX 20.1 Preliminary steps for the radiographer before mobile radiography is performed

- Announce your presence to the nursing staff and ask for assistance if needed.
- Determine that the correct patient is in the room.
- Introduce yourself to the patient and family as a radiographer and explain the examination.
- Observe the medical equipment in the room and other apparatus and IV poles with fluids. Move the equipment if necessary.
- Ask family members and visitors to leave. [a]

[a] The nonmobile projection is described in Chapter 3.

Communication and cooperation between the radiographer and nursing staff are essential for proper patient care during mobile radiography. In addition, communication with the patient is imperative, even if the patient is or appears to be unconscious or unresponsive.

Examination

Chairs, stands, IV poles, wastebaskets, and other obstacles should be moved from the path of the mobile machine. Lighting should be adjusted if necessary. If the patient is to be examined in the supine position, the base of the mobile machine should be positioned toward the middle of the bed. If the patient is to be seated, the base of the machine should be toward the foot of the bed.

For lateral and decubitus radiographs, positioning the base of the mobile machine parallel to or directly perpendicular to the bed allows the greatest ease in positioning the x-ray tube. Room size can also influence the base position used.

The radiographer may sometimes have difficulty accurately aligning the x-ray tube parallel to the IR while standing at the side of the bed. When positioning the tube above the patient, the radiographer may have to check the x-ray tube and IR alignment from the foot of the bed to ensure that the tube is not tilted.

For all projections, the primary x-ray beam must be collimated no larger than the size of the IR. When the central ray is correctly centered to the IR, the light field coincides with or fits within the borders of the IR.

A routine and consistent system for labeling and separating exposed and unexposed IRs should be developed and maintained. It is easy to "double expose" IRs during mobile radiography, particularly if many examinations are performed at one time. Using DR imaging eliminates the chance of double exposure.

Most institutions require additional identification markers for mobile examinations. Typically the time of examination (especially for chest radiographs) and technical notes (such as the position of the patient) are indicated. A log may be maintained for each patient and kept in the patient's room. The log should contain the exposure factors used for the projections and other notes regarding the performance of the examination.

Patient Considerations

A brief but total assessment of the patient must be conducted before and during the examination. Some specific considerations to keep in mind are described in the following sections.

Assessment of the patient's condition

A thorough assessment of the patient's condition and room allows the radiographer to make necessary adaptations to ensure the best possible patient care and imaging outcome. The radiographer assesses the patient's level of alertness and respiration and determines the extent to which the patient is able to cooperate as well as the limitations that may affect the procedure. Some patients may be experiencing varying degrees of drowsiness because of their medications or medical condition. Many mobile examinations are performed in patients' rooms immediately after surgery, so these patients may be under the influence of various anesthetics. It is always important to communicate with the patient even if they are not alert.

Patient mobility

The radiographer must never move a patient or part of the patient's body without assessing the patient's ability to move or tolerate movement. Gentleness and caution must prevail at all times. If unsure, the radiographer should always check with the nursing staff or physician. Many patients who undergo total joint replacement may be unable to move the affected joint for many days without assistance, but this may not be evident to the radiographer. Some patients may be able to indicate verbally their ability to move or their tolerance for movement. *The radiographer should never move a limb that has been operated on or is broken unless the nurse, the physician, or sometimes the patient grants permission.* Inappropriate movement of the patient by the radiographer during the examination may be harmful.

Fractures

Patients can have various fractures and fracture types, ranging from one simple fracture to multiple fractures of many bones. A patient lying awake in a traction bed with a simple femoral fracture may be able to assist with a radiographic examination, while another patient may be unconscious and have multiple broken ribs, spinal fractures, or a severe closed head injury.

Few patients with multiple fractures are able to move or tolerate movement. The radiographer must be cautious, resourceful, and work in accordance with the patient's condition and pain tolerance. If a patient's trunk or limb must be raised into position for a projection, the radiographer should have ample assistance so that the part can be raised safely without causing harm or intense pain.

Interfering devices

Patients who are in intensive care units or orthopedic beds because of fractures may be attached to various devices, wires, and tubing. These objects may be in the direct path of the x-ray beam and, consequently, produce artifacts on the image. Experienced radiographers know which of these objects can be moved out of the x-ray beam. When devices such as fracture frames cannot be moved, it may be necessary to angle the central ray or adjust the IR to obtain the best radiograph possible. In many instances, the objects have to be radiographed along with the body part (Fig. 20.9). The radiographer must exercise caution in handling any of these devices and should never remove traction devices without the assistance of a physician.

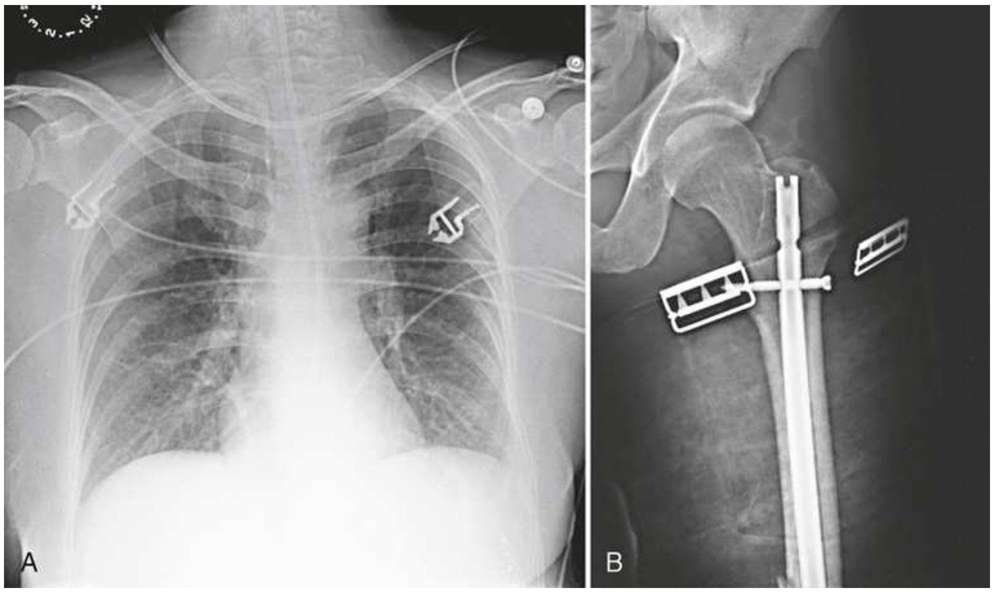


FIG. 20.9 (A) Mobile radiograph of chest. Note various objects in the image that could not be removed for the exposure. (B) Mobile radiograph of proximal femur and hip. Metal buckles could not be removed for the exposure.

Positioning and asepsis

During positioning, the patient often perceives the IR (with or without a grid) as cold, hard, and uncomfortable. Before the IR is put in place, the radiographer should warn the patient of possible discomfort and assure them that the examination will be for as short a time as possible. The patient will appreciate the radiographer's concern and efficiency in completing the examination as quickly as possible.

If the surface of the IR inadvertently touches bare skin, it can stick, making positioning adjustments difficult. An imaging plate cover over the IR protects the patient's skin, helps keep the IR clean, and assists with infection control. IRs should be wiped off with a disinfectant for asepsis and infection control after each patient. *The skin of older patients may be thin and dry and can be torn by manipulation of the IR if care is not taken.*

The IR must be enclosed in an appropriate, impermeable barrier in any situation in which it may come in contact with blood, body fluids, or other potentially infectious material. A contaminated IR can be difficult and sometimes impossible to clean. Approved procedures for disposing of used barriers must be followed.

Radiography

Chest

AP Projection [b]

Upright or supine

Image receptor: The IR should be 14 × 17 inches (35 × 43 cm) lengthwise or crosswise, depending on body habitus.

Position of patient

Depending on the condition of the patient, the projection should be performed with the patient in the upright position or to the greatest angle the patient can tolerate (if possible). Use the supine position for critically ill or injured patients.

Position of part

- Center the midsagittal plane to the IR.
- To include the entire chest, position the IR under the patient with the top about 2 inches (5 cm) above the relaxed shoulders. The exact distance depends on the size of the patient. When the patient is supine, the shoulders may move to a higher position relative to the lungs. Adjust accordingly.
- Make sure that the patient's shoulders are relaxed, then internally rotate the patient's arms to prevent scapular superimposition of the lung field if not contraindicated.
- Make sure that the patient's upper torso is not rotated or leaning toward one side (Fig. 20.10).

FIG. 20.10 Mobile AP chest: partially upright.

- *Shield gonads.*
- *Respiration*: Inspiration unless otherwise requested. If the patient is receiving respiratory assistance, carefully watch the patient's chest to determine the inspiratory phase for the exposure.

Central ray

- Perpendicular to the long axis of the sternum and the center of the IR; the central ray should enter about 3 inches (7.6 cm) below the jugular notch at the level of T7.

Collimation

- Adjust to at least 14 × 17 inches (35 × 43 cm) on the collimator, less for smaller patients.

Structures shown

This projection shows the anatomy of the thorax, including the heart, trachea, diaphragmatic domes, and most importantly, the entire lung fields (including vascular markings) (Fig. 20.11).

Evaluation Criteria

The following should be clearly shown:

- Evidence of proper collimation

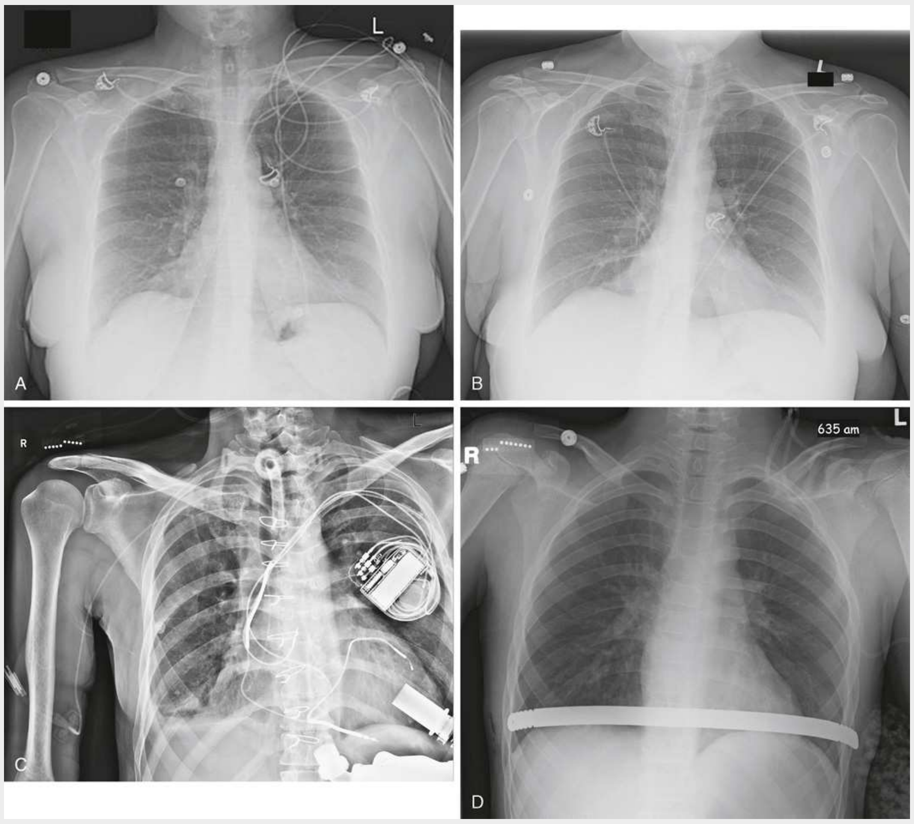


FIG. 20.11 Mobile AP chest radiographs. (A) AP chest image with incorrect cephalic tube angle resulting in an apical lordotic image in which the ribs appear boxy, the clavicles are projected too high, and the heart has a distorted silhouette. A tangle of lead wire is seen over the upper left chest. (B) Repeat image with the correct angle, central ray perpendicular to the long axis of the sternum. The radiographer has also positioned the lead wires appropriately. (C) Mobile peripherally inserted central catheter (PICC) placement image to visualize the PICC line from entrance to tip. Also seen are the tracheostomy, pacemaker, sternal wires, and ventricular assist device. (D) Adolescent postoperative patient with strut placed for pectus excavatum repair. Ice pack is seen in the lower right corner of the image.

(A) An x-ray view of the chest shows boxy ribs and the heart has a distorted silhouette. (B) An x-ray view of the chest shows lead wires are placed properly. (C) An x-ray view of the chest shows a tracheostomy, pacemaker, sternal wires, and ventricular assist device on it. (D) An x-ray shows a radiolucent horizontal thick object placed across the diaphragm.

- No motion and well-defined (not blurred) diaphragmatic domes and lung fields
- Lung fields in their entirety, including costophrenic angles
- Pleural markings
- Ribs and thoracic intervertebral disk spaces faintly visible through heart shadow
- No rotation with medial portion of clavicles and lateral border of ribs equidistant from vertebral column
- Radiograph markers as appropriate (R or L marker, and any to indicate how the patient is positioned; that is, supine, sitting upright, etc.).

NOTE: To ensure the proper angle from the x-ray tube to the IR, the radiographer can double-check the shadow of the shoulders from the field light projected onto the IR. If the shadow of the shoulders is thrown far above the upper edge of the IR, the angle of the tube must be corrected.

AP or PA Projection [C]

Right or left lateral decubitus position

Image receptor: The IR should be 14 × 17 inches (35 × 43 cm) with a lengthwise grid.

Position of patient

- Place the patient in the lateral recumbent position.
- Flex the patient's knees to provide stabilization, if possible.
- Place a firm support under the patient to elevate the body 2 to 3 inches (5 to 7.6 cm) and prevent the patient from sinking into the mattress.
- Raise both of the patient's arms up and away from the chest region, preferably above the head. An arm lying on the patient's side can imitate a region of free air.
- Make sure the patient cannot roll off the bed.

Position of part

- Position the patient for the AP projection whenever possible. It is much easier to position an ill patient (particularly the arms) for an AP.
- Adjust the patient to ensure a lateral position. The coronal plane passing through the shoulders and hips should be vertical.
- Place the IR behind the patient and below the support so that the lower margin of the chest is visible.
- Adjust the grid so that it extends approximately 2 inches (5 cm) above the shoulders. In order to avoid distortion, the IR should be supported in position and not leaning against the patient (Fig. 20.12).
- *Shield gonads.*
- *Respiration*: Inspiration unless otherwise requested.

FIG. 20.12 Mobile AP chest: left lateral decubitus position. Note gray pad placed under the chest to elevate it. The block is necessary to ensure that the left side of chest is included on the image.

A patient is in a left lateral decubitus position on the radiographic table with both his arms placed over his head. The I R is placed behind his back. A block is placed under the chest. The grid is positioned 2 inches above the shoulders.

Central ray

- Horizontal and perpendicular to the center of the IR, entering the patient at a level of 3 inches (7.6 cm) below the jugular notch for AP and T7 for PA.

Collimation

- Adjust to 14 × 17 inches (35 × 43 cm) on the collimator.

Structures shown

This projection shows the anatomy of the thorax, including the entire lung fields and any air or fluid levels that may be present (Fig. 20.13).

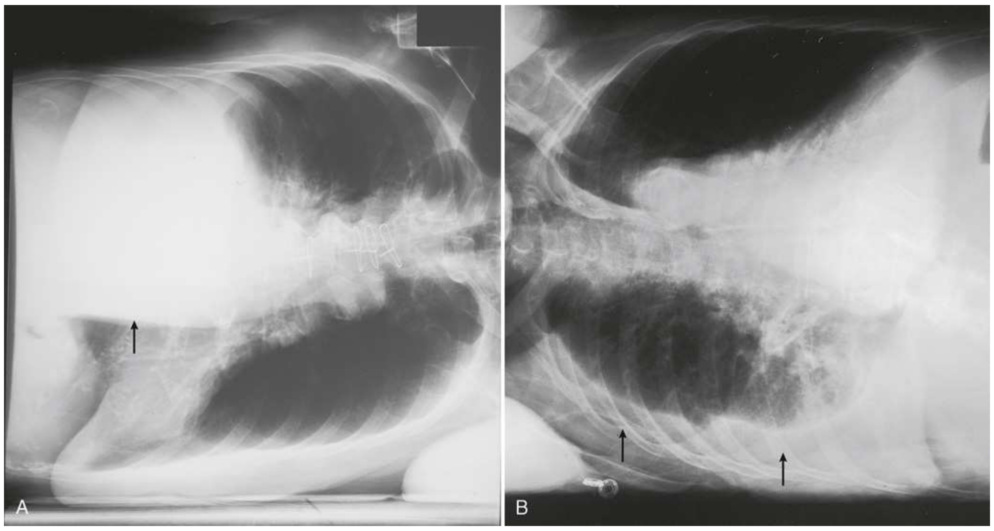


FIG. 20.13 Mobile AP chest radiographs performed in lateral decubitus positions in critically ill patients. (A) Left lateral decubitus position. The patient has a large right pleural effusion *(arrow)* and no left effusion. The complete left side of thorax is visualized because of elevation on a block. (B) Right lateral decubitus position. The patient has a right pleural effusion *(arrows)*, cardiomegaly, and mild pulmonary vascular congestion. The complete right side of thorax is visualized because of elevation on a block.

(A) An x-ray image of the chest in lateral decubitus position shows a large radiopaque area on the left side. It is indicated by an arrow. (B) An x-ray image of the chest in the lateral decubitus position shows a large radiopaque area on the right side. It is indicated by an arrow.

Evaluation Criteria

The following should be clearly shown:

- Evidence of proper collimation
- No motion
- No rotation
- Affected side in its entirety (upper lung for free air and lower lung for fluid)
- Patient's arms out of region of interest
- Radiographic markers as appropriate

NOTE: Fluid levels in the pleural cavity are best visualized with the affected side down, which also prevents mediastinal overlapping. Air levels are best visualized with the unaffected side down. The patient should be in position for at least 5 minutes before the exposure is made to allow air to rise and fluid levels to settle.

Abdomen

AP Projection [d]

Image receptor: The IR should be 14 × 17 inches (35 × 43 cm) with a lengthwise grid.

Position of patient

- If necessary, adjust the patient's bed to achieve a horizontal bed position.
- Place the patient in a supine position.

Position of part

- Position the grid under the patient to show the abdominal anatomy from the pubic symphysis to the upper abdominal region.
- Keep the grid from tipping side to side by placing it in the center of the bed and, if necessary, stabilize it with blankets or towels.
- Use the patient's draw sheet to roll the patient; this makes it easier to shift the patient from side to side during positioning of the IR and provides a barrier between the patient's skin and the grid.
- Center the midsagittal plane of the patient to the midline of the grid.
- Center the grid to the level of the iliac crests. If the emphasis is on the upper abdomen, center the grid 2 inches (5 cm) above the iliac crests or high enough to include the diaphragm.
- Adjust the patient's shoulders and pelvis to lie in the same plane (Fig. 20.14).
- Move the patient's arms out of the region of the abdomen.
- *Respiration*: Expiration.

Central ray

- Perpendicular to the center of the grid along the midsagittal plane and at the level of the iliac crests or the 10th rib laterally.

Collimation

- Adjust to 14 × 17 inches (35 × 43 cm) on the collimator.

FIG. 20.14 Mobile AP of the abdomen.

A patient is in a supine position on the radiographic table. The grid is positioned under the patient to show the abdominal anatomy from the pubic symphysis to the upper abdominal region. Both hands lie on the same horizontal plane.

Structures shown

This projection shows the inferior margin of the liver, the spleen, kidneys, and psoas muscles, calcifications, and evidence of tumor masses. If the image includes the upper abdomen and diaphragm, the size and shape of the liver may be seen (Fig. 20.15).

Evaluation Criteria

The following should be clearly shown:

- Evidence of proper collimation
- No motion
- Outlines of the abdominal viscera

- Abdominal region, including pubic symphysis or diaphragm (both may be seen on some patients)
- Vertebral column in center of image
- Psoas muscles, lower margin of liver, and kidney margins
- No rotation
- Symmetric appearance of vertebral column and iliac wings
- Radiographic markers (as appropriate)

NOTE: Hypersthenic patients may require two separate projections using a crosswise grid. One grid is positioned for the upper abdomen and the other for the lower abdomen.

FIG. 20.15 Mobile AP abdominal radiographs. (A) Abdomen without pathology. The entire abdomen is seen in this patient. (B) Because of this patient's large body habitus, two crosswise (landscape) images of the abdomen were necessary to include all abdominal structures. Counting of vertebral bodies ensures adequate overlap. Note the large amount of free air, indicative of a perforated bowel. (C) Mobile AP abdominal image of a pediatric patient. Ingested jewelry bead is seen in the fundus of the stomach.

(A) An x-ray view of the abdomen appears hazy. (B) An x-ray view of the abdomen is split into two halves. (C) An x-ray view of the abdomen shows a long segmented circular radiopaque object in the stomach.

FIG. 20.16 Mobile AP abdomen: left lateral decubitus position. Note black blocks placed under the abdomen to level the abdomen and keep the patient from sinking into the mattress.

A patient is in a left lateral decubitus position on the radiographic table. Bothe his elbows are flexed and the forearm is placed behind his head. The grid is positioned vertically in front of the patient above the iliac crests. The I R is placed behind the back.

AP or PA Projection [e]

Left lateral decubitus position

Image receptor: The IR should be 14 × 17 inches (35 × 43 cm) with a lengthwise grid.

Position of patient

- Place the patient in the left lateral recumbent position unless requested otherwise.
- Slightly flex the patient's knees to provide stabilization.
- If necessary, place a firm support under the patient to elevate the body and keep the patient from sinking into the mattress.
- If possible, raise both of the patient's arms away from the abdominal region. The right arm lying on the side of the abdomen may imitate a region of free air.
- Make sure the patient cannot fall out of bed.

Position of part

- Use the PA or AP projection, depending on the room layout.
- Adjust the patient to ensure a true lateral position; the coronal plane passing through the shoulders and hips should be vertical.
- Place the grid vertically in front of the patient for a PA projection and behind the patient for an AP projection. The grid should be supported in position and not leaned against the patient to prevent grid cutoff.
- Position the grid so that its center is 2 inches (5 cm) above the iliac crests to ensure that the diaphragm is included. The pubic symphysis and lower abdomen do not have to be visualized (Fig. 20.16).
- Before making the exposure, ensure that the patient has been in the lateral recumbent position for at least 5 minutes to allow air to rise and fluid levels to settle.
- *Respiration*: Expiration.

Central ray

- Horizontal and perpendicular to the center of the grid, entering the patient along the midsagittal plane

Collimation

- Adjust to 14 × 17 inches (35 × 43 cm) on the collimator.

Structures shown

Air or fluid levels within the abdominal cavity are shown, and these projections are especially helpful in assessing free air in the abdomen. The right border of the abdominal region must be visualized (Fig. 20.17).

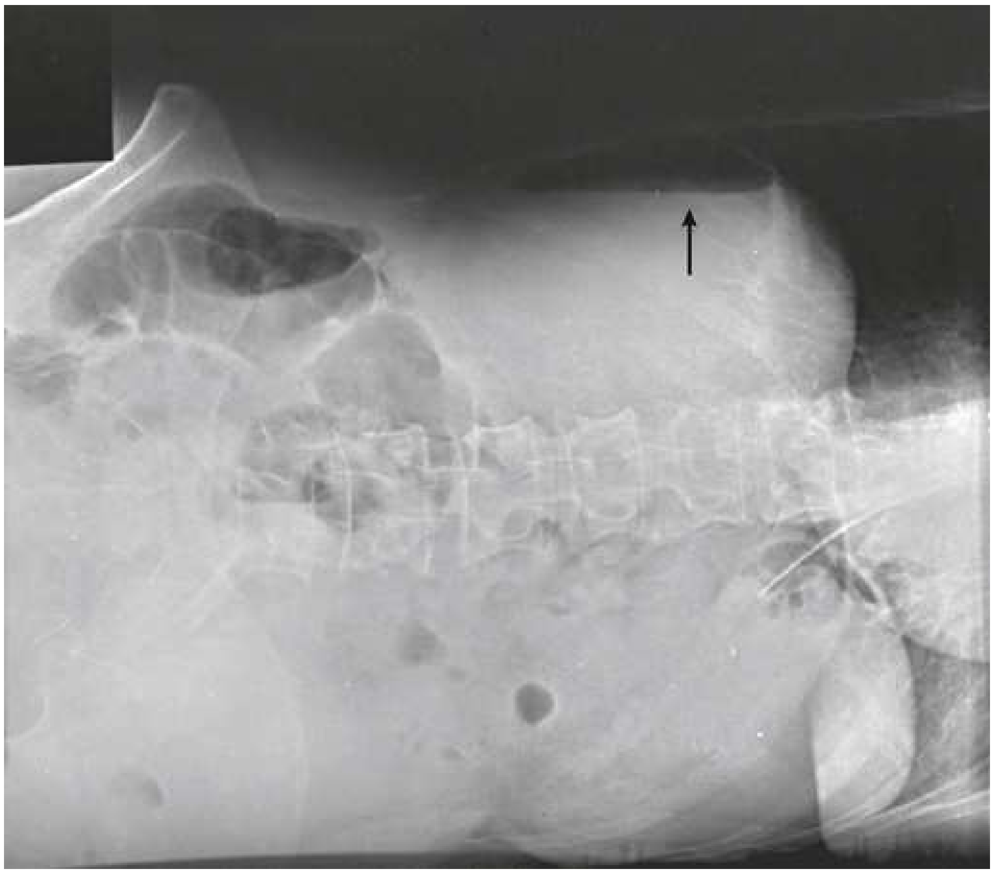


FIG. 20.17 Mobile AP of the abdomen: left lateral decubitus position. Free intraperitoneal air is seen on the upper or right side of the abdomen *(arrow)*. The radiograph is slightly underexposed to show free air more easily.

Evaluation Criteria

The following should be clearly shown:

- Evidence of proper collimation
- No motion
- Well-defined diaphragm and abdominal viscera
- Air or fluid levels if present
- Right and left abdominal wall and flank structures
- No rotation
- Symmetric appearance of vertebral column and iliac wings
- Radiographic markers (as appropriate)

NOTE: Hypersthenic patients may require two projections using a 14 × 17 inches (35 × 43 cm) grid positioned crosswise to visualize the entire abdominal area. A patient with a long torso may require two projections with the grid lengthwise to visualize the entire abdominal region.

Pelvis

AP Projection [f]

Image receptor: The IR should be 14 × 17 inches (35 × 43 cm) with a grid crosswise.

Position of patient

- Adjust the patient's bed horizontally so that the patient is in a supine position.
- Move the patient's arms out of the region of the pelvis.

FIG. 20.18 Mobile of the AP pelvis. Grid is placed horizontally and perpendicular to the central ray.

Position of part

- Position the grid under the pelvis so that the center is midway between the anterior superior iliac spine (ASIS) and the pubic symphysis. This is about 2 inches (5 cm) inferior to the ASIS and 2 inches (5 cm) superior to the pubic symphysis.
- Center the midsagittal plane of the patient to the midline of the grid. The pelvis should not be rotated.
- Rotate the patient's legs medially approximately 15 degrees when not contraindicated (Fig. 20.18).
- *Respiration*: Suspended.

Central ray

- Perpendicular to the midpoint of the grid, entering the midsagittal plane. The central ray should enter the patient 2 inches (5 cm) above the pubic symphysis and 2 inches (5 cm) below the ASIS.

Collimation

- Adjust to 14 × 17 inches (35 × 43 cm) on the collimator.

Structures shown

This projection shows the pelvis, including both hip bones; the sacrum and coccyx; and the head, neck, trochanters, and proximal portion of the femora (Fig. 20.19).

FIG. 20.19 Mobile AP of the pelvis. This patient has a comminuted fracture of the left acetabulum with medial displacement of medial acetabular wall *(arrow)*. Residual barium is seen in the colon, sigmoid, and rectum.

Evaluation Criteria

The following should be clearly shown:

- Evidence of proper collimation
- Entire pelvis, including proximal femora and both hip bones
- No rotation
- Symmetric appearance of iliac wings and obturator foramina
- Both greater trochanters and ilia equidistant from edge of radiograph
- Femoral necks not foreshortened and greater trochanters in profile
- Radiographic markers (as appropriate)

NOTE: It is common for the patient's weight to cause the bottom edge of the grid to tilt upward. The x-ray tube may need to be angled caudally to compensate and maintain proper grid alignment, preventing grid cutoff. The exact angle needed is not always known, however, or easy to determine. The radiographer may want to lower the foot of the bed slightly (Fowler position), shifting the patient's weight more evenly on the grid and allowing it to be flat. A rolled-up towel or blanket placed under the grid may also be useful to prevent lateral tilting. If the bed is equipped with an inflatable air mattress, the maximum inflate mode is recommended. Tilting the bottom edge of the grid downward is another possibility. Check the level of the grid carefully and compensate accordingly.

Femur

AP Projection [g]

Most mobile AP and lateral projections of the femur may be radiographs of the middle and distal femur taken while the patient is in traction. The anatomy demonstrated for the proximal femur would be included in an AP pelvis image, if a pelvic exam is also ordered on the same patient. If not, the technologist should include an AP proximal femur image. The femur cannot be moved, which presents a challenge to the radiographer.

Image receptor: The IR should be 14 × 17 inches (35 × 43 cm) with a grid lengthwise.

Position of patient

- The patient is in the supine position.

Position of part

- Cautiously place the grid lengthwise under the patient's femur, with the distal edge of the grid low enough to include the fracture site, pathologic region, and knee joint.
- If necessary, elevate the grid with towels, blankets, or blocks under each side to ensure proper grid alignment with the x-ray tube.

- Center the grid to the midline of the affected femur.
- Ensure that the grid is placed parallel to the plane of the femoral condyles (Fig. 20.20).
- *Shield gonads.*
- *Respiration*: Suspended.

FIG. 20.20 Mobile of the AP femur.

A patient is in a supine position on the radiographic table with both his hands resting on his chest. The I R is placed under the femur. The grid is placed parallel to the plane of the femoral condyles.

Central ray

- Perpendicular to the long axis of the femur and centered to the grid.
- Make sure that the central ray and grid are aligned to prevent grid cutoff.

Collimation

- Adjust to top at ASIS for hip, bottom at tibial tuberosity for knee, 1 inch (2.5 cm) on side of the shadow of the femur, and 17 inches (43 cm) in length.

DIGITAL RADIOGRAPHY

The thickest portion of the femur (proximal area) must be carefully measured, and an appropriate kVp must be selected to penetrate this area. The computer cannot form an image of the anatomy in this area if penetration does not occur. A light area of the entire proximal femur would result. Positioning the cathode over the proximal femur would improve CR image quality.

Structures shown

The distal two-thirds of the femur, including the knee joint, are shown (Fig. 20.21).

Evaluation Criteria

The following should be clearly shown:

- Evidence of proper collimation
- Most of femur, including knee joint for distal
- No knee rotation
- Adequate penetration
- Any orthopedic appliance, such as plate and screw fixation
- Radiographic markers as appropriate

FIG. 20.21 Mobile of the AP femur showing a fracture of the midshaft with femoral rod placement. The knee joint is included on the image.

NOTE: If the entire length of the femur must be visualized, an AP projection of the proximal femur can be performed by placing a 14 × 17 inch (35 × 43 cm) grid lengthwise under the proximal femur and hip. The top of the grid is placed at the level of the ASIS to ensure that the hip joint is included. The central ray is directed to the center of the grid and long axis of the femur (see Fig. 20.4).

FIG. 20.22 Mobile of the mediolateral left femur. An assistant wearing a lead apron holds and positions the right leg and femur and steadies the grid.

FIG. 20.23 Mobile lateromedial of the left femur. The grid is placed between the legs and steadied by the patient.

Lateral Projection [h]

Mediolateral or lateromedial projection

Dorsal decubitus position

It may not be possible to move the femur, which presents a challenge to the radiographer. The *mediolateral* projection is generally preferred because more of the proximal femur is demonstrated.

Image receptor: The IR should be 14 × 17 inches (35 × 43 cm) with a grid lengthwise.

Position of patient

- The patient is in the supine position.

Position of part

- Determine whether a mediolateral or lateromedial projection is to be performed.

Mediolateral projection

- Visualize the optimal length of the patient's femur by placing the grid in a vertical position next to the lateral aspect of the femur.
- Place the distal edge of the grid low enough to include the patient's knee joint.
- Have the patient, if able, hold the upper corner of the grid for stabilization; otherwise, support the grid firmly in position.
- Support the unaffected leg by using the patient's support (or a trapeze bar if present) or a support block.
- Elevate the unaffected leg until the femur is nearly vertical. An assistant may have to elevate and hold the leg of a critically ill patient. The assistant may also steady the grid and must wear a lead apron for protection (Fig. 20.22).

Lateromedial projection

- Place the grid next to the medial aspect of the affected femur (between the patient's legs) and make sure that the knee joint is included (Fig. 20.23).
- Make sure that the grid is placed *perpendicular* to the epicondylar plane.
- *Shield gonads.*
- *Respiration:* Suspended.

Central ray

- Perpendicular to the long axis of the femur, entering at its midpoint.
- Make sure that the central ray and grid are aligned to prevent grid cutoff; the central ray is centered to the femur and not to the center of the grid.

Collimation

- Adjust to top at ASIS for hip, bottom at the tibial tuberosity of the knee, 1 inch (2.5 cm) on the side of the shadow of the femur and 17 inches (43 cm) in length.

DIGITAL RADIOGRAPHY

The thickest portion of the femur (proximal area) must be measured carefully, and an appropriate kVp must be selected to penetrate this area. The computer cannot form an image of any anatomy in this area if penetration does not occur. A light area of the entire proximal femur would result. Positioning the cathode over the proximal femur would improve CR image quality.

Structures shown

This projection shows the distal two-thirds of the femur, including the knee joint, without superimposition of the opposite thigh (Fig. 20.24).

FIG. 20.24 Mobile of the lateral femur showing midshaft fractures and femoral rod placement. The knee joints are included on the image. (A) Mediolateral. (B) Lateromedial.

(A) An x-ray view of the femur shows a radiopaque rod with two screws in it. There is a fracture in the midshaft of the femur. (B) An x-ray view of the femur shows a radiopaque rod and a few screws on the other side of the joint.

Evaluation Criteria

The following should be clearly shown:

- Evidence of proper collimation
- Most of femur, including knee joint
- Patella in profile
- Superimposition of femoral condyles
- Opposite femur and soft tissue out of area of interest
- Adequate penetration of proximal portion of femur
- Orthopedic appliance (if present)
- Radiographic markers (as appropriate)

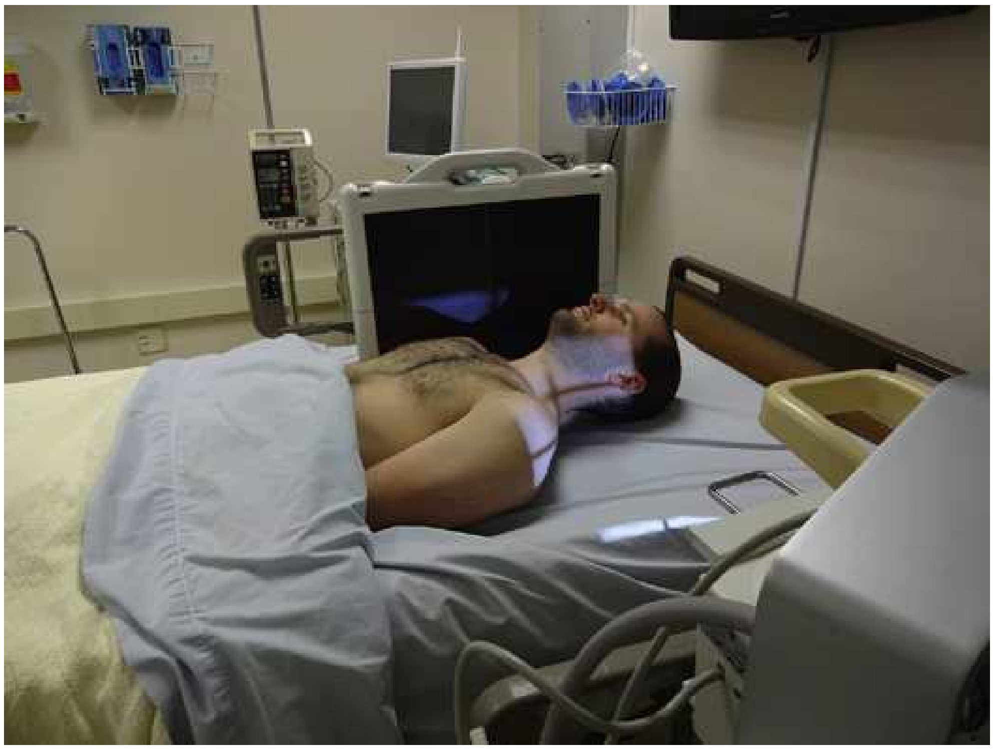


FIG. 20.25 Mobile of the lateral cervical spine.

Cervical Spine

Lateral Projection [h]

Right or left dorsal decubitus position

Image receptor: The IR should be 10 × 12 inches (24 × 30 cm) with a grid lengthwise; imaging may be performed with a nongrid IR on smaller patients.

Position of patient

- Position the patient in the supine position with arms extended down along the sides of the body.
- Observe whether a cervical collar or another immobilization device is being used. *Do not remove the device without the consent from the physician or authorized personnel.*

Position of part

- Ensure that the upper torso, cervical spine, and head are not rotated.
- Place the grid lengthwise on the right or left side, parallel to the neck.
- Place the top of the grid approximately 1 inch (2.43 cm) above the external acoustic meatus (EAM) so that the grid is centered to C4 (upper thyroid cartilage).
- Raise the chin slightly. *If the patient has a new trauma, suspected fracture, or known fracture of the cervical region, check with the physician before elevating the chin. Improper movement of a patient's head can disrupt a fractured cervical spine.*
- Immobilize the grid in a vertical position. The grid can be immobilized in multiple ways if a holding device is unavailable. Another method is to place pillows or a cushion between the side rail of the bed and the IR, holding the IR next to the patient. Tape also works well in many instances (Fig. 20.25).
- Have the patient relax the shoulders and reach for the feet if possible.
- *Shield gonads.*
- *Respiration:* Full expiration to obtain maximum depression of the shoulders.

Central ray

- Horizontal and perpendicular to the center of the grid. This should place the central ray at the level of C4 (upper thyroid cartilage).
- Make sure that proper alignment of the central ray and grid is maintained in order to prevent grid cutoff.
- Because of the great object-to-image receptor distance (OID), SID of 60 to 72 inches (158 to 183 cm) is recommended. This also helps show C7.

Collimation

- Adjust the top of ear attachment (TEA), bottom to jugular notch, and 1 inch (2.5 cm) on the sides of the neck.

DIGITAL RADIOGRAPHY

To ensure that the lower cervical vertebrae are fully penetrated, the kVp must be set to penetrate the C7 area.

Structures shown

This projection shows the seven cervical vertebrae, including the base of the skull and the soft tissues surrounding the neck (Fig. 20.26).

Evaluation Criteria

The following should be clearly shown:

- Evidence of proper collimation
- All seven cervical vertebrae, including interspaces and spinous processes
- Neck extended when possible so that rami of mandible are not overlapping C1 or C2
- C4 in center of grid
- Radiographic markers (as appropriate)
- Superimposed posterior margins of each vertebral body

NOTE: It is essential that C6 and C7 be included on the image. To accomplish this, the radiographer should instruct the patient to relax the shoulders toward the feet as much as possible. If the examination involves pulling down on the patient's arms, the radiographer should exercise extreme caution and evaluate the patient's condition carefully to determine whether pulling of the arms can be tolerated. Fractures or injuries of the upper limbs, including the clavicles, must be considered. Applying a strong pull to the arms of a patient in a hurried or jerking manner can disrupt a fractured cervical spine. If the lateral projection does not adequately visualize the lower cervical region, the Twining method (sometimes referred to as the "swimmer's" position), which eliminates pulling of the arms, may be recommended for patients who have experienced trauma or have a known cervical fracture. One arm must be placed above the patient's head (the Twining method is described in Chapter 9).

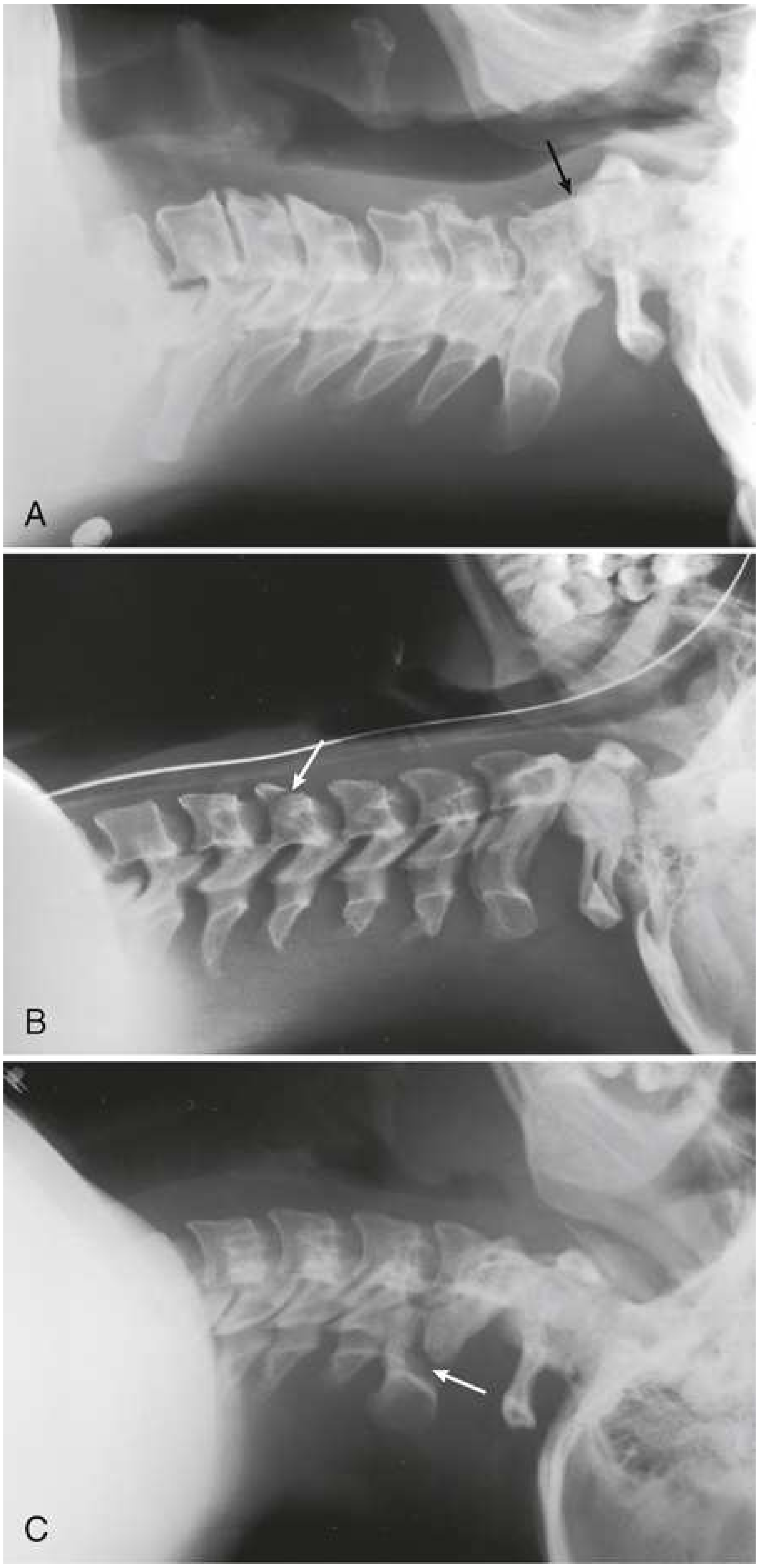


FIG. 20.26 Mobile of the lateral cervical spine obtained at the patient's bedside several weeks after trauma. (A) Entire cervical spine shows slight anterior subluxation of the dens on the body of C2 *(arrow)*. (B) Entire cervical spine shows nearly vertical fracture through the body of C5 with slight displacement *(arrow)*. (C) First five cervical vertebrae show vertical fractures through the posterior aspects of the C2 laminae *(arrow)* with 4-mm displacement of the fragments. Earlier radiographs showed that C6 and C7 were unaffected and did not need to be included in this follow-up radiograph.

(A) An x-ray shows the seven cervical vertebrae and slight anterior subluxation of the dens on the body of C 2. It is indicated by an arrow. (B) An x-ray shows the seven cervical vertebrae vertical fracture through the body of C 5. It is indicated by a white arrow. (C) An x-ray shows the first five cervical vertebrae and vertical fractures through the posterior aspects of the C 2. It is indicated by a white arrow.

Best Practices in Mobile Imaging

Mobile radiography (portable radiography) enables technologists to perform standard imaging procedures in an environment outside of a dedicated radiographic exposure room. Portable radiography requires the technologist to use critical thinking skills to provide quality images. The following best practices provide some universal guidelines for performing mobile radiography.

1. ***Speed:*** There are many circumstances that require radiographers to produce quality images as quickly as possible. Although speed is an excellent skill set, it is important to maintain image quality. The quality of an image should take precedence over how quickly an exam can be performed.
2. ***Knowledge:*** An understanding of alternate projections to meet routine protocols while, at the same time, considering how the patient's condition might affect positioning are necessary qualities to ensure optimal production of images.
3. ***Positioning accuracy:*** Performing mobile radiography creates opportunities to use critical thinking skills. Tube angles and IR placement with structures to be demonstrated must be similar to those radiographs obtained in routine exposure rooms. Most exams can be accomplished with mobile radiographic equipment while maintaining image quality in accordance with established imaging standards. Mobile radiographic images should demonstrate optimum detail of structures with only the minimum distortion of the image. The alignment of the central ray, part, and image receptor (IR) is equally important with mobile radiography as performing exams in departmental radiology rooms. To reduce motion, use a short exposure time to avoid blurring the image caused by involuntary patient motion.
4. ***Practice standard precautions:*** The risk of working in an environment where blood and body fluids are present is often a real and present danger to radiographers performing mobile radiography. The radiographer should be aware of signs posted outside of the patient's room listing certain isolation attire, including gloves, mask, gown, and or eye shields, that the radiographer must wear to perform the radiographic procedure. Image receptors and sponges should be placed in nonporous plastic to prevent contamination of body fluids. Hand hygiene should be performed frequently. All equipment and accessory devices should be cleaned after each patient to ensure everything is ready for its next use.
5. ***Immobilization:*** The radiographer must *never* remove any immobilization device without a physician's orders. The radiographer should provide proper immobilization and support to minimize patient movement. Additionally, radiographers must be cautious of moving or adjusting orthopedic devices that are attached to the patient.
6. ***Equipment:*** Radiology departments might have portable machines in the facility that are different models or from different manufacturers. All technologists assigned to perform mobile radiography must be proficient with each portable machine.
7. ***Attention to detail:*** Technologists should be informed of the patient's condition and continuously observe the patient during the exam. A radiographer should *never* leave a patient unattended during imaging procedures, because the patient's condition could quickly change for the worse. Radiographers also have the responsibility to note and report changes immediately to the nursing staff or attending physician.
8. ***Attention to department protocol and scope of practice:*** Radiographers should know department protocols. The scope of practice for radiographers varies from state to state and from country to country. Radiographers should know the scope of their role when performing mobile radiographic imaging procedures. For example, a radiographer should not give anything to a patient to eat or drink without first getting permission from the nursing staff or the attending physician.
9. ***Professionalism:*** Ethical conduct in all situations is a requirement for all health care professionals. All radiographers should adhere to the Code of Ethics for Radiologic Technologists (see Chapter 1) and the Radiography Practice Standards.

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[b] The nonmobile projection is described in Chapter 3.

[c] The nonmobile projection is described in Chapter 4.

[d] The nonmobile projection is described in Chapter 4.

[e] The nonmobile projection is described in Chapter 8.

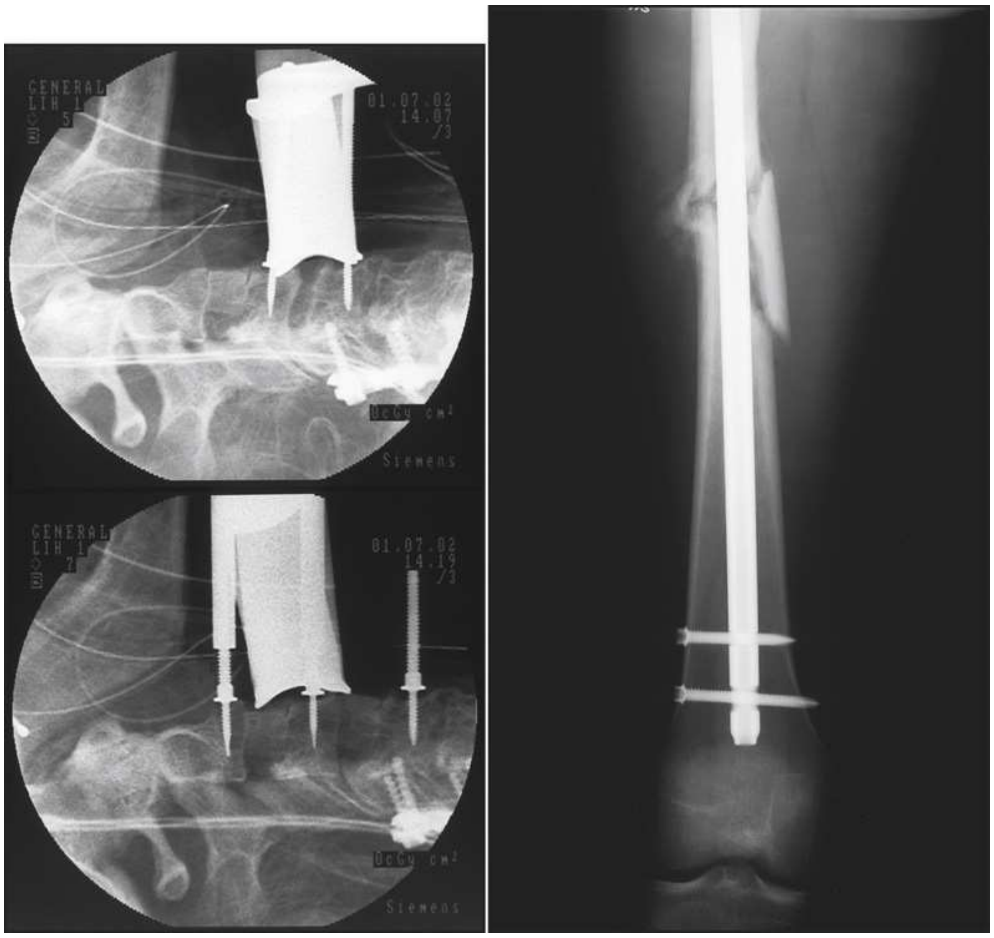
[f] The nonmobile projection is described in Chapter 7.

[g] The nonmobile projection is described in Chapter 7.

[h] The nonmobile projection is described in Chapter 9.

[h] The nonmobile projection is described in Chapter 9.

21: Surgical Radiography



J. Tyler Carter, and Garrett Johnson

OUTLINE

Surgical radiology is a dynamic experience. The challenges a radiographer encounters in the surgical suite are unique. Knowing the machinery and its capabilities and limitations is most important; in that regard, the radiographer can enter any operating room (OR) case, whether routine or extraordinary and, with good communication, be able to perform all tasks well. An understanding of common procedures and familiarity with equipment enables the radiographer to perform most mobile examinations ordered by the physician. Surgical radiography can be a challenging and exciting environment for the radiographer but can also be intimidating and stressful. Surgical radiology requires educated personnel familiar with specific equipment routinely used during common surgical procedures. Preparedness and familiarity with equipment are key. Standard health and safety protocols must be followed to avoid contamination and to ensure patient safety. These are the basics, and the pieces come together in surgical radiology in distinctive ways.

This chapter focuses on the most common procedures performed in the surgical area. The basic principles of mobile imaging are detailed, and helpful suggestions are provided for the successful completion of the examinations. This chapter is not intended to cover every possible combination of examinations or situations that a radiographer may encounter; rather, it provides an overview of the surgical setting and a summary of common examinations. The scope of radiologic examinations in a surgical setting is vast and may differ greatly among health care facilities (Box 21.1). The goals of this chapter are to (1) provide an overview of the surgical setting and explain the role of the radiographer as a vital member of the surgical team, (2) assist the radiographer in developing an understanding of the imaging equipment used in surgical situations, and (3) present common radiographic procedures performed in the OR. The radiographer should review the surgery department protocols, which vary from one institution to another.

Surgical Team

Members of the surgical team generally include a surgeon, one or two assistants, a surgical technologist, an anesthesia provider, a circulating nurse, and various support staff who surround the patient. Each member of the surgical team has a specific function to perform. The OR team has been described as a symphony orchestra. The medical staff is in unison and harmony with their colleagues for the successful accomplishment of the expected outcomes. The OR team is subdivided, according to the functions of its members, into sterile and nonsterile teams.

BOX 21.1 Scope of surgical radiography

Surgical fluoroscopic procedures

- Abdomen: cholangiogram
- Chest-line placement: bronchoscopy
- Cervical spine: anterior cervical discectomy and fusion
- Lumbar spine
- Hip: cannulated hip screws or hip pinning, decompression hip screw
- Femoral and tibial nailing
- Extremity fluoroscopy
- Humerus: shoulder in beach chair position
- Femoral/tibial arteriogram

Mobile surgical radiography procedures

- Localization examinations of cervical, thoracic, and lumbar spine
- Mobile extremity examinations in operating room

Sterile Team Members

Sterile team members scrub their hands and arms, don a sterile gown and gloves over proper surgical attire, and enter the sterile field. The sterile field is the area of the OR that immediately surrounds and is specially prepared for the patient. To establish a sterile field, all items necessary for the surgical procedure are sterilized. After this process, the scrubbed and sterile team members function within this limited area and only handle sterile items (Fig. 21.1). The sterile team consists of the following members:

- *Surgeon:* The surgeon is a licensed physician who is specially trained and qualified by knowledge and experience to perform surgical procedures. The surgeon's responsibilities include preoperative diagnosis and care, selection and performance of the surgical procedure, and postoperative management of care. The surgeon assumes full responsibility for all medical acts of judgment and for the management of the surgical patient.
- *Surgical assistant:* The first assistant is a qualified surgeon or resident in an accredited surgical education program. The assistant should be capable of assuming responsibility for performing the procedure for the primary surgeon. Assistants help to maintain visibility of the surgical site, control bleeding, close wounds, and apply dressings. The assistant's role varies depending on the institution and the type of procedure or surgical specialty.
- *Physician assistant:* The physician assistant is a non-physician allied health practitioner who is qualified by academic and clinical training to perform designated procedures in the OR and in other areas of surgical patient care.
- *Scrub nurse:* The scrub nurse is a registered nurse (RN) who is specially trained to work with surgeons and the medical team in the OR.
- *Certified surgical technologist (CST):* The CST is responsible for maintaining the integrity, safety, and efficiency of the sterile field throughout the surgical procedure. The CST prepares and arranges instruments and supplies and assists the surgical procedure by providing the required sterile instruments and supplies. In some institutions, a licensed practical nurse (LPN) or RN may assume this role.

FIG. 21.1 OR staff showing sterile *(left)* and nonsterile *(right)* team members.

A woman on the left is wearing scrubs, head cover, mask, eyewear, shoe covers, and gloves. A woman on the right is wearing a dark-colored scrub suit, mask, shoe covers, and headcover. A table behind has scrubs and other equipment on it.

Nonsterile Team Members

Nonsterile team members do not enter the sterile field; they function outside and around it. They assume responsibility for maintaining sterile techniques during the surgical procedure, but they handle supplies and equipment that are not considered sterile. Following the principles of aseptic technique, they keep the sterile team supplied, provide direct patient care, and respond to any requests that may arise during the surgical procedure.

- *Anesthesia provider:* The anesthesia provider is a physician (anesthesiologist) or certified RN anesthetist who specializes in administering anesthetics. Choosing and applying appropriate agents and suitable techniques of administration, monitoring physiologic functions, maintaining fluid and electrolyte balance, and performing blood replacements are essential responsibilities of the anesthesia provider during the surgical procedure.
- *Circulator:* The circulator is preferably an RN. The circulator monitors and coordinates all activities within the OR, provides supplies to the CST during the surgical procedure and manages the care of the patient.
- *Radiographers:* The radiographer's role in the OR is to provide intraoperative imaging in a variety of examinations and with various types of equipment.
- *Others:* The OR team may also include biomedical technicians, monitoring technologists, and individuals who specialize in the equipment or monitoring devices necessary during the surgical procedure.

Proper Surgical Attire

Surgical attire protocols may change from one institution to another but should be available for review, understood, and followed by all staff members. Although small variances in protocol exist among institutions, there are common standards.

Large amounts of bacteria are present in the nose and mouth, skin, hair, and on the attire of personnel who enter the restricted areas of the surgical setting. Surgical site infections have been traced to bacteria found on surgical personnel. According to FDA standards, solutions used for surgical scrub reduces microbes on the skin. In addition, wearing surgical attire limits microbial spread among the staff and patient. Proper facility design, adhering to Occupational Safety and Health Administration (OSHA) regulations, and requiring surgical attire are important ways of preventing the transportation of microorganisms into surgical settings where they may infect patient's open wounds.

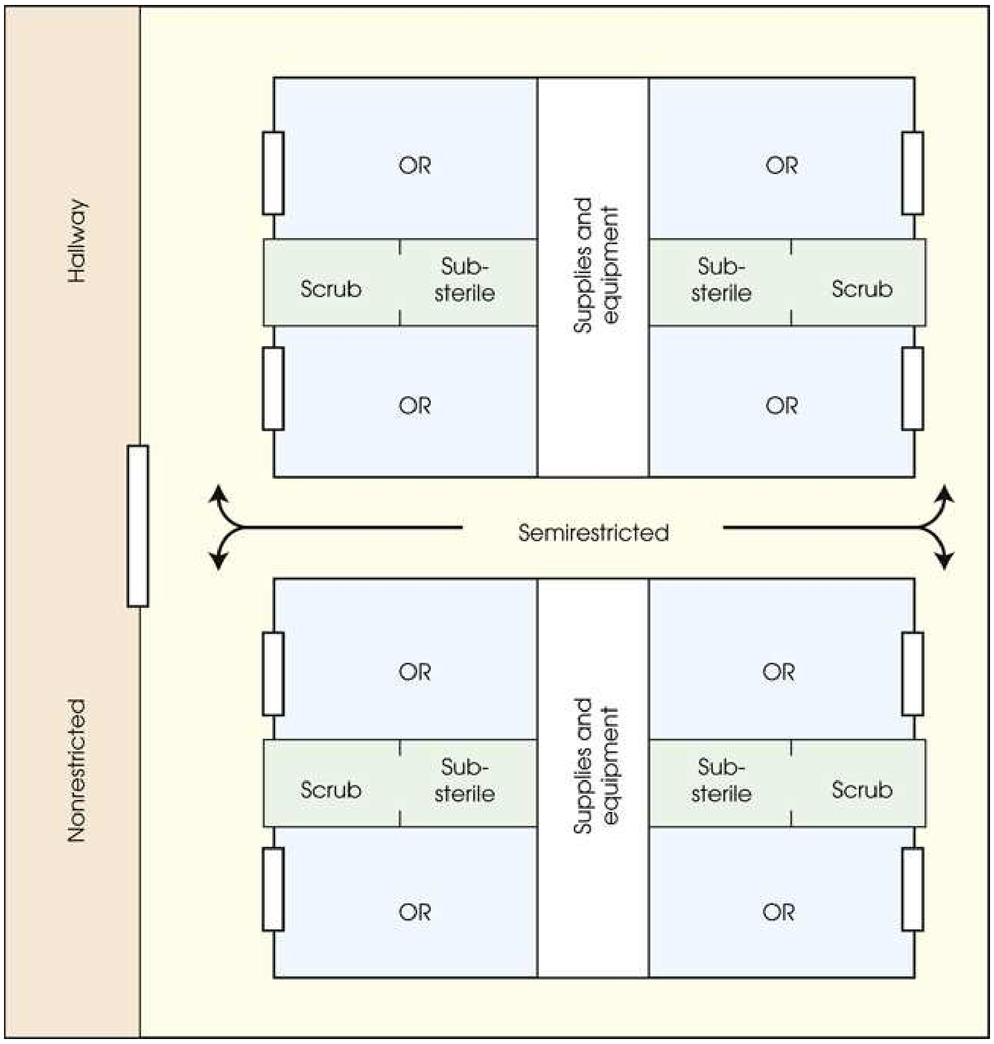


FIG. 21.2 OR suite layout showing restricted, nonrestricted, and semirestricted areas. ORs are "restricted."

Layout of O R suit shows the hallway is no restricted. The O R suite area is divided into two sets surrounded by semi restricted area. Each set has two scrub area, two sub-sterile area, a supplies and equipment area, and four O R's which are restricted. The supply and equipment area is between each set of Scrub and sub sterile area. An O R is on either side of scrub and sub-sterile area.

Operating Room Attire

The OR should have specific written policies and procedures for proper attire to be worn within the semi-restricted and restricted areas of the OR suite. The dress code should include aspects of personal hygiene important to environmental control. The protocol is strictly monitored so that everyone conforms to established policy.

Street clothes should never be worn within semi-restricted or restricted areas of the surgical suite (Fig. 21.2). Clean, fresh attire should be donned at the beginning of each shift in the OR suite and as needed if the attire becomes wet or soiled. Blood-stained or soiled attire, including shoe covers, is unattractive and can also be a source of cross-infection or contamination. Soiled attire is not worn outside of the OR suite, and steps should be taken to remove soiled clothing immediately on exiting. OR attire should not be stored in a locker for wearing a second time. Underclothing should be clean and totally covered by the scrub suit (Fig. 21.3). Other aspects of proper attire include the following:

- *Protective eyewear:* OSHA regulations require eyewear to be worn when contamination from blood or body fluids is possible.
- *Masks:* Masks should be worn at all times in the OR but are not necessary in all semi-restricted areas.
- *Shoe covers:* Shoe covers should be worn when contamination from blood or body fluids can be reasonably anticipated. Shoe covers should be changed whenever they become torn, soiled, or wet and should be removed before leaving the surgical area.
- *Caps:* Caps should be worn to cover and contain hair at all times in the restricted and semi-restricted areas of the OR suite. Hoods are also available to cover hair, such as facial hair, that cannot be contained by a cap and mask.
- *Gloves:* Gloves should be worn when contact with blood or body substances is anticipated.
- *Radiation badge and identification:* A radiation badge and proper identification should be worn at all times.

Personal Hygiene

A person with an acute infection, such as a cold, open cold sore, or sore throat, is known to be a carrier of transmittable conditions and should not be permitted within the OR suite. Daily body cleanliness and clean hair are also important because good personal hygiene helps to prevent transportation of microbial fallout that can cause open wound infections. Daily body cleanliness and clean, dandruff-free hair help prevent superficial wound infections.

FIG. 21.3 Properly attired radiographers with protective eyewear and additional headwear to cover facial hair or long hair.

Dance of the Operating Room

The concepts of sterile and aseptic technique date back to Hippocrates, who boiled wine and water to pour into open wounds in an attempt to prevent infection. Galen changed the technique a bit and began boiling the instruments instead, and shortly thereafter, Semmelweis noted a dramatic decline in postoperative infection by having the staff wash their hands and change gowns between surgical procedures.

Maintaining the sterile field in an OR suite can be like a well-choreographed dance when the team works well together. Certain moves and rules must be followed. Proper adherence to aseptic technique eliminates or minimizes modes and sources of contamination. Basic principles must be observed during the surgical procedure to provide the patient with a well-defined margin of safety. Everyone who cares for patients must carry out effective hospital and OR infection control programs. Infection control involves a wide variety of concepts, including methods of environmental sanitation and maintenance of facilities; cleanliness of the air and equipment in the OR suite; cleanliness of the skin and apparel of patients, surgeons, and personnel; sterility of surgical equipment; strict aseptic technique; and careful observance of procedural rules and regulations.

Up to 10,000 microbial particles can be shed from the skin per minute. Nonsterile team members should not reach over a sterile field. When working over the sterile field (e.g., performing a posteroanterior [PA] lumbar spine), the sterile field should be covered with a sterile drape to protect the field (Fig. 21.4). The technologist cannot move the radiographic equipment into position over the sterile field until after the sterile cover is in place. A sterile team member should fold over the sterile drape on itself, and then a nonsterile team member should carefully remove the covering drape, being careful not to compromise the sterile field. If a sterile field is compromised, the OR staff should be notified immediately.

FIG. 21.4 Radiographer leaning over the sterile field while positioning the x-ray tube. The sterile incision site over which the radiographer works is properly covered to maintain a sterile field. Note the sterile instruments in the foreground *(arrow)*. The radiographer should never move radiographic equipment over uncovered sterile instruments or an uncovered surgical site.

A radiographer is leaning over the sterile field while positioning the x-ray tube. There are sterile instruments in the foreground. It is indicated by a black arrow. The sterile incision site is covered.

Communication is of utmost importance. As a result of the surgical sterile field, the radiographer is unable to help position the IR or the patient. Good, professional communication is essential while using sound, basic knowledge of anatomy, and positioning. The radiographer may have to instruct the surgeon or resident on the proper position to visualize the desired portion of the anatomy best.

Proper IR Handling in the Sterile Field

To maintain proper universal precautions, the radiographer must follow specific steps when handling an IR in the OR.

- *Surgical technologist (CST) taking the IR:* The CST holds a sterile IR cover open toward the radiographer. The radiographer should hold one end of the IR while placing the other end of the IR into the sterile IR cover. The CST grasps the IR and wraps the protective cover securely (Fig. 21.5).

FIG. 21.5 Radiographer and CST place wireless DR detector into the sterile drape.

The C S T is holding a sterile I R cover open toward the radiographer. The radiographer is holding one end of the I R while placing the other end of the I R into the sterile I R cover. Both of them are wearing scrubs, head cover, additional headwear, radiation badges, mask, and shoe covers.

• *Radiographer accepting the IR after exposure:* After the exposure has been made, the radiographer needs to retrieve the IR. The CST should carefully open the sterile drape, exposing the detector for the technologist to grasp (Fig. 21.6). The CST would then dispose of the drape. In the event of an urgent situation in which the CST needs to hand the IR over, the radiographer must be wearing gloves to accept a covered IR that has been in the sterile field or under an open incision. The protective cover is possibly contaminated with blood or body fluids and should be treated accordingly. The radiographer should grasp the IR, open the protective cover carefully away from himself or herself or others so as not to spread blood or body fluids, and then ask another nonsterile person to remove the IR from the cover. The radiographer should dispose of the sterile cover in a proper receptacle and remember to remove gloves before handling the IR or any other equipment because the gloves are now considered contaminated. If contamination of the IR occurs, the radiographer should use hospital-approved disinfectant for cleaning before leaving the OR (Box 21.2). Hand hygiene should be performed whenever entering or exiting the OR.

Enemies of the Sterile Field

Lengthy or complex procedures increase the chance of sterile field contamination. Physical limitations, such as crowding, poor lighting, and staffing levels, are also a consideration. The floor is always considered contaminated. The radiographer should not place IRs, lead aprons, and shields on the floor.

FIG. 21.6 CST correctly opens the sterile drape for the radiographer to remove the IR from the now-contaminated bag, being careful not to brush contaminants from bag onto self or others.

The C S T is opening the sterile drape, exposing the detector and the technologist is grasping it. Both of them are wearing scrubs, head cover, additional headwear, radiation badges, mask, and shoe covers.

BOX 21.2 Principles of aseptic techniques

- Only sterile items are used within the sterile field.
- Only sterile persons handle sterile items or touch sterile areas.
- Nonsterile persons touch only nonsterile items or areas.
- Movement within or around a sterile field must not contaminate the sterile field.
- Items of doubtful sterility must be considered nonsterile.
- When a sterile barrier is permeated, it must be considered contaminated.

- Sterile gowns are considered sterile in front from the shoulder to the level of the sterile field and at the sleeves from the elbow to the cuff.
- Tables are sterile only at table level.
- Radiographers should not walk between two sterile fields if possible.
- Radiographers should avoid turning their backs toward the sterile field in compromised spaces. The radiographer should watch the front of clothing when it is necessary to be next to the patient.
- The radiographer must be aware of machinery close to the sterile field, including lead aprons hanging from the portable machine that may swing toward the sterile field.
- The lead apron needs to be secured if it is being worn next to the sterile field. The apron can easily slip forward when raising one's arms up to position the tube. A properly worn apron does not compromise the sterile field or jeopardize proper body mechanics.
- When positioning an IR under the OR table, the radiographer should not lift the sterile drapes above table level because this would compromise the sterile field.

FIG. 21.7 In-room urologic radiographic equipment used for retrograde ureterograms.

FIG. 21.8 (A) C-arm radiographic/fluoroscopic system used in the OR. (B) Mini-mobile C-arm used for extremity examinations in the OR.

(A) A mobile fluoroscopic unit has a C-shaped arm. It has two screens. (B) Two people wearing scrubs, head cover, additional headwear, and gloves are working with a C-arm. Each digit in the hand is attached to an elastic material in a metal piece. Two screens with images of the hand are behind them.

Equipment

The radiographer must be well acquainted with the radiologic equipment. Some procedures may seldom occur. The radiographer should not fear a rare procedure if good communication and equipment knowledge are in place. IR holders enable the radiographer to perform cross-table projections on numerous cases and eliminate the unnecessary exposure of personnel who may volunteer to hold the IR. In mobile radiography, exposure times may increase for larger patients, and a holder eliminates the chance of motion from handheld situations.

Some OR suites, such as those used for stereotactic or urologic cases, have dedicated radiologic equipment (Fig. 21.7). Most radiographic examinations in the OR are performed with mobile equipment, however.

Mobile image machines are not as sophisticated as larger stationary machines in the radiology department. Mobile fluoroscopic units, often referred to as *C-arms* because of their shape (Fig. 21.8), are commonplace in the surgical suite. Mobile radiography is also widely used in the OR.

Good communication is imperative when providing safe and efficient imaging during a surgical case. It is important to establish a common language of terms between the surgeon and the technologist for C-arm operation (Fig. 21.9).

Cleaning of Equipment

The x-ray equipment should be cleaned after each surgical case. If possible, the radiographer should clean the mobile image machine, including the base, in the OR suite, especially when the equipment is obviously contaminated with blood or surgical scrub solution. Cleaning within the OR helps reduce the possibility of cross-contamination. The x-ray equipment must be cleaned with a hospital-approved cleaning solution. Cleaning solutions should not be sprayed in the OR suite during the surgical procedure. If cleaning is necessary during the surgical procedure, opening the cleaning container and pouring the solution on a rag for use prevents possible contamination from scattered spray. Gloves should always be worn during cleaning. The underside of the image machine should be checked to ensure contaminants that might have splashed up from the floor are removed. Cleaning the equipment after an isolation case is necessary to prevent the spread of contaminants. All equipment that is less frequently used should undergo a thorough cleaning at least once a week and just before being taken into the OR.

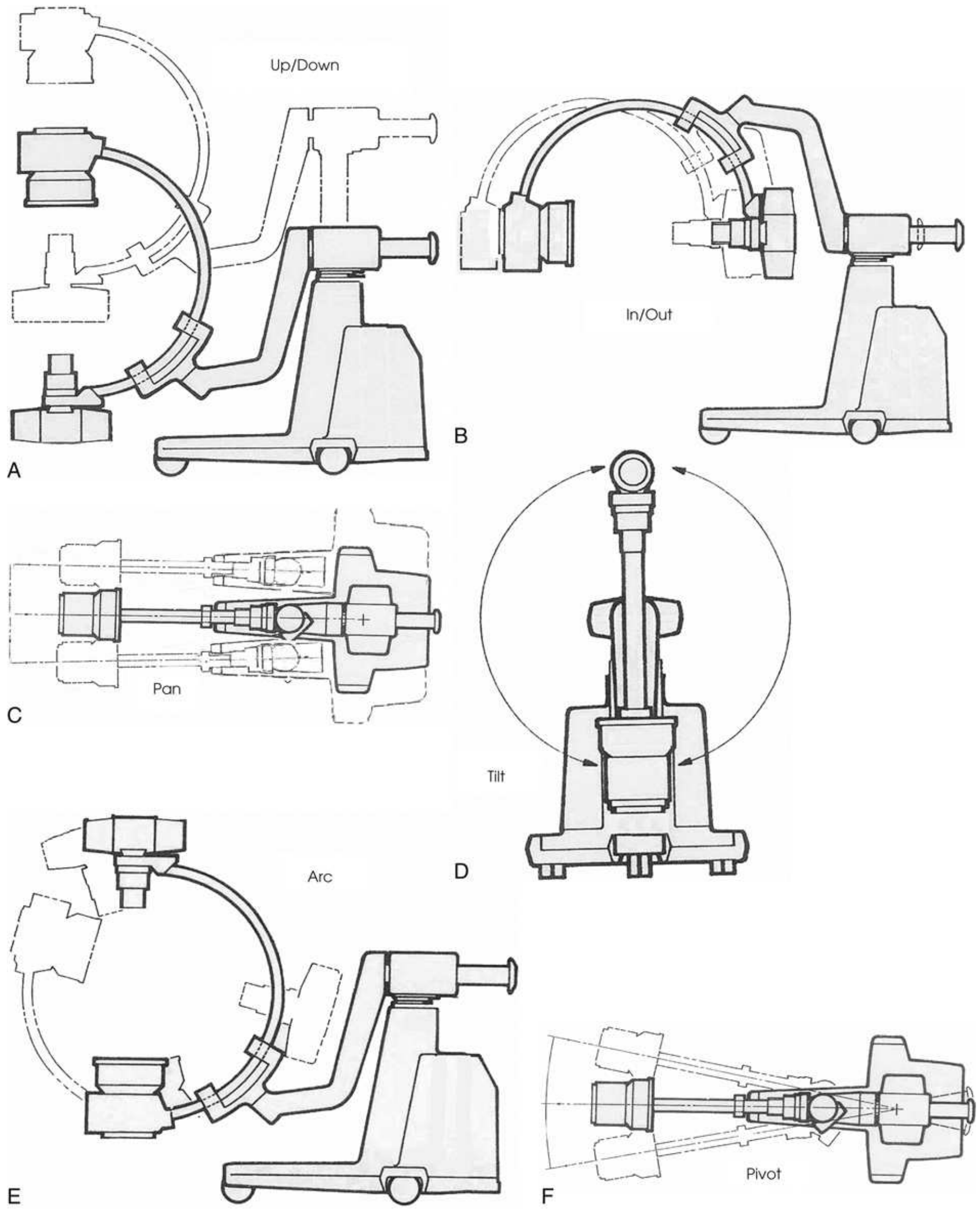


FIG. 21.9 (A) C-arm up or C-arm down movement. (B) When C-arm is positioned perpendicular to the patient C-arm in or C-arm out movement allows for medial to lateral movement without needing to move the patient. (C) C-arm *pan* movement allows scanning evenly along the long axis of a body part, for example, a femur during a femoral nailing. (D) C-arm *tilt* movement allows for angled images such as inlet or outlet images of the pelvis when the C-arm is positioned perpendicular to the patient. (E) C-arm *arc* movement allows for oblique projections such as Judet images of a fractured acetabulum when the C-arm is positioned perpendicular to the patient. (F) C-arm *pivot* allows limited pan-type movement without moving the base of the machine, while following contrast during an intraoperative cholangiogram, for example.

Diagram (A) shows a C-arm up or C-arm down movement. Diagram (B) shows the C-arm positioned perpendicular to the patient in C-arm in or C-arm out movement. Diagram (C) shows a C-arm pan movement evenly along the long axis by moving the base of the machine. Diagram (D) shows the C-arm tilting left and right. It is indicated by two arrows. Diagram (E) shows C-arm moving like an arc. Diagram (F) shows the C-arm pan movement evenly along the long axis without moving the base of the machine.

Radiation Exposure Considerations

Radiation protection for the radiographer, others in the immediate area, and the patient is of paramount importance when mobile fluoroscopic examinations are performed. The radiographer should wear a lead, or lead equivalent, apron and stand as far away from the patient, x-ray tube, and useful beam as the procedure, OR, and exposure cable allow. The most effective means of radiation protection is *distance*. The recommended *minimal* distance is 6 ft (2 m). When possible, the radiographer should stand at a right angle (90 degrees) to the primary beam and the object being radiographed. The least amount of scatter radiation occurs at this position. The greatest amount of scatter radiation occurs on the tube side of the fluoroscopic machine. It is recommended that the x-ray tube should always be placed *under the patient* (Fig. 21.10). Because of the significant amount of exposure to the facial and neck region, the x-ray tube should never be placed above the patient unless absolutely necessary.

The OR may have signs posted outside the room warning of radiation in use or "lead aprons required when entering this room." Lead or lead equivalent protection should be provided for individuals who are unable to leave the room. In addition, the source-to-skin distance (SSD) should not be <12 inches (29 cm) when imaging the patient.

Fluoroscopic Procedures for the Operating Room

Operative (Immediate) Cholangiography

Operative cholangiography, introduced by Mirizzi in 1932, is performed during biliary tract surgery. After the bile has been drained from the ducts, and in the absence of obstruction, this technique permits the major intrahepatic ducts and the extrahepatic ducts to be filled with contrast medium.

The value of operative cholangiography is such that it has become an integral part of biliary tract surgery. It is used to investigate the patency of the bile ducts and the functional status of the sphincter of the hepatopancreatic ampulla to reveal the presence of calculi that cannot be detected by palpation. Intraoperative cholangiography can also show such conditions as small intraluminal neoplasms and stricture or dilation of the ducts. When the pancreatic duct shares a common channel with the distal common bile duct before emptying into the duodenum, it is sometimes seen on operative cholangiograms because it has been partially filled by reflux.

After exposing, draining, and exploring the biliary tract, and frequently after excising the gallbladder, the surgeon injects the contrast medium. This solution is usually introduced into the common bile duct through a needle, small catheter, or (after cholecystectomy) an inlaying T-tube. When the latter route is used, the procedure is referred to as *delayed operative* or *operative T-tube cholangiography*.

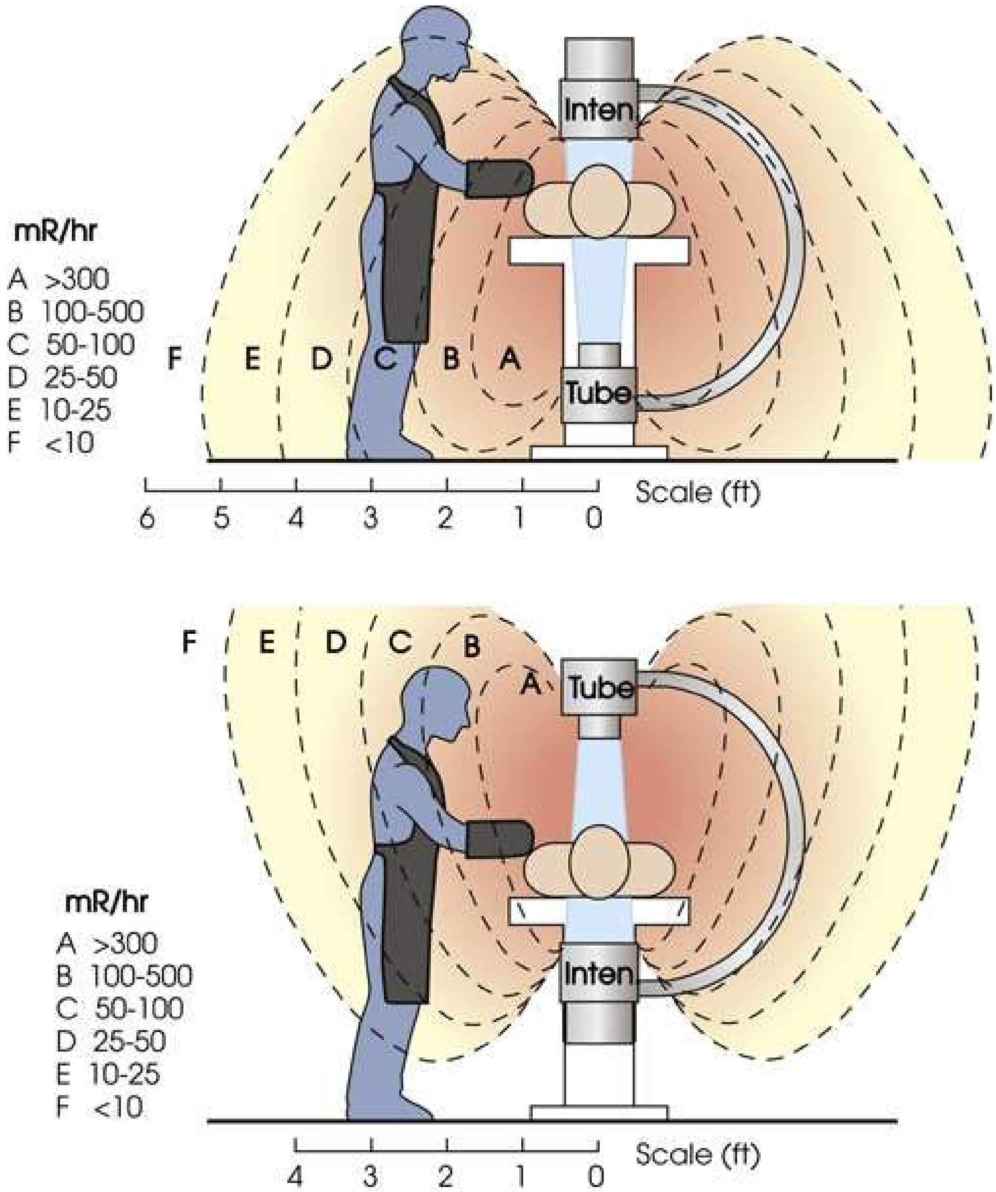


FIG. 21.10 Radiation safety with C-arm. In the *upper image*, less radiation reaches the facial and neck region when the x-ray tube is under the patient. This is the recommended position of the C-arm. In the *lower image*, there is a greater amount of radiation reaching the facial and neck regions. From Giese RA, Hunter DW. Personnel exposure during fluoroscopy. *Postgrad Radiol*. 1988;8:162.

Diagram on top shows a man wearing protective gear is operating the x-ray machine. A scale below has the calibration from 0 to 6 starting from the x-ray tube. The radiographer is standing at 3 meters at a right angle (90 degrees) to the primary beam and the object being radiographed. The least amount of scatter radiation occurs. A note titled millirem per hour reads, A is greater the 300, B 100 to 500, C 50 to 100, D 25 to 50, E 10 to 25, F is lesser than 10. Diagram at the bottom shows a man wearing protective gear is operating the x-ray machine. A scale below has the calibration from 0 to 4 starting from the inten. The greatest amount of scatter radiation occurs on the tube side of the fluoroscopic machine. A note titled millirem per hour reads, A is greater the 300, B 100 to 500, C 50 to 100, D 25 to 50, E 10 to 25, F is lesser than 10.

FIG. 21.11 (A) C-arm in correct position for an abdominal cholangiogram. The assistant surgeon checks syringe for air bubbles before handing it to the surgeon for injection. The radiographer positioned fluoroscopic image intensifier *(arrows)* carefully to avoid hitting laparoscopic instruments protruding from the patient's abdomen. (B) Surgeon, standing behind a sterile draped lead shield, injecting contrast media for an operative cholangiogram.

(A) The assistant surgeon is holding a syringe in his hand. The fluoroscopic image intensifier is positioned above the exposed area of the patient lying on the bed. It is indicated by two black arrows. (B) A surgeon is standing behind a sterile draped lead shield and is injecting it into a tube.

Position of patient

The patient is supine with the abdomen exposed. In laparoscopic cases, such as cholecystectomy, the abdomen is distended because air is injected into the abdominal cavity to allow adequate room for maneuvering of the camera and instruments. The radiographer should ensure no obstacles would impede the movement of the C-arm (Fig. 21.11).

NOTE: The CR comes from under the table, so appropriate shielding should be placed under the patient and placed so as not to obscure any pertinent anatomy.

Position of C-arm

Center the C-arm in the PA projection over the right side of the abdomen below the rib line. The patient may be tilted to the left or in the Trendelenburg position to aid in the flow of contrast medium to the complete biliary system. The C-arm should be tilted or canted until the PA projection is achieved. The C-arm may also have to be rotated to ensure that the spine does not obscure the biliary system. When the position is obtained, the surgeon injects contrast medium into the duct system under fluoroscopy. The radiographer should do the following:

- Provide radiation protection for all persons in the room.
- Remember that examination is optimal with suspended respiration.

Because of the length of time it may take for the contrast medium to fill all ducts, respiration may be suspended at intervals throughout the examination.

Structures shown

This examination shows the biliary system full of contrast medium, including a portion of the cystic duct, the branches of the hepatic duct, the common bile duct, and often the pancreatic duct.

Evaluation Criteria

- Biliary system should be completely filled with contrast medium (Fig. 21.12).
- No extravasation of contrast medium occurs at the injection site.
- Biliary system should not be obscured by any extraneous anatomy or instrumentation.
- Prompt emptying of contrast medium into the duodenum occurs.
- Proper radiographic technique is maintained.
- Sterile field is maintained.

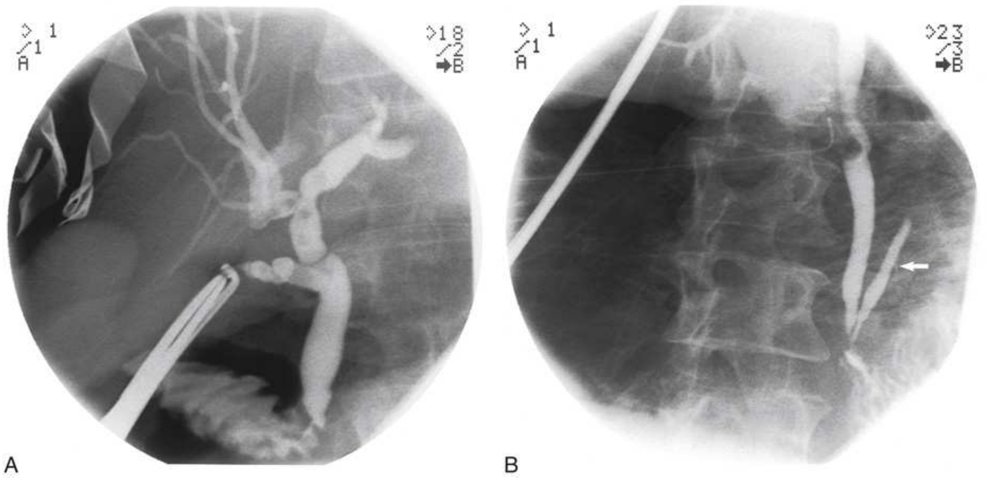


FIG. 21.12 Images of anatomy visualized during a cholangiogram using fluoroscopy. (A) Intraoperative cholangiogram. (B) Intraoperative cholangiogram showing pancreatic duct *(arrow)*.

(A) A cholangiogram shows a radiopaque biliary system. The branches of the hepatic duct and the common bile duct appear radiopaque. It branches into a network. (B) A cholangiogram shows a radiopaque pancreatic duct.

Chest (Line Placement, Bronchoscopy)

Position of patient

The patient is supine with the arms secured at his or her sides. The radiographer should ensure there are no bars or supports in the table that would obscure the view of the chest. Allow room under the table for the C-arm to maneuver.

Position of C-arm

The C-arm should be covered with a sterile drape before entering the field. The C-arm enters the sterile field perpendicular to the patient and in position for a PA projection. If the surgeon prefers, the radiographer can reverse or invert the image to obtain anatomic position. Radiation protection should be provided for all persons in the room.

- *Line placement*: Find the point of insertion and follow the catheter to its end (Fig. 21.13). This examination is done to ensure there are no kinks in the catheter and to show it is in proper position. Numerous catheters may be used in the OR. They are usually inserted to deliver medicines to chronically ill patients.
- *Rigid and flexible bronchoscopy:* Bronchoscopy may be done to perform biopsies, place stents, or dilate the bronchi.

Structures shown

Structures shown include all anatomy of the chest cavity, including the heart, lung fields, and ribs, and any instrumentation that may be introduced during the procedure. These instruments may include catheters, guidewires, bronchoscopes, stent devices, dilation balloons, or biopsy instruments.

Evaluation Criteria

- Pertinent parts of the chest are easily distinguished.
- Proper radiographic technique and contrast are maintained on the monitor.
- Image on the monitor is in true anatomic position or per the physician's preference.
- Sterile technique is maintained.

FIG. 21.13 Patient and C-arm in position for Hickman catheter placement. Introduction of catheter begins in the upper thorax and is completed with the catheter in the heart.

Cervical Spine (Anterior Cervical Diskectomy and Fusion)

Position of patient

The patient is supine with the chin elevated and the neck in flexion. The patient's arms are at his or her sides.

Position of C-arm

PA projection

Cover the C-arm with sterile drape. Enter the sterile field perpendicular to the patient. Tilt the C-arm 15 degrees cephalad and center the beam over the cervical spine. Raise the C-arm to allow the surgeon to work if necessary. Ensure the spine is in the center of the monitor, and the top of spine and skull are at the top of the screen with no rotation.

Lateral projection

Rotate the C-arm under the table into lateral position with the beam parallel to the floor. Angle the C-arm either cephalad or caudal to obtain a true lateral view. Raise or lower the C-arm to bring the spine into the center of the field of view. Rotate the image on the monitor to the same plane as the patient with the spine parallel with the floor. Cases in which a PA projection is unnecessary may opt to have the C-arm positioned in "rainbow" fashion or arched over the patient (Fig. 21.14).

- Ensure there are no obstacles under the table that impede movement of the C-arm.
- The C-arm is often positioned before the patient is draped. In this case, the surgical team drapes the C-arm into the sterile field. Ensure that the C-arm can be moved out of the way without disturbing any instrumentation.

Structures shown

These positions show the affected area of the cervical spine and any hardware that may be introduced (Fig. 21.15). Because this surgery is most often performed to repair physiologic defects, abnormalities (e.g., osteophytes, degenerated disk spaces, subluxation) may be visible, especially in the lateral view.

Evaluation Criteria

- Cervical spine and its affected part are in the center of the monitor to maintain proper radiographic technique.
- Image is rotated in the same plane as the patient.
- PA projection should show spinous processes in the center of spinous bodies.
- Lateral projection should show the bodies in profile and the interarticular facets aligned.
- Sterile field is maintained.

FIG. 21.14 C-arm placed in rainbow position for cervical procedures.

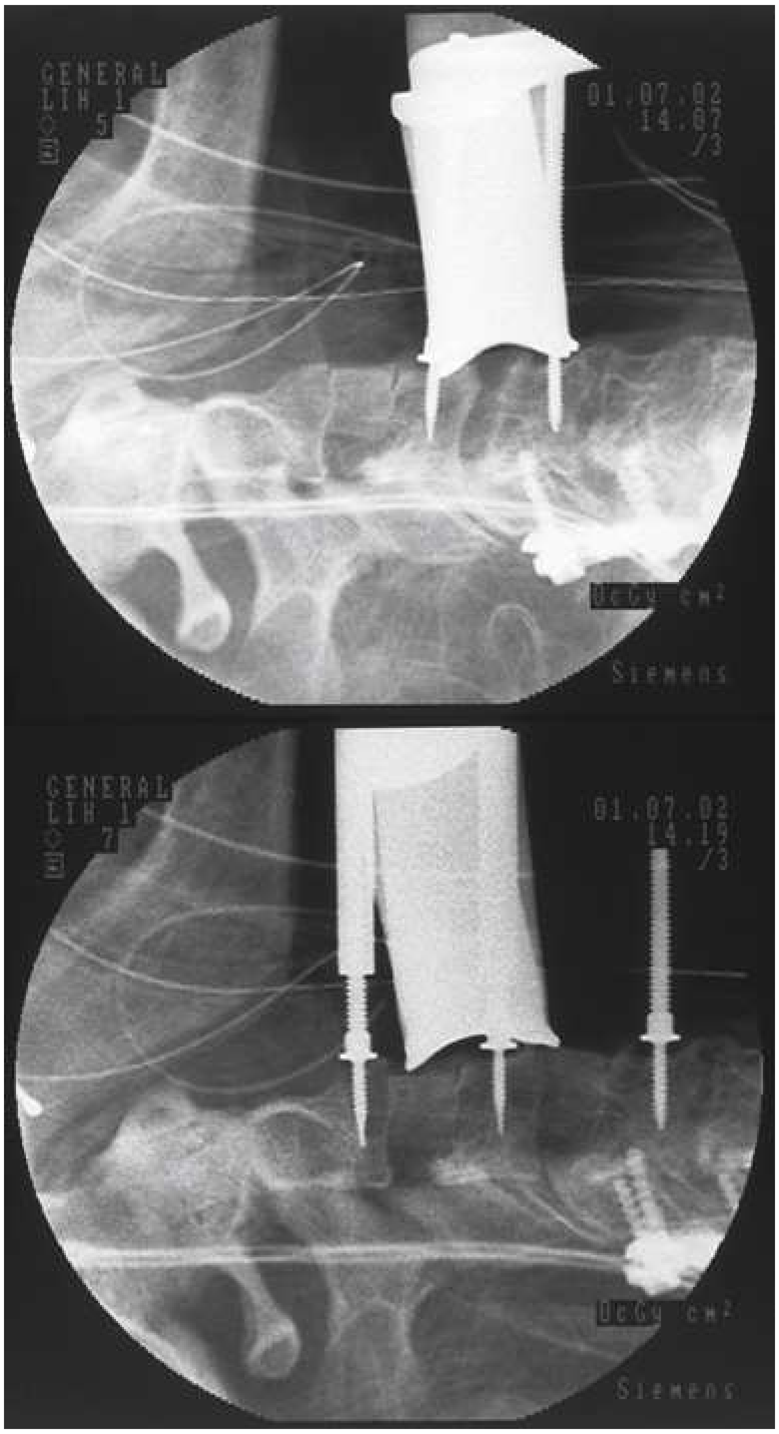


FIG. 21.15 Fluoroscopic image of cervical spine in lateral projection showing plate and screws used to fuse vertebrae.

Lumbar Spine

Position of patient

The patient is prone and positioned on chest rolls or a frame to flex the spine. His or her arms are placed on arm boards and located by the head of the table to bring them out of the field of view.

Position of C-arm

AP projection

Cover the C-arm with a sterile drape. The C-arm enters the field perpendicular to the patient. Center the beam in the AP projection over the affected area of the spine. Raise the C-arm to leave enough room between the IR and the patient so that the surgeon can work without being obstructed (Fig. 21.16). Ensure there is nothing in or under the table to impair the view of the spine.

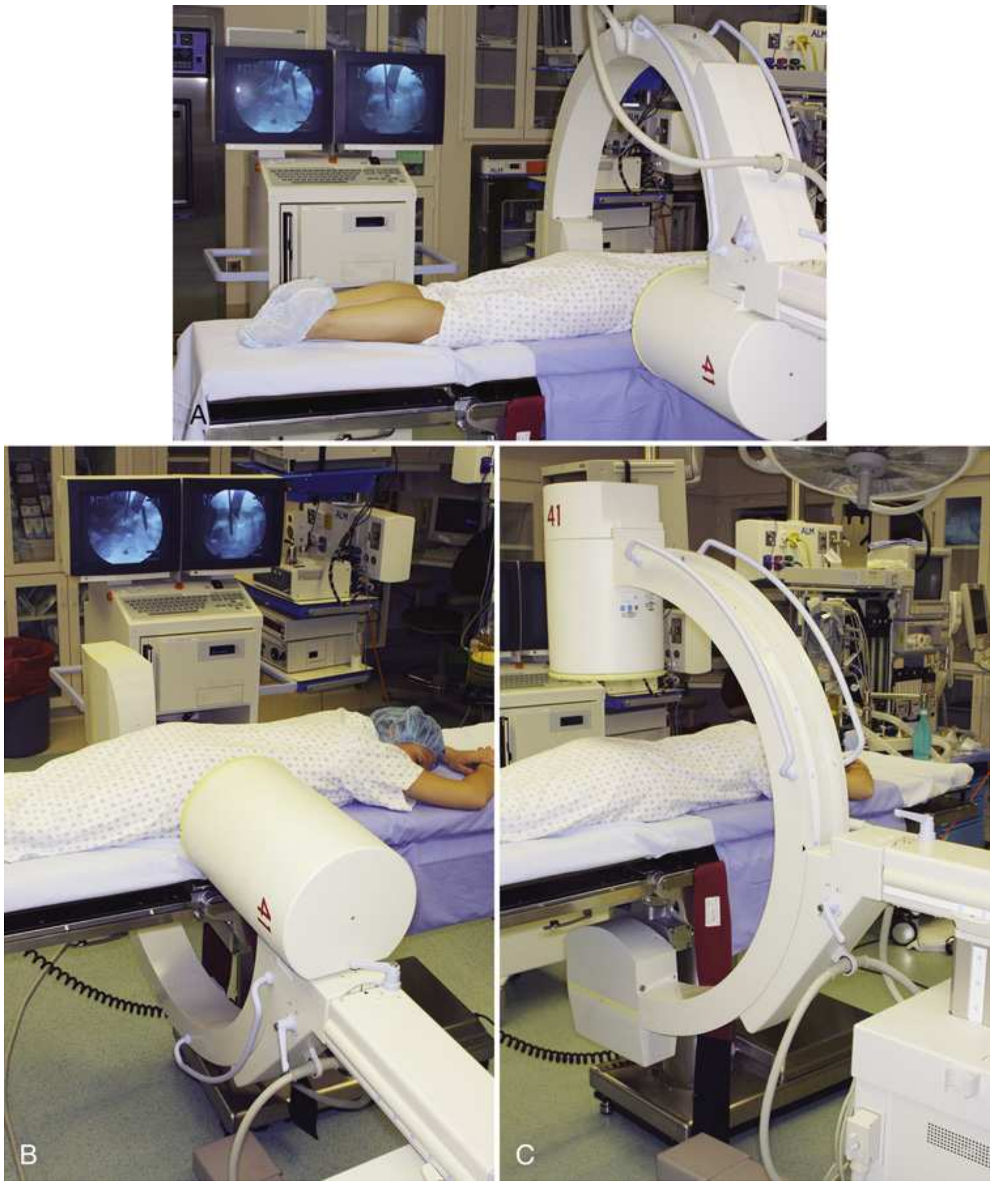


FIG. 21.16 (A) C-arm correctly placed in rainbow position for lateral lumbar procedures. The rainbow position is used especially for larger patients in which the table size or size of the patient would not allow enough elevation of the C-arm to include the lumbar spine. (B) C-arm positioned under the table. (C) C-arm positioned for AP projection of lumbar spine.

(A) A patient is in a prone position on the radiographic table. The C-arm is in a rainbow position. Two monitors behind the table have images on them. (B) A patient is in a prone position on the radiographic table. Both the arms are placed above the head. The C-arm is positioned under the table. (C) A patient is in a prone position on the radiographic table. Both the arms are placed above the head. The C-arm is positioned perpendicular to the lumbar spine.

Lateral projection

- Rotate the C-arm under the table into lateral position. Raise or lower the C-arm to bring the spine into the center of the monitor. The C-arm may need to be angled cephalad or caudal to obtain true lateral projection. Rotate the image on the monitor until the image is in same plane as the patient. The C-arm may be arched over the patient for the lateral projection, especially on hypersthenic patients, because rotating the C-arm under the table would not allow a great enough height to visualize the lumbar region.
- The surgical team members place sterile drapes over both ends of the C-arm when they drape the patient.

FIG. 21.17 Fluoroscopic lateral projection image of lumbar spine with instrumentation.

(A) A fluoroscopic image of the lumbar spine shows an instrument with a narrow and a pointy tip on the left. (B) A fluoroscopic view of the lumbar spine shows an instrument with a narrow and a pointy tip is in the disk space.

Structures shown

These projections show the affected area of the spine, which includes the bodies, disk spaces, spinous processes, lamina, pedicles, and facets. When the case is completed, there is hardware in the spine, such as rods, plates, and screws, to hold the spine in alignment. A bone graft or interbody fusion device may also exist in the disk space to fuse the bones together (Fig. 21.17).

Evaluation Criteria

- Affected area of the spine is viewed in its entirety (Fig. 21.18).
- Spine image is not rotated or angled on the monitor, showing true AP and lateral projections.
- Radiographic technique is maintained by properly centering the beam over the affected area.
- Image of the spine, whether AP or lateral, is rotated into the same plane as the patient. AP projection of the spine is in vertical axis, and the lateral view of the spine is in horizontal axis.
- Sterile field is maintained.

- Radiation protection is provided for the surgical team.

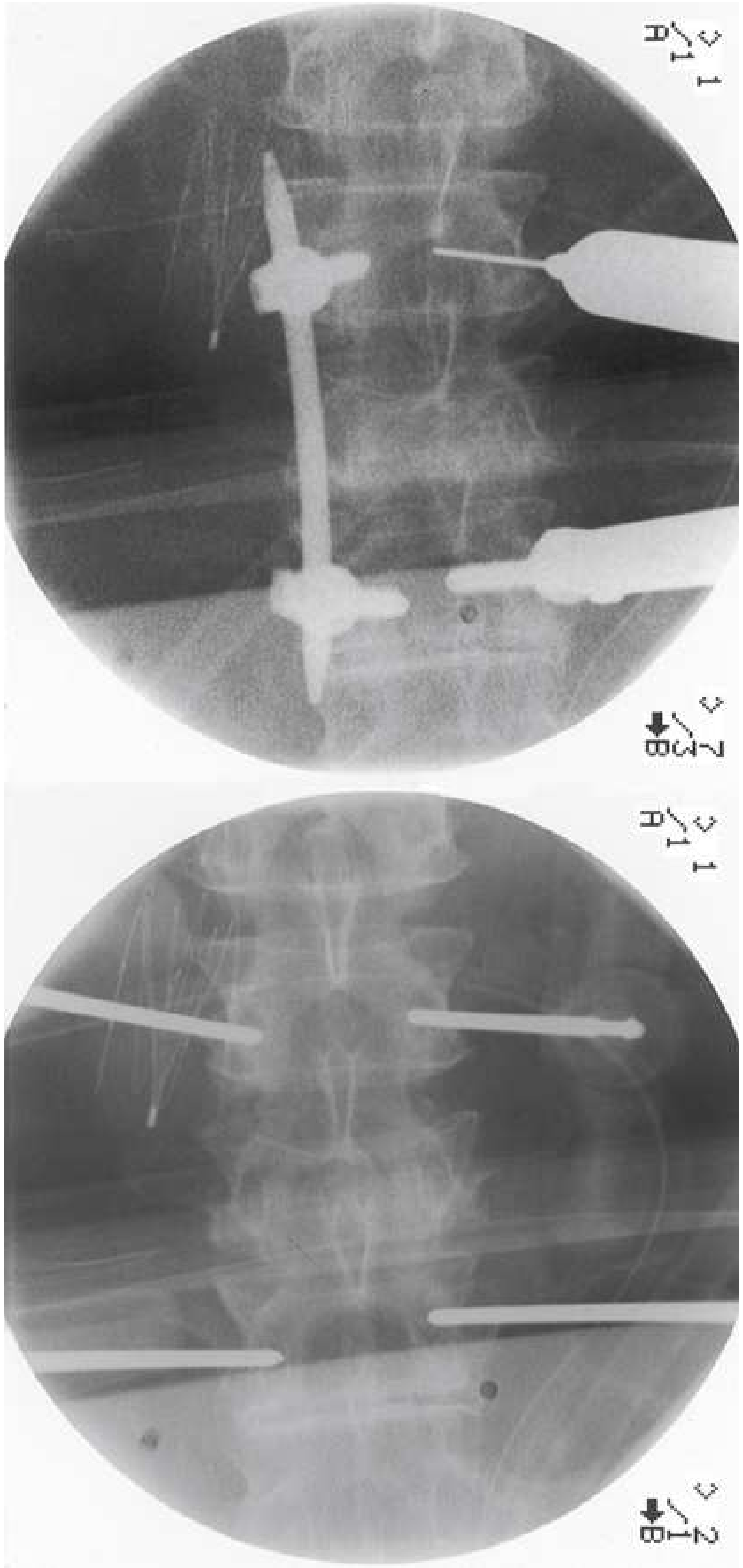


FIG. 21.18 AP projection fluoroscopic images during laparoscopic lumbar fusion.

A fluoroscopic image of the entire affected lumbar spine shows a device with a pointy tip inserted into the disk spaces between the fused bones. The image above shows two devices on the right and a long device with two projections inserted on the left. The image below shows two pointy devices on either side.

HIP (Cannulated HIP Screws or HIP Pinning)

Position of patient

The patient is supine with the legs abducted and the affected leg held in traction. The patient's arm on the affected side is crossed over the body to be kept out of the field of view.

- These procedures are often done using an isolation drape or "shower curtain." In these cases, it is not necessary to cover the C-arm with a sterile drape; however, a nonsterile bag over the tube is recommended to prevent povidone-iodine (Betadine) staining of the C-arm.

Position of C-arm

Position the C-arm between the patient's legs, and center the beam over the affected hip (Fig. 21.19). To obtain the lateral projection, rotate the C-arm under the leg and table to a lateral position (Fig. 21.20). Do not dislodge any instrumentation when rotating the C-arm.

FIG. 21.19 C-arm positioned for PA projection of the hip.

FIG. 21.20 C-arm properly positioned for lateral projection of the hip. After preliminary images are obtained, the hip is prepared for incision, and the C-arm is sterile draped.

(A) The C-arm is positioned under the leg of the patient and table to a lateral position. Two monitors behind the table have images on them. (B) The C-arm is sterile draped and is positioned under the leg of the patient and table to a lateral position.

- Before the procedure, the surgeon manipulates the leg under fluoroscopy to reduce the fracture (Fig. 21.21).
- The C-arm may have to be manipulated to achieve projections and may not be in true PA or lateral projection. Note the position of the C-arm on PA and lateral projections to return to this angle when necessary.
- When hardware is in the hip, rotate the C-arm under fluoroscopy to ensure that no hardware is in the hip joint space.

FIG. 21.21 PA projection of the hip with fracture of femoral neck.

Structures shown

This examination shows all parts of the proximal femur and hip joint, including the acetabular rim, femoral head and neck, and greater and lesser trochanters. Hardware may include cannulated screws or pins running parallel with the femoral neck used to reduce the fracture (Fig. 21.22).

Evaluation Criteria

- Hip is centered on monitor and in correct plane.
- Lateral side of femur and acetabular rim must be visualized to determine a starting point and to ensure no hardware enters the joint.
- Lesser trochanter is visible in profile on PA projection. Greater trochanter lies behind the femoral neck and shaft in lateral view.
- Proper radiographic technique is maintained.
- Sterile field is maintained.
- Radiation protection is provided for the surgical team.

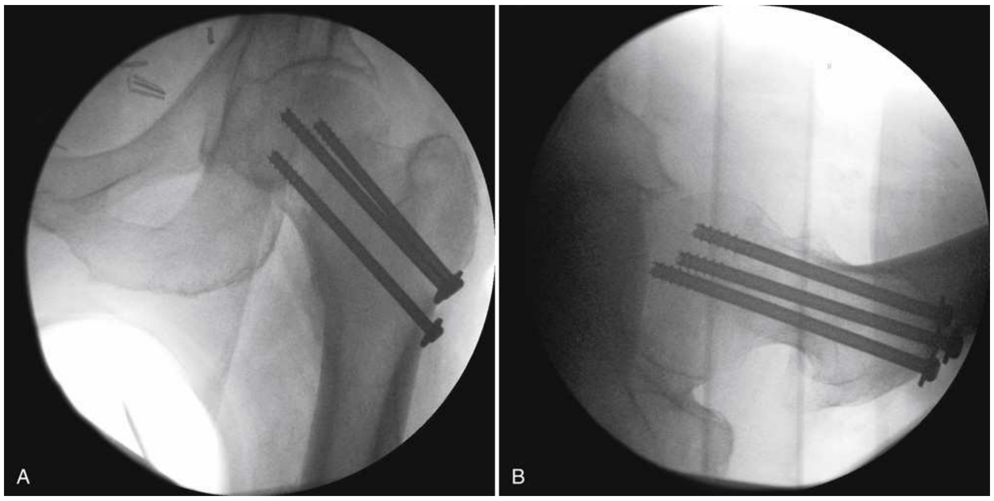


FIG. 21.22 PA projection (A) and lateral projection (B) fluoroscopic images of hip fracture reduction.

(A) A fluoroscopic image shows all parts of the proximal femur and hip joint, including the acetabular rim, femoral head and neck, and greater and lesser trochanters. Three screws are inserted into the hip joint. (B) A fluoroscopic image shows the hip joint. Three screws are inserted parallel into the joint.

Femur Nail

Position of patient and C-arm

During this procedure, a rod is inserted into the intramedullary (IM) canal to reduce a fracture of the shaft of the femur (Fig. 21.23). This rod or nail can be introduced either antegrade through the greater trochanter or retrograde through the popliteal notch.

Antegrade femoral nailing

During antegrade nailing, the patient is either supine or in the lateral position. In the supine position, the affected leg would most likely be in traction to help reduce the fracture. The legs would be abducted, and the unaffected leg would be flexed at the knee and hip and raised to allow the C-arm enough room to enter the sterile field. The patient's arm on the injured side is draped across the chest to keep it from obstructing the surgeon. The C-arm is positioned between the patient's legs, parallel to the unaffected leg, and centered over the hip. The C-arm may have to be rotated forward or backward to obtain a true PA projection. Rotate the C-arm under the table for a lateral projection.

With the patient in lateral position, the affected leg is extended forward to clear the opposite leg. The lateral position requires the radiographer to enter the sterile field and rotate the C-arm under the table to find a PA projection of the femur. Lateral projection is achieved with the tube starting in a true PA projection, rotating the C-arm forward 10 to 15 degrees, and tilting it 5 to 10 degrees cephalad.

FIG. 21.23 Image of midshaft femoral fracture with guide rod being inserted to align fracture.

Retrograde femoral nailing

During the retrograde femoral nailing, the patient is supine with the injured leg exposed and the knee flexed and supported with a bump. This position allows the surgeon access to the popliteal notch without injuring the patella.

The sterile field is entered with the C-arm perpendicular to the patient. The C-arm is tilted cephalad to account for the flexed knee and to find the PA projection. The C-arm is rotated under the table for lateral position (Fig. 21.24).

FIG. 21.24 (A) C-arm positioned between patient's legs for PA projection during femoral nailing. *Arrow* is pointing to femur. (B) C-arm rotated under femur *(arrow)* for lateral projection.

(A) The C-arm is positioned between the patient's legs. The Two monitors in front of the table have images on them. (B) The arrow is pointing to the femur. (B) The C-arm is rotated under the femur. Two monitors in front of the table have images on them. The arrow is pointing at the lateral projection.

Method

- Instruments or hardware may protrude from the operative site. Be sure to avoid disturbing these instruments or hardware or allowing them to puncture a sterile drape.
- Center the C-arm over the fracture site during canal reaming to ensure that the fracture remains reduced (Fig. 21.25).
- The table must allow for movement of the C-arm from the knee to the hip.
- Allow enough room between the patient and C-arm for the surgeon to work.

Screws are inserted into the femur and through the nail to fix the nail in place. When lining up the screw holes in the nail, the hole should be perfectly round and not oblong. Center the screw hole on the monitor. The magnification feature may be used to give the surgeon a better view. The C-arm may need to be tilted or rotated to obtain perfect circles. The surgeon also manipulates the leg to help align the screw holes. After the screws are inserted, check the length of the screws by placing the C-arm in PA projection. Screws should not protrude excessively from the cortical bone (Fig. 21.26).

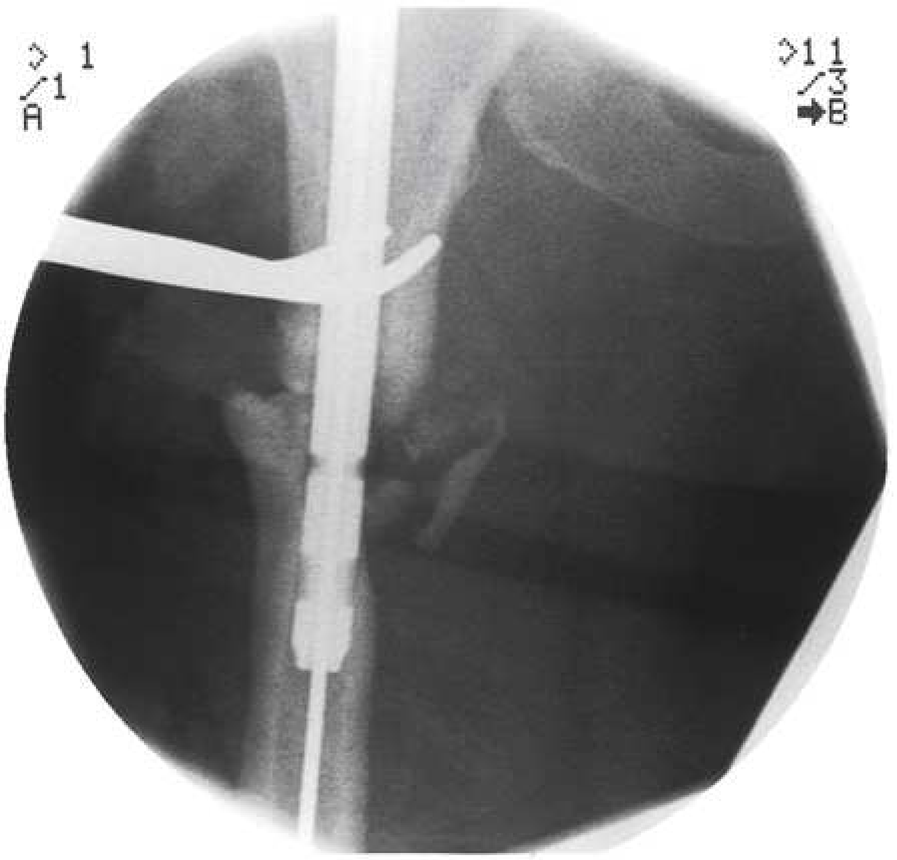


FIG. 21.25 Image of femur fracture during canal reaming.

Structures shown

All parts of the femur, including the greater and lesser trochanters, femoral neck, shaft, and condyles, are seen in the PA and lateral positions. Different instrumentation is in the IM canal beginning with a guide rod that is used to help reduce the fracture and provide a means for the canal reamers to pass through the fracture site (Fig. 21.27). After reduction, the nail and screws are seen.

FIG. 21.26 PA projection of proximal screw in a femoral nail.

Evaluation Criteria

- Appropriate projections are seen unobstructed and in correct plane on the monitor.
- Screw holes are perfectly round and in the center of the monitor.
- Sterile field is maintained.
- Proper radiographic technique is maintained.
- Radiation protection is provided for the surgical team.

FIG. 21.27 PA projection of femur fracture reduced with guide rod and distal interlocking screws inserted.

Tibia (Nail)

Position of patient

The patient is supine with the affected leg exposed. The knee is flexed to allow access to the tibial tuberosity without injuring the patella. The injured leg is on the opposite side of the table so that the C-arm does not interfere with the surgical team.

Position of C-arm

Cover the C-arm with a sterile drape. Move the C-arm into the field perpendicular to the patient. Center the beam over the leg and tilt the tube to match the angle of the leg (Fig. 21.28). No obstructions should be under the table to avoid interfering with the C-arm movement. Rotate the C-arm under the table and into the lateral position, taking care not to disturb any instrumentation protruding from the operative site. Center the leg on the monitor by raising or lowering the C-arm. The surgeon manipulates the leg, and the radiographer tilts or rotates the C-arm to obtain round holes (Figs. 21.29 and 21.30). The magnification feature can be used to enlarge the image if necessary. Advance the C-arm until its tube side is far enough from the injured leg to allow the surgeon to fit the drill and drill bit into the area.

- Along its shaft the tibia is triangular, so when checking the length of the screws the C-arm may have to be rotated forward or back to get a true length.
- Center the beam on the fracture site during canal reaming. When the leg is in the center of the monitor, turn the wheels of the C-arm horizontally to allow the machine to move longitudinally down the shaft of the leg without moving out of the field of view.

FIG. 21.28 C-arm positioned for tibial nailing. The radiographer tilted the fluoroscopic image intensifier to be parallel with the long axis of the leg.

A patient's leg is elevated on the table. The radiographer is tilting the fluoroscopic image intensifier to be parallel with the long axis of the leg. One of the surgeons is looking at the two monitors next to the table.

FIG. 21.29 Image of tibial nail screw holes in incorrect alignment and oblong in shape.

A fluoroscopic image shows a tibial nail screw inserted into the bone. It has a hole in it. The nail screw appears radiopaque. The bone appears grey and the surrounding region appears lighter than the bone.

FIG. 21.30 Image of tibial nail screw holes perfectly round and magnified to assist proper alignment.

A fluoroscopic image shows a tibial nail screw inserted into the bone. The hole in the rod appears perfectly round. The nail screw appears radiopaque. The bone appears grey and the surrounding region appears lighter than the bone.

Structures shown

Structures shown include the tibia and fibula, the tibial shaft along with any fracture, the tibial plateau, tibial tuberosity, distal tibia, and ankle joint (Fig. 21.31). After hardware is inserted, the tibial nail fills the IM canal, with proximal and distal screws prominent.

Evaluation Criteria

- The tibia is centered on the monitor, providing proper radiographic technique.
- Appropriate projections are seen unobstructed and in the correct plane on the monitor.
- Sterile field is maintained.
- Radiation protection is provided for the surgical team.

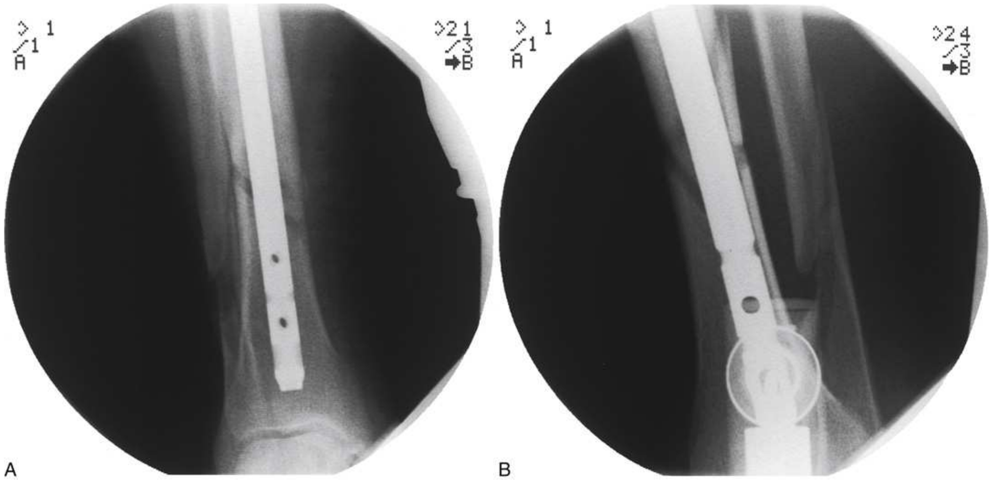


FIG. 21.31 (A) Improper alignment of distal screw holes. (B) Screw holes properly aligned with screwdriver over distal screw hole.

(A) A radiographic image shows the rod inserted into the tibia. There are two black holes on it. (B) A radiographic image shows the screw holes in the rod aligned with the screwdriver over the distal screw hole. It appears radiopaque.

Humerus

Position of patient

The patient is supine or in a reclining or beach chair position (Fig. 21.32). The injured arm may be resting on a Mayo stand with the surgeon's assistant holding the arm to stabilize and align the humerus. The patient should be positioned with the shoulder off the side of the table. This position allows the humerus to be seen in its entirety without being obscured by the table.

Position of C-arm

Cover the C-arm with a sterile drape. Enter the field parallel to, or at a 45-degree angle to, the patient. The assistant rotates the arm medially with the elbow bent 90 degrees. The C-arm is tilted and rotated to obtain a true lateral projection, depending on the angle of patient position. The arm is held at the elbow to provide support, and the arm is rotated until the hand is pointing upward. The C-arm is tilted to obtain PA projection according to the patient's angle. Center the beam on the humerus.

- When installing a nail or rod into the humerus and trying to locate and center the distal screws, place a sterile drape over the tube or pull the sheets draping the patient over the tube. Touch only the underside of the sheets when placing them over the tube. Raise the tube to magnify the screw holes and to allow the surgeon to work.

FIG. 21.32 (A) C-arm positioned for PA projection of the shoulder with patient in beach chair position for preliminary imaging. (B) C-arm positioned for axillary projection.

(A) A patient is in a supine position on the bed with the injured arm resting on a mayo stand. The C-arm is at a 45-degree angle to the patient. (B) A patient is in a supine position on the bed with the injured arm resting on a mayo stand with the surgeon's assistant holding the arm. The C-arm is covered in a sterile drape and is parallel to the patient.

NOTE: Do not leave any drape over the tube for a long time to prevent unnecessary heat buildup in the tube.

- Be careful not to strike the patient's head with the image intensifier.

Structures shown

This procedure should show all parts of the humerus, including the head, neck, greater and lesser tubercles, shaft, and distal portion of the humerus. Any fractures and the hardware used for repair (Fig. 21.33) are also seen.

Evaluation Criteria

- Angle of humerus and C-arm coincide to obtain true PA and lateral projections.
- When nailing the distal screws, holes should be perfectly round in order to allow screws to pass through the nail.
- Humerus is in the center of the monitor to maintain radiographic technique.
- Image is rotated in the same plane as the humerus.
- Sterile field is maintained, especially with the proximity of possibly nonsterile portions of the tube to the sterile field.
- Radiation protection is provided for the surgical team.

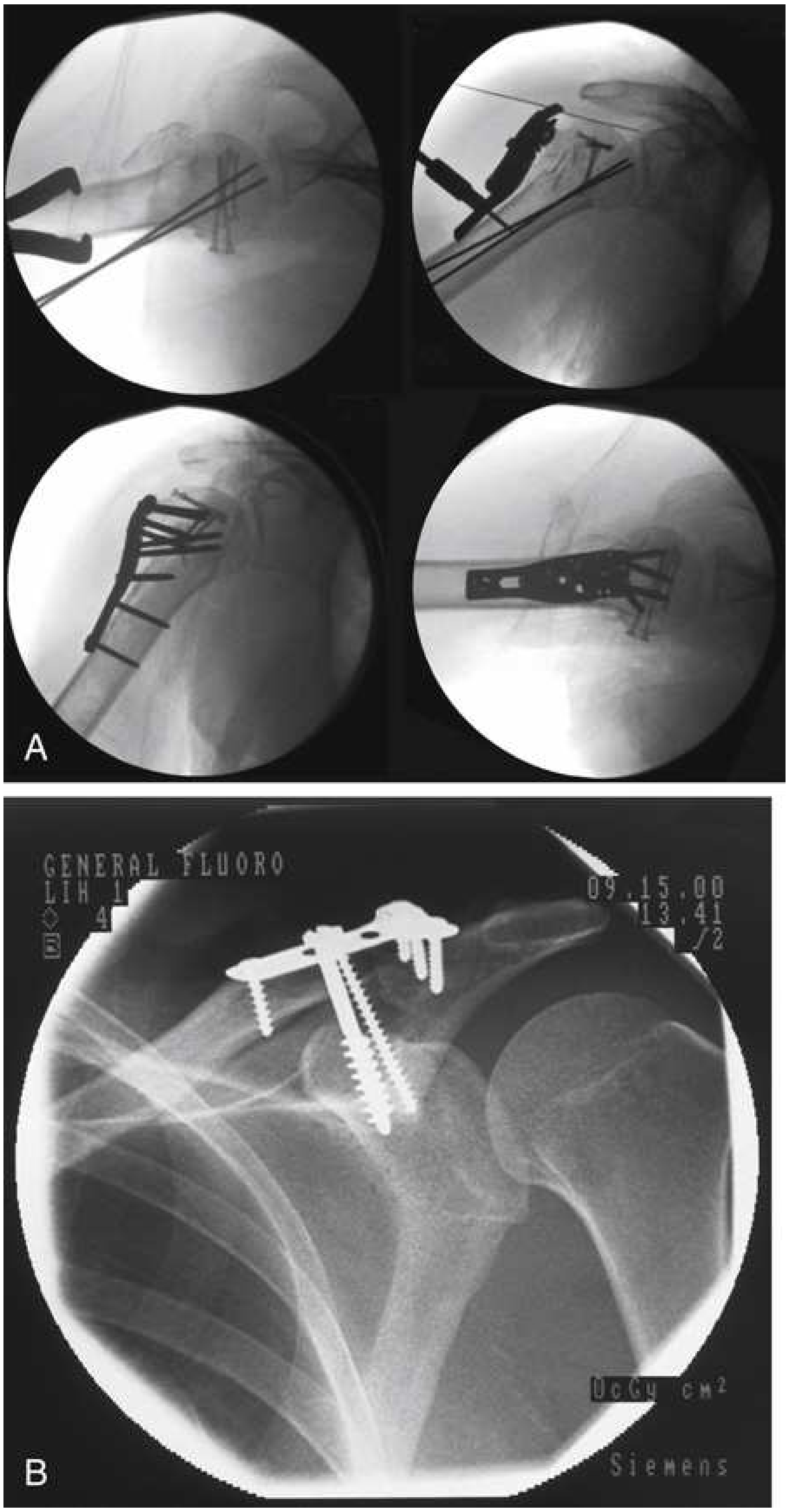


FIG. 21.33 (A) Images of humeral fracture with nails used to reduce fracture of the humeral head. (B) Image of clavicle fracture with plate and screw fixation.

(A) Four images show the different nails in the humerus. One of them holds the bone. The other one is inserted into the bone. One has several pointy tips and it is placed on top of the bone. The other one is completely disclosed inside the bone. The nails appear radiolucent. (B) An image shows a plate and a screw fixed on the clavicle. It appears radiopaque.

Femoral/Tibial Arteriogram

Position of patient

The patient is supine with the affected leg exposed from the groin area to the foot. There should be enough room under the table to allow the C-arm to move from the hip to the foot. The leg may be rotated medially or laterally to keep the femur or tibia from obscuring any vasculature (Fig. 21.34).

Position of C-arm

Cover the C-arm with a sterile drape and enter the field perpendicular to the patient. When the leg is in the center of the monitor, turn the wheels of the C-arm horizontally to allow the machine to move to the left or right without taking the leg out of the field of view. Use the subtraction or road-mapping feature to remove all structures except the contrast medium that is injected into the artery (Fig. 21.35). This feature shows any stenoses or injuries to the artery.

FIG. 21.34 Subtraction image of surgical femoral artery angiogram with stenosis *(arrow)*.

A femoral artery angiogram shows a dark tubular structure with narrowing of the tube at a certain point. It is indicated by a black arrow. Another dark tubular structure is connected to it below the narrowing.

Structures shown

The bones of the leg are seen before subtraction. After contrast medium is introduced, the femoral artery and its branches are seen, and, following the contrast medium down the leg, the popliteal and tibial arteries are seen. The contrast images show any pathologic defects in the arterial structures.

Evaluation Criteria

- All pertinent vasculature must be shown without being obscured by the table or bones of the leg.
- Integrity of the mask image should be maintained by not moving the leg or the C-arm during subtraction or road mapping.
- Proper radiographic technique is maintained.
- Sterile field is maintained.
- Radiation protection is provided for the surgical team.

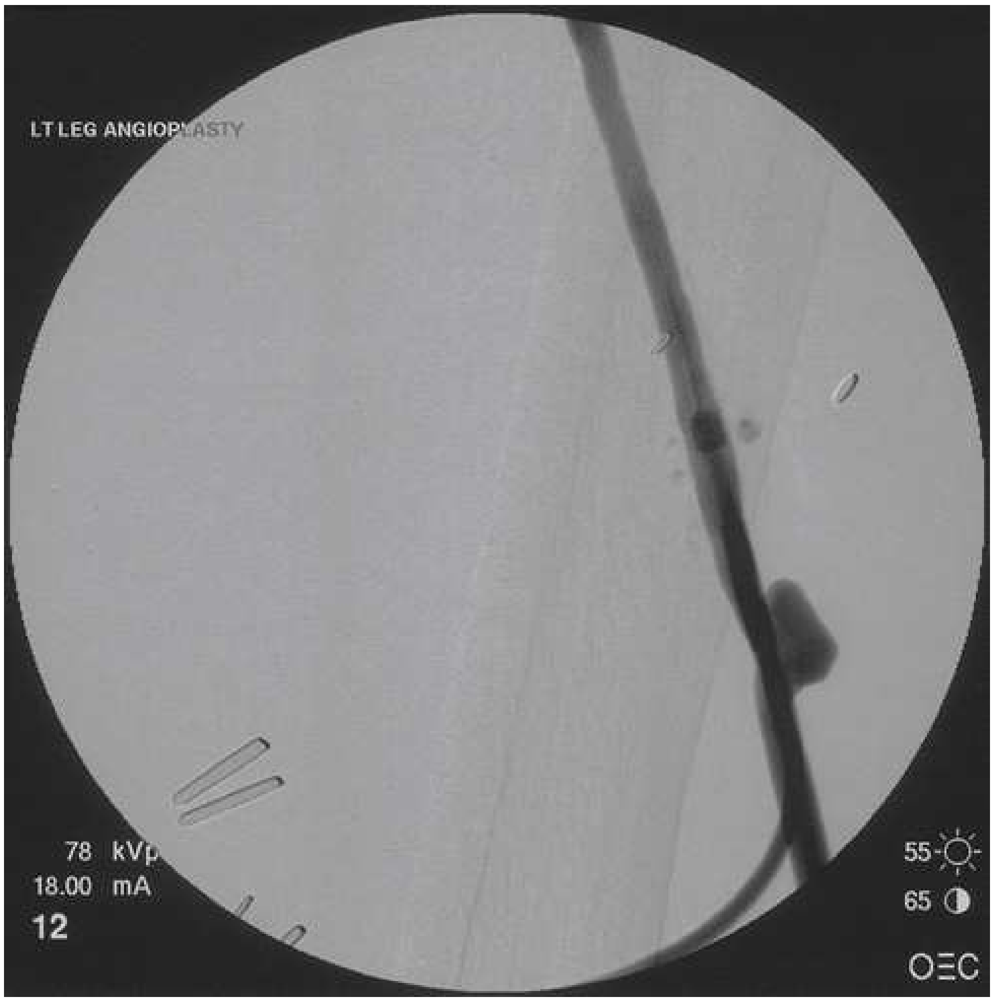


FIG. 21.35 Subtraction image of surgical femoral artery angiogram after balloon angioplasty.

A femoral artery angiogram shows a dark tubular structure. Another tube is inserted into the tubular structure. It has a darker area at the end of the tube. The popliteal and tibial arteries are visible.

Mobile Radiography Procedures for the Operating Room

Cervical Spine

Image receptor: The IR should be 14 × 17 inches (35 × 43 cm) grid IR crosswise. Adjust the radiation field above the external acoustic meatus (EAM) and below T1 on the collimator.

Position of patient

The patient is upright, prone, or supine. In the upright and prone positions, the patient's head is held in a traction device to align the spine. In the supine position, the chin is elevated and held with a strap or tape.

Position of image receptor and portable machine

- Place the grid IR in the IR holder and cover with a sterile drape (Fig. 21.36).
- Position the IR holder on the opposite side of the patient. The surgical technician moves the sterile back table so that the radiographer does not compromise the sterile field.
- Direct the beam perpendicular to the IR and parallel to the floor.
- The beam enters perpendicular to the IR to eliminate grid cutoff.
- Raise or lower the tube and IR to center on the cervical spine.

Structures shown

- Cervical spine in lateral projection (Fig. 21.37).
- Degenerative or pathologic defects, such as osteophytes, fractures, or subluxation.
- Radiograph may be taken at the beginning of the case to verify the correct portion of the spine to be repaired. Instruments are placed to designate the level of the spine (Fig. 21.38).

Evaluation Criteria

- Entire spine is on the radiograph.
- Spine is in the center of the radiograph and is not rotated.
- Proper radiographic technique is used.
- Radiation protection is provided.
- All hardware that may be used should be included.
- Grid cutoff is absent.

FIG. 21.36 Mobile radiographic machine *(arrow)* in position for upright lateral cervical spine. A surgical clamp, which is attached to the spinous process of interest, extends from the incision site. IR draped and in holder *(double arrow)* is centered to the patient.

A mobile radiographic machine is next to a surgical clamp, which extends from the incision site. The machine is indicated by a black arrow. The I R is draped and is in a holder which is central to the patient. It is indicated by a double arrow.

FIG. 21.37 Lateral cervical spine radiograph (patient in sitting position for surgery) showing localization marker in place on the spinous process of C6.

FIG. 21.38 Lateral projection of the cervical spine with patient supine. This was done to verify the correct position of instruments before continuing surgery. Often a spinal needle is placed in the disk space to show position. Note that even though a 14 × 17 wireless DR detector is used, the radiographer has properly coned to pertinent anatomy.

Thoracic or Lumbar Spine

Image receptor: The IR should be 14 × 17 inches (35- × 43-cm) grid IR crosswise.

Position of patient

The patient is prone or supine with the arms placed up by the head. The chest and abdomen are supported by a frame or chest roll to flex the spine into anatomic position. A radiograph may be done to verify that the surgeon is working on the correct vertebra or to show the position of hardware (Fig. 21.39).

Lateral projection

Place grid IR in IR holder and cover with a sterile drape. Position the holder next to the patient and move the IR up or down to center on the lumbar spine. Direct the beam perpendicular to the IR and parallel to the floor (Fig. 21.40). Respiration should be suspended during exposure.

PA projection

For the PA radiograph, slide IR in the slot under the table and center on the spine. Cover field with sterile drape. Center the beam to the IR and perpendicular to the long axis of the spine.

Structures shown

- The lumbar spine in PA and lateral projections.
- Vertebral bodies, spinous processes, facets, and lamina.
- Hardware to repair any defects. Bone grafts or interbody fusion devices may be used.
- Instrumentation is often seen on radiograph.
- PA projection may be obscured by the patient support.

Evaluation Criteria

- Spine is in the center of the radiograph and in true PA or lateral projection.
- Spine bodies are seen without any rotation.
- All hardware used must be seen on radiograph.
- All unnecessary instrumentation is removed to avoid obscuring spine.
- Proper radiographic technique is used.
- Radiation protection is provided for the surgical team.

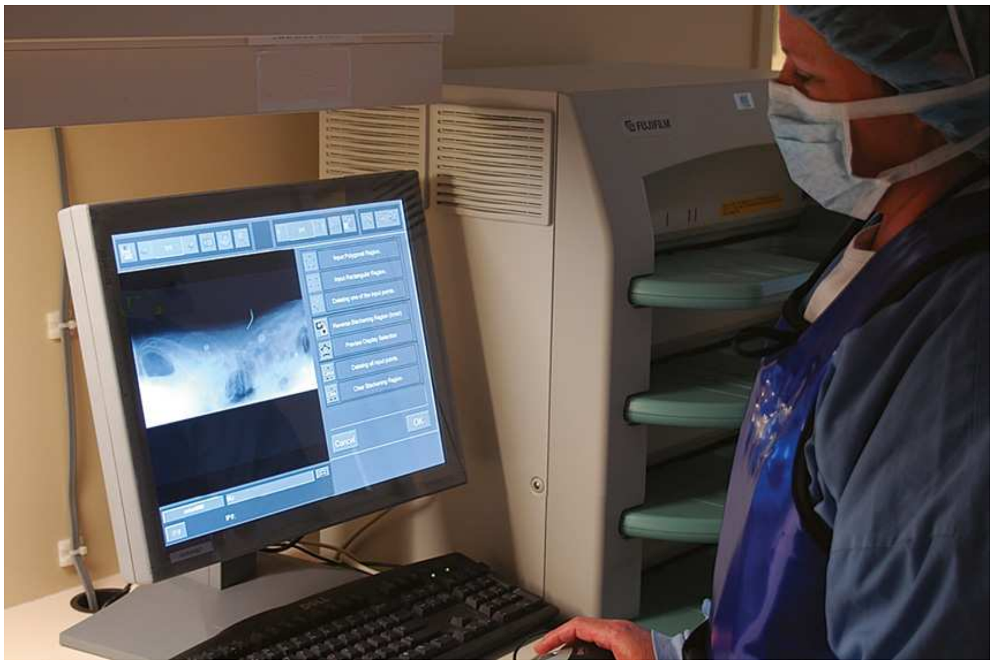


FIG. 21.39 Lateral lumbar spine with intraoperative marker to verify correct level of interest. CR and DR allow postprocessing adjustments.

FIG. 21.40 (A) Mobile x-ray machine correctly positioned for cross-table lateral lumbar spine. (B) Radiographer positioning mobile unit intraoperatively for lateral lumbar spine procedure.

(A) A mobile x-ray machine is positioned for a cross-table lateral lumbar spine. The beam is perpendicular to the I R. (B) A radiographer wearing scrubs and a headcover is positioning the mobile unit next to the bed.

FIG. 21.41 PA projection of a hip joint replacement with plate and screw fixation following a periprosthetic femur fracture.

FIG. 21.42 AP and lateral postreduction images of a comminuted ankle fracture. Some casting materials require an increase in technical factors for correct penetration and image quality.

Extremity Examinations

Image receptor: Choose the appropriate-size IR to include all appropriate anatomy and hardware.

Position of patient

The patient is supine, prone, reclining, or in the beach chair position. Portable machines approach perpendicular to the patient. Institutions may cover the tube or sterile field, or both, with a sterile drape. Angle the tube to match the IR or desired projection. The surgeon may choose to hold the patient's limb in position during the exposure. To reduce exposure to the surgeon, positioning aids, such as sterile towels, sponges, or mallets, may be used.

The surgeon may also cover the field with a cloth sterile drape rather than a plastic sterile drape. If so, the surgeon marks the location of the part to ensure proper centering. Lighting may also need to be adjusted for better visualization of the field. For cross-table examinations, the beam is directed perpendicular to the IR and parallel to the floor. Center the beam to the IR and raise or lower the tube to the center of the part.

Structures shown

- All pertinent anatomy in correct alignment.
- Hardware including plates, wires, pins, screws, external fixation, and joint replacement components used to repair fractures or degenerative problems (Figs. 21.41 through 21.47).

FIG. 21.43 AP and lateral image of the ankle with antibiotic beads. Antibiotic beads are placed at the site of infection to promote healing.

FIG. 21.44 AP and lateral projection of proximal tibia with plate and screw fixation used to repair tibial plateau fracture.

An x-ray on top shows the knee joint. The proximal tibia has plates and screws. It appears radiopaque. An x-ray at the bottom shows the tibia with a narrow plate with a few holes in it. Two screws are inserted into the holes. It appears radiopaque.

FIG. 21.45 AP and lateral projection of elbow with plate and screws used to reduce forearm fracture.

An x-ray view of the elbow joint on the left shows two plates on either side of the bone with screws embedded into it. It appears radiopaque. An x-ray view of the elbow joint on the right shows a long and narrow rod-like structure inserted into the joint. A fixation device is on the other side of the joint.

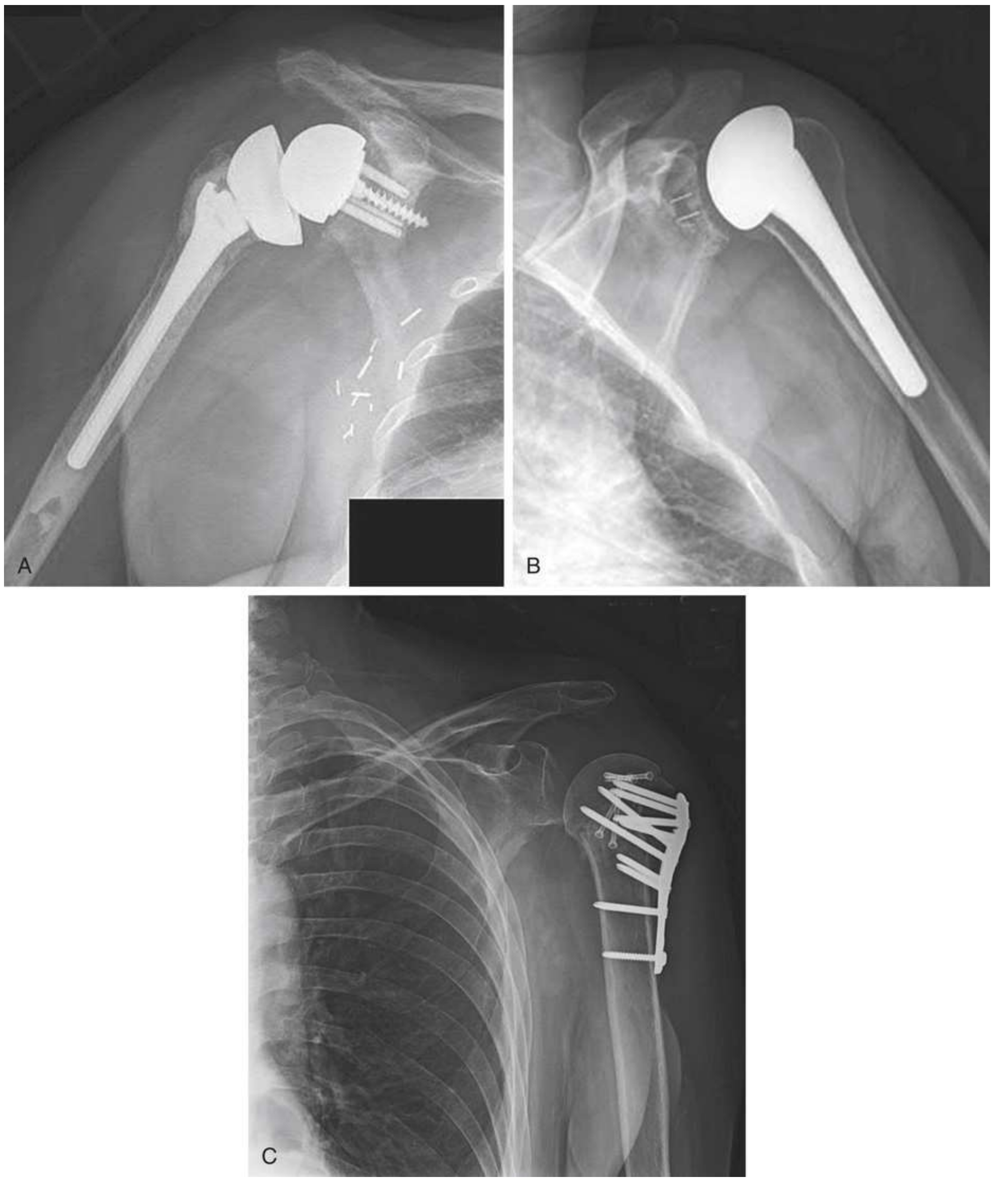


FIG. 21.46 (A) Total shoulder arthroplasty with polyethylene glenoid component. (B) Reverse total shoulder arthroplasty. (C) Shoulder with plate and screws fixation. Creative patient positioning or tube angulation may be necessary to achieve optimal images on complex comminuted fractures.

(A) An x-ray view of the shoulder joint shows a fixation device with a head. There are a few screws on the head of the device. (B) An x-ray view of the shoulder joint shows a broad head fixation device with a narrow body is inserted into the bone in the shoulder joint. (C) An x-ray view of the shoulder joint shows a plate with screws at the head of the humerus. The fixation devices appear radiopaque.

Evaluation Criteria

- Complete joint including all hardware is seen on the image.
- Proper radiographic technique is used.
- Sterile field is maintained.
- Radiation protection is provided.
- Collimation to include all hardware used.
- No unnecessary instruments are in field.

NOTE: Many surgeons request different projections depending on the individual case. When performing a wrist examination, the arm is positioned on one side of the imaging plate with the wrist in the AP or PA projection. Center the beam and collimate to the wrist to include all hardware. When the exposure is complete, the surgeon moves the arm to the other side of the imaging plate in the lateral position. Center the beam on the wrist and collimate (Figs. 21.48 and 21.49).

FIG. 21.47 AP (A) and lateral (B) postreduction images of a fifth metatarsal nonhealing fracture.

(A) An x-ray shows the dorsal surface of the foot. A screw is fixed into the fifth metatarsal. (B) An x-ray view of the lateral foot shows a screw is fixed into the fifth metatarsal. It appears radiopaque.

FIG. 21.48 Radiographer positioning a mobile machine for lateral projection of wrist.

FIG. 21.49 PA, lateral, and tilt lateral projections of wrist. Note proper radial tilt of 22 degrees shows joint space clear of reduction screws.

An x-ray view of the wrist on the left shows a brush-like fixation device in the wrist joint. It has a few spike-like projections at the ends. Two x-ray views of the lateral wrist in the middle and at the right shows a fixation device in the wrist joint. It has many screws attached to the device that is embedded in the wrist joint.

O-Arm Equipment and Basics

Another type of imaging equipment used in the OR is known as the O-arm (Fig. 21.50). Much like the C-arm, the O-arm is given this name due to the shape. In many ways, the O-arm is similar to the C-arm in that there are two main parts, the computer console and the imaging apparatus (Fig. 21.51). The key difference is an O-arm can obtain sectional images similar to CT. Sectional imaging can provide greater detail and spatial resolution in neurology procedures including the spine and brain. The sectional imaging provides the ability for 3D rendering similar to computed tomography; therefore, the O-arm does not need to be moved to an oblique or lateral position. The O-arm is similar in size to a C-arm, so it is still imperative to avoid contaminating the sterile field when bringing the machine into a surgical suite. Since most O-arm equipment is not dedicated to one surgical room, the mobile device will need to have a power source such as a plug-in, which is similar to most C-arms. The O-arm must be draped with sterile covers similar to the C-arm, and the radiographer should extend the O-arm from the neutral position to the halfway extended point. This aspect ensures the O-arm can be maneuvered in and out of the surgical area without moving the base. Once imaging is necessary, proceed to move the O-arm to the desired anatomy, using the guidance lights to ensure the image receptor and tube are correctly aligned (Figs. 21.52 and 21.53). It is imperative for the radiographer to communicate with other team members at this point since assistance will be needed to help guide the O-arm around the sterile field. Once in position, the O-arm can be closed using the control panel (Fig. 21.54). At this point AP and lateral images can be acquired (Fig. 21.55), and it is critical that the technologists orientate the O-arm to the patient anatomy (Fig. 21.56). If the O-arm is not orientated early, it is difficult to re-orientate later, resulting in repeat exposures. After AP and lateral imaging are obtained, the radiographer must re-orientate the O-arm in the 3D settings (Fig. 21.57); this must be done to ensure that the 3D reconstructions are correct for the navigation. The technologist can now construct the 3D rendered images allowing for more precise surgical processes. Before removing the O-arm from the surgical area, it must be reopened while maintaining the sterile field. Since the O-arm uses guided navigation algorithms, the 3D renderings can be uploaded into the navigational system for improved accuracy. The renderings can be used to make 3D-printed bone phantoms specific to patients with severe deformities which will allow for safer screw placement. Advancements in surgical imaging technology show progress in reduced surgical time, increased surgical accuracy, and decreased radiation exposure to the patient and surgical team.

Best Practices in Surgical Radiography

Performing examinations in the OR can present different challenges for the radiographer. One of the most important differences in the surgical suite is the presence of a team of individuals. Due to the team-based effort, radiation exposure and protection must become a top priority. The radiographer is responsible for all individuals in the exposure area. The uniqueness requires the radiographer to be familiar with the equipment and intraoperative examinations which allows them to be an effective member of the surgical team.

1. ***Radiation protection:*** Radiation safety is essential during surgical procedures. Examinations requiring a C-arm, O-arm, or other fluoroscopic equipment can increase exposure for radiographers, patients and other health care personnel. Proper shielding attire for the radiographer must be worn, and shielding must be available for other individuals who are in the room during procedures. During exposures, the radiographer should stand a minimum of 6 feet (2 meters) from the x-ray tube, and position the x-ray tube for the beam to enter the patient PA, whenever possible, to reduce exposure.
2. ***Sterile field:*** As part of the surgical team, radiographers are usually nonsterile, therefore an increased effort must be made to prevent contamination of the sterile field at all times. A radiographer can contaminate the sterile field by touching or reaching over the field. Also, radiography equipment must not compromise the sterile field, surgical procedure, instruments, and other personnel or equipment. If the radiographer believes the sterile has been contaminated, this must be communicated immediately. Radiology equipment can only be positioned over a sterile field when covered with a sterile drape.

FIG. 21.50 O-arm imaging equipment and computer console.

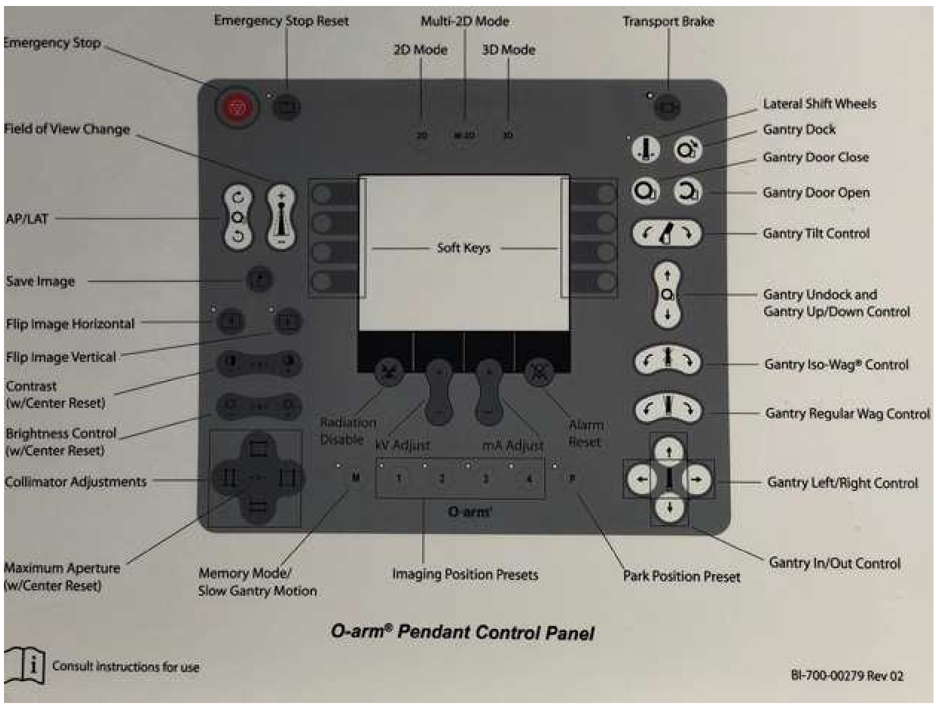


FIG. 21.51 Control panel of computer console.

The control panel of the computer device named O arm registered symbol pendant control panel has a red button on the top left corner which is labeled as emergency stop. Next to it is the emergency stop reset button. The transport brake button is at the top left corner. The following buttons are marked clockwise as follows: imaging position presets, memory mode or slow gantry motion, maximum aperture with center reset, collimator adjustments, brightness control with center reset, contrast with center rest, flip image vertical, flip image horizontal, save image, A P or L A T, filed of view change, emergency stop, emergency stop reset, multi 2 D mode, 2D mode, 3 D mode, transport brake, lateral shift wheels, gantry dock, gantry door close, gantry door open, gantry tilt control, gantry undock and gantry up or down control, gantry i s o wag registered symbol control, gantry regular wag control, gantry left or right control, gantry in or out control, gantry in or out control, park position preset.

FIG. 21.52 O-arm positioned over anatomy of interest.

FIG. 21.53 The *red arrow* indicates one of the guidance lights to which ensure image receptor and tube are correctly aligned with anatomy.

FIG. 21.54 O-arm closed in position.

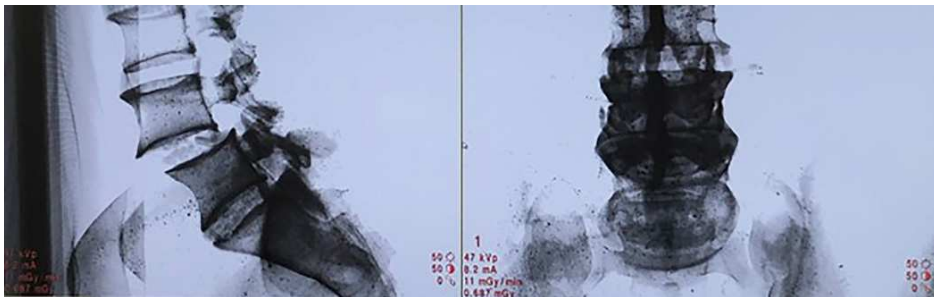


FIG. 21.55 AP and lateral lumbar spine fusion.

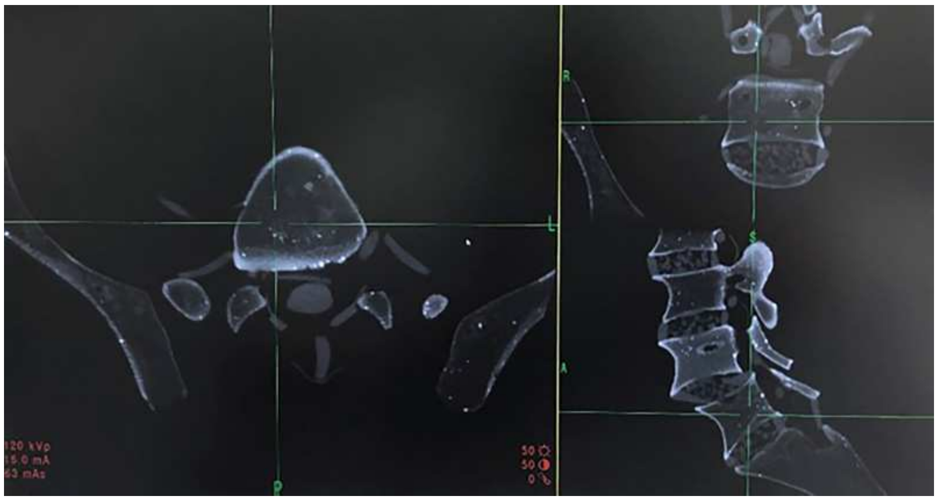


FIG. 21.56 Orientation of the O-arm to the patient anatomy of lumbar spine fusion.

A radiological image on the left shows the lumbar spine fusion. A triangular bone is in the middle and a few irregularly shaped bones are beneath it. Its long and narrow bones point outside at the right and left sides. A radiological image on the right shows the lumbar spine fusion. A rectangular bone with a line in the middle is on the top. The vertebrae segments are below it.

FIG. 21.57 Control panel re-orientating the O-arm into the 3D settings.

The control panel of the computer device named O arm registered symbol has a red button on the top left corner which is the emergency stop. Next to it is the emergency stop reset button. The transport brake button is at the top left corner. The multi 2 D mode, 2D mode, 3 D mode buttons are above a square-shaped grey box in the middle. It is labeled as 3 D. The orientation is on the left and the anatomy is on the right. The following markings are inside the grey square: low dose, patient thickness, 120 kilovolts, 16 milliampere, 64 milliampere seconds. The markings on the panel are collimator adjustments, brightness control with center reset, dock, close, open, up or down, M 1, 2, 3, 4, P, save, lay.

3. ***Equipment:*** Surgical suites will vary by facility. Some have devoted radiography units while others require mobile units to move from one surgical suite to another. Most C-arm units will be of similar construction and features, however, becoming familiar with the imaging equipment is the best way to be effective and efficient. Radiography equipment must be cleaned and disinfected after each procedure. Ideally, imaging equipment is cleaned before it is removed from the surgical suite.
4. ***Communication:*** Effective communication is essential to ensure exams are performed accurately and efficiently. The surgical team must be informed before imaging equipment will be used, and the radiographer must announce an exposure before it is made. Removing obstacles, positioning equipment, maintaining the sterile field, and reducing personnel exposure are all aspects of how adequate communication between the radiographer and other team members can be beneficial.
5. ***Anatomical structures:*** Radiographers must possess proficient knowledge of the anatomical structures visualized in the surgical site during procedures. Understanding the structures and hardware involved in the procedure will allow proper and efficient positioning resulting in better quality images and decreased radiation dose for the patient and personnel.
6. ***Intraoperative examinations:*** Familiarity with surgical procedures will benefit the radiographer and surgical team. Since imaging equipment is frequently used during orthopedic surgeries, the radiographer should have an understanding of applicable surgical instruments and medical hardware used for the procedure, including pins, screws, plates, and devices. Fracture repairs, spinal fusions, and laminectomies are a few common types of orthopedic surgeries that might use a C-arm. Also, anticipating which examinations require more than one projection enables the radiographer to be an integrated surgical team member.

Definition of Terms

antisepsis: Chemical disinfection of the skin.
asepsis: Absence of infection or germs or elimination of infectious agents.
aseptic technique: Principles involved with manipulation of sterile and nonsterile items to prevent or minimize microbiologic contamination.
contamination: Presence of pathogenic microorganisms.
microbial fallout: Microorganisms normally shed from skin that can contaminate sterile surfaces or areas.
restricted area: Operating rooms, clean core or sterile storage areas.
semirestricted area: Area of peripheral support, such as hallways or corridors leading to restricted areas.
sterile: Substance or object that is completely free of living microorganisms and is incapable of producing any form of organism.
teamwork: The Association of Surgical Technologists (AST) Standards of Practice Standard I states: “Teamwork is essential for perioperative patient care and is contingent on interpersonal skills. Communication is critical to the positive attainment of expected

outcomes of care. All team members should work together for the common good of the patient, for the benefit of the patient and the delivery of actions with the health care team, the patient and family, superiors, and peers. Personal integrity and surgical conscience are integrated into every aspect of professional behavior."

unrestricted area: Areas in which street clothes are permitted, such as outer hallways, family waiting areas, locker rooms, and employee lounges.

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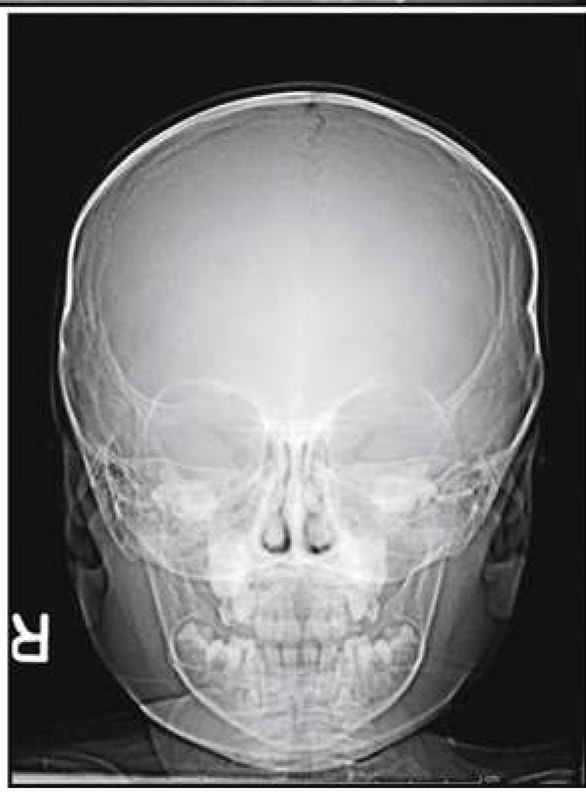
22: Pediatric Imaging



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Introduction to Pediatric Imaging

Imaging children is one of the most fascinating and worthwhile specialties in radiography. To witness their cheerful resilience and the parents' acceptance of immense challenges is a privilege. At the same time, pediatric imaging can be one of the most confounding experiences. Radiographers gain skills in multitasking, such as quickly engaging and reassuring the child using an age-appropriate approach, then switching gears to gain the confidence of the parents, explaining and instructing them on immobilization techniques for the exam, all while keeping in mind that other patients are waiting. It is important to be mindful of the various stressors parents may have endured before finding their way to the imaging room. In addition to the stress of a pending diagnosis, parents may have experienced an early or long commute, an unsettled child, a busy parking lot, and difficulty navigating their way through the institution. Do not take family moods personally. The radiographer's primary job is to actively listen to, communicate with, and understand the parents and their child. This is the primary path to achieving cooperation and quality diagnostic radiography. Children take their behavioral cues from facial expressions, intonations, and body postures; an ill-at-ease parent will convey that mood to the child, making the exam more difficult to perform. This overview will present common pediatric exams, mobile considerations, and prevalent pathologies and syndromes.

Waiting Room

Waiting and procedure rooms that are well equipped can reduce anxiety and act as a diversion for both the parents and the children. Children are attracted to and amused by toys, thus leaving the parents free to check in, register, and ask pertinent questions. Gender-neutral toys or activities, such as coloring with crayons located at a small age-appropriate table, are most appropriate. (Children should be supervised to prevent them from putting the crayons in their mouths.) Books or magazines for older children are also good investments. The Child Life services of the hospital can provide advice and make appropriate recommendations (Figs. 22.1 through 22.3).

FIG. 22.1 (A) Radiology outpatient and family viewing the interactive media wall. (B) The interactive media wall from the first-floor lobby.

(A) A boy sitting on a stroller is looking at the interactive medial wall. There are a few circular holes in the wall with white dots in blue. A woman and a man are sitting next to the boy. (B) Few kids are standing in front of an interactive media wall. There is a kite and a few butterflies in the sky. A monkey is peeking from the corner on the media wall.

Best Practices for Pediatric Imaging

Safety

- Never leave the patient unattended.
- Keep items that could be swallowed out of reach.

Pediatric Radiography Protocols

- Protocols provide an easy reference for ordering physicians concerning the required projection based on the pathology indication. Protocols are helpful references for rotating resident staff or new staff radiologists.
- Use of the standardized pediatric protocols clarifies the projection/pathology indication, increases image quality, and minimizes radiation (risk) to the patient and staff.

Communication

- Introduce yourself while making eye contact with the patient and parents (if culturally appropriate).
- Always speak to a child using language appropriate for the child's developmental level.
- Explain the exam and anticipated team approach.
- Take history (as required) and discuss pertinent medical information on a level the family can understand.
- Avoid medical jargon and unfamiliar terms. If a medical term cannot be avoided, explain it in lay terms.
- Be mindful not to engage in inappropriate conversations in the presence of the patient.
- Before beginning the exam, ask if there are any questions or concerns.
- Use family teaching sheets when applicable. (These are web-based outlines of your hospital's procedures for the patient/family.)

Respect for Patient/Parent Rights and Dignity

- Listen to patient's/parents' questions and concerns.
- Some patients/parents speak English as a second language, which may impede their complete understanding of the exam and the communication of exam results. To better serve the family (and for medicolegal reasons), have an interpreter present.

FIG. 22.2 Nuclear medicine waiting room.

- Be mindful of cultural preferences and taboos. Ask your interpreter or the family or seek out resources within your institution.
- Always knock before entering and avoid entering an imaging room while an exam is in progress.

Provision of Adequate Care and Service to the Patient and Family

- Create a child-friendly environment.
- Use appropriately sized equipment.
- Remember: parents know their children best, so seek and make use of their advice.
- Utilize your child life specialist (CLS); they are invaluable for facilitating cooperation.
- If not contraindicated by the study, use a soft pad with a sheet on the exam table for patient comfort.

FIG. 22.3 Transition hallway from nuclear medicine to ultrasound.

Age-Based Development

The pediatric patient may not always fit neatly into the following developmental stages for a variety of reasons (e.g., pathology, developmental delays, parenting, chronic illness or prolonged hospital stay, or mood at the time of exam); however, there are some universal approaches to interacting with children that will always apply (e.g., setting limits, making eye contact, and addressing their fears). Be observant, take cues from the patient and family, and tailor your approach to their interaction. Watch their eyes and body postures. Are the parents gripping things tightly? Do you need to set limits for their children? Is the child tense or clinging to a parent's leg? Listen to the child's choice of words.

With a team approach, connect with the family before the exam begins. Introductions should always be made in a slow and relaxed fashion. Cultural norms are important, and although the family might make allowances for ignorance, it is best to educate yourself on the norms and appropriate behaviors related to the family's cultural practices. Learn a few words or phrases in the languages most common to your patient's demographic. Cultural biases can also work in reverse; the family might make assumptions about you and how they treat you based on your sex or their socioeconomic status in their country of origin. Consulting your interpreter for advice is the first place to start.

Premature Infants

Generally, bedside radiography and procedures in GI and GU using fluoroscopy encompass most of the contact radiographers will have with premature infants in the department. Elevate the room temperature 10 to 15 minutes prior to the patient's arrival. When these babies are in radiology for a procedure, an intensive care unit (ICU) nursing team will accompany them. The nursing team will provide care for the patient, but you will need to explain the procedure and how the nursing team can help. Obtain the current status of the patient and any special requests from the nursing staff. As with any exam, suction and oxygen must always be available and the room well stocked. Leave the patient in the incubator (warmed isolette) until just before the procedure. Depending on the exam, you may be able to use a radiolucent cushion on the exam table for patient comfort. Discuss the patient immobilization plan (who will hold, how, what body part) with the nursing staff to ensure that you accommodate the patient's medical conditions. Have warming lights available, wash hands, wear gloves, and adhere to all isolation precautions.

Neonate (0 to 28 Days)

The neonatal period is a time of transition from the uterine environment to the outside world. During this first month, the newborn is forming attachments with caregivers. They are sensitive to the way they are held, rocked, and positioned. They love to be swaddled, which gives them a sense of security and keeps them from being disturbed by their own startle reflex. Newborns are easily startled when moved quickly or upon hearing a loud noise. Bright lights cause them to blink frequently or close their eyes. Understandably, the hospital environment particularly creates stressors for neonates, which should be minimized whenever possible.

Because newborns are most secure and comfortable when swaddled, keep them in this position until just before you are ready for imaging. Decrease noise and brightness levels whenever possible, maintain a warm room, and always use warming lights unless the nursing team directs otherwise. Speak soothingly and try to avoid sudden, quick movements. Let the caregivers know exactly what is expected during imaging and involve them in soothing and calming their infant. Pacifiers, oral sucrose (check with the nursing team), a personal blanket, and quiet singing can all help to soothe newborns, enabling them to feel safe and secure.

Infant (28 Days to 18 Months)

During different periods of infancy, babies experience stranger and separation anxiety. When working with infants, involve the parents whenever possible; the comfort of seeing the parent's/caregiver's face, hearing that familiar voice, and feeling the caregiver's touch can be invaluable when calming the infant.

The radiographer and the CLS play important roles in establishing a relationship with the infant by talking and smiling; this will help put the parents at ease and demonstrate care and concern for their baby. The caregiver knows the infant best, so ask what soothes and comforts the baby when they are distressed. Personal objects, such as a pacifier or a blanket, can distract and soothe the infant during the exam. To ease the transition from the parent's arms to the exam table, it is advisable to decrease stimuli and eliminate loud noises. Keeping the baby swaddled or in their carrier until just prior to imaging minimizes transitions and reduces the baby's time on the exam table. The first rule of imaging infants is to never leave the infant unattended; the radiographer or parent should always have a hand on the infant. The second rule is to always cushion the exam table under the infant's skull. Be sure not to flex the head forward, which may cause respiratory difficulties.

Toddler (18 Months to 3 Years)

Toddlers can be a challenge for both radiographers and staff. Toddlers are not abstract thinkers and are unable to understand the concept of "inside their body." They operate very much in the "here and now." They are seldom able to keep their bodies still, which can make imaging problematic, and they also have a short attention span and become overwhelmed quickly. Toddlers are fearful of medical experiences and often become unruly while they are being positioned for an exam. Unfamiliar exam positions and faces can escalate their movement.

In an effort to provide adequate care and minimize reactions, keep language brief and use concrete words. Because keeping their body still is most often an issue, efficiency is crucial. Be sure the room is organized before the patient and family enter. If the toddler has a toy or blanket, keep it within reach during the examination if possible. Distraction techniques can be extremely helpful in keeping the toddler calm. A screaming toddler can often be distracted and calmed by being allowed to blow bubbles or use a tablet computer with an age-appropriate application.

After the imaging has been completed, let the child know they did a great job, that you are proud of them, and that they should be proud of themselves. Praise may be in the form of positive statements or a small reward, like a sticker or balloon.

Preschooler (3 to 5 Years)

New places, faces, and experiences can be overwhelming to preschoolers. Unfamiliar sights, sounds, and faces can be quite intimidating and can leave the preschooler feeling frightened. In addition, preschoolers are establishing routines and greatly benefit from structure and knowing what to expect. For preschoolers, the medical environment is unpredictable, so often these patients need time to explore and familiarize themselves with the imaging room, even if it is brief. They also need to feel comfortable with the clinicians who will be working with them. Taking the time to establish rapport will be instrumental in making preschoolers feel comfortable, thus enhancing their coping abilities (Fig. 22.4).

Additional steps include letting them know exactly what to expect and what is expected of them. For example, mention the loud sounds of the "camera," show the movement of the "camera," let them feel the coldness of a solution or cotton ball, and most importantly, assure them that you will let them know before you do anything. These simple courtesies facilitate trust and cooperation and help the child feel more comfortable. Some preschoolers may have difficulty understanding the exam through dialogue. Therefore, when speaking with them about imaging or "taking pictures," it may be helpful to model this process using a doll or stuffed animal.

FIG. 22.4 The radiographer should make an introduction to the child and show the child how the collimator light is used.

Although preschoolers are developing independence and want to establish themselves apart from their parents, they can become fearful if separated from them; utilizing parents can be instrumental to the success of the exam. If the parents are not able to remain with the child during imaging, allow the parents to pick up and comfort the child when the procedure is completed.

When working with patients of this age, use directive statements to facilitate cooperation; for example, "It's time to…" or "You can help me by…" are directive statements that will limit their response, leaving them more likely to comply. Open-ended questions that begin with "Do you want to (e.g., get on the table)?" leave preschoolers feeling as if they have a choice, when in reality, getting on the table and having the exam is not optional. Open-ended statements confuse preschoolers and can leave them feeling overwhelmed. Preschoolers are constantly seeking approval from others and respond well to positive affirmations. Praise and encouragement are beneficial for this age group, as they will create a positive experience and help boost the preschooler's confidence in future medical appointments.

School Age (6 to 12 Years)

School-age children are becoming logical thinkers and developing a fear of failure, so positive affirmations and reassurances are extremely beneficial. They are curious and full of questions; take the opportunity to connect using age-appropriate explanations. Break down the exam into steps, let them know exactly what to expect and what is expected of them, and most importantly, let them know before you do anything. These simple courtesies will facilitate trust and cooperation and help the child feel more comfortable.

Avoid unfamiliar medical jargon, as this will only confuse school-age children and can decrease their ability to cope. Children of this age range are very literal, so it is crucial to avoid words that can be misconstrued, such as shoot, shot, or dye. School-age patients benefit from being given choices; this will give them a sense of control and entitlement, which inevitably enhances their coping abilities. However, be cautious to only give realistic choices; cajoling the child using open-ended questions could mislead the child.

It is important to make imperative or interrogative statements, such as "It's time to get changed; would you like the green gown or the blue one?" or "You need to get on the table; would you like me to help you, or would you like your mom to help you?" These choices are direct and allow for realistic decisions. Coping and distraction techniques available to patients and staff, like taking deep breaths, blowing bubbles, listening to music, watching a movie, or playing games with a tablet, can be instrumental in helping children cope during exams.

Adolescent (12 to 18 Years)

When imaging adolescents, respect their need for privacy by providing a private area for changing, knocking before entering their exam room, and limiting the number of staff involved. These actions will help to alleviate stress. If you have clinicians (GI/GU, MR, CT) and radiographers of both sexes (and time permits), ask the patient if they would feel more comfortable with a male or female performing the exam. In many pediatric centers, girls who have reached the age of 10 to 12 years must be asked if there is any chance they might be pregnant. You may also ask if the girl has started menstruating. A truthful response is more probable if the parent is not present when these questions are asked. The patient's response will dictate whether further explanation is required. For example, you may need to add, "We ask these same questions of all girls because unborn babies are extremely sensitive to radiation exposure."

If it is necessary for adolescent patients to disclose their medical history, speak directly to them and their parents rather than just the parents. Radiographers tend to ask the parents this information, but it is important to remember that adolescents most often know their body best. As adolescents, they do not always discuss things with their parents for reasons of embarrassment or shame. In addition, before beginning the exam, ask the adolescent patient if they would like to have a parent present during imaging. This gives adolescents a choice and lets them know it is okay to ask parents to step out.

It is not uncommon for the adolescent patient to respond negatively to having an exam. In addition to being extremely modest, they often see themselves as invincible and do not believe that anything could possibly be wrong with them. Adolescents also fear being "different" and are afraid of something happening to their bodies that would alter their appearance or make them unlike their peers. Validating their feelings and letting them know you want to help will reassure them. For example: "I understand the way you are feeling; lots of teenagers have this test done and they feel the same way" or "I am here to help you as best I can." Assisting adolescents with preparation, explaining the rationale for why the exam is taking place, and giving them tools for coping will facilitate cooperation and decrease fears. Deep breathing, listening to music, or having a conversation with a caregiver can help put the patient at ease.

Patients With Special Needs

The radiographer should consider age and behavior when approaching children with physical and mental disabilities. School-age children with disabilities strive to achieve as much autonomy and independence as possible. They are sensitive to the fact that they are less independent than their peers. The radiographer should observe the following guidelines:

- Introduce yourself and identify the patients at their level (you may have to kneel down), then briefly explain the procedure to the child and parents. All children appreciate being given the opportunity to listen and respond. As with all patients, children want to be spoken to rather than talked about.
- If this approach proves ineffective, turn to the parents. Generally, the parents of these patients are present and can be very helpful. In strange environments, younger children may trust only one person—the parent. In that case, the medical team can gain cooperation from the child by communicating through the parent. Parents often know the best way to lift and transfer the child from the wheelchair or stretcher to the table. Children with physical disabilities often have a fear of falling and may want only a parent's assistance.
- Place the wheelchair or stretcher parallel to the imaging table, taking care to explain that you have locked the wheelchair or stretcher and will be getting help for the transfer. These children often know the way they should be lifted—*ask them.* They can tell you which areas to support and which actions they prefer to do themselves.

Finally, children with spastic contractions are often frustrated by their inability to control movements counterproductive to the exam. A gentle massage or a warm blanket may be used to help relax the muscles.

Communicating with a child who has a mental disability can be difficult, depending on the severity of the disability. Some patients react to verbal stimuli, whereas loud or abrupt noises may startle or agitate them. Ask the parent or caregiver if there is anything you should know about the child to help achieve a quick and accurate exam. Limitations of psychological, behavioral, or physical impairments may not be obvious or referenced on the exam order.

Autism Spectrum Disorders [a]

Medical imaging of individuals with autism spectrum disorders (ASDs) can be difficult. In addition to difficulties with communication, there are also behavioral issues, medical issues, and environmental concerns that need to be considered. There are important steps that should be taken before the patient is brought into the examination room and, in some cases, before they come to the imaging facility.

According to the Centers for Disease Control and Prevention (CDC), ASDs are a group of developmental disabilities that can cause significant social, communication, and behavioral challenges. People with ASDs handle information differently than other people. The word “spectrum” means that autism can range from very mild to severe. There are some similar symptoms across the spectrum, such as problems with social interaction; however, there are differences in time of onset, severity, and the nature of the symptoms. One popular saying within the autism community is, “If you know one person with autism, then you know one person with autism.” Patients with ASDs require specialized treatment plans for parents, caregivers, and physicians. What works well for one individual may not be effective for another, which makes imaging individuals with ASDs a unique challenge.

The prevalence of autism is on the rise. In 2020, the CDC estimated the prevalence of ASD among children in the US at 1 in 54 diagnosed by age 8 in 2016, an approximately 10% increase since 2014, when the estimate was 1 in 59. Males are four times as likely to be diagnosed as females, and on average the diagnosis is earlier for those with more severe symptoms. Parents may notice the difference as early as 6 months, whereas high-functioning individuals, such as those with Asperger syndrome, may be diagnosed at around 6 years of age.

Occasionally patients with ASDs are identified before scheduling imaging procedures. The CDC has several publications on the diagnosis for ASDs; however, for facilitating imaging procedures, the following are commonly recognized signs of autism:

- Difficulty with social interaction.
- Problems with verbal and nonverbal communication.
- Repetitive behaviors or narrow, obsessive interests.

Special considerations for imaging

Once an ASD patient is identified, there are many things we can do to provide for a successful imaging experience for both radiographer and patient. Whether or not the patient is in the department, we should begin by asking more questions. Box 22.1 is an example of a patient questionnaire. It might be beneficial to schedule the exam at a time when the department is not busy. Loud noises or visual overstimulation can be distracting and, in some cases, can cause severe behaviors. This can be especially true during the adolescent years. Because these children are larger, aggressive or violent behavior can be dangerous for the patient or staff. It is wise to prepare for all possibilities. A good patient questionnaire can help gather resources and prepare the environment. You can use the questionnaire to know when to eliminate noises or adjust lighting.

Box 22.1 Autism patient questionnaire

Is your child sensitive to fluorescent lighting?
Is your child comfortable in a dimly lit room?
Is your child tactile defensive, or sensitive to touch?
    If yes, explain.
Is your child sensitive to loud noises?
    High frequencies?
    Low frequencies?
Is your child uncomfortable in cool or cold situations?
Is your child uncomfortable in warm or hot situations?
Do you have any calming objects you would like your child to have in the imaging suite?
Will your child find a video played during the procedure calming?

Try to give the patient with an ASD the first or last appointment of the day. People with an ASD find waiting around for an appointment extremely stressful. Waiting in busy hospital corridors will increase the stress levels of an already anxious child or adult. If possible, find a small side room the family can wait in. Alternatively, they may prefer to wait outside or in the car, and a member of staff should be identified to collect them or call their cell phone when the radiographer is ready. If the appointment is likely to be delayed, the family may wish to leave the building completely and return at a later agreed-upon time.

Temperature is often difficult to adjust, but patient dress can be modified if it is an issue. Many individuals with autism are sensitive to touch. They have difficulty habituating stimuli of any type. Some may wear socks inside out so they cannot feel the seam on their toes. These are serious issues for individuals on the spectrum.

Sometimes we need to modify our positioning techniques for individuals who are tactile defensive, or sensitive to touch. A sensitivity to the “poking” often used to find anatomic landmarks can also be problematic. Some barbers have found that once you touch, you maintain the touch until you are finished with the haircut. One hand must remain on the head until the haircut is complete. We can use this same concept with imaging; once you begin to touch, do not remove your hand until you have all the information you need.

Videos can be a double-edged sword. Although a familiar video can be calming, if it varies in any small way from the one the child is used to, it can instead cause a severe reaction. It might be best if patients bring in videos of their own, especially if the procedure is expected to be long.

Personal space and body awareness

A crowded waiting room may be distressing for people with an ASD who may need their personal space. Similarly, close proximity to the radiographer could be uncomfortable for the patient.

Problems can also occur when trying to explain where pain is experienced. Those who have difficulty with body awareness may not be able to experience where different body parts are.

Touch

Individuals with ASDs may be hyposensitive to touch, or tactile defensive. They may find a light touch very painful. Some of these patients may prefer more deep pressure in touching, or you may not be able to touch them at all.

Patient responses

Do not be surprised if the patient does not make eye contact, especially if they are distressed. Lack of eye contact does not necessarily mean the patient is not listening to what you are saying. Allow the patient extra time to process what you have said. Do not assume that a nonverbal patient cannot understand what you are saying.

People with an ASD can have a high pain threshold. Even if the child does not appear to be in pain, they may, for example, have broken a bone. ASD patients may show an unusual response to pain that may include laughter, humming, singing, and removal of clothing. Agitation and behavior may be the only clues that the child or adult is in pain.

Communication

Use clear, simple language with short sentences. People with ASDs tend to take everything literally. Thus, if you say, “It will only hurt for a minute,” they will expect the pain to have gone within one minute.

Make your language concrete and avoid using idioms, irony, metaphors, and words with double meanings (e.g., “It’s raining cats and dogs out there,” which could cause the patient to look outside for cats and dogs). Avoid using body language, gestures, or facial expressions without verbal instructions, as the patient may not understand these nonverbal messages.

Consider involving a caregiver to facilitate communication. Many individuals respond slowly, and patience is required.

Noise

Some departments use buzzers to indicate when it is a patient’s turn to have an exam. They may also have music playing in the waiting room. Crying babies or children in the waiting room may also be quite noisy. For those with hypersensitive hearing, these types of noises can be magnified and become disturbing or even painful. Additionally, with this heightened volume, surrounding sounds could become distorted. This could make it difficult for the person with an ASD to recognize sounds, such as a name being called. Individuals may respond by putting their fingers in their ears, whereas others may “stim” (e.g., flap hands, flick fingers, rock back and forth). This kind of behavior is calming to the individual, so do not try to stop it unless absolutely necessary. Individuals with ASDs often retreat when overstimulated.

Injections/needle sticks

If the patient needs an injection or blood test, divert their attention elsewhere. The use of pictures or a doll is a good idea to demonstrate what is going to happen. People with an ASD can be either undersensitive or oversensitive to pain, such that some may feel the pain acutely and be very distressed, whereas others may not appear to react at all.

It is advisable to assume that the patient will feel pain. Use a local anesthetic cream, such as a eutectic mixture of local anesthetics, to numb the site of injection. Sand timers and clocks can be used as distracters during procedures such as injections, allowing the person with autism to see a definite end.

Tips for radiographers

Relaxation techniques such as deep breathing, counting, singing favorite songs, talking about a favorite interest, or looking at favorite books or toys could also help during physical examination or treatments. Parents may be instructed to bring a favorite toy or video if a player is available in the procedure room.

Make sure directions are given step by step, verbally, visually, and by providing physical supports or prompts as needed by the patient. Patients with ASDs often have trouble interpreting facial expressions, body language, and tone of voice. Be as concrete and explicit as possible in your instructions and feedback to the patient. Demonstrating on others or on toys to show what will happen during a physical examination can reassure an individual with an ASD.

Many children with autism fixate on routines. Most medical imaging will fall outside of their routines. To make something unfamiliar seem more routine, social stories can be used. A social story can be a written or visual guide describing various social interactions or situations. These stories can be in books, on flashcards, or provided online by the department so that the family can share with the patient what it is like to go to the x-ray department. The caregiver can revisit or practice these social stories prior to the exam. Pictures of the parking garage, waiting room, imaging room, and even the individual radiographer can be added. The more accurate these pictures are, the better they will work. It might even be helpful to take pictures from the perspective of the individual with the ASD. If the patient is lying on an x-ray table, a picture taken up toward the tube or scanner might be appropriate. In this way, a social story can be used to make something the individual has never done before seem routine. Parents of many children with ASDs create social stories for vacations, plane rides, trips to the amusement park, and so on. Parents and caregivers who use these social stories will vouch for their effectiveness. In addition to social stories, allowing the patient with autism and their caregivers access to the facility before the exam may be helpful. This allows a “dry run” of the procedure, which may reduce anxiety during the actual exam.

In summation, a combination of a questionnaire, social stories, and the patient application of the aforementioned principles should greatly help when imaging individuals with ASDs. Preparation is key, but it need not be prohibitively time consuming. Creating a social story for every exam an imaging department does is ideal, but simplification is possible. Making social stories accessible online is desirable. Adding pictures and images, especially accurate ones of specific facilities, increases the comfort level of patients. These practices are also good for all patients, not just those with ASDs. Many advocates would say that better serving individuals with ASDs (or others with “different” abilities) have improved schools, social services, and the lives of all they touch. The same could be said of our imaging departments.

Radiation Protection

Dose and Diagnostic Information

The goal in administering radiation for a specific clinical indication is to ensure that the *diagnostic* information obtained will be of greater value than the potential risks associated with the radiation. To protect our patients, we should identify through scientific testing an acceptable level of quantum mottle for each exam that will not compromise the diagnostic goal of the image. As medical practitioners, we attempt to use the minimum radiation dose required to produce a *clinically diagnostic* image for a specific clinical indication; this is our primary goal as radiographers and radiologists. Radiographers should observe the following steps:

- Take direct efforts toward proper centering and selection of exposure factors as well as precise collimation, which all contribute to safe practice.
- Use strategic placement of gonadal and breast shielding, when required by department protocol or state statues, and employ effective immobilization techniques to reduce the need for repeat examinations.

- Instead of the anteroposterior (AP) projection, use the posteroanterior (PA) projection of the thorax and skull to reduce the amount of radiation reaching the breast tissue and lens of the eye, respectively.
- Use pulsed fluoroscopy with “last image hold” to reduce patient dose and length of examination.

A cautionary note: The fact that digitally acquired images can be “postprocessed,” thereby correcting some exposure errors, does not negate an important truth—images of diagnostic quality are achieved by proper positioning. The anatomy to be demonstrated must be in proper alignment with the AEC detector.

Child versus adult

The possible long-term stochastic effects of a low linear energy transfer (LET) radiation dose on pediatric patients, if they exist, are much greater than the same dose to an adult because the child has a longer lifetime over which to express any long-term effects, and due to the child’s smaller body volume, the potential exists to expose multiple organ systems to radiation for any given exam.

Shielding and dose reduction

Shielding for initial images for PA scoliosis and female pelvic exams should follow department guidelines (Fig. 22.5). Males can be shielded on the initial AP pelvic image provided the shield is positioned below the pubic symphysis (Fig. 22.6).

Discussing radiation risks and benefits with parents

Just as you have developed exam-based routines, you should have an example-based “script” for discussing the risk/benefit equation of radiation exposure. When parents have questions, listen carefully and hear their questions, fears (which may only be implied), point of reference for understanding radiation dose (usually CT), and educational level. Be aware that people in medical settings, especially when under stress, often hear only 50% of what is being said; additionally, they often give greater weight to negative information. Be knowledgeable and confident with your answers (e.g., through body language, tone, interest, and clarity of presentation without technical jargon); a rambling or confusing presentation will do more harm than good. “In risk perception theory, perception equals reality. This means there may be no correlation between public perceptions of risk and scientific or technical information. Therefore, you must discuss the risk based on the perception.” [1]

FIG. 22.5 Proper positioning of female gonadal shield.

Reframing the way patients and parents understand radiation risks (if they exist) and benefits should be your first goal. Human exposure to x-radiation is usually "understood" through the subjectivity of the lay press, the sensationalism of TV shows, and the half-truths of word of mouth. A wonderfully clear and effective, but often overlooked, approach to help place radiation exposure in perspective is to reference the dose the child will receive for any given exam to the background radiation we all receive daily. Background equivalent radiation time (BERT) equates a particular exam-based radiation dose to the equivalent amount of radiation dose received daily from our natural background (Table 22.1). The BERT method has several advantages: (1) the patient readily understands it, (2) it does not mention radiation risk, which is unknown, and (3) it educates the patient that he or she lives in a sea of natural background radiation.

FIG. 22.6 Males can be shielded on the initial AP pelvic image provided the shield is positioned below the pubic symphysis. (A) Shows correct shielding and positioning (femoral heads are centered), but collimation should be tighter and the patient should have been changed prior to imaging. (B) Incorrect shielding; shield covering part of symphysis and inferior rami.

(A) An x-ray view of the male pelvis shows a shield below the pubic symphysis. It appears radiopaque. The femoral heads are centered. (B) An x-ray view of the male pelvis shows a shield on the pubic symphysis. It appears radiopaque. The femoral heads appear inverted inside.

TABLE 22.1

Comparison of pediatric exam dose to background radiation level

Exam	Natural background radiation equivalent [a] (time to receive equivalent background radiation)
Chest CT, high resolution (pulmonary embolism, angiogram)	730 days (6 mSv)
Abdominal CT	365 days (3 mSv)
Abdomen/pelvic radiograph	90 days (0.75 mSv)
Chest radiograph, two view	2.5 days (0.02 mSv)
Natural background radiation	1 day (0.008 mSv)

[a] Using an average background radiation level of 3 mSv/year.

Data from https://www.imagewisely.org/imaging-modalities/computed-tomography/medical-physicists/articles/how-to-understand-and-communicate-radiation-risk. (Accessed September 2018); Colang JE, Killion JB, Vano E: Patient dose from CT: a literature review, *Radiol Technol* 79:17, 2007.

The lay public's preoccupation with the perceived risks of x-radiation often overshadows the benefits of the diagnostic imaging exam. When a physician orders a radiation-based exam, it is with the confidence that the diagnostic information obtained will outweigh any potential risks (if there are any) of an image. Declining an exam based on perceived risks creates the real risk of a missed diagnosis.

Radiographers holding for exams

Effective use of immobilization techniques must always be attempted, which means imaging pediatric patients may require the radiographer to hold the patient. Radiographers are encouraged to hold only as a last resort, but there are many challenging exams that would, even with the best of instruction, have a low chance of success using only parents to hold the patient. In deciding whether to hold for an exam, radiographers seek to balance the potential stochastic risks of radiation exposure to themselves (scatter) against the possibility of having to repeat a child's x-ray (primary beam) because of a parent's unsuccessful attempt at immobilization. If our ultimate goal is to reduce the overall dose to the patient and ourselves, where is the balance?

Evaluating the parents' ability to hold their child firmly enough to prevent movement and achieve correct positioning should begin when you introduce yourself. Is the parent/guardian attentive to what you say? Are they tentative first-time parents? Are they overindulgent and unable to set limits? Are they so concerned with radiation exposure that they have difficulty listening to instructions? Are they overwhelmed with parenting? Do they come with an attitude that will prevent them from listening? Does the patient's physical condition make them a challenge to hold? An affirmative answer to any of these questions may suggest that a radiographer do the holding. Allowing a parent who is probably not capable of successfully holding the patient to do so in order to prevent a small, low LET, occupational dose (scatter) to the radiographer is not in the patient's best interest; the patient, now facing a repeat, receives twice the primary beam radiation dose, and the radiographer will still end up having to hold. Before making the decision to hold, the radiographer should make every attempt at immobilization or to instruct the parent/caregiver clearly and slowly, using lay terms, while demonstrating the technique. After the parent has attempted to hold the child, the radiographer must decide whether to continue allowing the parent to hold or to step in themselves, thereby assuring that a diagnostic exam is achieved on the first try. The goal of any radiographic exam is to produce an image with a radiation dose as low as diagnostically achievable while providing good patient and family care. This is a lot to juggle even for the seasoned pediatric radiographer, and it takes a lot of experience to perform well.

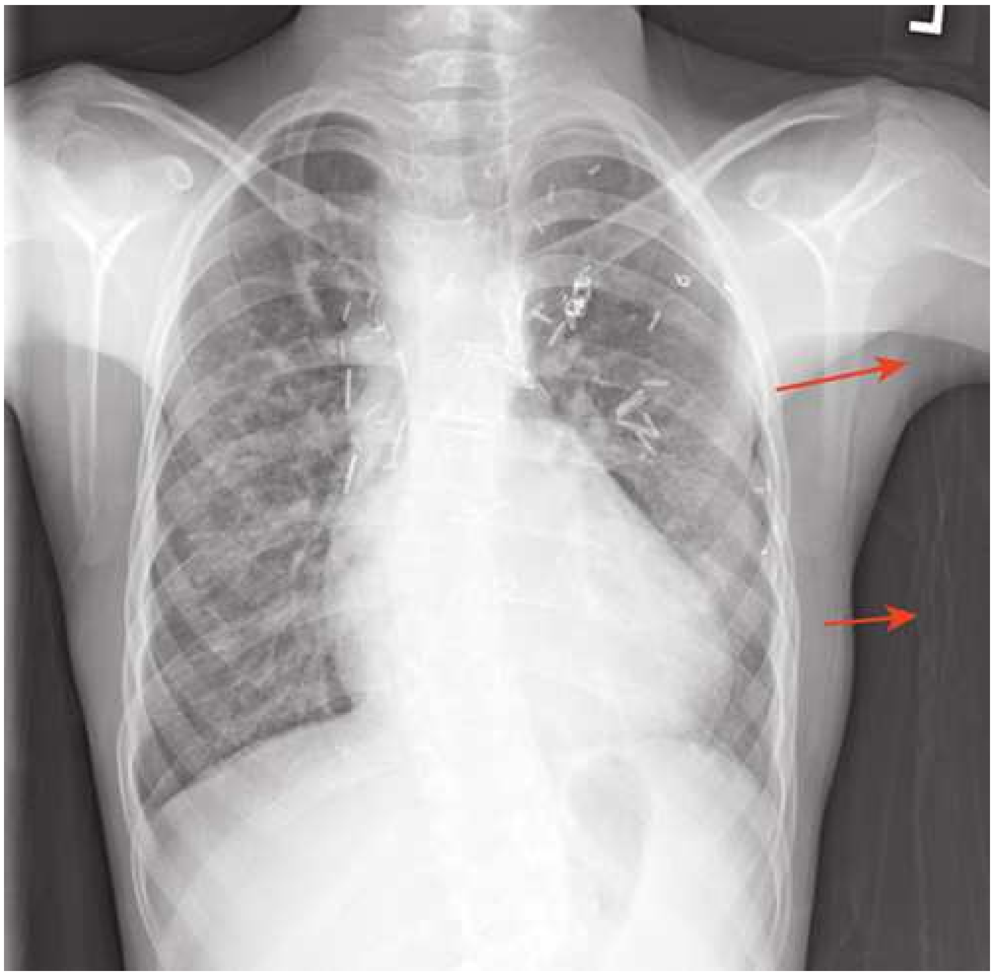

FIG. 22.7 Soap or starches in patient gowns appear as long slender irregular densities *(red arrows).*

Artifacts

The dynamic range of digital radiography has increased the universe (number and type) of artifacts visible on images. The usual suspects are dirt, scratches, metallic or radiopaque objects on the patient, equipment errors, and motion. The following is a partial list of artifacts unique to digital radiography:

- Soap or starches in patient gowns that appear as long, slender objects of irregular densities (Fig. 22.7).
- Textured or thick hair, cornrows, dreadlocks, ponytails, bobby pins, hair clips, or any object woven into the hair.
- Clothing seams, sweatpants eyelets, silkscreen designs, appliqué or embroidery, textured t-shirts, onesies, dry or wet diapers, and sanitary pads.
- Glitter, rhinestones, pearls, belly button rings, or other piercings. You may encounter some resistance from parents concerning the removal of an infant's new ear piercing studs; assure the parent that the holes will not close during the time it takes to generate the exam images.

The ratio of artifact size to body volume is greater in pediatric patients than adults. In other words, given two images, one of an adult and one of an infant and both of the same anatomic area, and given two artifacts of the same size, shape, and density located in the same spot within those same anatomic areas, the likelihood of detecting the artifact in the infant's image would be greater due to the artifact's size relative to the anatomy. To reduce clothing artifacts, remove any piece of clothing covering the anatomy of interest. Paper shorts are radiolucent and can be used for pelvic and abdominal imaging. Years of experience support this approach; failure to remove clothing will result in repeat images. When there is a need to observe breathing patterns (chests), particularly on children who cannot hold their breath (those younger than 6 or 7 years old), clothes should be removed from the waist up so the radiographer can observe breathing. As noted earlier, it is well documented that patients in a hospital setting hear about 50% of what is said, so when the patients/parents enter the exam room after changing, ask them again if they have removed the requested pieces of clothing. Clear communication is paramount, followed closely by checking for compliance. Trust, but verify. Do not assume (Fig. 22.8).

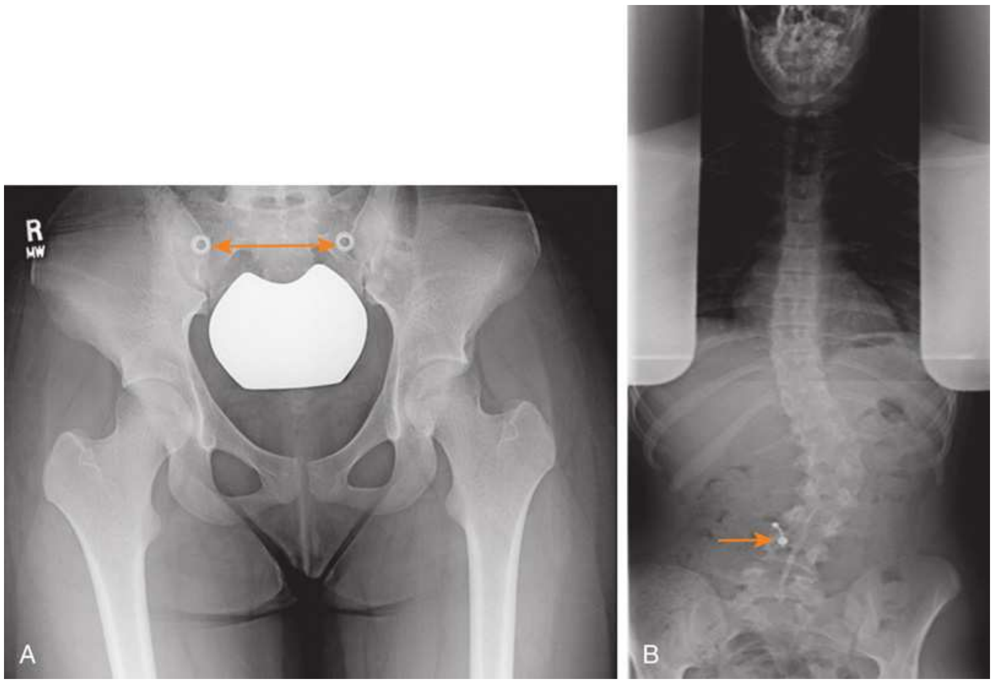

FIG. 22.8 (A) Eyelets on sweatpants *(orange arrow).* (B) Belly-button ring *(orange arrow).*

(A) An x-ray view of the female pelvis shows a radiopaque shield above the pelvis area. Two circles with a hole in them are on either side of the pelvis. (B) An x-ray shows a tiny radiopaque object on the abdomen.

Common Pediatric Positions and Projections

Abdomen, Gastrointestinal, and Genitourinary Studies

Abdomen

Abdominal radiography in children is requested for different reasons than it is for adults. Consequently, the initial procedure or protocol differs significantly. In addition to supine and upright images, the assessment for acute abdomen conditions or the abdominal series in adult radiography usually includes images obtained in the left lateral decubitus position. Often the series is not considered complete without a PA projection of the chest. To keep radiation exposure to a minimum, the pediatric abdominal series need only include two images: the supine abdomen and an image to show air-fluid levels. The upright image is preferred over the lateral decubitus in patients younger than 2 or 3 years old because, from an immobilization and patient-comfort perspective, it is much easier to perform. The upright image can be obtained with a slight modification of the Pigg-O-Stat (Modern Way Immobilizers, Gainesboro, TN) (Fig. 22.9), whereas the lateral decubitus position requires significant modification of the Pigg-O-Stat. As mentioned for hip radiography, the diaper should be completely removed for all abdominal and pelvic imaging to avoid artifacts.

FIG. 22.9 The Pigg-O-Stat, modified with the seat raised to suit upright abdominal radiography. The sleeves and seat are cleaned, and the seat is covered with a cloth diaper or thick tissue before the patient is positioned. Note the gonad shield placed anterior.

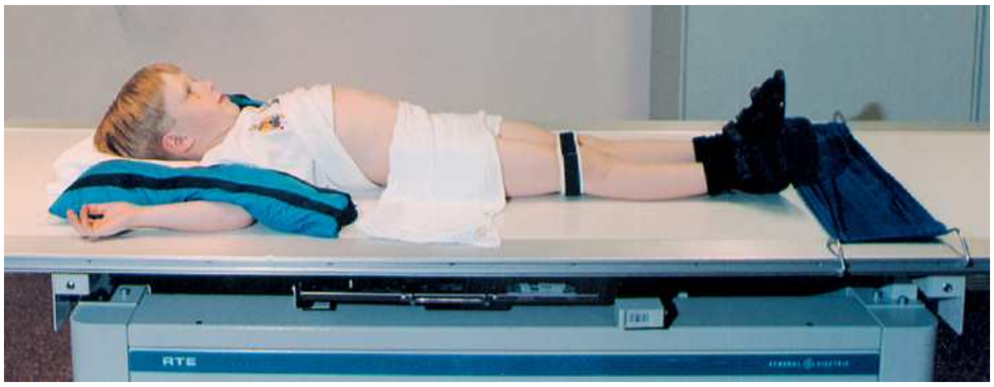

FIG. 22.10 Immobilization of the active child: sandbags over the arms, Velcro strips around the knees, and a Velcro band beside the patient's feet to be secured over the legs.

Young children can be immobilized for supine abdominal imaging with the same methods used for radiography of the hips and pelvis (Fig. 22.10), which provide basic immobilization of a patient for supine table radiography. All boys should be shielded using methods described for radiography of the hips and pelvis. The central ray should be located midway at the level of L2. The radiographer should observe the following guidelines for upright abdominal imaging:

- Effectively immobilize newborns and children up to 3 years old for the upright image using the Pigg-O-Stat.
- Raise the seat of the Pigg-O-Stat to avoid projecting artifacts from the bases of the sleeves over the lower abdomen (see Fig. 22.9).
- For the best results in an older child, have the child sit on a large box, trolley, or stool, then spread the legs apart to prevent superimposition of the upper femora over the pelvis.

FIG. 22.11 The immobilization used for lateral abdominal imaging is also effective for lateral thoracic and lumbosacral spine images. A 45-degree sponge and sandbag are used anteriorly.

Lateral images of the abdomen are occasionally required in children, generally to localize something in the AP plane. Immobilization for lateral images is challenging; this difficulty, along with the fact that patient immobilization is the same as for lateral spine images, makes it worthy of mention here. Properly instructed, the parent can be helpful with obtaining this image. The radiographer should observe the following steps:

- Remember that the parent can do only one job.
- Ask the parent to stand on the opposite side of the table and hold the child's head and arms.
- Immobilize the rest of the child's body using available immobilization tools. These tools include large 45-degree sponges, sandbags (large and small), a "bookend," and a Velcro band.
- Accomplish immobilization by rolling the child onto their side and placing a small sponge or sandbag between the knees.
- Snugly wrap the Velcro band over the hips; to prevent backward arching, place the "bookend" against the child's back with the 45-degree sponge and sandbag positioned anteriorly (Fig. 22.11).

Note that it is common for pediatric clinicians to request two projections of the abdomen. This should be supported by the clinical indications. A neonatal patient with necrotizing enterocolitis requires supine and left *lateral decubitus* images to rule out air-fluid levels indicative of bowel obstruction. However, the patient with an umbilical catheter needs supine and *lateral* images to verify the location and position of the catheter. *When in doubt, consult the radiologist.*

Pathology

Intussusception

Intussusception is the invagination or telescoping of the bowel into itself; most cases (90%) are ileocolic (Fig. 22.12). Idiopathic intussusception is most common and is the most frequent cause of small intestinal obstruction in the infant–toddler age group, reaching peak incidence between 2 months and 3 years of age. The majority of cases (60%) occur in males. Intussusception can present with an abrupt onset of abdominal pain that becomes more frequent over time. There can be bouts of diarrhea, vomiting, and lethargy. Blood and blood clots in the stool with the consistency and color of currant jelly are highly suggestive of intussusception. No matter how high the clinical index of suspicion is for intussusception, an abdominal image is always indicated; in some patients, this supine image may be negative. Bowel perforation and degree of obstruction are ruled out with a horizontal beam image, whereas a prone or left-side-down decubitus is more likely than the supine position to demonstrate a soft tissue mass. The combination of diminished colonic stool and bowel gas, especially when accompanied by a visible soft tissue mass, indicates a high likelihood of intussusception. An abdominal physical exam by an experienced surgeon is a useful precaution before proceeding to reduction.

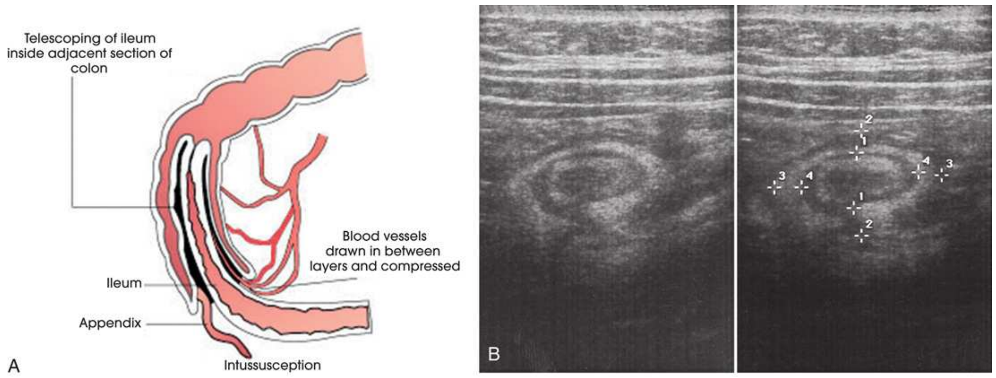

FIG. 22.12 (A) Intussusception. (B) Ultrasound image illustrates doughnut-shaped lesion marked for measurement. A, From Van Meter K: *Gould's pathophysiology for the health professions*, ed 5, St. Louis, 2014, Elsevier. B, From Eisenberg RL, Johnson NM: *Comprehensive radiographic pathology*, ed 5, St. Louis, 2010, Mosby/Elsevier.

Diagram (A) shows the invagination or telescoping of the bowel. The parts labeled are as follows: telescoping of ileum inside adjacent section of colon, ileum, appendix, blood vessels drawn in between layers and compressed. (B) Two ultrasound images show a doughnut-shaped region in the middle. It is marked in the second image.

Although there are significant procedural variations among radiologists for the reduction of intussusceptions, many pediatric radiology departments use the pneumatic enema under fluoroscopic guidance as the treatment of choice because of its ease of use, reduced risk for peritonitis in the event of a perforation (as compared with hydrostatic), reduced time of procedure, and reduced radiation dose. The pneumatic filling of a large portion of the small bowel is usually necessary to confirm reduction. Contraindications to radiologic reduction are intestinal perforation, frank peritonitis, and hypervolemic shock.

Pneumoperitoneum

Intraperitoneal air/gas is most commonly the result of perforation of the hollow viscera (stomach or intestines) and can be caused by surgical complications, such as abdominal drainage tubes, percutaneous gastronomy tubes, or insufflation of CO_2 or air during liver and renal biopsies or during laparoscopy (Fig. 22.13A). These causes may have the same radiologic appearances but different clinical significance. Patients normally have pneumoperitoneum following abdominal surgery, which clears more rapidly in children than adults. Studies have demonstrated clearing of free air in most postoperative children within 24 hours.

Diagnosis of pneumoperitoneum is most easily made with a cross-table horizontal beam projection, which is also indicated to rule out free air or intestinal obstruction. However, when small amounts of free air are suspected, the decubitus position is recommended (see Fig. 22.13B). A properly positioned abdominal image, upright, cross-table, or decubitus, will include both pubic symphysis and the bases of both diaphragms. In the upright image, free air is easily demonstrated under the diaphragms, displacing the liver on the right and stomach, liver, and spleen on the left. A child who is younger than 1 year or unable to stand can be examined in the left decubitus position, which allows the liver to fall away from the wall of the peritoneal cavity, revealing lucency between the abdominal wall and the liver.

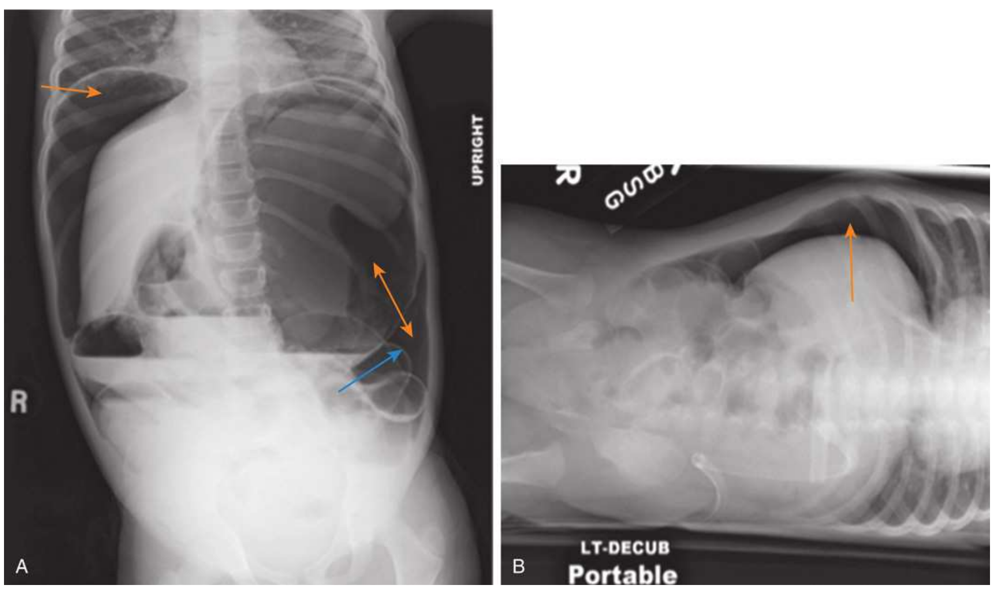

FIG. 22.13 (A) Pneumoperitoneum resulting from a fundoplication procedure *(orange arrows).* Rigler's sign (air on both sides of bowel wall) is present at *blue arrow*. (B) Pneumoperitoneum seen *(orange arrow)* as a complication from percutaneous gastronomy tube procedure.

(A) An x-ray view of the abdomen shows radiolucent areas on the top left side and bottom right side. The top left side is marked by an arrange arrow. The bottom right side is marked by a blue arrow and a double-headed orange arrow. (B) An x-ray view of the abdomen shows a radiolucent convex area on the top in the center. It is marked by an orange arrow.

The tabletop decubitus view is most successfully achieved when the patient's back is parallel and in contact with the imaging IR. Arms are on either side of the head and above the shoulders, with elbows bent on either side of the head. The patient's pelvis is perpendicular to the table with knees bent and legs stacked one atop the other. The person holding will immobilize the patient's arms and head as one unit (left hand) and hold the lower torso just below the buttocks (right hand). A gonadal shield should be used on males, but make sure to keep it below the pubic symphysis.

The horizontal beam image may be useful in distinguishing a pneumoperitoneum caused by bowel perforation (air-fluid levels present) and a dissecting pneumomediastinum presenting with air in the peritoneal space and no fluid levels (this difference is not always present). Pneumomediastinum is usually suspected when there is a history of assisted ventilation or chest trauma and is best visualized in PA and lateral views of the chest.

Gastrointestinal and genitourinary studies

As with any radiology procedure-based modality, a team approach to the care of the patient and family is essential. There are many procedures unique to pediatrics that fall under the headings GI/GU. Although it is beyond the scope of this chapter to delve into the specifics of each of these exams, many of which are complex, some of the most common procedures and indications are discussed. Common to each of these procedures is the use of a contrast medium, which enhances the visualization of soft tissue. These media can be either water-soluble iodine-based or non-water-soluble barium sulfate-based. The water-soluble contrast media are used for intravenous (IV) injection and non-IV excretory urography studies, for postsurgical assessments where leakage might occur, and for suspected perforations. They are characterized as being either nonionic (fewer side effects) with low osmolality (low-osmolality contrast agents [LOCAs]) or ionic (increased side effects) with high osmolality (high-osmolality contrast agents [HOCAs]). The choice of which LOCA to use is based on the desired concentration of iodine within the blood plasma and urine, the cost, and safety. Dosage is based on patient weight for IV injections; after injection of a bolus at a moderate rate, contrast excretion begins almost immediately and peaks at 10 to 20 minutes. Studies have shown that the adoption of a LOCA offers a definite improvement in patient experience and safety compared to that of a HOCA. The American College of Radiology (ACR) has specific criteria for the use of LOCAs, which include questions about previous history of contrast reactions, asthma, allergies (especially to shellfish), and cardiac issues. Adverse reactions can be life threatening. When administering a contrast agent, the trained radiographer should have a nurse present and a doctor available.

Barium sulfate–based contrast agents are not water soluble and are for oral or rectal administration to investigate esophageal problems, perform swallow studies, or rule out malrotation or Hirschsprung disease. The patient should be advised to drink plenty of liquids after the study, as the body does not break down barium. Barium is contraindicated for suspected perforations, instances of lower bowel obstructions, or attempted reduction of meconium ileus or meconium plug (Table 22.2).

Radiation protection

When performing exams using conventional fluoroscopic units, it is good practice to cover most of the tabletop with large mats of lead rubber (the equivalent of 0.5 mm of lead is recommended) (Figs. 22.14 and 22.15). Operators and patients can be effectively protected by positioning the mats so that only the areas being examined are exposed.

TABLE 22.2

FIG. 22.14 Another modification of the "bunny" technique. The arms are left free and are raised above the head to prevent superimposition over the esophagus. In this example, tape is used to secure the blanket; however, Velcro strips are easier to use if a parent is not available to assist. Note lead under patient when tube is under the table.

A boy is in a supine position on the radiographic table. His arms are raised over his head and a woman standing next to him is holding his arms. The blanket on him is secured with velcro strips. A lead shield is placed under him. A drawing of a rainbow and a boat with a zebra, an alligator, pigs are in the background.

FIG. 22.15 The octagonal immobilizer (or, for this child, a “rocket ship”) permits the child to be immobilized in a variety of positions. Note lead under patient when tube is under the table.

A boy is in a supine position on the radiographic table. His arms are raised over his head. His legs and arms are held in place by a lock. The blanket on him is secured with velcro strips. A lead shield is placed under him. A drawing of a rainbow and a boat with a zebra, an alligator, pigs are in the background.

Vesicoureteral reflux

For infants and small children experiencing first-time febrile urinary tract infections (UTIs), the goal after antibiotic treatment is to rule out the possibility of reflux, existing renal scarring, and structural or functional abnormalities of the urinary tract that may predispose the patient to reflux and infection, particularly anomalies that may require prompt surgical treatment. This is accomplished with an ultrasound (US) and, if indicated, a voiding cystourethrogram (VCUG). Patient assessment may begin with a noninvasive US to assess the upper urinary tracts and kidneys. If the US is negative, the decision to proceed with the VCUG is made after a thorough discussion between the parents, the attending urologist, and the pediatrician. Some radiologists feel that a VCUG for a first-time nonfebrile UTI with a negative US is not indicated. The VCUG is an invasive procedure in which a Foley catheter (5 to 8 French) is inserted into the urethra, advanced into the bladder, and then taped to the inside of the leg in a female or to the shaft of the penis in a male. An iodinated contrast agent (see Table 22.2) designed for the lower urinary tract is instilled into the bladder by gravity. The volume used is based on the patient’s age. Bilateral, oblique, pulsed fluoroscopy captures are made to check for reflux (Fig. 22.16A) and assess urinary anatomy. Fluoroscopy captures are made of voiding as the Foley is removed (see Fig. 22.16B). VCUG teams often include an attending fellow or resident, a radiographer, and a CLS with access to a registered radiologist assistant (RRA) as required. The parents are encouraged to participate, as this can help soothe and calm the infant or child. Age-appropriate distraction devices are employed as required.

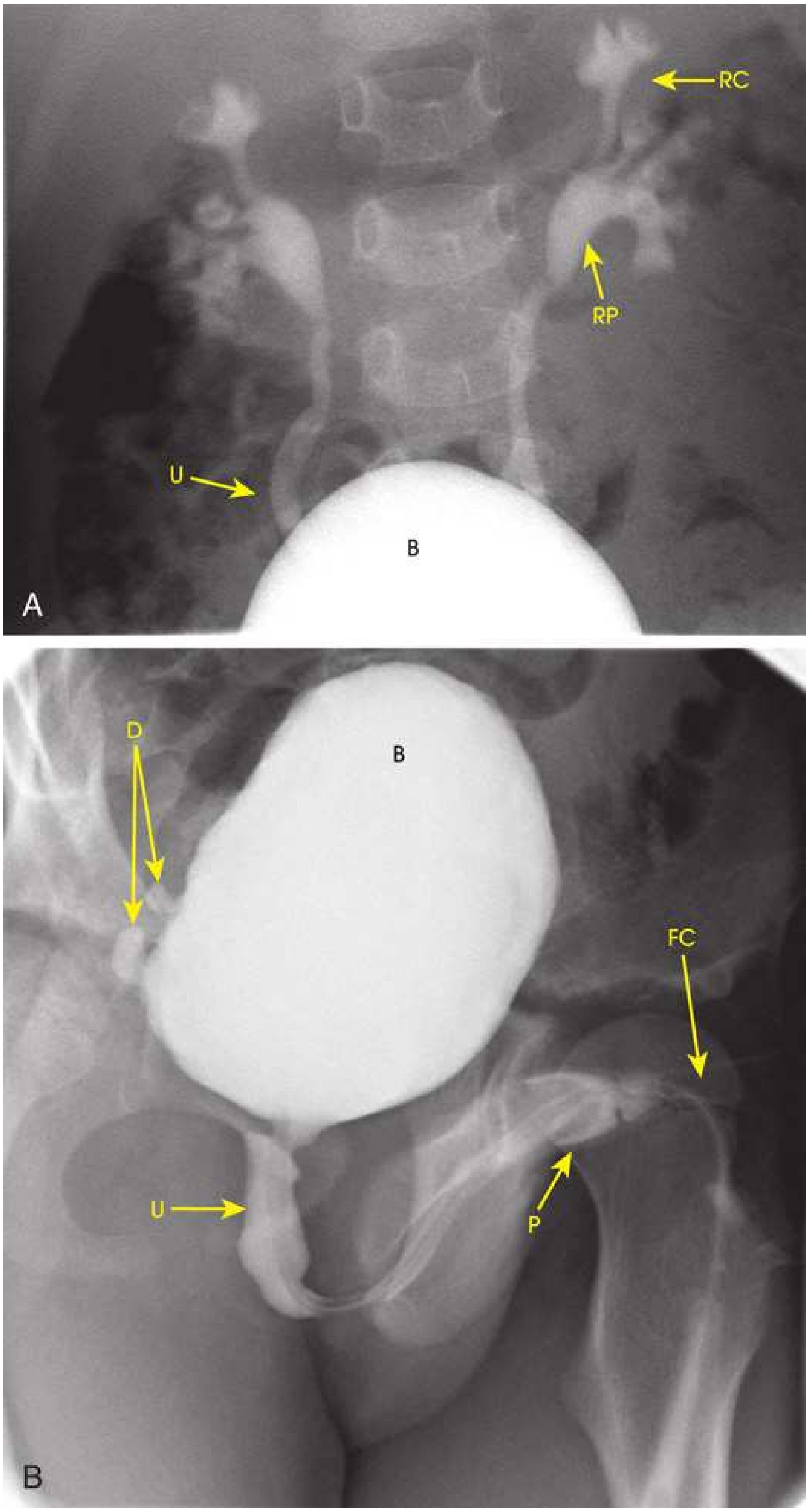

FIG. 22.16 (A) VCUG, 33-month-old female with bilateral grade 3 reflux as seen in the AP projection under fluoroscopy. Bladder *(B)*, ureter *(U)*, renal pelvis *(RP)*, and renal calyx *(RC)*. (B) VCUG, 8-year-old male with bladder diverticula *(D)* as seen in the LPO projection. Voiding shows moderate dilatation of the posterior urethra *(U)*. Foley catheter *(FC)*, bladder *(B)*, and uncircumcised penis *(P)*.

(A) A fluoroscopic image of the female urinary system shows a radiopaque bladder. The ureter, renal pelvis, and renal calyces appear white and pale. They are marked by yellow arrows. (B) A fluoroscopic image of a male urinary system shows a radiopaque bladder. The posterior urethra, a tube-like structure, bladder, and penis appear white and pale.

Chest

The most frequently ordered and one of the most challenging imaging exams in pediatric imaging is the chest x-ray. Patients between 1 and 4 years can be difficult to immobilize and position because they are relatively strong and in an unfamiliar setting. The anxiety level created in this situation can be high for parents, students, and even the experienced radiographer. Take the time to adequately explain to the parents the goals of the exam and how to correctly hold the child for it. Even if you are assured the parent can hold properly, it is essential that you remain vigilant in your transition from the patient to the exposure control station, ensuring that the parents continue to immobilize correctly and effectively. If the parent is struggling and frustrated, consider using the Pigg-O-Stat (Fig. 22.17) or, as a last resort, a radiographer to hold the child. Radiation delivered to the patient must always be as low as diagnostically achievable, and every attempt must be made to acquire the image on the first attempt. Quite simply, if you think the positioning is compromised or the immobilization ineffective, do not make the exposure.

FIG. 22.17 Position for PA chest image. The Pigg-O-Stat (Modern Way Immobilizers, Clifton, TN) is a pediatric positioner and immobilization tool. The IR is held in the metal extension stand.

The central ray for PA and lateral projections is directed to the level of T6-7 (nipple line). Adjust the radiation field on the collimator to below the earlobes and approximately 1.5 inches (3.8 cm) above the umbilicus. Inclusion of the mastoid tips shows the upper airway; narrowed or stenotic airways are a common source of respiratory problems in pediatric patients. By collimating just above the iliac crests, the radiographer will be sure to include the inferior costal margins. Numerous children arrive in the imaging department with long lung fields resulting from hyperinflation (e.g., patients with cardiac disorders and asthma).

Most radiologists will agree that upright chest images yield a great deal more diagnostic information than supine images. However, it is important that you be able to achieve diagnostic quality in both positions. Infants needing supine and cross-table lateral images can be immobilized using Velcro straps around the knees and a Velcro band across the legs. The patient is supine on a radiolucent pad with the arms held above the head for both the AP and the cross-table lateral. This technique is particularly useful for patients with chest tubes, delicately positioned gastrostomy tubes, or soft tissue swellings or protrusions that may be compromised by the sleeves of the Pigg-O-Stat.

Chest (<1 year)

One device that has proven invaluable for immobilizing and positioning the infant with minimal discomfort and helping to ensure a diagnostic and reproducible exam in a timely manner is the “baby box.” This device was invented by technical director Linda Poznauskis at the Boston

Children's Hospital (BCH). All non-bedside, two-view chest exams and most decubitus projections of infants 0 to 365 days old are performed using the "baby box" (Fig. 22.18). The patient must be nude from the waist up with all heart monitor leads removed (when safe) and lines and tubes (especially nasogastric tubes) positioned away from the chest anatomy. The baby is placed supine on the box, shielded, and the lower torso immobilized with the attached Velcro (Velcro USA, Inc., Manchester, NH) strap and sandbag as necessary. The parent is directed to slowly raise the baby's arms up and alongside its head. While holding the arms at the level of the elbows, the parent places their thumbs at the sides of the head or on the forehead to ensure that the baby's head is in a true supine position (Fig. 22.19). A small rotation of the head will cause distortion of the infant's lung fields, and if the baby arches its back the image will be rendered lordotic. Special attention should be paid to the tendency of parents to pull the arms and baby toward them rather than simply holding the arms and head together. This results in the patient being slowly pulled out from under the Velcro and off the IR, causing the lung apices to be clipped. Adjust collimation, ensure that the parent continues to immobilize effectively, and expose when the baby's belly is fully distended, indicating a full inspiration. Do not rush the exam—activate the rotor, observe the rhythm of the infants breathing, and time the exposure. If the infant is hyperventilating, an inspiratory image will be obtained, although it may not be at full inspiration.

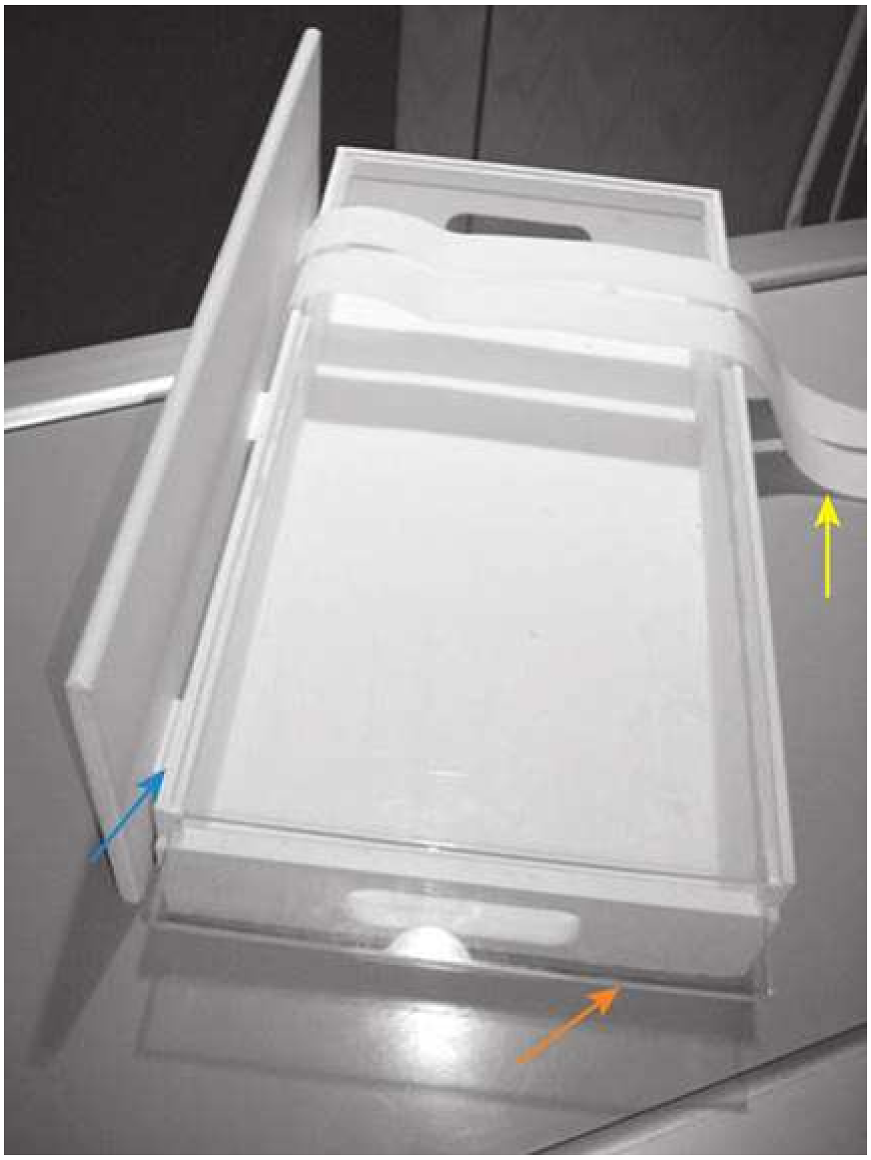

FIG. 22.18 The baby box aids in the immobilization of an infant (0 to 12 months) for AP and cross-table lateral chest x-rays, soft tissue neck and C-spine imaging. There is a sliding tray *(orange arrow)* that holds the imaging plate for supine positions, a slot on the side *(blue arrow)* holds the IR for cross-table work, and Velcro straps *(yellow arrow)* are used to immobilize.

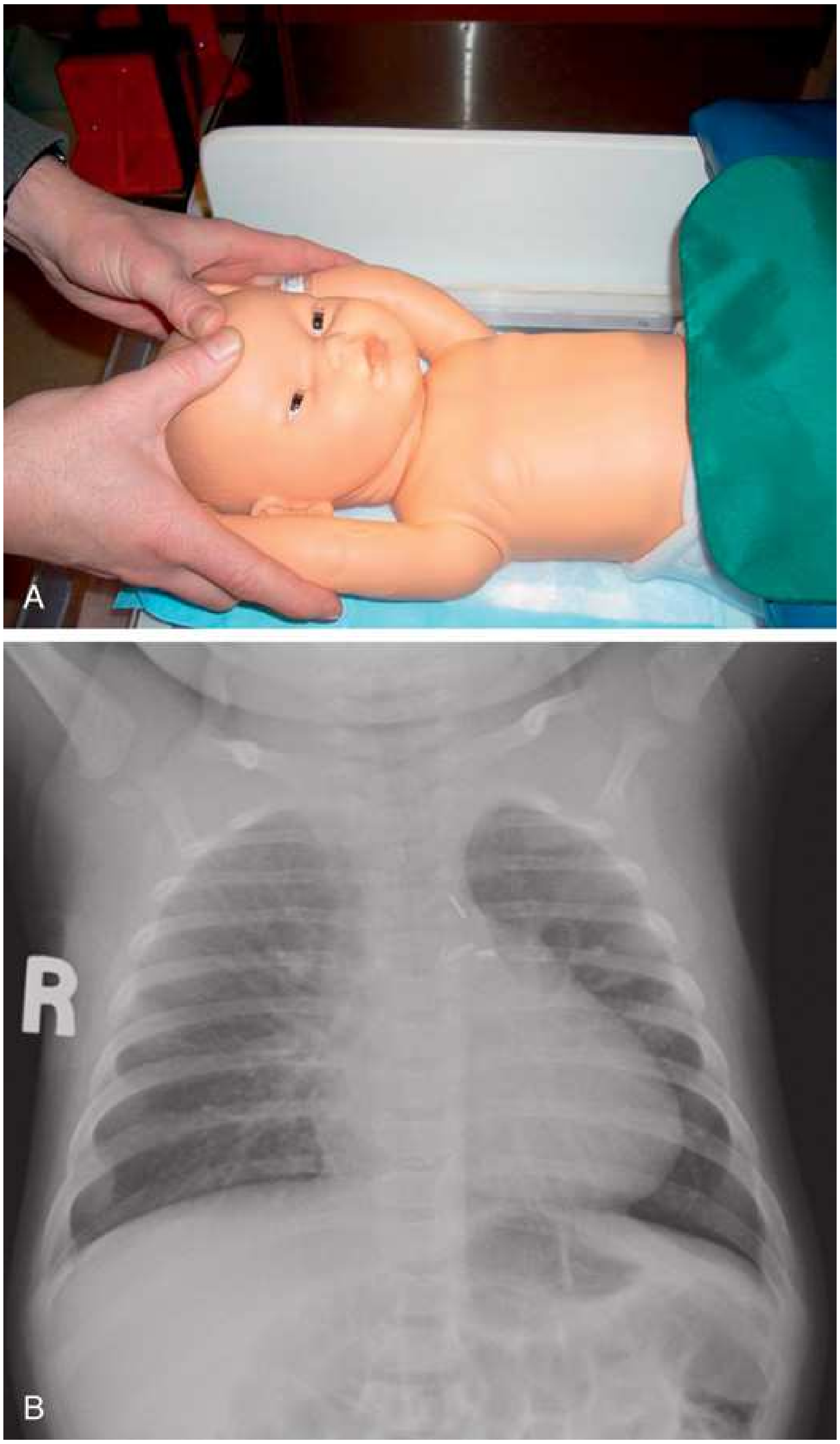

FIG. 22.19 (A) Supine AP chest x-ray for an infant younger than 12 months. Parent immobilizes at the elbows with thumbs at or on sides of forehead. (B) AP chest image of infant younger than 12 months.

(A) An infant is in a supine position. Two hands are holding both hands and are immobilizing the elbows with thumbs on the sides of the forehead. (B) shows an x-ray view of the chest of the infant. The ribs are clearly visible.

The left, cross-table, lateral projection (Fig. 22.20) is obtained by placing the IR in the shallow groove on the left side of the baby box. Using the same holding technique, the Velcro is released and the patient is moved closer to the IR, thus minimizing OID (magnification); the Velcro is then refastened. Collimation should allow the x-ray beam to overlap onto the side of the box closest to the x-ray tube to prevent clipping the posterior lung fields. It is imperative, especially for medicolegal reasons, that all first-time AP images and all subsequent images contain the correct marker placement.

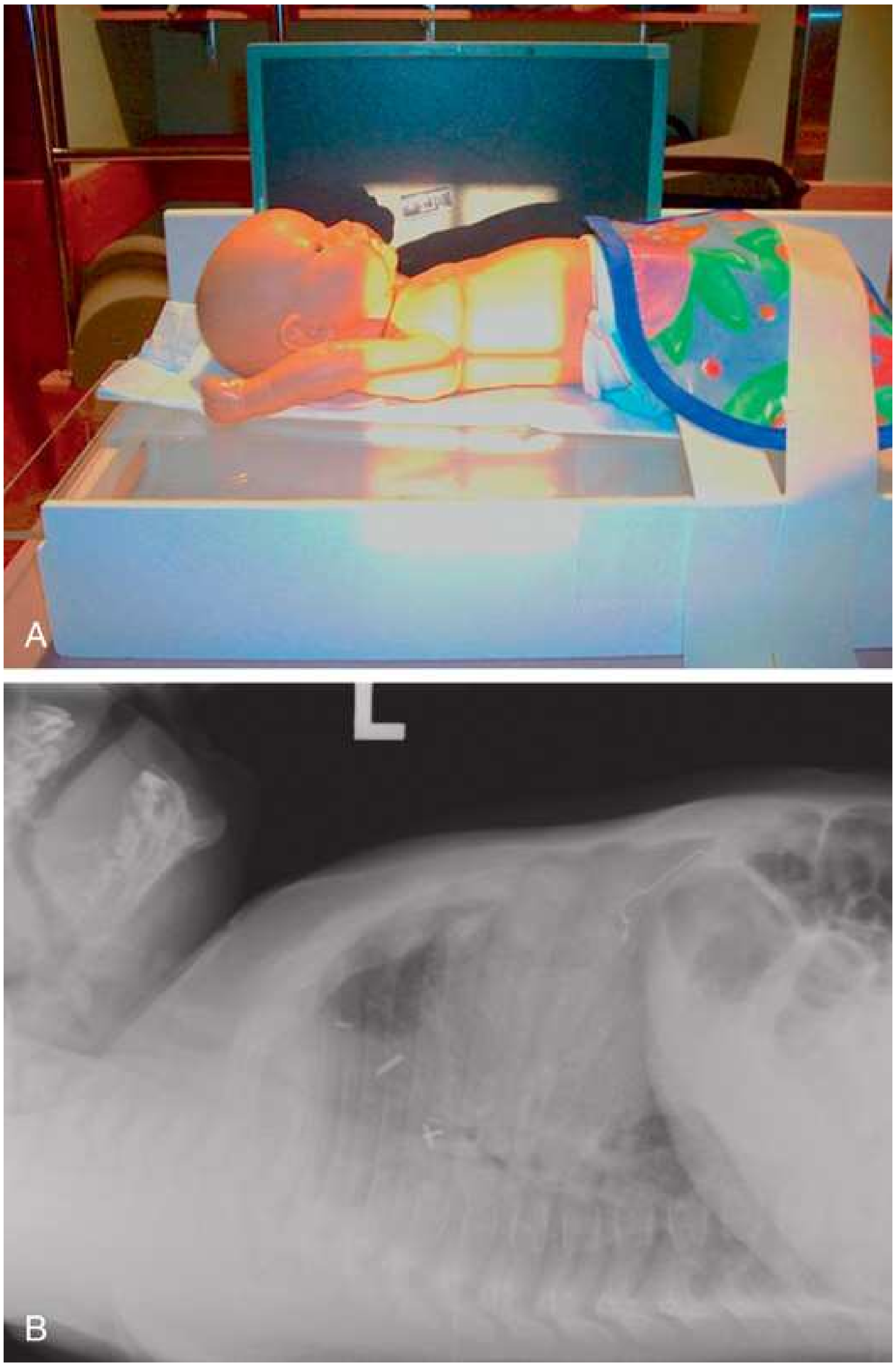

FIG. 22.20 (A) Left, cross-table, lateral chest projection: same immobilization as for AP, but infant must be moved closer to the IR to reduce OID and avoid clipping the spine. (B) Lateral projection chest image of an infant younger than 12 months.

Chest (>1 year)

This population of little patients will resist any positioning the radiographer attempts by wiggling, twisting, crying, contorting, or all of the above in what appears to be an effort to force a repeat image. The biggest reason for repeats in this age group is the patient pulling away from the image receptor, resulting in a lordotic image. Properly positioning this age group requires good communication between the radiographer and parents. Parents can be tentative about holding their child firmly. If the child is allowed to twist or lean away from the IR, the image will be nondiagnostic. If the parents are unsuccessful in immobilization, use the Pigg-O-Stat (if age-appropriate) or use a radiographer as a last resort.

Chest x-rays (for children 1 to 6 years old) can be obtained by seating the child at the end of the exam table using a custom-made frame that supports the IR and aids in the positioning of the child. The PA chest x-ray is accomplished with the child's arms raised next to the head with instructions to the parent that the child's head and arms be held as a unit (Fig. 22.21). A slight upward pull on the child's body will keep a straight torso. Do not let the patient lean away from the IR, as this will produce a lordotic image; this can be prevented either by moving the patient's bottom away from the IR or by placing a 15-degree positioning sponge between the patient and the IR at the level of the patient's abdomen, with the thicker portion at the level of the pelvic ilia. Patients should be nude from the waist up in order to visualize and time the inspiration. (The Medical Physicist at Boston Children's has approved this position. Primary beam radiation is confined to the IR and there is no primary beam exposure to the technologist or the parent. This has been the routine standard of care at this hospital for the past 15 years.)

For the sitting left lateral, patients are held from behind or the front, with arms in the same position as used for the PA (Fig. 22.22). A large, firm positioning sponge can be placed between the parent's chest and the patient's back (positioning can be done without the sponge on older children). While holding the child's head and arms as a unit, the parent is instructed to exert a slight upward pull while keeping the patient's back against the sponge and perpendicular to the IR. If the patient is unruly, a second person will be required to hold down on the child's knees. Make sure you have a clear view of the patient's belly to check for inspiration. Older patients are examined standing with an upright bucky.

Image evaluation

The criteria used to evaluate the image are inclusion of the full lung fields, airway, visibility of peripheral lung markings, rotation, inspiration, cardiac silhouette, mediastinum, and bony structures. In the PA chest image, the ideal technical factor is a selection that permits visualization of the intervertebral disk spaces through the heart (the densest area) while showing the peripheral lung markings (the least dense area). Rotation should be assessed by evaluating midline structures (e.g., sternum, trachea, and spinous processes). These anterior and posterior midline structures should be superimposed. Similar to chest radiography in adults, the visualization of eight to nine posterior ribs is a reliable indicator of an image taken with good inspiration (Table 22.3).

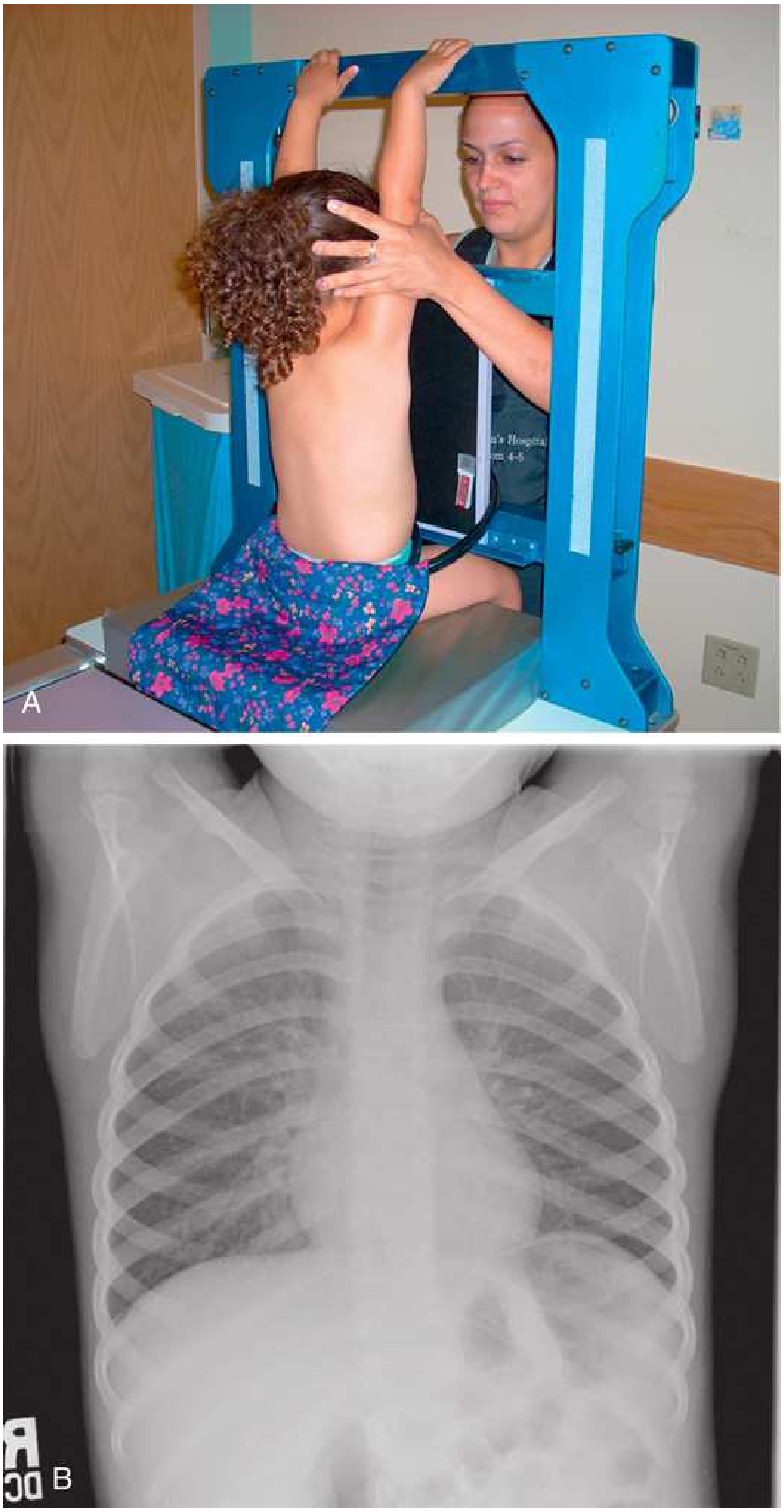

FIG. 22.21 (A) Parent holding for a PA chest on a child older than 1 year. (B) Resultant chest image. Care should be taken to tie up textured hair, as it can show as an artifact on digital images.

(A) A girl is sitting on the radiographic table with her arms raised over her head. The hands are grasping the bar over her head. A woman standing in front is holding both her hands close to her head. (B) An x-ray view of the chest shows many spirals of white region on the chest.

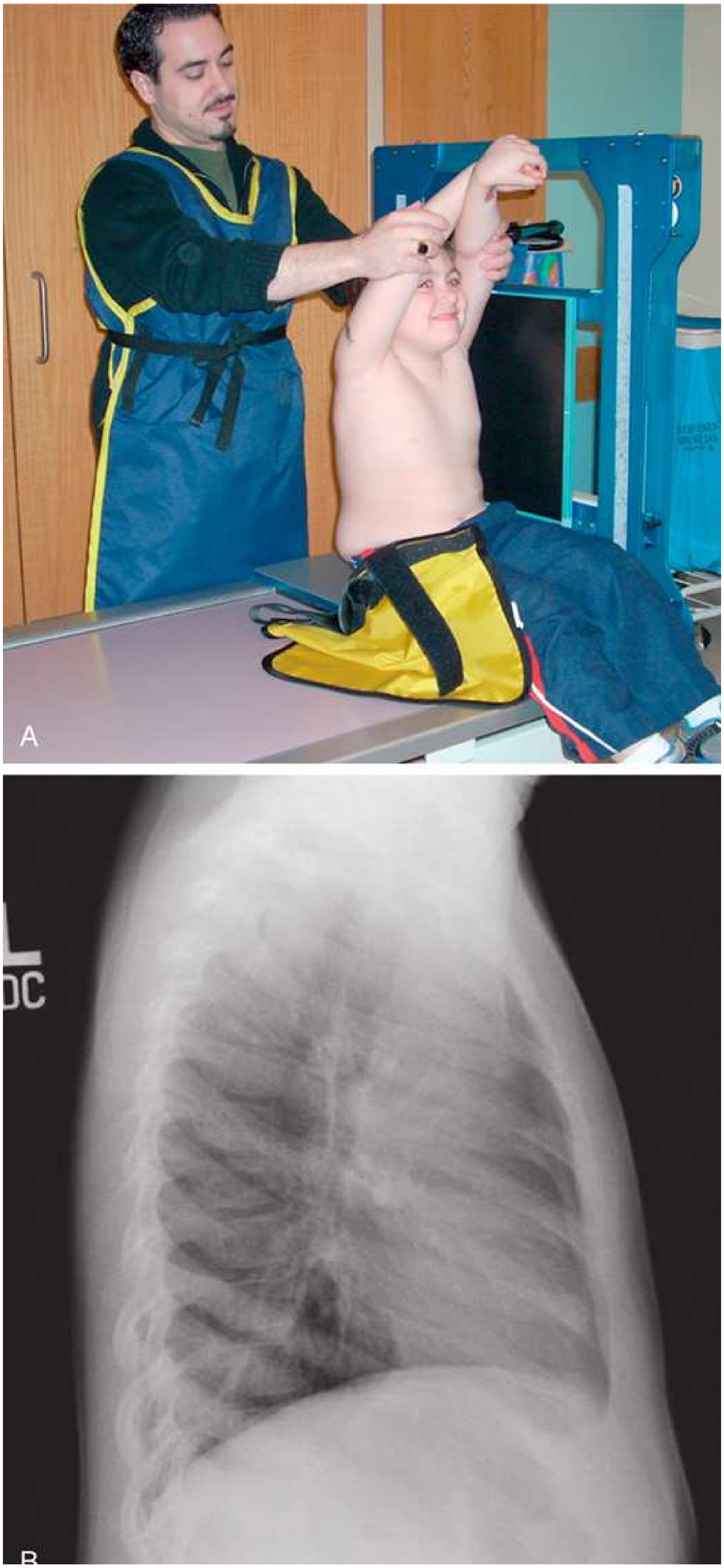
A
B

FIG. 22.22 (A) Parent holding for a lateral chest on a child older than 1 year. (B) Resultant chest image.

(A) A boy is sitting on the radiographic table with his lateral chest against the I R. A man wearing a lead apron is standing behind and is holding both the hands of the boy over his head. Lead shields are placed below his abdomen. (B) shows an x-ray view of the lateral chest.

TABLE 22.3

Evaluating the image to determine its diagnostic quality is a practiced skill. This chart, designed as a quick reference guide, outlines the five important technical criteria and the related anatomic indicators used in critiquing images.

Chest (3 to 18 years)

Upright

Upright images on children 3 to 18 years old are easily obtained by observing the following steps:

- Help the child sit on a large wooden box, a wide-based trolley with brakes, or a stool, with the IR supported using a metal extension stand. Young children are curious and have short attention spans. By having them sit, the radiographer can prevent them from wiggling from the waist down.
- For the PA position, have the child hold onto the side supports of the extension stand, with the chin on top of or next to the IR. This prevents upper body movement.
- When positioning for the lateral image, have the parent (if their presence is permitted) assist by raising the child's arms above the head and holding the head between the arms (Fig. 22.23).

Supine

Infants needing supine and cross-table lateral images can be immobilized using Velcro straps around the knees and a Velcro band across the legs (Fig. 22.24). The patient is elevated on a sponge with the arms held up, and a cross-table lateral projection is performed. This technique is particularly useful for patients with chest tubes, delicately positioned gastrostomy tubes, or soft tissue swellings or protrusions that may be compromised by the sleeves of the Pigg-O-Stat.

Image evaluation

As in adult chest radiography, the use of kVp is desirable in pediatric chest imaging; however, this is relative. In adult imaging, high kVp generally ranges from 110 to 130, but for pediatric PA projections, kVp ranges from 80 to 90. The use of higher kVp is not always possible because the corresponding mAs are too low to produce a diagnostic image.

The criteria used to evaluate recorded detail include the resolution of peripheral lung markings. Evaluating any image for adequate density involves assessing the most and least dense areas of the anatomy that is shown. In the PA chest image, the ideal technical factor is a selection that permits visualization of the intervertebral disk spaces through the heart (the densest area) while showing the peripheral lung markings (the least dense area). Rotation should be assessed by evaluating the position of midline structures. Posterior and anterior midline structures (e.g., sternum, airway, and vertebral bodies) should be superimposed. The anatomic structures to be shown include the airway (trachea) to the costophrenic angles. Similar to chest radiography in adults, the visualization of eight to nine posterior ribs is a reliable indicator of an image taken with good inspiration (see Table 22.3).

FIG. 22.23 (A) PA chest images should be performed on the 3- to 18-year-old with the child sitting. (B) The parent, if present, can assist with immobilization for the lateral image by holding the child's head between the child's arms. Metal extension stands (*arrows* on A and B) are commercially available from companies that market diagnostic imaging accessories.

(A) A boy is sitting on a stool facing the vertical grid. A lead shield is placed below the lower back. (B) A woman wearing a lead apron is holding the arms of the boy sitting on a stool against the I R. A lead shield is placed below the pelvis.

FIG. 22.24 The patient is raised on a sponge with arms held up by the head, and the legs are immobilized using Velcro straps. The IR is in place for the horizontal lateral beam (cross-table lateral).

Pelvis and Hips

General principles

The initial radiography examination of the pelvis and hips is routinely done for children older than 1 year. Ultrasonography is used for infants younger than 1 year. With a basic comprehension of the most common pediatric pelvic positions, pathologies, and disease processes, the radiographer can provide the radiologist with the superior diagnostic images required to make an accurate diagnosis.

Despite the importance of radiation protection, little written literature is available to guide radiographers on the placement of gonadal shields and when to use shielding. The radiographer should observe the following guidelines:

- *Always* use gonadal shielding on boys. However, take care to prevent potential lesions of the pubic symphysis from being obscured.

- In girls, use gonadal protection on all images *except* the first AP projection of the *initial* examination of the hips and pelvis.
- After sacral abnormality or sacral involvement has been ruled out, use shielding on subsequent images in girls.
- Before proceeding, check the girl's records or seek clarification from the parents regarding whether this is the child's first examination.

FIG. 22.25 (A) The male gonadal shield should cover the scrotum without obscuring the pubic symphysis. The greater trochanters indicate the upper border of the pubic symphysis; the top of the shield should be placed approximately a half inch below this level. The gonadal shield rests on a 15-degree sponge, which prevents the radiographer's hands from coming close to or touching the scrotal area. (B) A 3.5-year-old normal pelvis; note the shielding.

(A) A boy is in a supine position on the radiographic table reading a book. The legs are held in place by velcro bands. The male gonadal shield is placed over the pubic symphysis. (B) An x-ray view of the male pelvis shows a shield below the pubic symphysis. It appears radiopaque. The femoral heads are centered.

- Because the female reproductive organs are located in the mid-pelvis with their exact position varying, ensure that the shield covers the sacrum and part or all of the sacroiliac (SI) joints, making sure it does not cover the hip joints or pubic symphysis.

NOTE: Many children have been taught that no one should touch their "private parts." Radiographers need to be sensitive and use discretion when explaining and carrying out the procedure.

- *Never touch the pubic symphysis in a child,* regardless of whether you are positioning the patient or placing the gonadal shield.
- The superior border of the pubic symphysis is always at the level of the greater trochanters. Use the trochanters as a guide for positioning and shield placement. The CR should be located midline, at a point midway between the anterior superior iliac spine (ASIS) and the symphysis.
- In boys, keep the gonadal shield from touching the scrotum by laying a 15-degree sponge or a cloth over the top of the femora. The top of the shield can be placed 3 cm below the level of the trochanters, and the bottom half of the shield can rest on top of the sponge or cloth (Fig. 22.25).
- In girls, place the top (widest) part of the shield in the midline, level with the ASIS.

Initial images

Hip examinations on children are most often ordered to assess for Legg-Calvé-Perthes disease (aseptic avascular necrosis of the femoral head), developmental dysplasia of the hip (DDH), and slipped capital femoral epiphyses (SCFE) and to diagnose nonspecific hip pain. These conditions require the evaluation of the symmetry of the acetabula, joint spaces, and soft tissue; therefore, symmetric positioning is crucial. The initial examination of the hips and pelvis in children older than 1 year includes a well-collimated AP projection and a lateral projection commonly referred to as a frog lateral. This position is more correctly described as a coronal image of the pelvis with the thighs in abduction and external rotation, or the Lauenstein position (see Chapter 8). This bilateral imaging serves as a baseline for future imaging and allows comparison of right and left hips.

Preparation and communication

All images of the abdomen and pelvic girdle should be performed with the child's underwear or diaper removed. Buttons, silk screening, and metal on underwear, as well as wet diapers, produce significant artifacts on images, often rendering them nondiagnostic. The radiographer should have all required positioning devices on the table prior to the patient's arrival.

Positioning and immobilization

As described previously, *symmetric positioning* is crucial. As in many examinations, the hip positions that are the most uncomfortable for the patient are often the most crucial. When a child has hip pain or dislocation, symmetric positioning is difficult to achieve because the patient often tries to compensate for the discomfort by rotating the pelvis. The radiographer should observe the following steps when positioning the patient:

- As with hip examinations in any patient, check for an equal distance of the ASISs to the table.
- After carefully observing and communicating with the patient to discover the location of pain, use sponges to compensate for rotation. Sponges should routinely be used to support the thighs in the frog-leg position. This can help prevent motion artifacts.
- Do not accept poorly positioned images. Repeat instructions as necessary to achieve optimal positioning.

Because *immobilization techniques* should vary according to the aggressiveness of the patient, the radiographer can follow these additional guidelines:

- Make every effort to use explanation and reassurance as part of the immobilization method. A child may require only a Velcro band placed across the legs as a safety precaution.
- For an active child, wrap a Velcro strip around the knees and place large sandbags over the arms (see Fig. 22.10). The Velcro strip over the knees keeps the child from wiggling one or both legs out from under the Velcro band and possibly rolling off the table.
- If the child has enough strength to free their arms from the sandbags, ask a parent to stand at the side of the table opposite the radiographer and hold the child's arms. The parent's thumbs should be placed directly over the child's shoulders (Fig. 22.26). This method of immobilization is used extensively. It also works well for supine abdominal images, intravenous urograms (IVUs), overhead GI procedures, and spinal radiography.

Leg-length discrepancies, which can cause hip problems, are diagnosed using a *Scanogram,* a technique in which three exposures of the lower limbs (single exposures centered over the hips, knees, and ankles) are made on a single 35 × 43 cm IR (see Chapter 7). Two radiolucent rulers with radiopaque numbers are included bilaterally and within the collimated field, making it possible for the orthopedic surgeon to then calculate the difference in leg lengths.

Image evaluation

Rotation or symmetry can be evaluated by ensuring that midline structures are in the midline and that the ilia appear symmetric. Depending on the degree of skeletal maturation, visualization of the trochanters can indicate the position of the legs when the image was taken. Symmetry in the skin folds is also an important evaluation criterion for the diagnostician. The anatomy to be shown includes the crests of the ilia to the upper quarter of the femora. The image should demonstrate the bony trabecular pattern in the hip joints, which is the thickest and most dense area within the region. The visualization of the bony trabecular pattern is used as an indicator that sufficient recorded detail has been shown; this should not be at the expense of showing the soft tissues—the muscles and skin folds (see Table 22.3).

FIG. 22.26 If the child is strong enough or aggressive enough to remove the sandbags (see Fig. 22.10), the parent can hold the child's humeri by placing the thumbs directly over the child's shoulders.

A boy is in a supine position on the radiographic table with both arms raised over the head. The hands are held in position by holding the boy's humeri by placing the thumbs directly over the boy's shoulders. The legs are held in place by velcro bands.

Limb Radiography

Limb radiography accounts for a high percentage of pediatric general radiographic procedures in most clinics and hospitals. Producing a series of diagnostic images will require you to assess the child's age-appropriate development, behavior, and age in order to determine which forms of immobilization you will employ. This is best accomplished in consultation with the parents; an active 3-year-old may require that you use immobilization techniques that are one or two age groups below the patient's chronologic age group.

FIG. 22.27 (A) With a simple modification of the “bunny” technique using a towel (or pillowcase), the child can be immobilized for upper limb radiography. Plexiglas *(dashed lines)* and “bookends” *(B)* can be used to immobilize the hands of children 2 years old and younger. Note that after the child is wrapped, a Velcro band is used for safety, and a small apron is placed diagonally over the body to protect the sternum and gonads. The IR is placed on a lead mat, which prevents the image receptor from sliding on the table. (B) Nine-month-old normal right hand.

(A) A boy is in a supine position with velcro bands wrapped around the boy. The arm is extended and is placed between the two blocks labeled B. Two dashed lines are drawn on either side of the blocks. (B) shows an x-ray view of the right hand. There is a gap between the carpals and the metacarpals.

Immobilization

Newborn to 2 years old

Depending on the exam, swaddling the child in a blanket, towel, or pillowcase will make the child manageable when performing upper limb radiography. This wrapping technique, a modification of the “bunny” method (Fig. 22.27), keeps the infant warm and allows one parent to concentrate on immobilizing the injured limb. When imaging small hands, a piece of Plexiglas can be used to firmly hold the hand while making the exposure. Lower extremities are best imaged with the help of swaddling, a Velcro band, or a parent holding down the abdomen with a large sandbag placed over the unaffected leg (Fig. 22.28).

FIG. 22.28 (A) The challenges of immobilizing lower limbs are greater than those of immobilizing upper limbs. After wrapping both of the patient’s arms in a towel and placing a Velcro band over the abdomen, the radiographer can place a large sandbag over the unaffected leg. With careful collimation and proper instruction, the parent can hold the limb as demonstrated. Normal 21-month-old AP (B) and lateral (C) tibia and fibula.

(A) A child's leg is on the I R. Sandbags are placed on both ends. A hand is holding the ends of the leg in place. The side marker in the collimated exposure field. (B) An x-ray shows the lateral leg. (C) An x-ray shows the tibia and fibula.

Preschool age

The upper limbs of preschoolers are best imaged with the child sitting on the parent’s lap as shown in Fig. 22.29. If the parent is unable to participate, these children can be immobilized as described previously.

With parental participation, radiography of the lower limbs can be accomplished with the child sitting or lying on the table. Preventing the patient from falling from the table is always a primary concern with preschoolers. Instruct the parent to remain by the child’s side if the child is seated on the table or stool. If the examination is performed with the child lying on the table, a Velcro band over the abdomen or a parent holding should be employed.

NOTE: The child’s ankle should be in flexion, not extension.

School age

School-age children generally can be managed in the same way as adult patients for upper and lower limb examinations.

Radiation protection

The upper body should be protected from scatter radiation in all examinations of the upper limbs because of the proximity of the thymus, sternum, and breast tissue. Child-sized lead aprons with cartoon characters are both popular and practical (Fig. 22.30).

Fractures

Fractures in children's bones occur under two circumstances: abnormal stresses in normal bone and normal stresses in abnormal bone. A fracture is defined as the breaking or rupture of a bone caused by mechanical forces either applied to the bone or transmitted directly along the line of the bone. Children's bone fractures differ from those of adults because growth is active and favors rapid repair and remodeling. In general, children's bones are less dense than those of adults, and the ability to visualize soft tissue and bony detail are of utmost importance; in particular, small linear fractures are difficult to discern without good soft tissue detail. Fat pad displacement and tissue swelling may be the only radiographic signs of injury. Such subtle findings can disguise an epiphyseal growth plate fracture, which could result in irregularity or cessation of growth in the affected bone if left untreated. Overriding and distraction deformities may correct without residual deformity, but rotational deformities will not. Consequently, images of the fractured bone showing the relative positions of the two ends of the bone (AP, lateral, oblique) are necessary for evaluation of rotation; preliminary assessment may require the *contralateral* side to be examined for comparison.

FIG. 22.29 Preschoolers are best managed sitting on a parent's lap. A lead mat is used to keep the IR from sliding. Note the use of Plexiglas to immobilize fingers. (The parent's hands are shown without lead gloves and not draped in lead for illustration purposes only.)

The earlier in a child's life this epiphyseal fracture occurs, the better the chances of spontaneous correction of angulation fractures. Here is an abbreviated list of some of the more common pediatric extremity fractures.

FIG. 22.30 The teddy bear on this full-length apron *(left)* makes it appropriate for young children.

Salter-Harris

About one-third of all skeletal injuries to children are at the epiphyseal growth plates, especially in the ankle and wrist. Salter and Harris described these fractures in 1963 as Salter-Harris types I through V (Fig. 22.31).

Plastic or bow

The bones of children, compared to those of adults, can absorb and deflect more energy without breaking due to a lower bending resistance. Plastic or bowing fractures occur in children when this bending resistance is exceeded, and the bone or bones bow without breaking. The bowing fracture is a bending deformity that usually occurs in the forearm. There is no grossly visible fracture in the tubular structure of the bone; however, microfractures are visible using microscopy. The bowing is appreciable on plain images and often requires a comparison view to confirm the deformation. A bowing fracture is usually reduced under general anesthesia, as the force required to reduce the bowing is substantial.

FIG. 22.31 Salter-Harris fractures. The black lines represent the fracture lines. (A) A type I fracture occurs directly through the growth plate. (B) A type II fracture extends through the growth plate and into the metaphyses. (C) A type III fracture line extends through the growth plate and into the epiphyses. (D) A type IV fracture line extends through the metaphyses, across or sometimes along the growth plate, and through the epiphyses. (E) A type V fracture involves a crushing of all or part of the growth plate. Fractures that occur through the epiphyses are significant injuries because they can affect growth if not recognized and treated properly. A proper radiographic technique is required for the demonstration of both soft tissue and bone. This is especially important with type I fractures in which the growth plate is separated as a result of a lateral blow, and type V fractures in which the growth plate has sustained a compression injury. Types I and V fractures do not occur through the bone.

(A) An x-ray view of the knee joint shows a horizontal black line on the growth plate. (B) An x-ray view of the knee joint shows a black line extending through the growth plate and into the metaphyses. (C) An x-ray view of the knee joint shows a black line extending through the growth plate and into the epiphyses. (D) An x-ray view of the knee joint shows a black line extending along with the growth plate, and through the epiphyses. (E) An x-ray view of the knee joint shows a horizontal black line on the growth plate. An arrowhead below the gap between the joints points at the gap.

Greenstick

A greenstick fracture occurs when one cortex of the bone's diaphysis breaks and the side remains intact.

Torus

The torus fracture is a type of greenstick fracture in which the load on the bone is in the same direction as the diaphysis, causing the cortex to fold back on itself.

Toddler's fracture

A toddler's fracture is described as a subtle, nondisplaced, oblique fracture of the distal tibia in children 9 months to 3 years of age; the fracture may only be seen on one view of the lower shaft of the tibia. If AP, lateral, and oblique projections are radiographically negative but there is strong suspicion of a toddler's fracture, a radionuclide scan may be indicated. The child's age and the presentation are significant to this diagnosis. It is important to realize that this is a common accidental injury that the parents may not have witnessed. If the onset of symptoms (e.g., pain, non-weight-bearing) is rapid and the patient's age is within the noted range, a toddler's fracture has a high index of suspicion. Remember, however, that a similar fracture in a very young infant who is not yet a "toddler" cannot be ascribed to accidental falls and, therefore, would be suspicious of abuse.

Supracondylar fracture

More severe than the toddler's fracture, the supracondylar fracture is the most common elbow fracture in children, accounting for 60% of all pediatric elbow fractures (Fig. 22.32). Occurring frequently in children between the ages of 3 and 10 years of age, the supracondylar fracture is caused by the child falling on an outstretched hand with hyperextension of the elbow. The most extensively displaced of these fractures can cause serious vascular and nerve damage. Great care should be taken when positioning for this fracture.

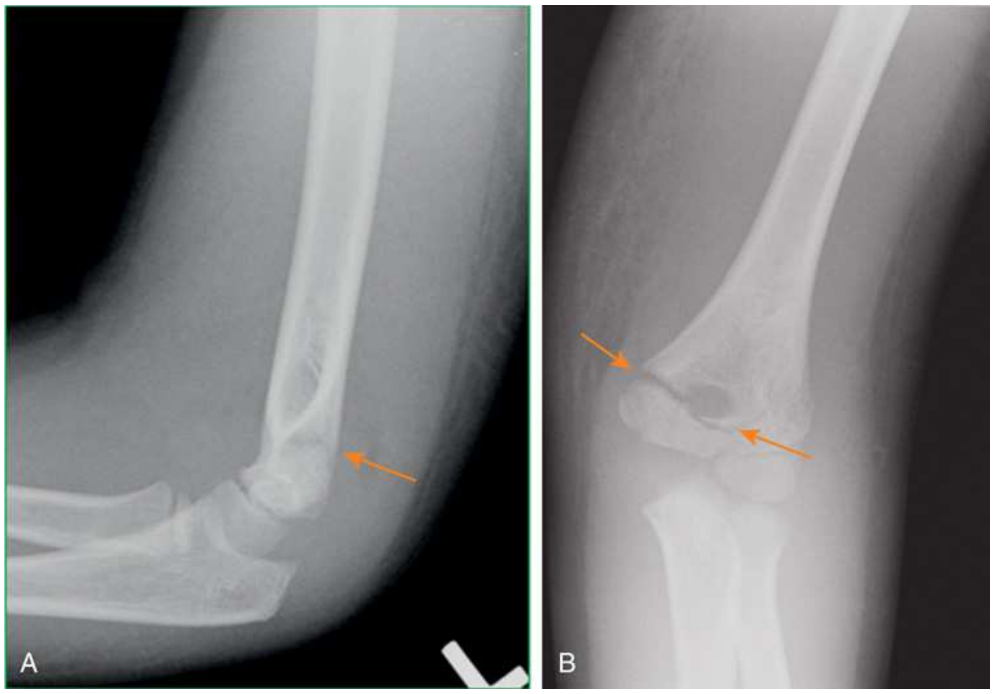

FIG. 22.32 (A and B) AP and lateral projections of a supracondylar fracture *(arrows)*.

(A) An x-ray shows a fracture in the supracondylar bone. The fracture gap appears radiolucent. (B) An x-ray shows the fracture in the supracondylar bone. The fracture gap is thin and appears radiolucent.

Image evaluation

Among the many striking differences in radiographic appearance between adult and pediatric patients are the bone trabeculae and the presence of epiphyseal lines or growth plates in pediatric patients. As they gain experience in evaluating pediatric images, radiographers develop a visual appreciation for these differences. For example, to the uneducated eye, a normally developing epiphysis may mimic a fracture. For this reason, and because fractures can occur through the epiphyseal plate, physicians (and to a certain degree, radiographers) must learn to recognize epiphyseal lines and their appearance at various stages of ossification. Fractures that occur through the epiphysis are called *growth plate fractures* (Salter-Harris). Because the growth plates are composed of cartilaginous tissue, the *density* of the image must be such that soft tissue is shown in addition to bone (see Table 22.3). Visualization of the bony trabecular pattern is used as an indicator that sufficient *recorded detail* has been achieved. Because of the small size of pediatric extremities, an imaging system with superior resolution is required. Generally, the speed of the imaging system should be half that used for spines and abdomens.

Skull and Paranasal Sinuses

Skull

The two most common indications for a pediatric radiographic skull series are to rule out craniosynostosis and fracture. Synostosis is the fusion of two bones, and it can be normal or abnormal. The term *craniosynostosis,* or *premature cranial suture synostosis,* describes the premature closure of one or more of the cranial sutures and may be isolated or part of a craniofacial syndrome; both result in the deformity of the calvaria's shape. Etiologically, abnormal synostosis is described as either primary or secondary. Primary craniosynostosis is characterized by some type of defect in one or more of the cranial sutures and can be intrinsic or familial. The familial form manifests as a component of a craniofacial syndrome (e.g., Pfeiffer, Apert, Crouzon, or Beare-Stevenson) and may be the result of one of several genetic mutations. Secondary craniosynostosis is the result of some underlying medical condition, which can be systemic or metabolic (e.g., hyperthyroidism, hypercalcemia, vitamin D deficiency, sickle cell, or thalassemia). Microcephaly, encephalocele, and shunted hydrocephalus can diminish the growth stretch at sutures, which can lead to craniosynostosis secondarily.

Calvarial growth takes place perpendicular to the suture lines. The suture lines involved, time of onset, and the sequence in which individual sutures fuse will determine the nature of the deformity. When sutures fuse prematurely, calvarial growth occurs along the axis of the fused suture. The altered skull shape is diagnostic. Restoring growth is dependent on the early release of all fused sutures.

The birth prevalence of craniosynostosis ranges from approximately 3 to 5 cases per 10,000 live births. The isolated variety (only one suture affected) constitutes 80% to 90% of cases, and the sutures most commonly involved, in descending order of frequency, are the sagittal, coronal, metopic, and lambdoid. The syndromic variety accounts for up to 10% to 20% of cases. Coronal synostosis is more frequently seen in females, whereas sagittal synostosis is more common in males. Most cases are diagnosed early in life. Skull images of infants are obtained in the supine position. Radiographic views include (1) a supine AP projection obtained to demonstrate the calvaria, (2) one or both lateral projections obtained to demonstrate the calvaria and skull base (both lateral projections are indicated in trauma and focal lesion evaluation), and (3) an AP axial Towne projection, but only with a 30-degree caudad angle (due to differing skull morphology in pediatric patients younger than 10 years of age), obtained to demonstrate the occipital bone and foramen magnum.

Skull fractures occurring in children are usually the result of blunt force trauma and include both accidental and nonaccidental trauma, as well as those sustained from forceps extraction at birth. Fractures can occur with minimal force in the abnormally fragile bone associated with osteogenesis imperfecta (OI). Diastatic fracture lines (breaks along the sutures) present as more lucent and linear and exhibit no interdigitations, which distinguish them from sutures. Depressed skull fractures appear dense due to the overlapping bone fragments. Skull radiography will demonstrate horizontal linear fracture lines that may not be visible on CT when the fracture is parallel to the CT axis. All skull imaging is done with a grid, a large focal spot, using a set technique (can use AEC for AP), and with no clothing from the waist up. Immobilizing an infant for a skull series is accomplished most efficiently by using the "bunny immobilization" technique (Fig. 22.33), as all three projections can be accomplished with minimal help. The parents can also be drafted to immobilize the shoulders, torso, and legs (sandbags will work if the patient is younger than 2 years); however, this technique requires much more instruction and is less reliable.

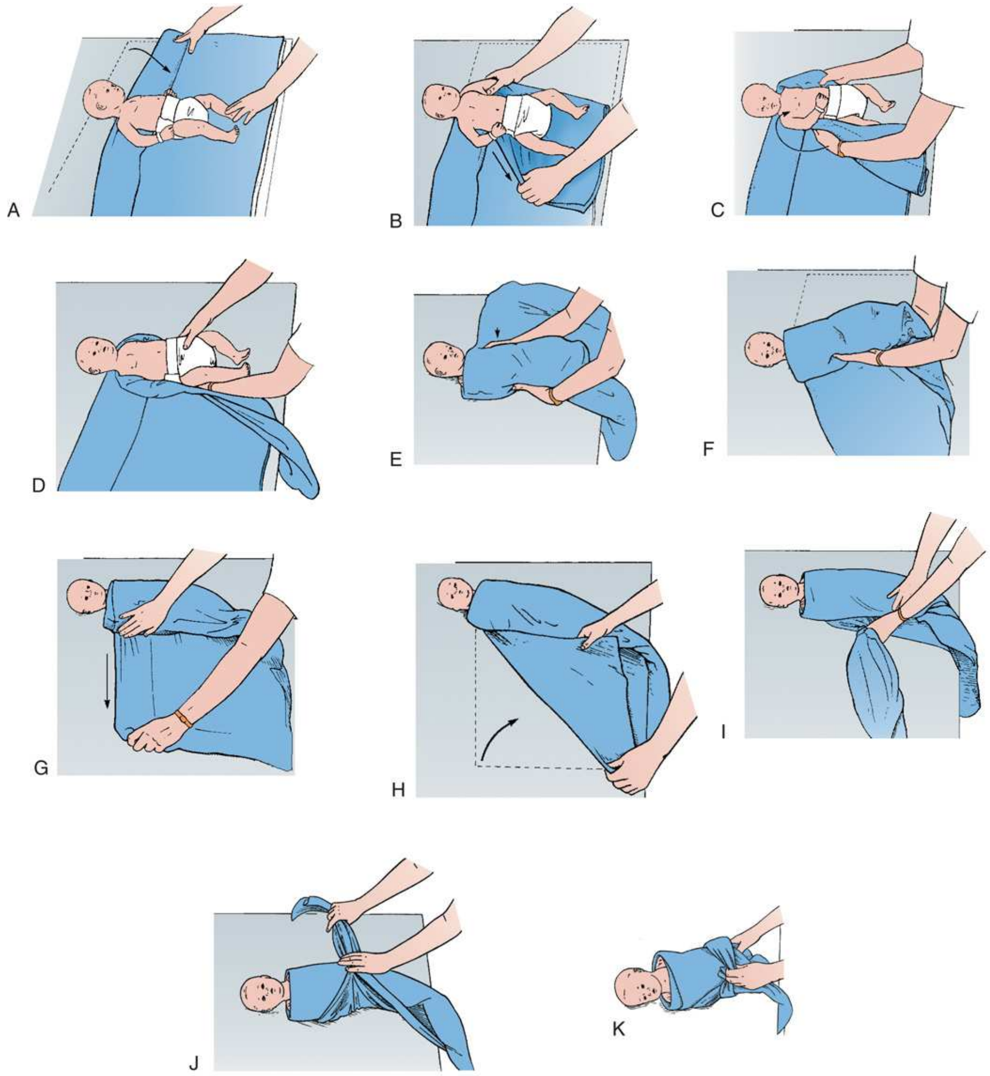

FIG. 22.33 The "bunny" method used to immobilize the patient for cranial radiography. (A) to (D) focus on immobilization of the shoulders, (E) to (G) concentrate on the humeri, and (H) to (K) illustrate the way the sheet is folded and wrapped to immobilize the legs. (A) Begin with a standard hospital sheet folded in half lengthwise. Make a 6-inch fold at the top and lay the child down about 2 feet from the end of the sheet. (B) Wrap the end of the sheet over the left shoulder and pass the sheet under the child. (C) This step makes use of the 6-inch fold. Reach under, undo the fold, and wrap it over the right shoulder. (Steps B and C are crucial to the success of this immobilization technique because they prevent the child from wiggling their shoulders free.) (D) After wrapping the right shoulder, pass the end of the sheet under the child. Pull it through to keep the right arm snug against the body. (E) Begin wrapping, keeping the sheet snug over the upper body to immobilize the humeri. (F) Lift the lower body and pass the sheet underneath, keeping the child's head on the table. Repeat steps (E) and (F) if material permits. (G) Make sure the material is evenly wrapped around the upper body. (Extra rolls around the shoulder and neck area produce artifacts on 30-degree fronto-occipital and submentovertical images.) (H) Make a diagonal fold with the remaining material (approximately 2 feet). (I) Roll the material together. (J) Snugly wrap this over the child's femora. (The tendency to misjudge the location of the femora and thus wrap too snugly around the lower legs should be avoided.) (K) Tuck the end of the rolled material in front. (If not enough material remains to tuck in, use a Velcro strip or tape to secure it.) From the Michener Institute for Applied Health Sciences, Toronto, Ontario, Canada.

Diagram (A) shows a child laying on a sheet. A hand is folding the sheet lengthwise. It is indicated by an arrow. Diagram (B) shows the hand wrapping the ends of the sheet over the left shoulder and is passing the sheet under the child. It is indicated by an arrow. Diagram (C) shows a hand reaching under the sheet and another hand is wrapping over the right shoulder. It is indicated by an arrow. Diagram (D) shows a hand pulling the sheet under the child. Diagram (E) shows a hand keeping the sheet snug over the upper body. Diagram (F) shows lifting the lower body and passing the sheet underneath the child. Diagram (G) shows a hand stretching the sheet. It is indicated by an arrow. Diagram (H) shows a hand making a diagonal fold with the remaining material. It is indicated by an arrow. Diagram (I) shows a hand, rolling the material together. Diagram (J) shows a hand wrapping it over the femora. Diagram (K) shows a hand tucking the ends of the rolled material in front.

The AP skull (Fig. 22.34A) is positioned with the orbitomeatal line (OML) perpendicular to the IR using two round, 10-cm, radiolucent sponges, one on either side of the head. It is important when using these sponges to use your palms rather than pressing your fingers into the sponge (which will appear on the image). The axial Towne method (see Fig. 22.34B) is also performed supine using the "mouse ears" sponges to bring the chin toward the chest so that the OML is perpendicular to the exam table and IR. The central ray is directed 30 degrees caudad and enters 2.5 to 5 cm above the glabella. The lateral skull can be imaged using one of two methods. The first projection is a left, cross-table lateral (see Fig. 22.34C) with the infant supine and elevated on a radiolucent pad and positioned supine. The grid holder with IR is parallel to the skull and extends to the tabletop (below the pad) to avoid clipping of the posterior skull. The infant's shoulder is in contact with IR (Fig. 22.35). The central ray is perpendicular and enters 1 cm superior to the external auditory meatus (EAM). Use the flat surface of the hand to position one round "mouse ear" sponge just superior to the vertex of the skull and the other hand to hold the mental protuberance of the mandible. Leave the infant supine and rotate the skull to a lateral position with the side of interest down. The central ray enters 1 cm superior to EAM. Position one "mouse ear" sponge just posterior to the vertex of the skull using a flat hand, and use the other hand to hold the mental protuberance of the mandible. This is an awkward position for infants, so expect them to struggle (Table 22.4).

FIG. 22.34 (A) AP skull. (B) Townes 30 degrees. (C) Lateral (method 1 as mentioned previously).

(A) An x-ray shows the anterior skull. The nostrils appear radiolucent. (B) An x-ray shows the posterior skull. It appears radiopaque. Diagram (C) shows the lateral skull. The cervical vertebra is visible.

Paranasal sinuses

The main indication for performing a paranasal sinus series on the pediatric patient is to rule out sinusitis. However, radiographic opacification is not a clear indication of sinus disease; incidental findings of mucosal thickening with magnetic resonance imaging (MRI) are common in children younger than 5 years when examined for other indicated reasons. Because errors in positioning may simulate pathologic change in this age group, demonstrating air-fluid level in an upright exam with compelling clinical and laboratory support would probably warrant the diagnosis of sinusitis without resorting to CT. The maxillary, ethmoid, and sphenoid sinuses are present and aerated at birth, whereas the frontal sinuses do not usually appear until the second year.

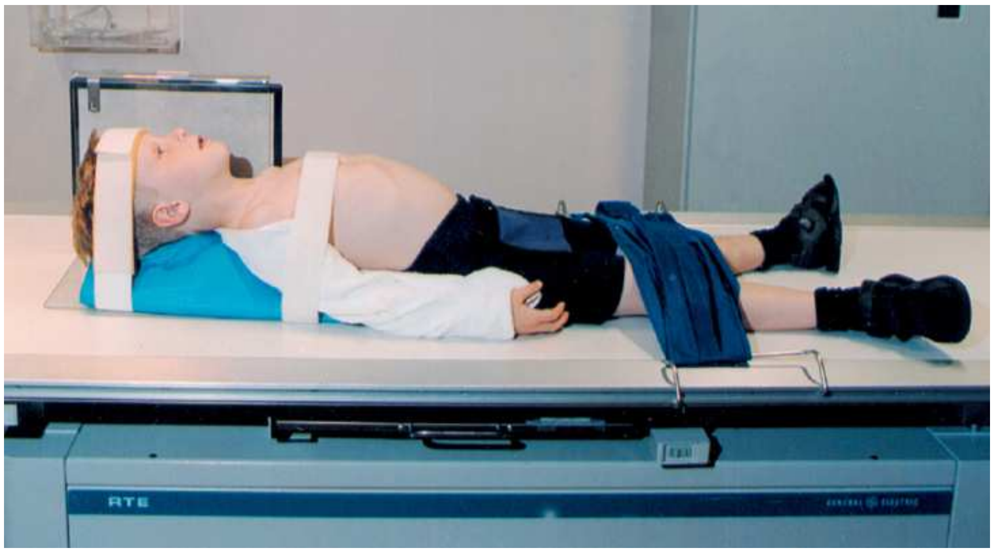

FIG. 22.35 Effective immobilization for lateral skull images with a horizontal beam can be achieved using the infant head and neck immobilizer.

A boy is in a supine position on the radiographic table. The boy is elevated on a radiolucent pad. The grid holder with IR is parallel to the skull and extends to the tabletop (below the pad). The infant's shoulder is in contact with I R.

TABLE 22.4

Summary of skull projections

AP skull	No angle on central ray, which enters at the nasion with the orbitomeatal line perpendicular to the imaging plate
AP axial Towne	Central ray 30-degree caudad, enters at the nasion
Lateral 1	Dorsal decubitus projection (cross-table lateral); central ray enters superior to external auditory meatus
Lateral 2	Supine with side of interest down; central ray enters superior to external auditory meatus

The paranasal sinus protocol may include three views: Caldwell (Fig. 22.36), Waters (Fig. 22.37), and a left lateral projection (Fig. 22.38), which should include frontal sinus anatomy, C-spine, and airway to the thoracic inlet. Improper collimation to the area of interest is the single most common shortcoming. To preserve image quality, consider precollimating before moving the patient into position; collimate to the area of interest only. Adjusting your light field on the back of the head does not allow for the divergence of the central ray, leading to the inclusion of too much of the skull. Experience has shown that in children younger than 8 years, the Caldwell method requires no central ray angulation and can be positioned with forehead and nose against the bucky. This is possibly due to the immature and varying morphology of the pediatric skull (Fig. 22.39).

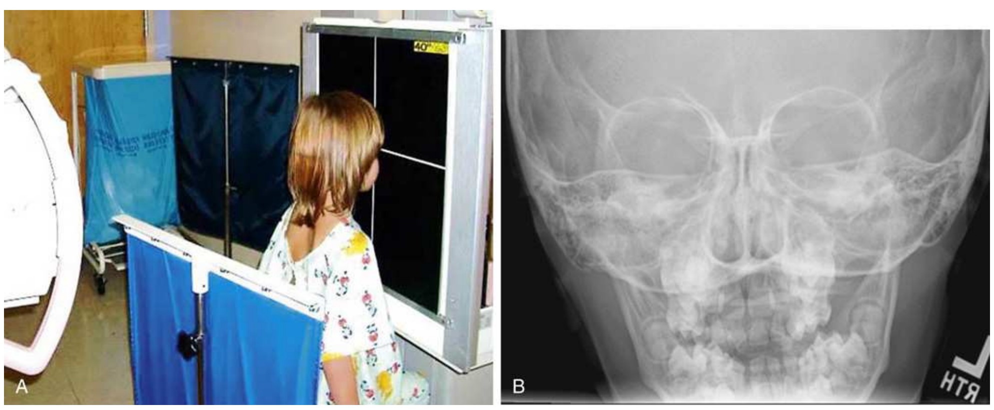

FIG. 22.36 (A) Caldwell without 15-degree angle. Note that both nose and forehead touch the grid at this age. (B) Caldwell image.

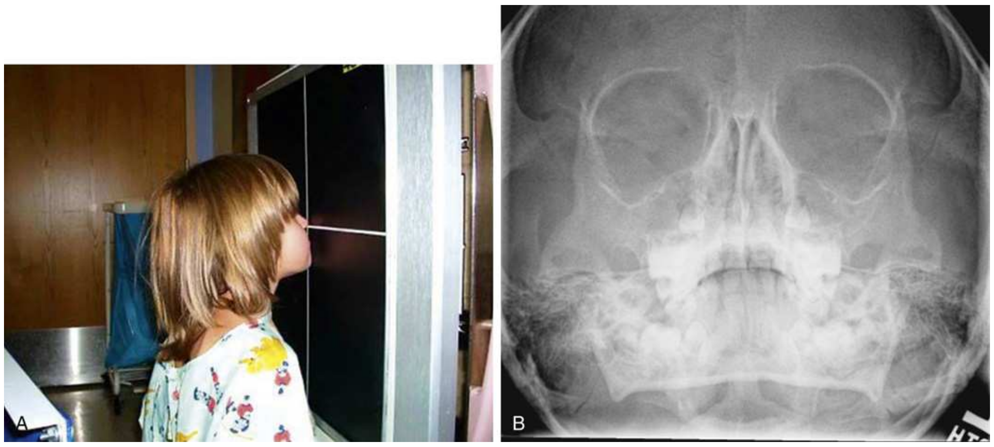

FIG. 22.37 (A) Waters method with chin and nose touching grid. (B) Waters image.

The central ray is horizontal and exits at the nasion for the Caldwell method. For the Waters method, the child's nose and chin touch the bucky and the central ray remains horizontal, exiting at the acanthion and projecting the petrous ridges below the maxillary sinuses. The major pitfall is too much central ray angulation, which causes the sinuses to either not be visualized or falsely appear to be obliterated. The left lateral is equivalent to a soft tissue neck (STN), which includes the vertical plate of the frontal bone (where frontal sinuses will be seen, but not usually prior to 2 years), the nasal shadow, the C-spine, and the thoracic inlet. With both the Waters and the Caldwell methods, ask the patient to move away from the bucky or upright grid once you have determined the appropriate receptor height, precollimate to the area of interest, and then place the patient back in the light field. The image quality will be improved and radiation to the patient will be reduced. This technique takes some getting used to because the projected light field on the back of the head will appear too small, but trust science: the beam will diverge. Place your marker so it will not appear over an area of interest.

FIG. 22.38 Lateral projection for sinus series. The indication for the exam is normally noisy breathing with suspected adenoid hypertrophy. Often collimation includes from the frontal sinus to the thoracic inlet on inspiration through the nose in cases of other possible causes such as foreign bodies and retropharyngeal space anomalies (e.g., abscess). This collimation is also used for soft tissue neck for similar reasons.

Soft Tissue Neck

Indications for the STN include foreign bodies (FBs), stridor, laryngo- and tracheomalacia, laryngotracheal bronchitis, epiglottitis, and adenoid hypertrophy. The diagnostic quality of this exam requires careful instructions, neck extension, an inspiratory exposure, and complete immobilization. These requirements are more easily achieved with the infant or child in the supine position, although the exam can be done successfully with the patient in the upright position depending on how much the child cooperates. The only contraindication to the supine position is the presence of epiglottitis (Fig. 22.40); these patients must always be imaged in the sitting or upright position. *Never place these patients in the supine position, as a swollen epiglottis can block the airway*. A "baby box" can be used for STN exams with infants and small children (6 months to 3 years). A 15-degree radiolucent sponge is placed under the infant's/child's shoulders to achieve a slight extension of the neck and airway (shielding and immobilization are identical to the chest x-ray). A parent will hold the patient at the shoulders, pulling down slightly. The second holder, using two round, Mickey Mouse ear sponges (using flat hands), one on either side of the head and above the sella turcica, will hold the head in a true lateral position in extension and without rotation (Fig. 22.41). Collimation should be from the nasion (including complete nasal passage) to the thoracic inlet, including the entire C-spine. The head in flexion or an expiratory image may cause a false positive for enlargement of the retropharyngeal soft tissues. The lateral projection should be done with a set technique, no grid, at a 182-cm SID.

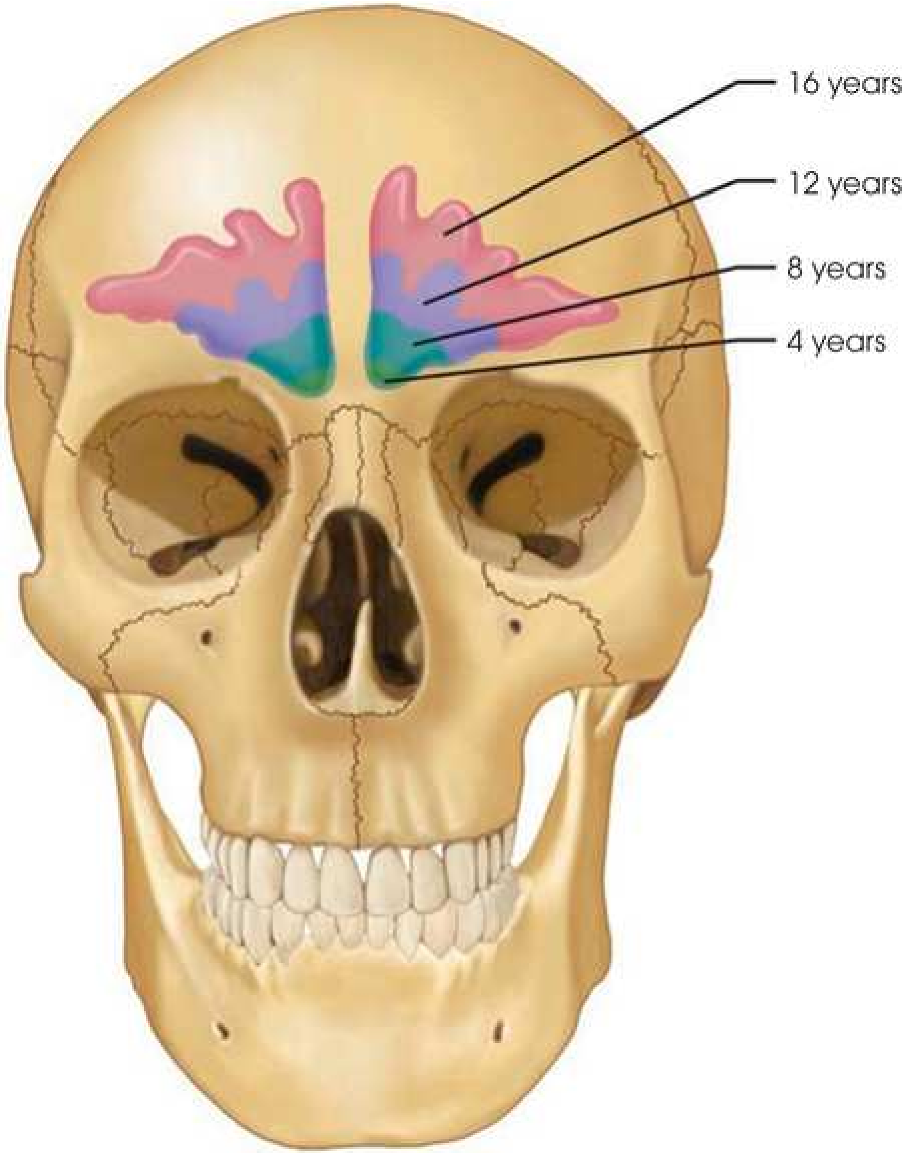

FIG. 22.39 Frontal sinus development correlated with age—*green*, 4 years; *blue*, 8 years; *purple*, 12 years; *pink*, 16 years. From Fonseca RJ, Barber DH, Powers M, Frost DE: *Oral and maxillofacial trauma*, ed 4, St. Louis, 2013, Elsevier.

Diagram shows the anterior view of the skull. The front sinus development is marked on the forehead. Green is labeled as 4 years, blue is labeled as 8 years, purple is labeled as 12 years, and pink is labeled as 16 years.

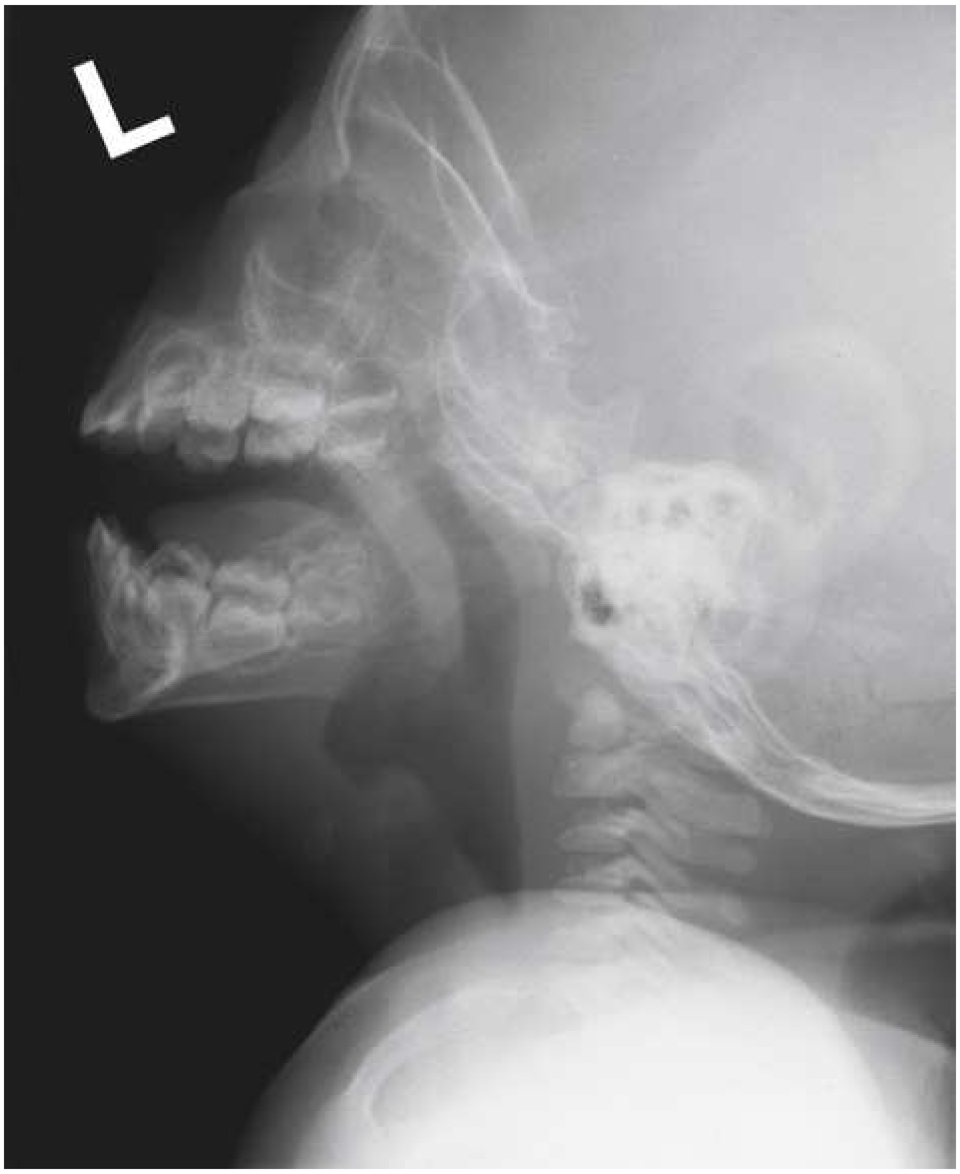

FIG. 22.40 Diffuse swelling of the epiglottis, aryepiglottic folds, and the retropharyngeal soft tissues. These findings are consistent with epiglottitis.

The AP STN projection must be performed with a 102-cm SID grid. Patients from infants to adolescents should be positioned with the patient's occlusal plane perpendicular to the image receptor (exact positioning will vary with age) to prevent the occipital bone from superimposing the airway (overextension). Flexion will also cause superimposition of the airway. The thick part of a 15-degree radiolucent sponge placed under the patient's shoulders will help position the skull for the AP supine extension (Fig. 22.42; using a 15-degree extension of the skull). A small cephalad angle can also be used with the AP projection to better visualize C-1 and C-2.

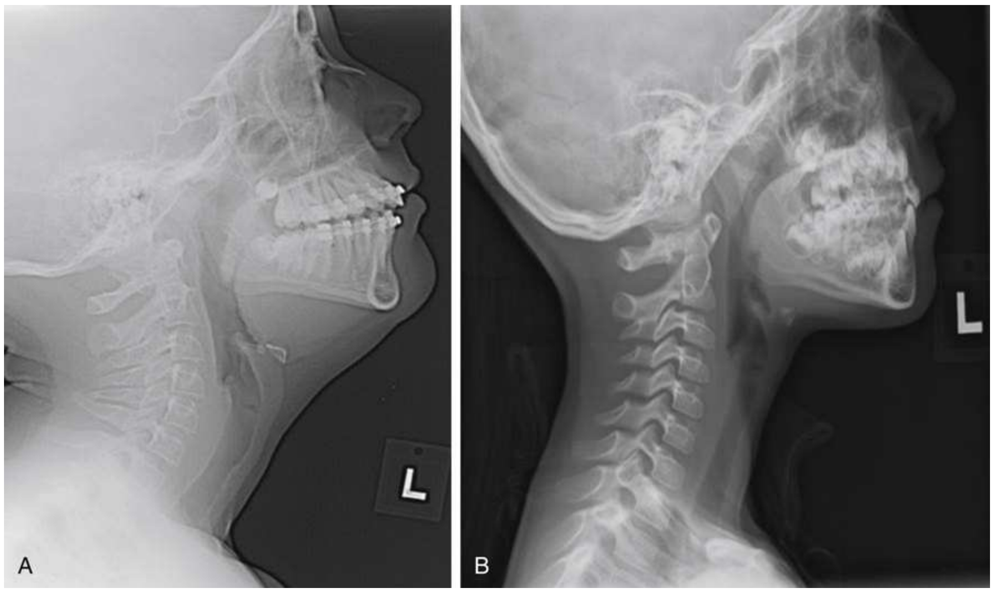

FIG. 22.41 (A) Soft tissue neck (STN) with a Fuji Synapse soft tissue preset. (B) STN without preset.

(A) An x-ray view of the lateral skull and neck shows the soft tissues appearing white and pale, The chin is elevated. The image appears dull and hazy. (B) An x-ray view of the skull and neck shows distinct outlines of the bones and the borders of the skull.

FIG. 22.42 A well-positioned and collimated AP projection with a 15-degree wedge radiolucent sponge placed under the patient's shoulders and a small cephalad angle.

Foreign Bodies

Airway Foreign Body

Airway FBs occur frequently in children ages 6 months to 3 years and are not uncommon in teenagers. Radiolucent objects include firm vegetables, peanuts, hard candy, peas, carrots, and raisins. Round-shaped foods are the most frequently aspirated. Radiopaque FBs (Fig. 22.43) include coins (most common), hair clips, safety pins, and small toys. Splintered wood and glass have also been discovered, usually as the result of traumatic injury. Balloons are most likely to result in death. A young child with a persistent cough but without a fever carries a high index of suspicion for FB aspiration. Clinical presentations may also include stridor, a wheezing cough, recurrent pneumonia, or hemoptysis. If a radiolucent FB is in the trachea, the chest image may be normal and require a CT, or it may demonstrate bilateral over- or under-inflation (air trapping). More commonly, the FB is found in the bronchial tree, and most frequently the right main stem bronchus, which is larger and more in line with the trachea. In images, the FB presents most commonly as a unilateral hyperlucent lung (see Fig. 22.43A).

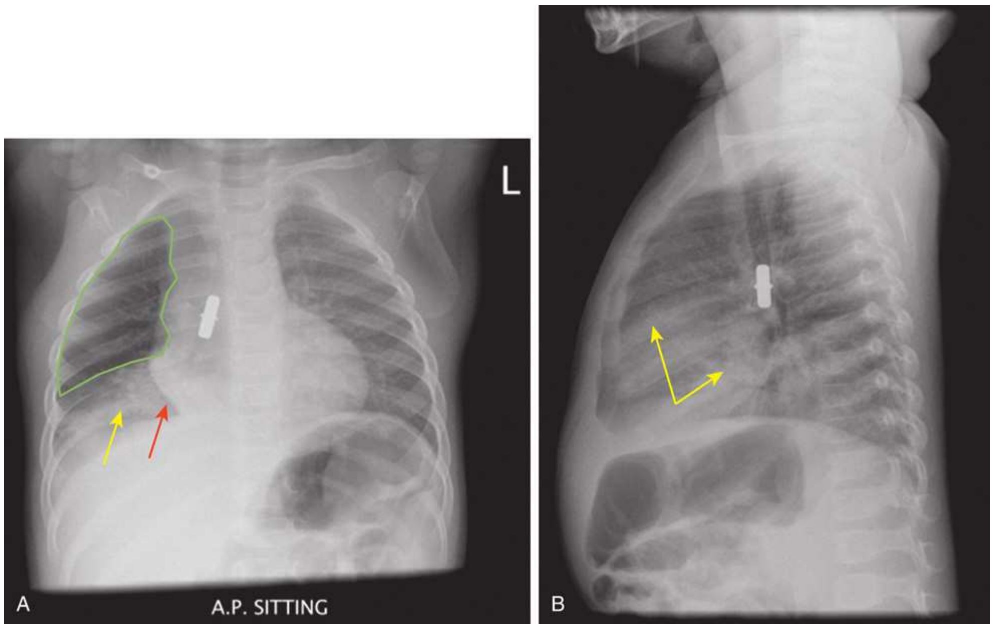

FIG. 22.43 (A) A foreign body in the right main stem bronchus. There is atelectasis (collapse) predominantly affecting the right lower lobe *(yellow arrow).* Note the distinct right heart border on the AP *(red arrow)* and unilateral hyperlucent lung *(green outline).* (B) Note the patchy opacities below the foreign body in the lateral view *(yellow arrows).* Used with permission from Lifeinthefastlane.com at http://lifeinthefastlane.com/lower-airway-foreign-body/.

(A) An x-ray view of the anterior chest shows a short cylindrical radiopaque object on the right side. The hyperlucent lung next to it is marked in green. A small projection below is marked by a red arrow. A hazy region next to it is marked by a yellow arrow. (B) An x-ray view of the lateral chest shows a short cylindrical radiopaque object in the middle. There are patchy white areas around it. It is marled by two yellow arrows.

The STN is accomplished with the help of an infant head and neck immobilizer (see Fig. 22.35). If an FB is suspected clinically, inspiratory and expiratory images may be obtained to rule out air trapping, as younger children will be unable to cooperate with inhalation and expiration commands; right and left decubitus views would then be indicated. The hyperinflated lung will not deflate when the patient is lying on the affected side. A routine protocol for imaging FB includes an AP chest to include the full airway, an abdomen to include lung bases and pubic symphysis, and a lateral STN (nasion to thoracic inlet including C-spine). All images must overlap. This survey ensures that multiple objects are not missed and provides a complete imaging of the airway and alimentary tract. If the FB is suspected of being in the airway, then bilateral decubitus views would be indicated.

Ingested Foreign Body

Whereas older children and parents might provide a history of FB ingestion, young children may simply present with unexplained drooling or the inability to swallow solids. The image readily demonstrates a radiopaque object, of which coins are the most common. A coin in the esophagus will usually lie in the coronal plane (Fig. 22.44), whereas a coin in the trachea will be visualized in the sagittal plane; a nonradiopaque FB may require an esophagogram for visualization. If a contrast study is indicated, a small amount of low-osmolar, nonionic, water-soluble contrast should be used, such as Iohexol (Omnipaque 350). Pica, or the compulsive ingestion of nonfood articles, may be common in those with serious mental impairment or developmental delay (Fig. 22.45). Pica is the medieval Latin name for a magpie, which is claimed to have a penchant for eating almost anything.

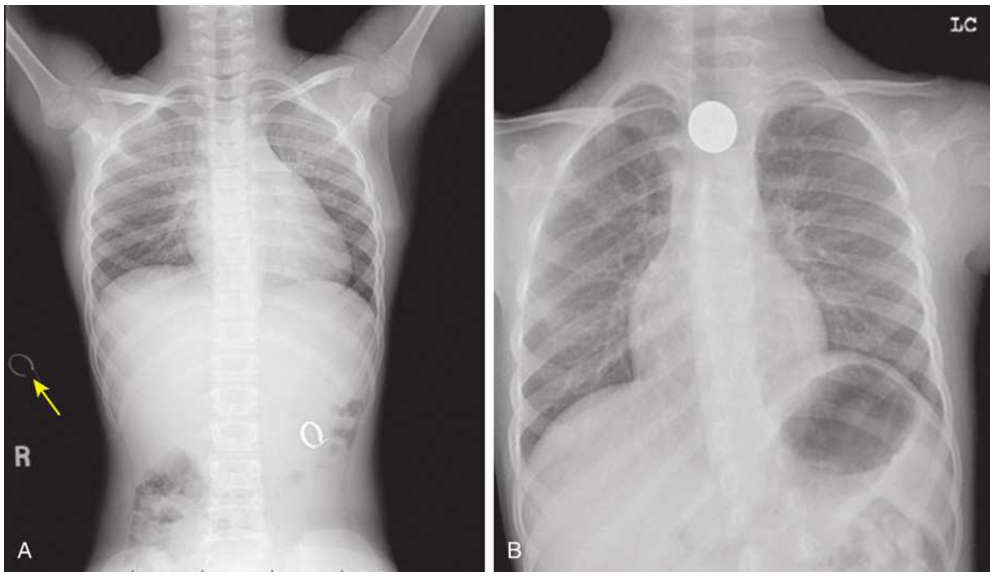

FIG. 22.44 (A) Ingested earring. Reference earring placed lateral to the patient *(yellow arrow)* to assist in confirmation. (B) Coin in the coronal plane.

(A) An x-ray view of the anterior chest and abdomen shows a ring with a radiopaque outline on the right side of the x-ray. It is marked by a yellow arrow. (B) Ab x-ray view of the anterior chest shows a circular radiopaque structure on the coronal plane.

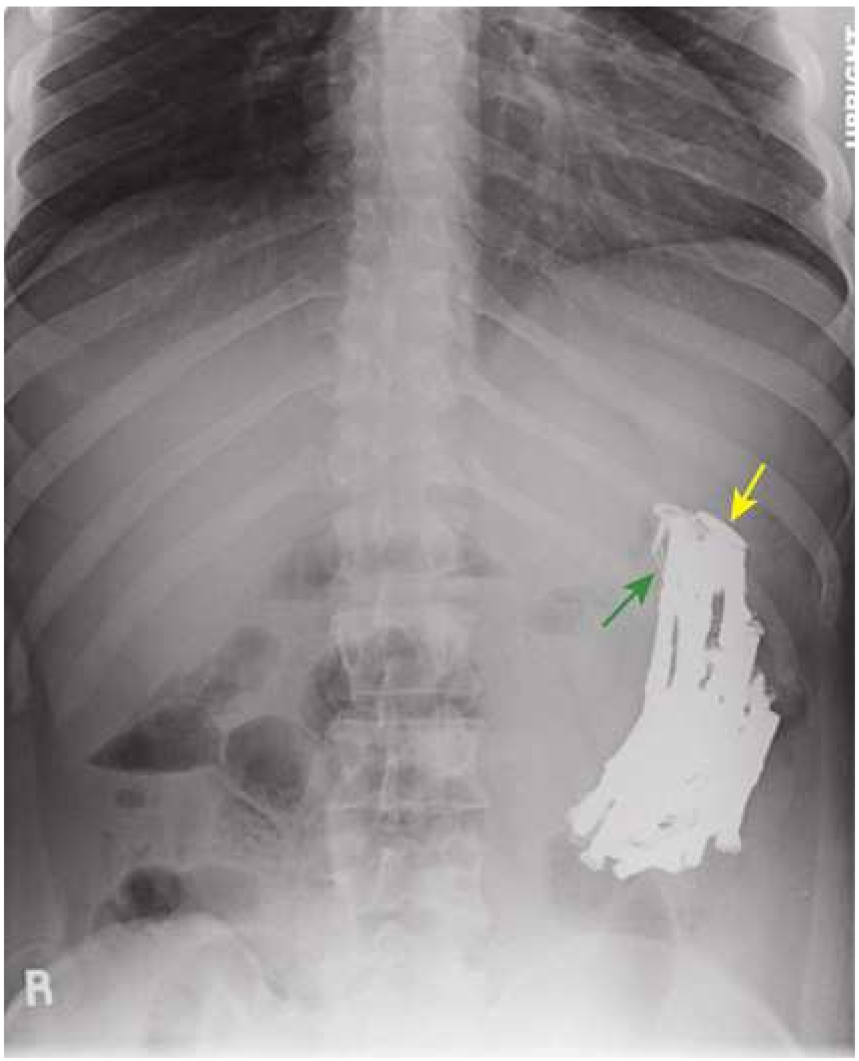

FIG. 22.45 Gastrointestinal pica with paper clip *(green arrow)* and coin *(yellow arrow)*.

Mobile Considerations for Neonatal Intensive Care Unit (NICU)

Neonate radiography is a specialty within itself, and assertive radiographers are imperative to producing diagnostic images. Neonate imaging requires a systematic approach and specialized training. This section will address medical efficacy from the ordering physician to the technical and positioning challenges presented to the radiographer when performing mobile radiography in the NICU environment. Teamwork, communication, procedure considerations, soft tissue landmarks, and standardized neonate radiography protocols are discussed. Recommendations of simulation exercises for student radiographers are presented.

Team-based approach

Communication and teamwork with NICU nursing and surgical staff are critical to creating a quality neonate radiograph. Creating a friendly dialogue with NICU staff is essential to expediting the exam. In most cases, the NICU nurse is anticipating the arrival of the radiographer and will have the NICU patient ready for the exam (free of artifacts). Monthly meetings and opportunities to meet with the NICU physicians, charge nurses, and staff nurses can create a cohesive partnership of team-based communication and expectations.

Elements of an acceptable image

The radiographer should consider specific elements when producing an acceptable or diagnostic neonate image. Some of the important elements include but are not limited to the following:

- Exams are performed at a standardized source-to-image-receptor-distance (SID) of 40 inches (102 cm).
- Radiograph includes correct marker.
- Proper exposure factors to demonstrate pathology, soft tissue, and bony detail.
- Correct positioning of structural anatomy (i.e., free from rotation).
- Removal of artifacts (e.g., diapers, ECG leads, tubes, radiopaque wires). Follow departmental protocol and request assistance.
- Exhibits proper collimation to the anatomy of interest.
- Optimal image contrast and exposure index range.

When performing a neonatal exam, radiographers are presented with additional challenges. The patient's condition in the NICU is almost always compromised. The neonate is normally intubated, has central venous access devices (CVADs), feeding tubes, chest tubes, and endotracheal tubes (ETT). Before entering the NICU, the radiographer should clean the mobile unit, disinfect markers, wash their hands, and don proper PPE. The radiographer should also wash their hands and change gloves between patients. The radiographer must always first verify patient identification and confirm the order with the nurse prior to exposure. Proceeding without the help of a nurse and moving the patient could result in desaturation of the patient, further compromising the patient's condition, and may be considered negligent. Always seek help from the NICU nurse assigned to the patient when performing exams.

Neonate soft tissue landmarks

An additional challenge to imaging neonates is determining the anatomy to include for each exam. In nearly all cases, the radiographer only has soft tissue landmarks of the chest or abdomen. In general, it is good practice to avoid palpating for any bony landmarks to reduce infection. The (1) earlobes, (2) chest nipple line, (3) umbilicus, and (4) pubic symphysis (bottom of buttocks) are four visible soft tissue landmarks that every radiographer can identify.

Neonate nuances

When performing neonate radiographs, the easiest way to determine inspiration is to observe the rise and fall of the neonate's chest and abdomen. In general, when the belly "rises" and is at its maximum height, this is full inspiration. Other items that may be considered prior to exposure are the removal of the diaper, leads, and wires that will cause image artifacts. Check first to make sure removing artifacts do not compromise the patient's condition. Be sure to check departmental protocol before removal of ECG leads and request assistance to reduce infection. In many institutions, there are commercially available radiolucent neonate ECG leads (electrodes). Using radiolucent ECG leads reduces artifacts on images and frees the radiologist from "reading" through the myriad of radiopaque ECG wire leads that may obscure anatomy or pathology (see Figs 22.46A and 22.46B).

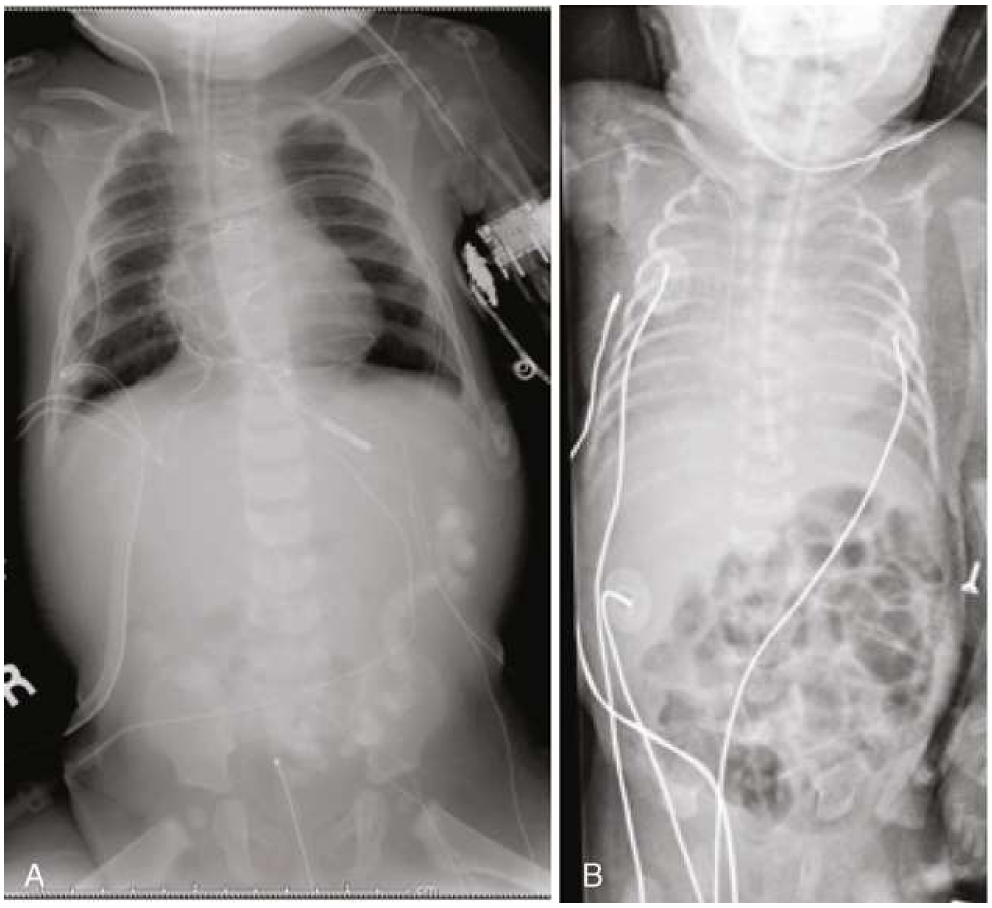

FIG. 22.46 (A) AP chest and abdomen with radiolucent ECG leads (electrodes). (B) AP chest and abdomen with radiopaque ECG leads (electrodes).

The following are recommendations for performing neonate imaging exams.

Portable Ap Neonate Chest

Pre-exposure positioning

- If the IR size allows, place inside tray located underneath incubator (Fig. 22.47). If the IR does not fit, wrap or cover the IR and place directly under the neonate patient. A warm blanket is recommended.
- Adjust the patient and center the chest to the IR.
- Ensure the four (4) borders (top, bottom and two sides) of the IR include the anatomy of interest (caution: patients tend to migrate to the edge of the image receptor).

FIG. 22.47 IR placement in incubator (isolette) tray.

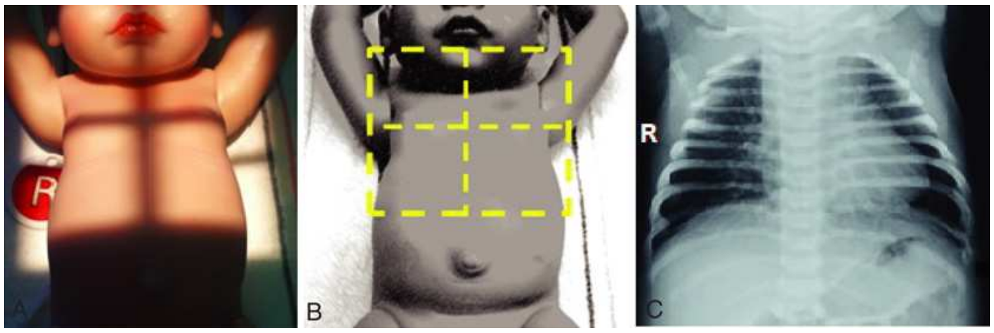

FIG. 22.48 (A) AP chest, central ray directed to nipple line. (B) AP chest, radiation light field. (C) AP chest radiograph.

(A) shows a neonate in a supine position with arms raised over the head. The central ray is directed perpendicular to M S P at level T 7 near the nipple line. (B) shows a neonate in a supine position with arms raised over the head. The radiation field on the collimator below the earlobes and approximately 1.5 inches above the umbilicus are marked by dashed lines. (C) An x-ray view of the chest of the infant.

- Have the nurse adjust the neonate's head until MSP is perpendicular to IR to avoid chest rotation. Check first to make sure moving the head will not compromise the patient's condition.
- Ask the nurse to move arms out of chest area and hold if necessary. Provide the nurse with a lead apron to hold for the exposure.
- Direct the central ray perpendicular to MSP at level T7 near the nipple line (Fig 22.48A) with 40 inches (102 cm) SID.
- Place side marker in the collimated exposure field.
- Adjust radiation field on the collimator to below the earlobes and approximately 1.5 inches (3.8 cm) above the umbilicus (Fig 22.48B).
- When the neonate's chest and abdomen rises to its maximum height for full inspiration, make the exposure.
- Shield the patient accordingly.

Image evaluation

- Upper airway to the gastric bubble.
- Evidence of proper collimation and presence of a side marker placed clear of anatomy of interest.
- Entire lungs, from the apices to the costophrenic angles (Fig. 22.48C).
- No rotation as demonstrated by the sternal ends of the clavicles equidistant from the spine.

Portable Decubitus Neonate Chest

R or L lateral recumbent

Pre-exposure positioning

• Place the patient in a lateral decubitus position, lying on either the affected or the unaffected side, as indicated by the existing condition. Assess the patient's condition and request assistance with positioning.
• Place the radiolucent sponge (covered) directly under the neonate patient.

FIG. 22.49 Radiolucent sponge and IR.

FIG. 22.50 AP left lateral decubitus chest position.

A neonate is held in a left lateral decubitus chest position. One hand is holding both the hands of the child close to the child's head and the other hand is holding the legs together. Tubes are attached to the child. The central ray is directed at level T 7.

- Wrap or cover the IR and ensure that the bottom edge of vertical IR drops below the sponge to include anatomy on side down (Fig. 22.49).
- Have the nurse extend the patient's arms above the head and position the thorax in a true lateral position. Indicate the side up/down.
- Direct the central ray horizontal and perpendicular to MSP at level T7 near the nipple line (Fig. 22.50) and ensure 40 inches (102 cm) SID.
- Place side marker in the collimated exposure field.
- Adjust radiation field on the collimator to include the earlobes and approximately 1.5 inch (3.8 cm) above the umbilicus. This collimation will ensure inclusion of upper airway and gastric bubble.
- Observe the patient's breathing and expose on inspiration.
- Shield the patient accordingly.

Image evaluation

- Entire lungs, from the apices to the costophrenic angles (Fig. 22.51).
- No rotation as demonstrated by the sternal ends of the clavicles equidistant from the spine.
- Evidence of proper collimation and presence of a side marker placed clear of anatomy of interest.
- Fluid levels in the pleural cavity are best visualized with the affected side down. Air levels are best visualized with the affected side up.

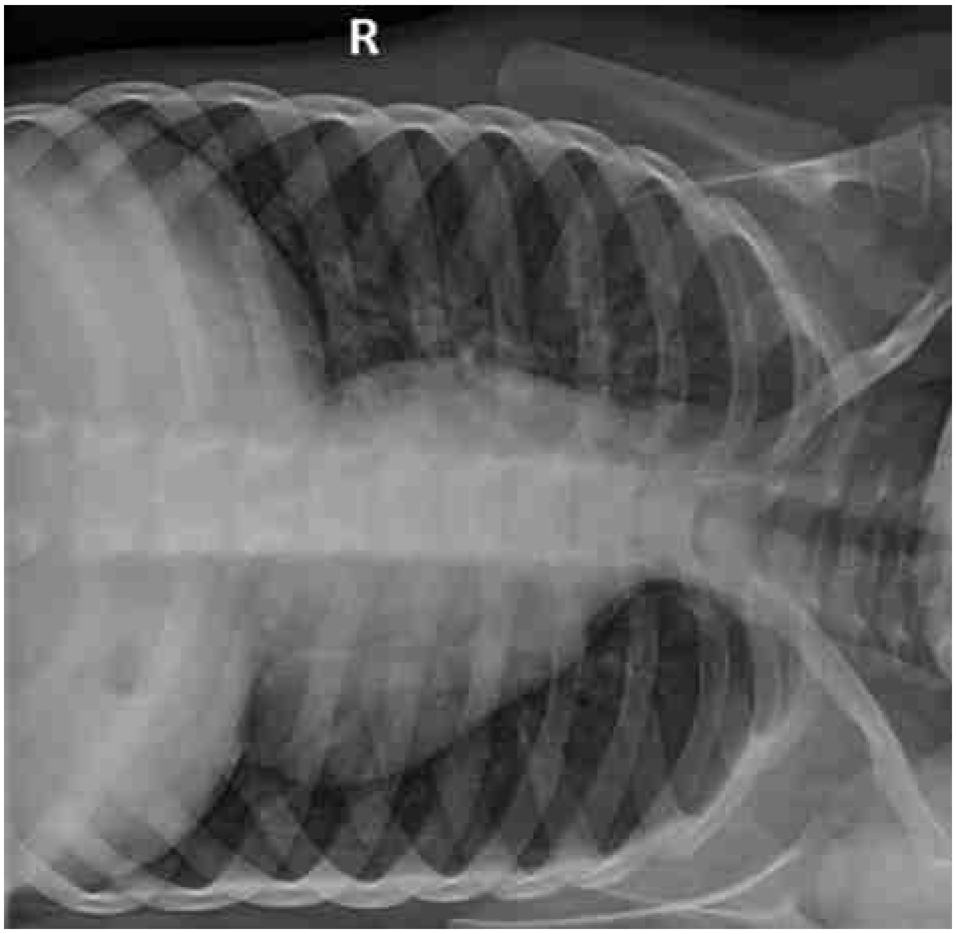

FIG. 22.51 AP left lateral decubitus chest radiograph.

Portable Neonate Abdomen

Pre-exposure positioning

- If the IR fits, place inside tray located underneath incubator. If the IR does not fit, wrap or cover the IR and place directly under the neonate patient.
- Have the nurse remove the patient's diaper if possible (soiled/wet diaper causes artifacts).
- Center the area of interest to the IR and ensure the four (4) borders (top, bottom and two sides) of the IR includes the anatomy of interest.
- Have the nurse adjust the neonate's head until MSP is perpendicular to IR to avoid rotation. Make sure this will not compromise the patient's condition.

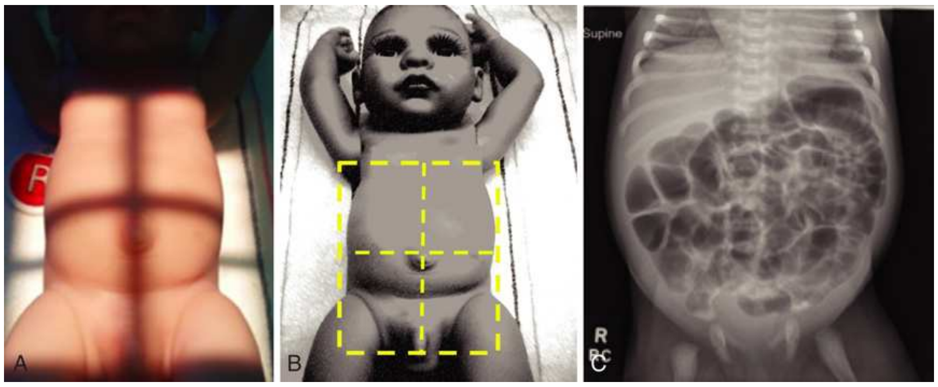

FIG. 22.52 (A) AP abdomen, central ray directed at level of iliac crest. (B) AP abdomen, radiation light field. (C) AP abdomen radiograph.

(A) shows a neonate in a prone position. The central ray is directed perpendicular to I R entering M S P at the level of the iliac crest with 40 inches S I D. (B) shows a neonate in a supine position with arms raised over the head. The radiation field on the collimator includes from the nipple line to the pubic symphysis. (C) An x-ray shows the diaphragm of pubic symphysis.

- Direct the central ray perpendicular to IR entering MSP at level of iliac crest with 40 inches (102 cm) SID (Fig. 22.52A).
- Adjust radiation field on the collimator to include from the nipple line to the pubic symphysis (Fig. 22.52B). This collimation will ensure inclusion of the diaphragm and pubic symphysis.
- Place side marker in the collimated exposure field.
- Observe patient's breathing and expose at the end of expiration.
- Gonadal shielding is discretionary to avoid obscuring pertinent anatomy.

Image evaluation

- Diaphragm to pubic symphysis (Fig. 22.52C).
- Free from wet diaper artifacts.
- No rotation of the abdomen as demonstrated by spinous processes in the center of the lumbar vertebrae and symmetric wings of the ilia.

Portable Decubitus Neonate Abdomen

R or L lateral recumbent

Pre-exposure positioning

- Have the nurse remove the patient's diaper, if possible, to reduce artifacts.
- Place the patient in a lateral decubitus position, lying on either the affected or the unaffected side, as indicated by the existing condition. Assess patient's condition and request assistance with positioning.
- Place a radiolucent sponge (covered) directly under the neonate patient.
- Wrap or cover the IR and ensure that the bottom edge of vertical IR drops below the sponge and obtain 40 inches (102 cm) SID.
- Have the nurse raise the arms above the head (Fig. 22.53).
- Adjust radiation field on the collimator to include from the nipple line to the pubic symphysis. This collimation will ensure inclusion of the diaphragm and pubic symphysis. Place side marker in the collimated exposure field.
- Direct the central ray horizontal and perpendicular to IR entering MSP at level of iliac crests.
- Observe patient's breathing and expose at the end of expiration.
- Gonadal shielding is used at discretion to avoid obscuring pertinent anatomy.

Image evaluation

- Diaphragm to pubic symphysis (Refer to Fig. 23.13B).
- Free from wet diaper artifacts.
- No rotation of the abdomen as demonstrated by spinous processes in the center of the lumbar vertebrae and symmetric wings of the ilia.

FIG. 22.53 AP left lateral decubitus abdomen position.

A neonate is held in a left lateral decubitus abdomen position. One hand is holding both the hands of the child close to the child's head and the other hand is holding the legs together. Tubes are attached to the child.

Portable Dorsal Decubitus Neonate Chest or Abdomen

Pre-exposure positioning

- When the condition of the neonate will not permit the patient to roll into lateral recumbent, perform the exam with the patient supine and central ray horizontal.
- Place a radiolucent sponge (covered) directly under the neonate patient. Assess patient's condition and request assistance with positioning.
- Ensure that the bottom edge of vertical IR drops below the sponge and obtain 40 inches (102 cm) SID.
- Have the nurse extend the neonate's arms above the head, and ensure the chest and pelvis are flat.
- Adjust radiation field on the collimator:
  - For chest, below the earlobes and approximately 1.5 inches (3.8 cm) above the umbilicus.
  - For abdomen, from the nipple line to the pubic symphysis.
- Place side marker in the collimated exposure field.
- Direct the central ray horizontal and perpendicular to IR entering MCP:
  - For chest, at level T7 (Refer to Fig. 22.20).
  - For abdomen, at level of iliac crests (Fig. 22.54A).
  - For a combination chest and abdomen, at midpoint between thorax and pubic symphysis.
- Observe patient's breathing and expose at the end of inspiration for chest or expiration for abdomen.
- Gonadal shielding is used at discretion to avoid obscuring pertinent anatomy.

Image evaluation

- Structural anatomy:
  - For chest, from apices to costophrenic angles.
  - For abdomen, from diaphragm and pubic symphysis (Fig. 22.54B).
  - For combination chest and abdomen, from apices to pubic symphysis.
- Evidence of proper collimation and presence of side marker placed clear of anatomy of interest.
- No rotation as demonstrated by sternum, ribs posteriorly, superimposed ilia, superimposed lumbar vertebrae pedicles, and open intervertebral foramina.

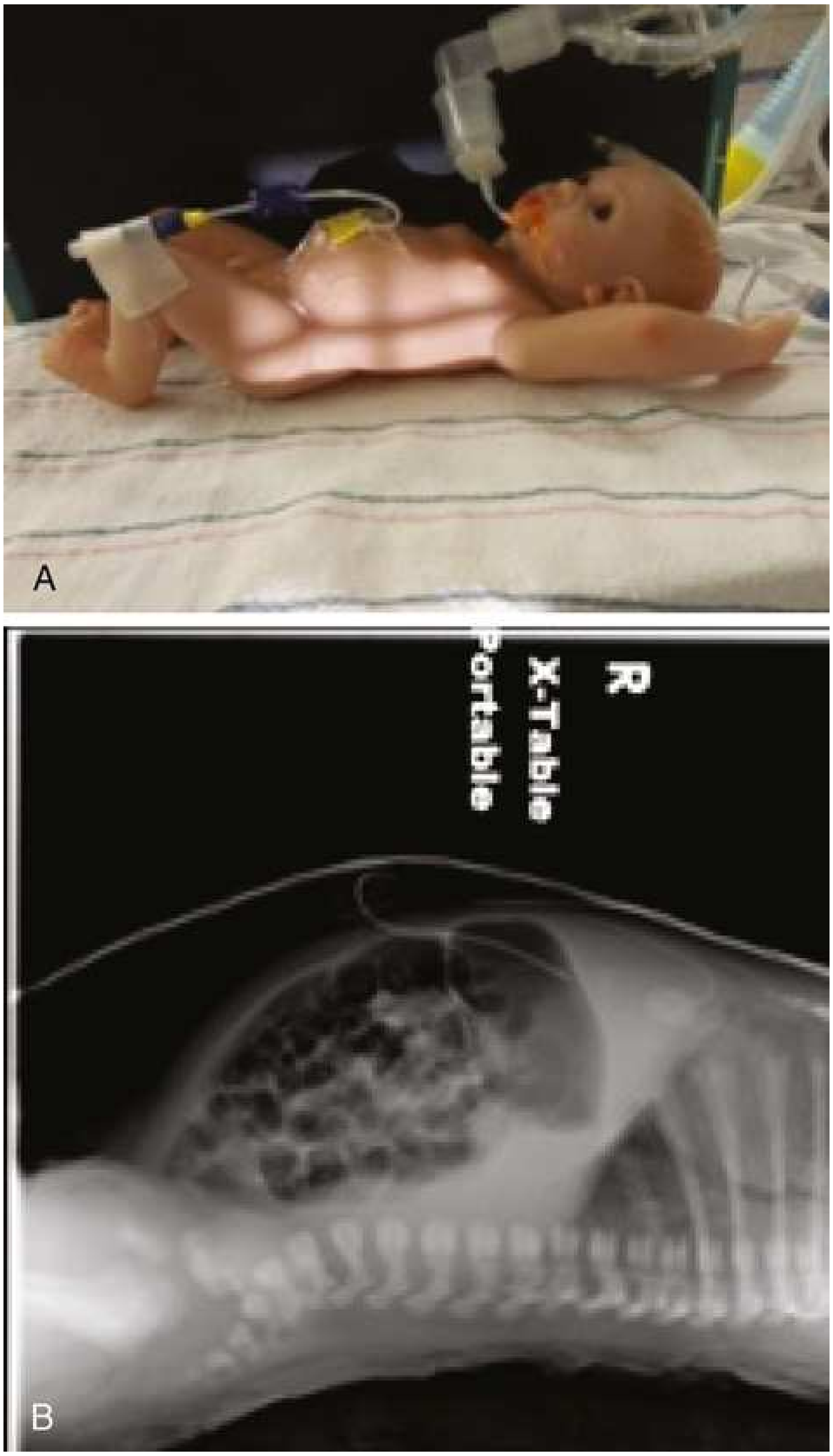

FIG. 22.54 (A) Right lateral dorsal decubitus abdomen position. (B) Right lateral dorsal decubitus abdomen radiograph.

(A) A neonate is held in the right lateral dorsal decubitus position by extending the arms above the head. The central ray is directed at the level of iliac crests. (B) An x-ray shows the diaphragm and pubic symphysis.

Portable Chest and Abdomen for Line Placement

The chest and abdomen combination described in this section is typically ordered for premature newborns. IV access is often necessary to provide medication and nutrition needed for growth and development. When prolonged IV support is required, maintaining access with peripheral IV catheters can reduce infection and the number of needle sticks. Peripherally inserted central catheters (PICCs) are the most common type of central line utilized in NICU patients. Although PICCs have many benefits, they also have potential complications. Confirming the catheter tip position is essential to decreasing complications. Physicians caring for NICU patients frequently order chest and abdomen combination views for PICC or CVC (central venous catheter) placement. In many cases, the exam is ordered STAT during or after placement under a sterile field. Chest and abdomen combination exams, sometimes referred to as "babygrams," result in a loss of radiographic detail and contrast when compared to separate images. In some instances, the radiographer may need to question the physician's order. Are both the chest and abdomen anatomy really warranted if only looking at chest pathology or for upper PICC? Is inclusion of the chest warranted for abdomen pathology or lower PICC? These are important questions. The order must reflect the pathology indication and region of interest to be demonstrated. Overuse of chest and abdomen (babygram) radiographs should be avoided. The following are recommendations for imaging the chest and abdomen combination exam.

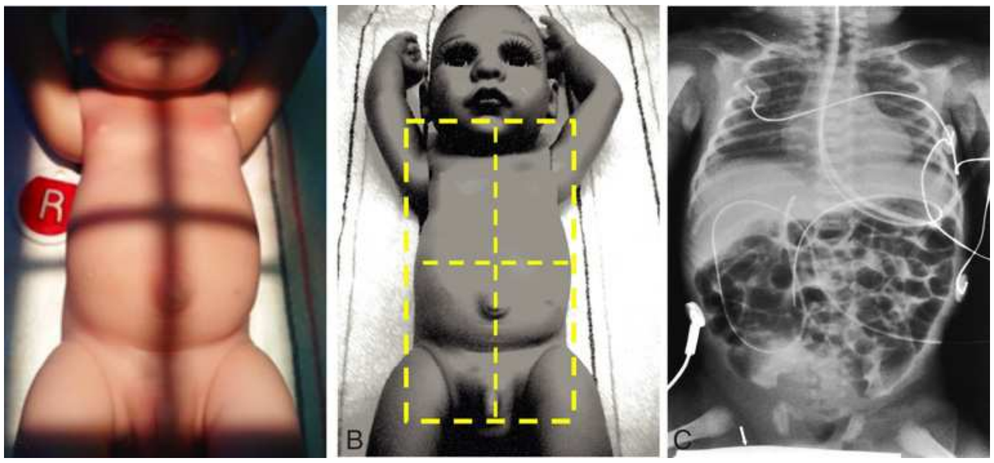

FIG. 22.55 (A) Central ray directed to midpoint of chest and abdomen. (B) AP chest and abdomen, radiation light field. (C) AP chest and abdomen radiograph.

(A) shows a neonate in a supine position with arms raised over the head. The central ray is directed perpendicular to the midpoint of the chest and abdomen along the M S P. (B) shows a neonate in a supine position with arms raised over the head. The radiation field on the collimator includes from apices to pubic symphysis. (C) An x-ray view of the abdomen shows the apices to pubic symphysis in the thoracic and abdominal regions.

Pre-exposure positioning

- If the IR size allows, place inside tray located underneath incubator. If the IR does not fit, wrap or cover the IR and place directly under the neonate patient.
- Adjust the patient and center the chest and abdomen to the IR.
- Ensure the four (4) borders (top, bottom and two sides) of the IR include the anatomy of interest.
- Have the nurse move the infant's arms away from the body or over the head, bring the legs down and away from the abdomen, and adjust pelvis flat to avoid rotation. The arms and legs may need to be held by a nurse, who should wear a lead apron.
- If possible, keep the head and neck of the infant straight so that the anatomy in the upper chest and airway is accurately visualized. However, straightening the head of a neonate in the supine position can inadvertently advance an ETT too far into the trachea. Sometimes it is more important to leave the head of an intubated neonatal patient rotated in the position in which the infant routinely lies to obtain accurate representation of the position of the ETT.
- Direct the central ray perpendicular to the midpoint of the chest and abdomen along the MSP with 40 inches (102 cm) SID (Fig. 22.55A).
- Place side marker in the collimated exposure field.
- Adjust radiation field on the collimator to include from apices to pubic symphysis (Fig. 22.55B).
- When the neonate's chest and abdomen rise to their maximum heights for full inspiration, make the exposure.
- Shield the patient accordingly.

Image evaluation

- Anatomy from apices to pubic symphysis in the thoracic and abdominal regions (Fig. 22.55C).
- Evidence of proper collimation and presence of side marker placed clear of anatomy of interest.
- No motion.
- No blurring of lungs, diaphragm, and abdominal structures.
- No rotation of patient.

Tips for performing chest and abdomen line placement with sterile field

Approach the patient with caution to avoid compromising the sterile field with equipment (Fig. 22.56). Communicate with the scrub physician to request one of the following:

FIG. 22.56 Mobile unit positioned over sterile field.

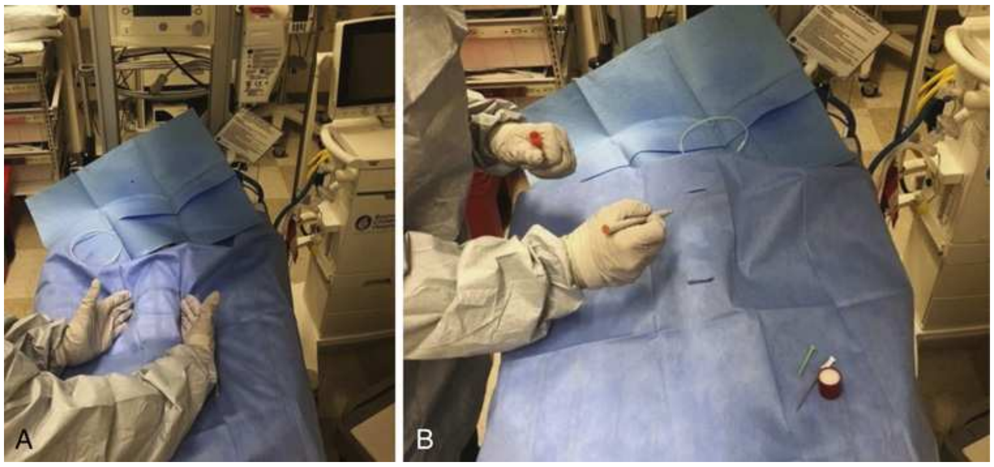

FIG. 22.57 (A) Scrub physician molding the patient's body habitus and shape with the sterile drape. (B) Scrub physician using sterile marker to draw boundary points or region of interest.

(A) A physician wearing scrubs is molding the patient's body habitus and shape with the sterile drape. (B) A physician wearing scrubs is using a sterile marker to draw boundary points or regions of interest on the drape.

- Ask the neonate PICC scrub physician to mold the patient's body habitus with the sterile drape to accentuate the shape of the neonate's body (Fig. 22.57A).
- Ask the neonate PICC scrub physician to use a sterile marker and draw boundary points or region of interest (Fig. 22.57B).

Adjust technical factors to clearly demonstrate the PICC/CVC line and tip placement.

If the tip of the catheter is not in the correct location, the line is re-positioned and a follow-up image is expected.

Simulation: Practicing in a Safe Environment

Radiography in the NICU at any institution in lieu of experience can be somewhat intimidating to a new or student radiographer. Practicing simulated exams in a safe environment is an excellent way to achieve positive outcomes without the real-time environment stressors of the NICU (e.g., phones ringing, compromised neonates, alarms, stressed clinicians, worried parents, and sterile fields). Simulation in a *safe environment* can be achieved using a neonate doll, a portable x-ray machine, and a neonate bed (Fig. 22.58). Similar to using a phantom in adult radiography in the exposure lab, simulation is an excellent way to develop good radiography habits before heading to the NICU to perform images on the live neonate population. A simulation workshop can go a long way to improve image quality and develop technical skills to create a timely approach to any neonatal exam. A simulation lab in a safe environment can exponentially improve centering, collimation, and positional issues with neonates. According to the well-known educator Edgar Dale, who developed the *Cone of Learning* theory, “actively doing and simulating the real experience” results in a retention rate of 90% for up to 2 weeks later. Important elements to consider during simulation training include soft tissue positional landmarks, minimizing artifacts, adjusting technical factors, collimation, shielding, developing a team-based approach, verifying orders, reducing infection, and the importance of standardized protocols.

Selected Pediatric Conditions and Syndromes

Cystic Fibrosis

Cystic fibrosis (CF) is an autosomal recessive disorder of the exocrine system caused by mutations located on chromosome 7. Generally speaking, these mutations affect the sodium and chloride ion transport system, which operates at the surface level of epithelial cells, resulting in thick mucus that cannot be cleared. These cells line the airways, sweat glands, GI tract, and GU system. The organ systems most impacted are the lungs, sinuses, pancreas, intestines, hepatobiliary tree, and spermatic ducts in the male (vas deferens), and reduced fertility rates in the female. There are approximately 30,000 CF patients in the United States and 70,000 worldwide. In the United States (U.S.), the median life expectancy for persons born with cystic fibrosis between 2013 and 2017 was 44 years of age or longer. As a result of current treatment strategies, 80% of CF patients should reach adulthood.

FIG. 22.58 Radiography students practicing mobile exam in NICU simulation lab.

One of the earliest manifestations of CF is meconium ileus in the neonate. Most patients are diagnosed in the first year, with 50% presenting with a chronic cough by 10 months. Pulmonary complications are the leading cause of morbidity and mortality with CF. In a healthy person, the surfaces of the respiratory tract are bathed in a salty surfactant that traps and, with the help of cilia, removes pathogens and foreign substances from the lungs. This system is compromised in the CF patient, allowing microbes such as *Pseudomonas aeruginosa, Staphylococcus aureus,* and *Haemophilus influenza* to flourish in stagnant mucus leading to inflammation and bronchoconstriction, ultimately causing irreversible lung damage. Due to its low radiation dose, chest radiography is the modality of choice for evaluating respiratory complications resulting from CF. The earliest sign of irreversible lung disease in these patients is bronchiectasis. Radiographic findings include bronchial thickening and dilation, peribronchial cuffing, mucoid impaction, and cystic radiolucencies (Fig. 22.59).


FIG. 22.59 AP chest of patient with CF.

Non-respiratory manifestations include a whole range of GI complications, from meconium ileus in neonates to adult gastroesophageal reflux and rectal mucosal prolapse. As the patient ages, GU complications include renal compromise, nephrolithiasis (3% to 6% of patients), and diabetic nephropathy. Musculoskeletal disorders include abnormal bone mineralization of unknown etiology and metabolic bone disease due to malnutrition and decreased lung function. Reproductive manifestations include late onset puberty (by 1 to 4 years), a 95% to 99% infertility rate in male patients due to blockage or absence of the spermatic ducts (vas deferens), and incomplete epididymides.

Depending on the course and severity of the disease, CF can develop into one of the most debilitating illnesses of adolescence. It is important that radiographers understand the challenges facing these teenagers.

Standard precautions for CF patients include the following:

1. Departments sending a CF patient for imaging must call ahead to place a room on hold.
2. Check-in sends the arriving patient immediately to the room on hold.
3. The patient is assigned a "fast pass," which pushes them to the front of the imaging queue.

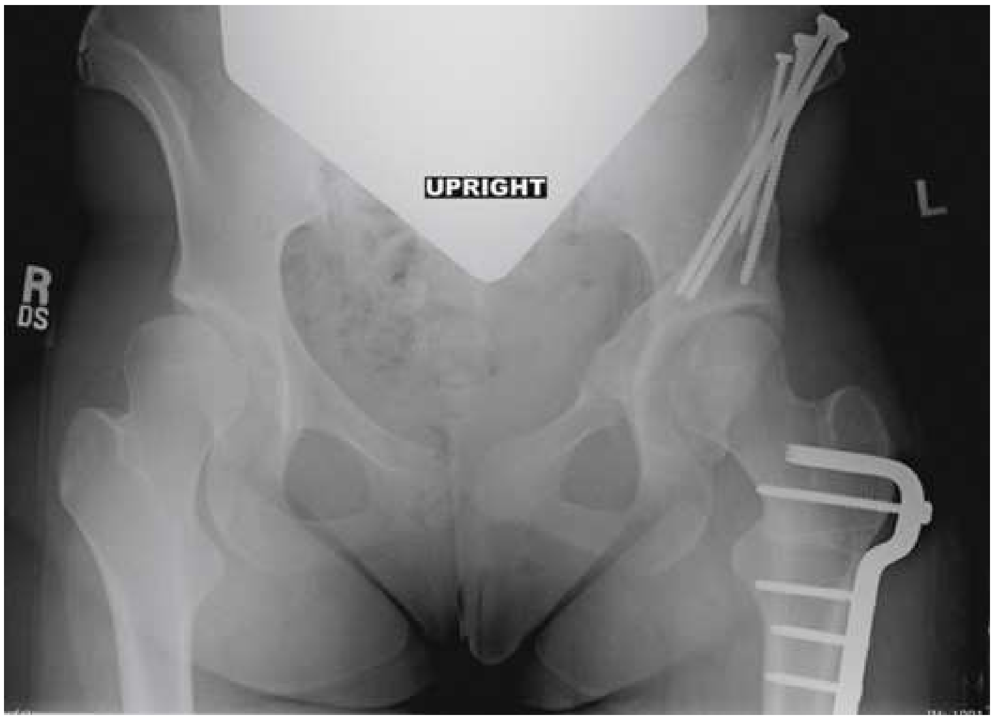

FIG. 22.60 Follow-up image post left periacetabular osteotomy surgery to correct DDH. The right femur also suffers from a lack of acetabular coverage due to a malformed acetabulum.

4. The patient is dressed appropriately (chest or KUB).
5. The radiographer is gowned and gloved and should attempt to maintain a 3-foot separation from the patient.
6. The radiographer, in the presence of the patient, should clean all surfaces that the patient will contact during the exam.
7. Gown and gloves must be replaced if the radiographer must leave the room.
8. Upon completion of the exam, the patient is sent back to the ordering department and all horizontal surfaces that were within 6 feet of the patient, as well as surfaces the patient contacted, must be disinfected.

Developmental Dysplasia of the Hip

DDH is the malformation of the acetabulum in utero and is usually the result of fetal positioning or a breech birth. The acetabulum fails to form completely, and the femoral head or heads are displaced superiorly and anteriorly. The ligaments and tendons responsible for proper alignment are often affected. Females are affected at a rate five times higher than males, the left hip is involved more than the right, and 5% to 20% of cases occur bilaterally. The clinical diagnosis is made when there is partial or complete displacement of the femoral head from the acetabulum relative to the pelvis. With infants younger than 6 months of age, the modality of choice is US due to its lack of radiation and because the cartilaginous nature of the hip is better visualized at this stage of development. US is used for infant follow-up until 6 months, at which time images can be used to confirm placement of the femoral head(s).

Radiographic exams used to diagnose DDH include the frog lateral and the von Rosen positions. There is some discussion among radiologists saying that because the frog lateral position is used to reduce the dysplasia, the von Rosen should be the preferred position. Treatment of DDH varies with the diagnosis. Subluxation of the hip in the neonate may be stabilized in weeks if the femora are abducted in flexion, aided by double and triple diapering. A dislocated hip, or hips suspected to dislocate easily, may be stabilized and immobilized by the use of a Pavlik harness worn for 1 to 2 months; more complex cases may require surgery and a spica cast. During follow-up imaging, care should be taken when the spica cast is removed to keep the legs abducted to ensure hip stability. Later interventions include periacetabular osteotomy surgery to correct the developmental dysplasia (Fig. 22.60).

Nonaccidental Trauma (Child Abuse)

Although no *universal* agreement exists on the definition of child abuse, the radiographer should have an appreciation of the all-encompassing nature of this problem. *Child abuse* has been described as "the involvement of physical injury, sexual abuse or deprivation of nutrition, care or affection in circumstances, which indicate that injury or deprivation may not be accidental or may have occurred through neglect." [2] Although diagnostic imaging staff members are usually involved only in cases in which physical abuse is a possibility, they should realize that sexual abuse and nutritional neglect are also prevalent.

It is mandatory in all states and provinces in North America for health care professionals to *report suspected cases of abuse or neglect*. The radiographer, while preparing or positioning the patient, may be the first person to suspect abuse or neglect (Fig. 22.61). The first course of action for the radiographer should be to consult a radiologist (when available) or the attending physician. After this consultation, the radiographer may no longer have cause for suspicion because some naturally occurring skin markings mimic bruising. *If the radiographer's doubts persist, the suspicions must be reported to the proper authorities, regardless of the physician's opinion.* Recognizing the complexity of child abuse issues, many health care facilities have developed a multidisciplinary team of health care workers to respond to these issues. Radiographers working in hospitals have access to this team of physicians, social workers, and psychologists for the purpose of reporting their concerns.

FIG. 22.61 A 7-year-old with loop marks, representative of forceful blows by a looped belt.

The ACR defines a skeletal survey as "a systematically performed series of radiographic images that encompasses the entire skeleton or those anatomic regions appropriate for the clinical indications." There are three indications for a skeletal survey according to the ACR: suspected nonaccidental trauma (abuse), skeletal dysplasias, syndromes and metabolic disorders, and neoplasms. Fractures in the first year of life are relatively rare, so their occurrence might warrant a skeletal survey to rule out child abuse. Although 64% of all reported cases of maltreatment with major physical injury occur in patients 0 to 5 years of age, those with radiologic evidence of abusive injury will be younger than 2 years of age. Pediatric imaging departments have specific protocols that protect the patient when there is suspicion or evidence of child abuse. The diagnosis of abuse becomes more likely when there is a discrepant history of minor trauma in a child with complex, multiple fractures. Although policies vary from institution to institution, the goal is always protection of the child. Nonaccidental traumas often present in the emergency room (ER) for other indications, and when imaged are found to have fractures of a suspicious nature. A scenario may go something like this:

1. Parent and 9-month-old infant are seen in the ER, where the infant presents with shortness of breath, wheezing, and low-grade fever for 2 days.
2. The patient is assigned to an exam room for nurse/doctor interview, assessment, and physical examination.
3. Routine standard-of-care chest x-rays are ordered to rule out pneumonia.
4. Radiographer alerts radiologist to the presence of what appears to be two healing posterior rib fractures (Fig. 22.62) and corner fractures (Fig. 22.63).
5. Radiologist consults with a child protection team and ER attending.
6. Hospital social services are called to conduct an interview with the parent.
7. The hospital's child protection team, ER attending, and social worker explain the findings to the parent. The family is then escorted, by security, to radiology for an immediate skeletal survey.

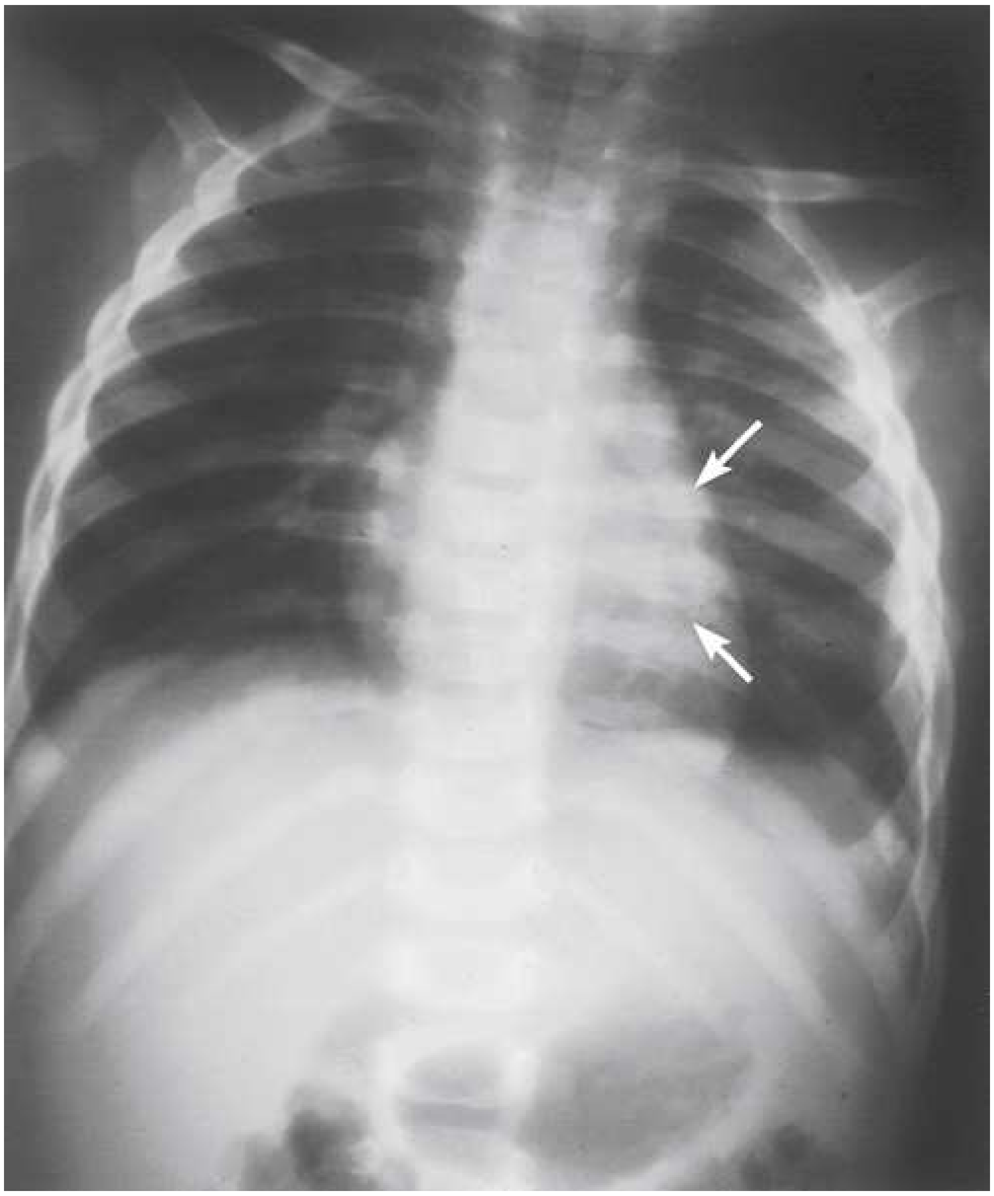

FIG. 22.62 Chest radiograph showing different stages of healing posterior rib fractures *(arrows)*.

Depending on the findings, the infant may be admitted for care or removed from the home by Child Protective Services. Children presenting with emergent head trauma would be admitted and transferred to a surgical ICU. The abuse of a child is so repugnant that the urge to judge the parents will almost be reflexive; try to resist this temptation and stay focused on the very difficult and emotional task of providing medical care to the patient. Give a thorough explanation of what the skeletal survey entails: the time involved, the special accommodations that are provided for their infant, and inform them that the infant will cry. Allowing the parents to participate in the exam is a judgment call; overly emotional parents may be more of a hindrance, whereas calm parents may help to soothe their infant. The parents who will not be helping should be escorted to a nearby waiting room. The survey can be accomplished quickly and efficiently with experienced radiographers.

FIG. 22.63 Images demonstrating physical abuse. Left and right corner fractures (*arrows,* A and B) and bucket-handle fractures (*arrow,* C) are considered classic indicators of physical abuse in children. The bucket-handle appearance is subtle and demonstrated only if the "ring" is seen on profile *(arrow).*

(A) An x-ray shows a fracture in the left corner. It is indicated by a white arrow in the left corner of the bone. (B) An x-ray shows a fracture in the right corner of the bone. It is indicated by a white arrow. (C) An x-ray shows a ring-like appearance below the bone. It is indicated by a white arrow.

Due to the medicolegal sensitivity of the skeletal survey and to expedite the exam, it is always best to have three radiographers working the exam: one immobilizes and positions; the second sets technique, positions, shields, collimates, and makes the exposure; the third supplies the two-person team with image plates (if CR) and immobilization devices, and also processes and assesses the quality of each image. A skeletal survey for nonaccidental trauma on infants younger than 1 year should be done on high-resolution mammography imaging plates using a dedicated processor. The table should have a pad with sheet, chucks, positioning sponges, pacifier, Sweeties (if not contraindicated), and gonadal shield. Have all supplies at the table or readily accessible within the room. The room should be warmed as appropriate, and warming lights used as required. All images are made with the infant lying on the IR (nothing is placed between the IR and patient). The patient can stay in a diaper, which will be removed when the abdomen/pelvis/femurs are imaged. Imaging should be timely and efficient, with repeats avoided. The radiologist accesses the images when the imaging is complete and will request additional images as needed.

Imaging protocol at Boston Children's Hospital

- For efficiency and for medicolegal reasons, two radiographers should be in the room when imaging.
- Only AP projections are required for long bones unless there is a positive finding (Boxes 22.2 and 22.3).
- Equivocal findings in a long bone may necessitate a lateral projection.
- Hand images should be slightly oblique rather than PA.
- Use mammography-imaging plates (increased resolution) and expose one body part per plate.
- Reduce motion by using the large focal spot, exposing only on expiration, with complete immobilization.
- All skeletal survey images should be done with 60 kVp (increased bony detail for CR-based systems).
- The 2-week follow-up exam does not require skull images.
- There should be nothing between the IR and the body part.
- Chest and abdominal images should overlap.

Box 22.2 is a skeletal survey protocol for nonincidental traumas in infants younger than 12 months and is tabletop at 102 cm SID, using a large focal spot with bone technique and mammography imaging plates. Box 22.3 lists radiologic findings.

Box 22.2 Survey skeletal projections

AP and lateral skull (a positive finding may require right and left laterals and Townes)
AP and lateral chest
Bilateral shallow obliques of chest to show ribs
Abdomen (to overlap with chest)
AP bilateral femurs
AP bilateral tibias
AP bilateral feet

AP bilateral humeri
AP bilateral forearms
Bilateral hands, oblique 20 degrees
Lateral C spine
Lateral L spine

A positive finding may require laterals of extremities.

Box 22.3 Specificity of radiologic findings

High specificity

Metaphyseal lesions
Rib fractures, especially posterior
Scapular fractures
Spinous process fractures
Sternal fracture

Moderate specificity [a]

Multiple fractures, especially bilateral
Fractures of different ages
Epiphyseal separations
Vertebral body fractures and subluxations
Fractures of the digits
Complex skull fractures

Low specificity (but common)[a]

Clavicle fractures
Long bone shaft fractures
Linear skull fractures
Subperiosteal new bone formation

[a] Moderate and low-specificity lesions become high when history of trauma is absent or inconsistent with injuries.

Used with permission of Dr. Paul Kleinman, Boston Children's Hospital, Boston, MA, United States.

Childhood Pathologies

Osteogenesis Imperfecta

OI means "imperfectly formed bone." It is a serious but rare heritable or congenital disease of the skeletal system (20,000 to 50,000 cases in the United States). It results from a genetic defect on two genes that encode for type 1 collagen, the main collagen of osseous tissue, tendons, teeth, skin, inner ear, and sclera of the eyeballs. Although people with OI may have different combinations of symptoms, they all have weaker bones. Some common symptoms of OI include the following:

- Short stature.
- Triangular-shaped face.
- Breathing problems.
- Hearing loss.
- Brittle teeth.
- Bone deformities, such as bowed legs or scoliosis.

There are several types of OI, which vary in severity and symptoms and are classified as types I to IV.

Type I

Type I is the most common and mildest form. In this type, the collagen is normal but is produced in reduced quantities. There is little or no bone deformity, although the bones remain fragile and easily broken. Teeth are prone to caries and are easily broken. The sclera of the eyes may have a purple, blue, or gray tint.

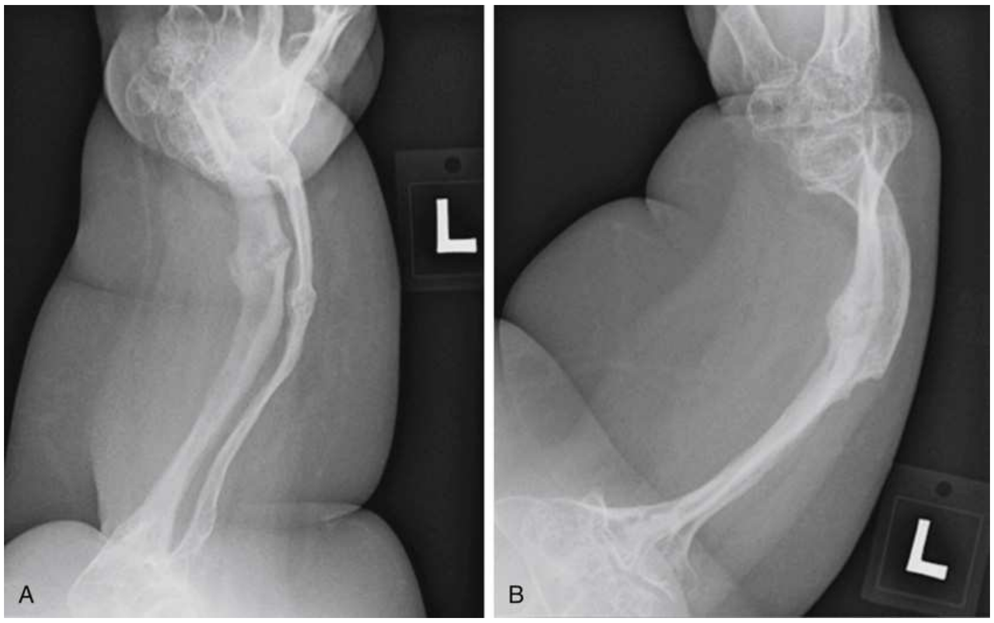

FIG. 22.64 AP (A) and lateral (B) projections of the left tibia and fibula. Patients with OI are not only fragile, but their anatomy can be misshaped, making it difficult to determine the correct position for AP and lateral projections.

Type II

Type II is the most severe form of the disease, and many infants do not survive. The collagen suffers from the genetic defect, and bones may break in utero (Fig. 22.64).

Type III

Type III patients have improperly formed collagen, often with severe bone deformities, as well as other complications. The infant is often born with numerous fractures and tinting of the sclera. Children are generally shorter and have spinal deformities, respiratory complications, and brittle teeth.

Type IV

Type IV is moderately severe, and the collagen defect and bones, although easily fractured, are only mildly to moderately deformed. Some people may be shorter than average with brittle teeth.

Use verbal communication when imaging the patient with OI, being careful not to physically move or position the body. Let the patient position themselves, possibly with the help of a parent, to avoid causing new fractures. The caregiver or parent should do the transfer and changing, and aid in positioning. The exam table will require a radiolucent pad with a sheet, a pillow, or a towel under the patient's head, and radiolucent positioning devices to help support the patient. The radiographer should communicate the exact positioning required and then review the position before exposure. Positioning devices may be employed, but the family should place them. The radiographer will use their positional skills with the radiographic tube (move tube, not patient) to obtain two projections differing by 90 degrees, thereby avoiding manipulating the part of interest. One of the reasons it is important to ask the patient, "Is there anything I should know about your medical condition that would help me to help you?" is because the patient might have OI without it being indicated on the exam requisition. Although the omission of such critical information is hard to believe, it does happen, which is why we have "time-outs" before invasive procedures.

Pathologic Fractures and Benign and Malignant Neoplasms

Long bones, ribs, and facial bones are susceptible to fibrous displacement of their osseous tissue, creating a benign condition called fibrous dysplasia. As these neoplasms grow, they erode the bone, causing the cortices to thin and weaken, which may lead to pathologic fracture. These dysplasias can become filled with fluid and are then known as bone cysts, often occurring in the upper ends of the humeri, femurs, and tibias of children, which are usually located beneath the epiphysis traveling down the metaphysis as they grow. The cysts often appear as incidental findings from another exam or following a pathologic fracture. Radiographically, they present as thin-walled lucencies with sharp boundaries.

FIG. 22.65 (A) A 14-year-old with a right, distal, tibial, pedunculated osteochondroma, and deformation of distal fibula. (B) Bilateral osteochondromas. Courtesy Dr. George Taylor, Radiology, Boston Children's Hospital.

Osteochondroma

One of three types of chondromas, also known as osteochondromas, does not appear in the fetal skeleton and is virtually nonexistent until the second year of life. Growing from the bone's shaft, the tumor widens the bone, weakening the cortex (Fig. 22.65). Covered in periosteum that is continuous with the bone shaft and with its tip covered by a proliferative cartilage cap, the exostosis usually grows away from the joint using a similar mechanism to that of the epiphysis; there is no involvement of the bone's epiphyseal ossification center. When the person reaches maturity, bone growth ceases as it does in the tumor. There can be secondary vascular and neural manifestations; the patient can present with pain and swelling or, alternately, the patient may be asymptomatic.

Aneurysmal bone cyst

Aneurysmal bone cysts (ABCs) occur in children and young adults and have an unknown etiology. Secondary ABCs make up about 50% of all cases, and there is preponderance in females. The most commonly affected sites are both long and short tubular bones (Fig. 22.66A), neural arches of the vertebral bodies, pelvic, and facial bones. The cyst is composed of blood and connective tissue with connective tissue predominating as the ABC ages (see Fig. 22.66B). The most characteristic radiologic finding is a thin shell of bone containing the dilated cyst. ABCs are classified into five types, I through V, and should be removed immediately due to their potential for rapid and extensive damage.

Osteoid osteoma

A small, benign, ovoid tumor rarely exceeding 1 cm in diameter, osteoid osteomas occur most commonly in the tibia, femur, and the tubular bones of the hands (basal phalanges) and feet, including their respective epiphyses (Fig. 22.67A). About 90% of these lesions occur in the first two decades of life. Radiographically, they appear as a well-circumscribed radiolucency with a density at the center (nidus) in the midst of extensive bony thickening and sclerosis. These tumors are hard to penetrate radiographically and may require an increased technique. Although the lesion rarely exceeds 1 cm in diameter, the sclerosis that accompanies it can reach to 2 cm. A lesion larger than 2 cm is most likely an osteoblastoma. Treatment of osteoid osteomas includes, but is not limited to, tetracycline localization in the nidus. Radiofrequency (RF) ablation is another treatment option, in which an electrode tip at 90-degree centigrade is placed into the nidus for 6 minutes (see Fig. 22.67B).

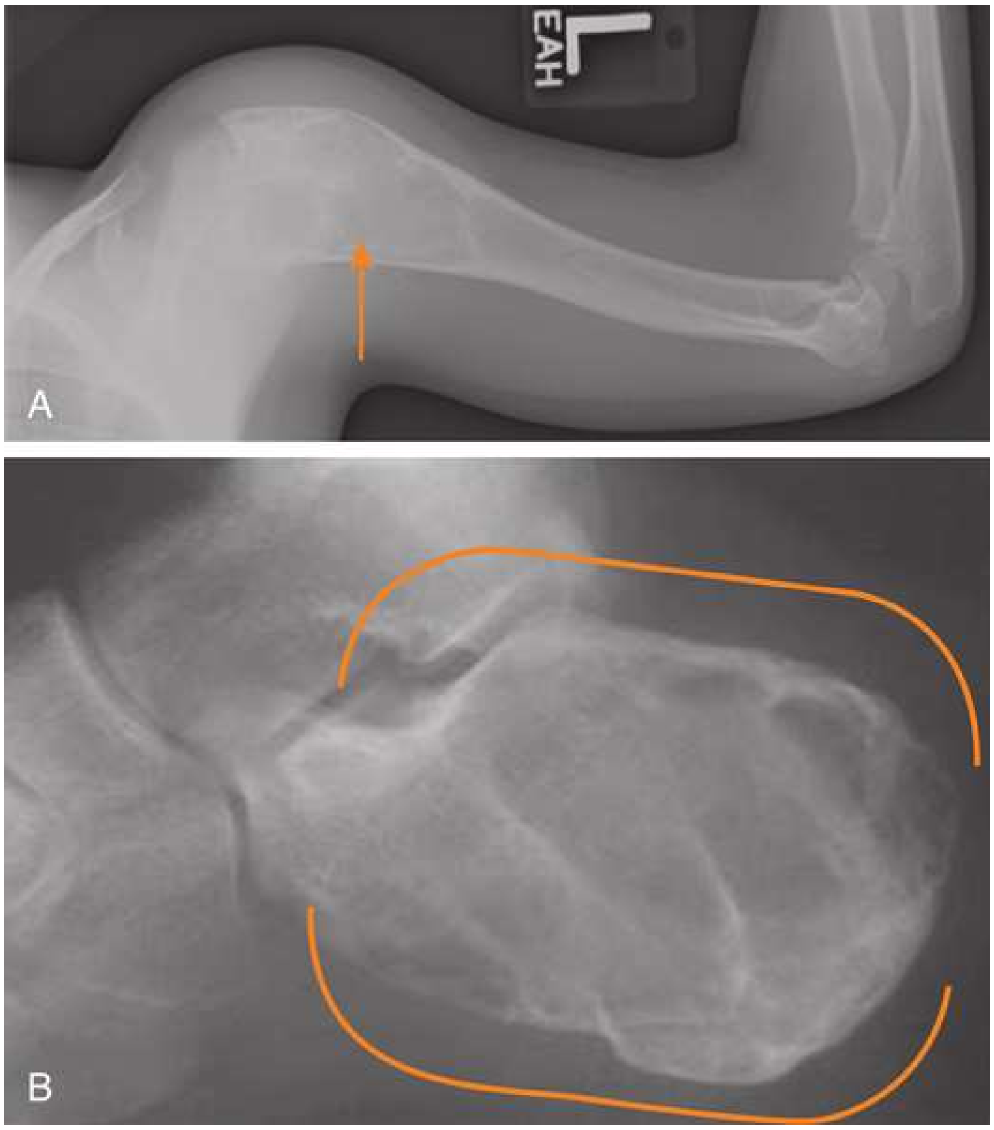

FIG. 22.66 (A) ABC of the left proximal humerus *(orange arrow).* (B) ABCs in the tarsus *(orange parentheses).*

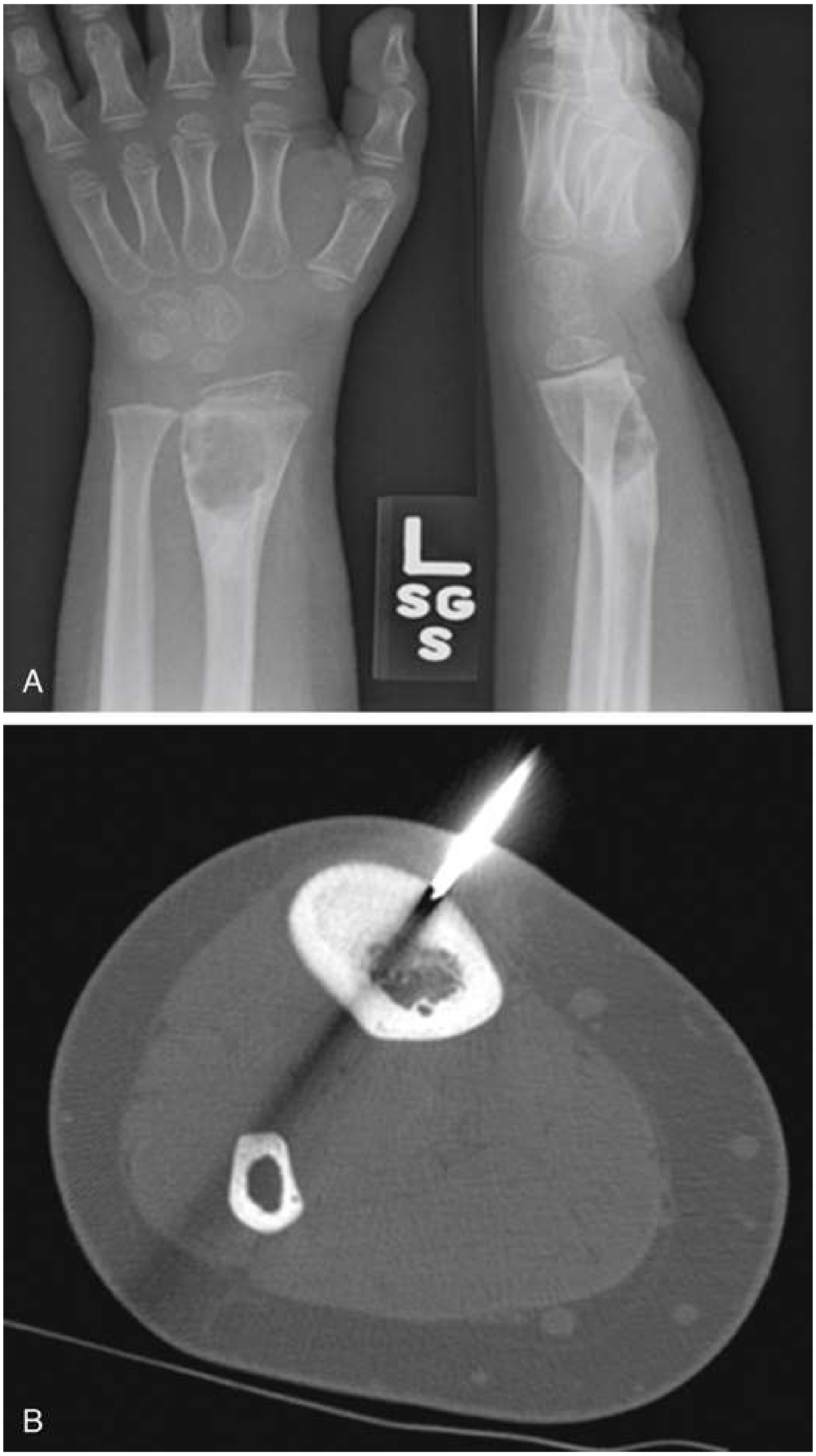

FIG. 22.67 (A) AP and lateral views of distal radial osteoid osteoma. (B) Radio frequency ablation of an osteoid osteoma of the right tibia.

(A) An x-ray shows an anterior view of a broad hand with tubular bones. (B) An x-ray shows the lateral view of a broad hand with tubular bones. (C) An x-ray shows a circular grey region with two irregularly shaped white regions on it.

Malignant neoplasms

Osteosarcoma

Alternatively known as osteogenic sarcoma, it is the most common of the primary malignant tumors. Usually appearing in the second decade of life, it often begins in the center of the metaphysis, enlarges, and destroys the bone. Males seem to have a slight preponderance. The most common sites are the metaphysis of the proximal humeri and proximal tibias, as well as the femurs. The earliest presentations of this rapidly growing tumor are pain and swelling at the site. Pathologic fractures are not uncommon, and systemic signs attesting to its rapid growth are weight loss, anemia, and dilated surface veins at the site. The chief radiologic finding is an increase in ossification of the tumor tissue, which may present as an irregularly radiolucent, multiloculated mass. Metastases occur early, usually in the lungs, and chemotherapy increases the risk for secondary tumors, both sarcomas and osteosarcomas, after the treatment of the primary tumor. Bone sarcomas show a chromosome band that supports a recessively transmitted predisposition for this tumor and for retinoblastomas.

Ewing sarcoma

Occurring usually at the end of the first decade or beginning of the second, Ewing sarcoma is the second most common malignant tumor in children, and almost any bone in the body may be affected. These tumors grow most frequently in the ilium, femurs, humeri (Fig. 22.68), and tibias. Unlike most of the primary malignancies, Ewing sarcoma does present with fever, weakness, pallor, and lassitude in contrast to most of the primary malignancies. It is not an osteogenic tumor, and the distinctive radiographic findings are the normally opaque spongiosa and cortical bone replaced by more radiolucent tumor tissue with bone destruction, layered periosteal new bone (onion-skin), and overlying large and swollen soft tissue mass.

Pneumonia

Pneumonia is the most frequent type of lung infection, resulting in inflammation with compromised pulmonary function. It ranks sixth among the leading causes of mortality in the United States and is the most lethal nosocomial infection. Viruses are the most common cause of both upper and lower respiratory tract infections, whereas bacteria account for about 5% of all childhood pneumonias. In children younger than 2 years old, 90% of cases are viral, with the respiratory syncytial virus responsible for about one-third of these cases. Viral or interstitial pneumonias are more common, are usually less severe than bacterial pneumonia, and are frequently caused by influenza. Radiographic findings are minimal, and the infection is usually confirmed clinically or through serologic tests.

Although chest images are important in determining the location of the inflammation, they are not definitive as to whether the causative agent is viral or bacterial; some knowledge of the suspected pathogens and their radiographic appearances can offer clues (Fig. 22.69). Pneumonias appear as soft, patchy, ill-defined alveolar infiltrates or pulmonary densities. The inflammation may affect the entire lobe of a lung (lobar pneumonia), a segment of a lung (segmental pneumonia), the bronchi and associated alveoli (bronchopneumonia), or the interstitial lung tissue (interstitial pneumonia).

FIG. 22.68 Neutral view of right humerus postosteotomy and plating for Ewing osteosarcoma. (*Orange arrow* points to osteotomy site.)

The single most common pneumonia-producing bacterial agent in school-age children is *Mycoplasma pneumonia* (present in 40% to 60% of cases). Pneumococcal (lobar) pneumonia is the most common bacterial pneumonia, probably because the bacteria are present in our healthy throats. It presents on the image as a collection of fluid in one or more lobes; the degree of segmental involvement can usually be identified with a lateral view. Staphylococcal and streptococcal bacterial pneumonia are far less common. Staphylococcal pneumonia occurs infrequently except during epidemics of influenza, when it can be common and life-threatening, especially in infants. Streptococcal pneumonia is even rarer, accounting for less than 1% of all hospital admissions for acute bacterial pneumonia. Radiographic findings are localized around the bronchi, usually of the lower lobes.

Mycoplasma pneumonia is caused by mycoplasmas and is most common in older children and young adults. This disease appears as a fine reticular pattern in a segmental distribution, followed by patchy areas of air space consolidation. In severe cases, the radiographic appearance may mimic tuberculosis. The morbidity rate associated with mycoplasma pneumonia is very low, even when the disease is not treated. Aspiration (chemical) pneumonia or chemical pneumonitis is caused by aspirated vomitus and appears on the image as densities radiating from either hilum.

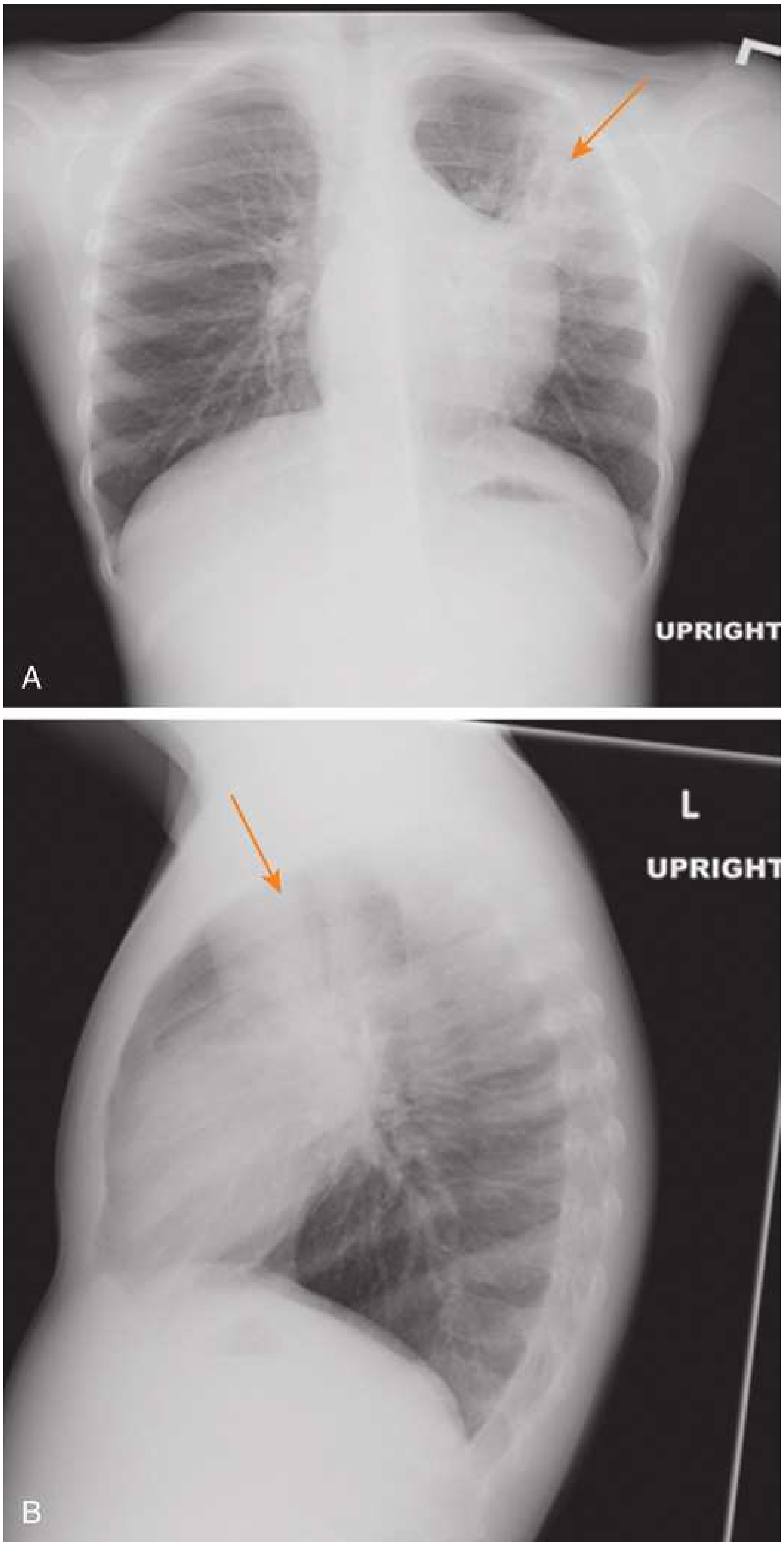

FIG. 22.69 PA (A) and lateral (B) chest images of an adolescent with pneumonia *(orange arrows).*

(A) An x-ray view of the posterior chest shows hazy white regions near the heart. It is indicated by an orange arrow.
(B) An x-ray view of the lateral chest shows a hazy white region on the left. It is indicated by an orange arrow.

One of the most common challenges facing the radiologist is to rule out pneumonia. In most cases, the PA and lateral positions of the chest will suffice. In equivocal cases, the decubitus views are helpful in clarifying a suspected pulmonary abnormality. Images should be made with short exposure times (large focal spot) and must be inspiratory. Artifacts, possibly leading to a false positive, can be avoided with careful patient positioning, a peak inspiratory image, and ensuring the neonate's head is midline without any rotation. Pathologic conditions, such as CF and asthma with atelectasis, will distort the lung fields and could lead to an erroneous finding of pneumonia. Comparison to earlier images is essential to rule out residual or recurrent problems that might suggest an underlying abnormality. A pneumatocele (a thin-walled, radiolucent, air-containing cyst) is the characteristic radiographic lesion and is more typically seen in children. In later stages of the disease, these can enlarge, forming empyemas.

Progeria

Progeria is a rare combination of dwarfism and premature aging also known as Hutchison-Gilford syndrome. It is one of the many genetically based premature aging disorders that occur sporadically, with an incidence of 1 in 8 million births and a male-to-female ratio of 1.5:1. There is a strong racial susceptibility for Caucasians, who represent 97% of patients. Derived from the Greek, meaning "prematurely old," the progeria patient ages up to 7 years for every 1 year of life. These children fall within the expected growth percentile at birth, but after the first decade, they have only achieved the stature of a 3-year-old. The child's average life span is 13 years (range 7 to 27 years).

There is no cure for progeria, and death is mainly due to cardiovascular complications like myocardial infarction or congestive heart failure. Symptoms include scleroderma, loss of hair and subcutaneous fat, short stature (average 100 cm), low weight (12 to 15 kg), abnormal dentition, an increased prominence of scalp veins, coxa valga, and osteopenia (Fig. 22.70). Progeria is probably an autosomal recessive syndrome affecting the *LMNA* gene that produces a defective lamina A protein, resulting in a weakened cell nucleus. This unstable nucleus apparently results in premature aging.

Scoliosis

Scoliosis is an abnormal lateral curvature of the spine in excess of 10 degrees, which has a component of rotation, bringing the ribs anteriorly in the direction of the rotation, and affecting lung function in more serious cases (Fig. 22.71). The scoliotic curve may be simple or may involve a compensating curve that results in an "S" shape; the spinal curvature may occur on the right, the left, or both sides. In the greater population, between 3 and 5 children out of every 1000 develop a scoliosis that requires treatment. It affects girls about seven times more than boys, and idiopathic scoliosis tends to run in families, although no genetic link has been found. Scoliosis occurs, and is treated, as three main types.

FIG. 22.70 A progeria patient with osteopenia.

Idiopathic

The most common type occurs mostly in preadolescent and adolescent girls; however, most cases either remain asymptomatic or the curves are too small to require treatment. Idiopathic scoliosis is comprised of three subtypes.

Adolescent. Represents the majority of cases, mostly in girls between 10 and 13 years old, and often requires no treatment.
Juvenile. Represents about 10% of cases in the age range of 3 to 9 years.
Infantile (early onset). Accounts for about 5% of cases, occurring in boys from birth to 3 years old, and is mostly self-resolving.

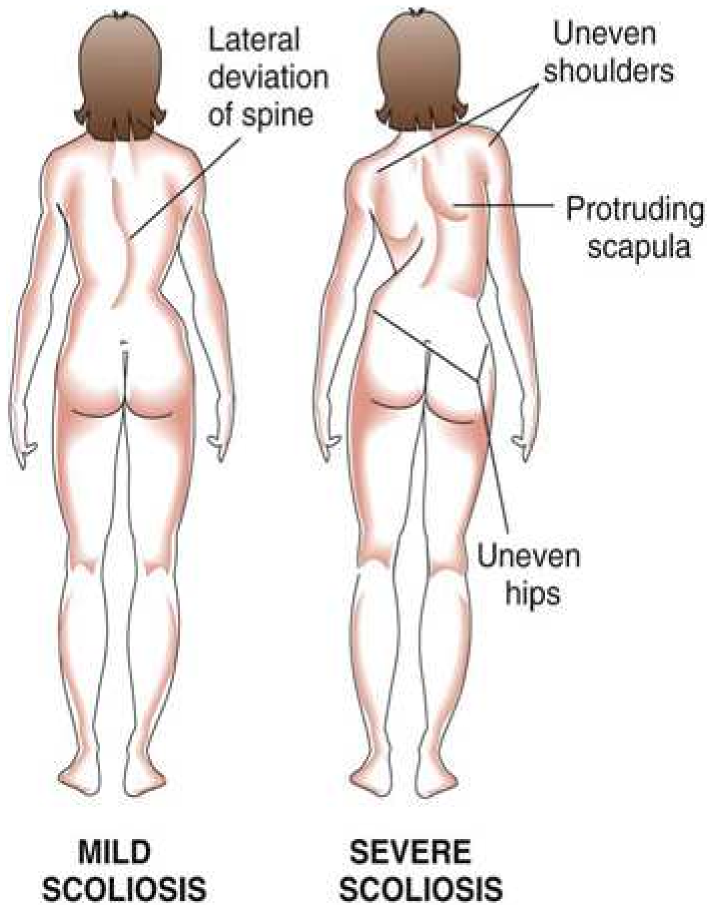

FIG. 22.71 Symptoms that suggest scoliosis. From VanMeter: *Gould's pathophysiology for the health professions*, ed 5, St. Louis, 2014, Elsevier.

Neuromuscular

This refers to scoliosis that is associated with disorders of the nerve or muscular systems (e.g., cerebral palsy [CP], spina bifida, muscular dystrophy, or spinal cord injury).

Congenital

This is the least common form and occurs in utero between 3 and 6 weeks, causing partial, missing, or fused vertebrae.

Scoliosis imaging

Usually indicated are standing *erect* AP and lateral images of the entire spine from the EAM to the SI joints at 182 cm (see Volume I, Chapter 9, scoliosis projections, for references). The first PA image is without breast shields to allow for visualization of the ribs and spine in their entirety. The lateral view should always be protected, regardless of the patient's sex, by the use of a shadow shield to cover the face and breast tissue while being careful to avoid clipping the anterior C-spine and the anterior L-spine in lordotic patients, and must include the EAM. In subsequent PAs, breast tissue should be protected for both male and female patients by using a shadow shield; the inexperienced radiographer should consult the patient's previous PA images to determine the location and severity of the curve before shielding (Fig. 22.72).

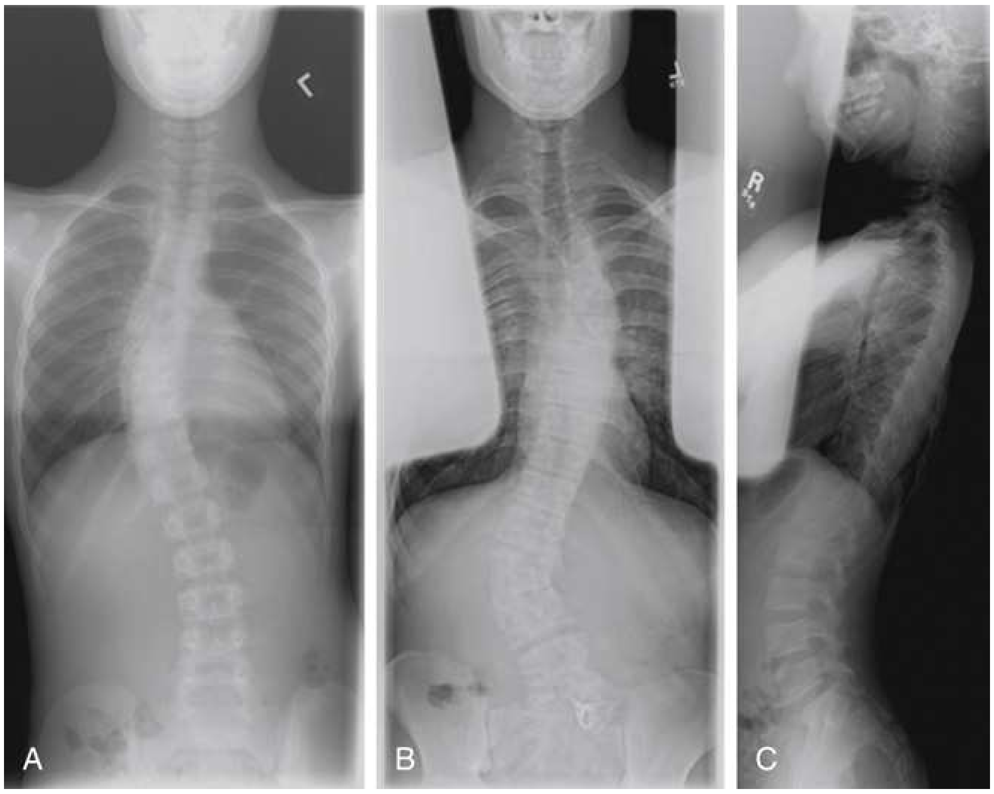

FIG. 22.72 (A) Often the initial PA scoliosis image is made without shielding to reveal the relationships of spine, ribs, and pelvis. (B) Follow-ups require breast shields. (C) Shadow shields for breast tissue and eyes and a secondary stand-shield are used with all lateral views unless ordered otherwise.

Filtration should always be used to compensate for thickness and density differences of the C-spine and thoracic cavity, respectively. The C-spine filter is placed at the x-ray tube window, and its projection should begin at the top of the shoulders and extend superiorly. The thoracic filter, again mounted at the x-ray tube window, begins at the mid-horizontal line and extends superiorly. A hypersthenic patient will dictate the need for additional C-spine compensating filters. The patient should remove all piercings, be undressed, wearing only underwear or boxers (check to make sure females have removed their bras), a hospital gown, and socks. Posture should be as the patient normally carries themselves and erect. Sitting images are more involved and require care in patient transfer to the special scoliosis-imaging chair. Holding help will most likely be required, and the lateral position should have a positioning sponge between the patient's back and the holder for support. The patient's pelvis should be as close to the grid or sponge as possible. This can be difficult with CP patients, as they tend to slide away from a support and may require that their knees be held so they cannot slide forward. If the patient is in a wheelchair with removable sides, they can be imaged in their chairs, but great care should be made to maintain *erect* posture. Make every attempt to shield these patients, although breast protection may not be possible due to the severity of the curve(s) and pelvic structure. A more advanced modality is the slot-scan EOS system (Biospace Med, Paris, France), which is covered later under "Advances in Technology."

Cobb angle, patterns of scoliosis, and estimation of rotation

The degree of curvature is measured from the PA view using the Cobb method. The image is examined to see what type of curve is present—acute (possible fracture?), smooth and arcuate, lumbar or thoracic, single or double—and whether there are any rib or vertebral anomalies. To measure the Cobb angle, one identifies the curve's superior and inferior end vertebrae, which are the two vertebrae that tilt most severely toward the concavity of the curve. Straight lines are then drawn across the superior and inferior end plates of the curve's upper and lower end vertebrae; the lines extend toward the concavity. These lines will intersect off the image, making the Cobb angle impossible to measure, so to the right of the spine from each end plate line, extend a perpendicular line until they both intersect. The angle superior to the intersection represents the Cobb angle. Once the Cobb angle is determined, an estimation of the degree of rotation can be determined with reference to the vertebrae at the apex of the curve.

Lateral bends

Pediatric patients scheduled for surgery will have bending images to assess the rigidity and flexibility of the curve(s). A left thoracolumbar curve would be considered the major curve (structural) if it failed to correct with either right or left bends. The lumbar curve on the same patient would be considered a compensatory curvature (nonstructural) if it corrects on the right bend. Once the patient has reached skeletal maturity, curves of less than 30 degrees will not progress.

Skeletal maturity

In pediatric radiology, evaluation of skeletal maturity is made based on bone growth in an image of the left hand and wrist. In children with endocrine abnormalities and growth disorders, the determination of skeletal maturation (bone age) is important in their diagnosis and treatment. In clinical practice, bone age is most often obtained by comparing the image with a set of reference hand images from the atlas by Greulich and Pyle. This reference work is the result of a 1950s survey of a healthy, white, middle-to-upper class population. A study by Zhang [5] questioned the validity of using the Greulich and Pyle atlas for an ethnically diverse population and found that ethnic and racial differences in growth patterns exist at certain ages with both Asians and Hispanics; this was seen in both male and female subjects, especially in girls aged 10 to 13 years and boys aged 11 to 15 years. A recent paper by Tsai et al. [6] in *Pediatric Radiology* provides strong support for using fibular shaft length as a more accurate alternative to current methods for bone age estimation with infants aged less than 1 year.

Treatment options

Options for treatment of scoliosis range from observation and monitoring to physical therapy, bracing, casting, and surgery. Invasive treatments may include spinal fusion/instrumentation, dual posterior growing rods to control spinal deformity, rod lengthening for infantile scoliosis, thoracoscopic anterior spinal surgery and instrumentation, osteotomy, or a combination of surgical procedures.

Advances in Technology

Radiography

Although this technology has been available in Europe for some time, it has been approved in North America more recently. The EOS system (Biospace Med) (Figs. 22.73 and 22.74) for orthopedic imaging has three advantages over conventional x-ray-based systems according to the company:

1. Greatly reduces dose to patient.
2. Allows three-dimensional modeling for the evaluation of rotation, torsion, and orientation.
3. Imaging is always on-axis and distortion free.

EOS allows the slot-scan-based image to be made weight-bearing, sitting (without assistance), and without the need for stitching. Various clinical parameters useful in evaluating and developing a patient's path to recovery are calculated automatically, including a patient report with images. Lower limb modeling is not adapted for patients younger than 15 years. Spine modeling is not adapted for patients aged 7 and younger or for the following pathologies: supernumerary vertebrae, congenital deformities, and spondylolisthesis.

Magnetic Resonance Imaging

Many imaging centers routinely see young children before an MRI, incurring anesthesia costs, overnight admissions for infants, costs associated with sedation, anesthesia preparation, and recovery, and reduced patient and family satisfaction. To this end, BCH conducted two pilot studies during 2009 and 2010 to assess the feasibility of pediatric scans without sedation ("Try Without," unpublished); in the initial pilot, children between the ages of 5 and 7 were assessed, and in the second pilot, children from 4 to 6 years and infants 0 to 6 months were assessed. With adequate preparation and age-appropriate distractions, some children under the age of 7 remained still without sedation for 20 to 60 minutes. Results showed that 88% of children between the ages of 5 and 7 and 82% of children 4 to 6 years old including infants 0 to 6 months completed their scans without sedation. Since 2010, 3300 children have completed their MRI scans without sedation. You will see more of this cost/benefit/patient satisfaction analysis in the future of health care.

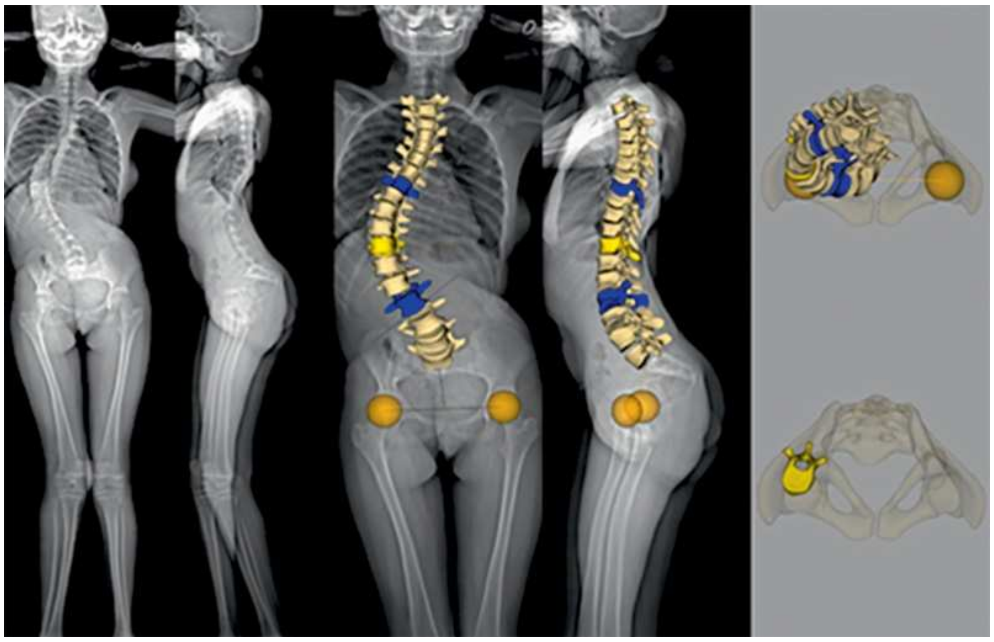

FIG. 22.73 EOS slot-scan standing scoliosis images of a 13-year-old female CP patient, with 3D remodeling showing axial rotation of individual vertebrae and large lateral ejection of the apical vertebrae. Courtesy EOS Imaging, Cambridge, MA.

An E O S slot scan shows the anterior view of the body with a laterally deviated spine. The lateral view shows a bend in the spine. Another anterior view and lateral show the vertebrae highlighted in yellow and blue. Two orange circles are on each femur.

FIG. 22.74 Patient positioned for simultaneous acquisition of PA and lateral full spine views for scoliosis.

A "noiseless" MRI system (Silent Scan, GE Healthcare, Waukesha, Wisconsin), which scans at a noise level of about 4 dB, compared to 86 to 110 dB with current technology, is available commercially; the reduced noise is the result of 3D MR acquisition, in combination with proprietary high-fidelity gradient and RF system electronics according to the company (Fig. 22.75). If this technology meets expectations, it could offer the potential for further reductions in sedation for younger patients.

Ultrasound

A wireless transducer (Siemens) is available that will transmit over a distance of 3 meters, which may assist with imaging infants and children. Called a point-of-care system, the transducer will expand the use of US in both interventional radiology and therapeutic applications. US has made huge advances through the years, but it is still largely constrained by bandwidth (0 to 50 MHz) and sensitivity. In a collaborative effort to overcome these limitations, Texas A&M University, King's College London, the Queen's University of Belfast, and the University of Massachusetts, Lowell, have developed a new meta-material that converts US waves into optical signals, making images with greater detail (0 to 150 MHz) possible, maintaining sensitivity, and allowing one to see deeper into tissues.

FIG. 22.75 MRI suite with Siemens Skyra scanner. This machine can be used for adults and children.

Computed Tomography

In pediatric patients, CT has been useful in diagnosing congenital anomalies, assessing metastases, and diagnosing bone sarcomas and sinus disease. Young children have difficulty following the instructions needed for a diagnostic scan. Suggestions regarding approach and atmosphere are presented at the beginning of this chapter. As in the care of any pediatric patient, the role of the CT radiographer is essential to the success of the examination; the radiographer must gain the respect and confidence of the young patient and the caregiver, if present. The CT scanner itself is an imposing piece of equipment that needs careful explanation to help allay the patient's fears. One of the most significant fears is claustrophobia, which can be reduced through distraction devices like virtual goggles and music and creative room décor (Fig. 22.76).

Toshiba has unveiled its Aquilion One Vision 640-slice CT scanner. This new system is equipped with a gantry rotation of 0.275 seconds, a 100-kW generator, and 320 detector rows (640 unique slices) covering 16 cm in a single rotation, with the industry's thinnest slices at 500 microns (0.5 mm). The One Vision uses an alternating focal spot that allows 16-cm *z*-axis coverage to be sampled twice, generating 640 slices in one rotation. The system can accommodate larger patients with its 78-cm bore and fast rotation, including bariatric patients and patients with high heart rates. More slices and shorter scan times reduce the possibility of patient motion (cardiac CT) and allow for scanning bariatric patients or those with larger anatomy. The faster scan times should reduce the number of patients requiring sedation. The Image Gently campaign has suggested CT protocols for reducing CT dose to patients.

FIG. 22.76 A Siemens Sensation CT scanner decorated for children.

Interventional Radiology

Image-guided, minimally invasive IR has dramatically changed the role of the radiology department in teaching and nonteaching hospitals and clinics. In the past, the justifications and rationales for radiology departments were diagnostic ones. Radiology departments with interventional staff now offer hospitals therapeutic services in addition to diagnostic procedures. This heightened awareness has largely resulted from the nature and efficacy of interventional procedures. Therapeutic procedures performed in IR provide an attractive alternative to surgery for the patient, parent, hospital, and society. A procedure performed in IR is much less invasive and expensive than one performed in the operating room. Shortened inpatient stays for IR procedures translate into economic savings for the parents and the hospital.

For simplicity, interventional radiology can be divided into vascular and nonvascular procedures. Vascular procedures are generally performed in angiographic suites. During these therapeutic interventions, angiography and ultrasonography are also performed for diagnostic and guidance purposes. Angiography can be arterial or venous; pediatric vasculature is well suited to both. IV injection of contrast media is favored in infants because their relatively small blood volume and rapid circulation allow for good vascular imaging. In infants, hand injections are often preferred over power injections to help avoid extravasation. Intra-arterial digital subtraction angiography (DSA) (see Chapter 27) has become a valuable tool. DSA is performed using a diluted contrast medium, which can reduce pain. Road mapping is a software tool, available on newer angiographic equipment, that uses the *intra-arterial* contrast injection and fluoroscopy to display arterial anatomy—a useful tool for imaging tortuous vessels.

Vascular procedures can be neurologic, cardiac, or systemic in nature. Nonvascular procedures often involve the digestive and urinary systems; examples include the insertion of gastrostomy tubes to supplement the nutrition of pediatric patients and the insertion of cecostomy tubes in chronically constipated patients with spina bifida. Vascular access devices are of three types: non-tunneled, tunneled, and implanted. The selection of device is often determined by a combination of factors, including the purpose of the access and estimated indwelling time. The physician or patient may choose a particular device after assessing issues of compliance or underlying clinical factors.

Non-tunneled catheters are commonly referred to as *peripherally inserted central catheters (PICCs)*. They are available with single or multiple lumens. The insertion point is usually the basilic or cephalic vein, at or above the antecubital space of the nondominant arm. Multiple lumens are desirable when a variety of medications (including total parenteral nutrition) are to be administered (Fig. 22.77). These devices must be strongly anchored to the skin because children often pull on and displace the catheters, resulting in damage to the line and potential risk to themselves.

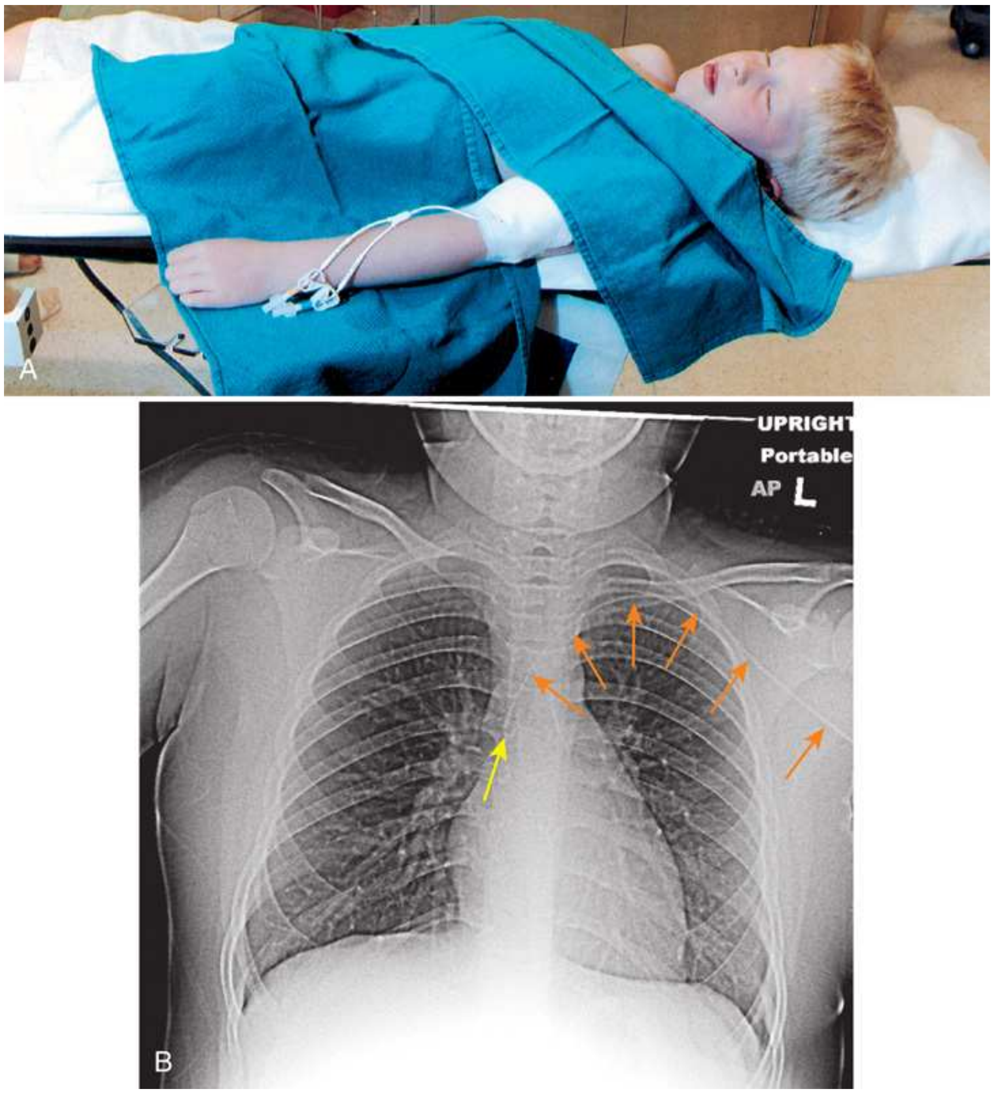

FIG. 22.77 (A) Postinsertion image of a double-lumen PICC in a 7-year-old boy (shown in the interventional suite). Conscious sedation was used for this procedure. (B) Left-sided PICC. *Orange arrows* track the double lumen PICC to its terminus *(yellow arrow)* in the superior vena cava.

(A) A boy is in a supine position with his eyes closed. His head is resting on a pillow. There are a couple of tubes and catheters around his arm. (B) An x-ray view of the chest shows a yellow arrow on the vertebra and a few orange arrows pointing at the vertebra and the anterior ribs.

Tunneled catheters, as with PICCs, can have multiple lumens. In contrast to PICCs, they are not inserted into the peripheral circulation; rather, they are inserted via a subcutaneous tunnel into the subclavian or internal jugular veins. The tunneling acts as an anchoring mechanism for the catheter to facilitate long-term placement (Fig. 22.78). Tunneled catheters are used to administer chemotherapy, antibiotics, fluids, and hemodialysis, and are referred to as Hickman lines when placed in subclavian or internal jugular veins.

Implanted devices are often referred to as ports. These are titanium or polysulfone devices with silicone centers attached to catheters. The whole device is implanted subcutaneously with the distal end of the catheter tip advanced to the superior vena cava or right atrium. A port is the device of choice for noncompliant patients, and children and adults who are undergoing chemotherapy, and for aesthetic purposes or long-term use, would rather not have the limb of a catheter protruding from their chest (Fig. 22.79).

FIG. 22.78 External appearance of tunneled, double-lumen central venous access device. These catheters are used for long-term therapy. Their short track to the heart can increase the risk of infection, necessitating proper care for maintenance.

Vascular access devices have dramatically changed the course of treatment for many patients in a positive way. Patients who would have previously been hospitalized for antibiotic therapy can now go home with the device in place and resume normal activity. The increased prevalence of these devices means that patients with vascular access devices are in the community and visiting radiology departments everywhere. PICCs have a smaller likelihood of introducing catheter-related infections; tunneled lines present a greater risk.

Radiographers must recognize vascular access devices and treat them with utmost care. They should report dislodged bandages and sites showing signs of infection (i.e., redness, exudate immediately). Catheter-related infections constitute the largest nosocomial source of infection; they can be life threatening and cost hospitals hundreds of thousands of dollars each year.

Postprocedural care vascular access devices currently represent a significant and ongoing challenge for all personnel who treat, manage, and come in contact with these patients.

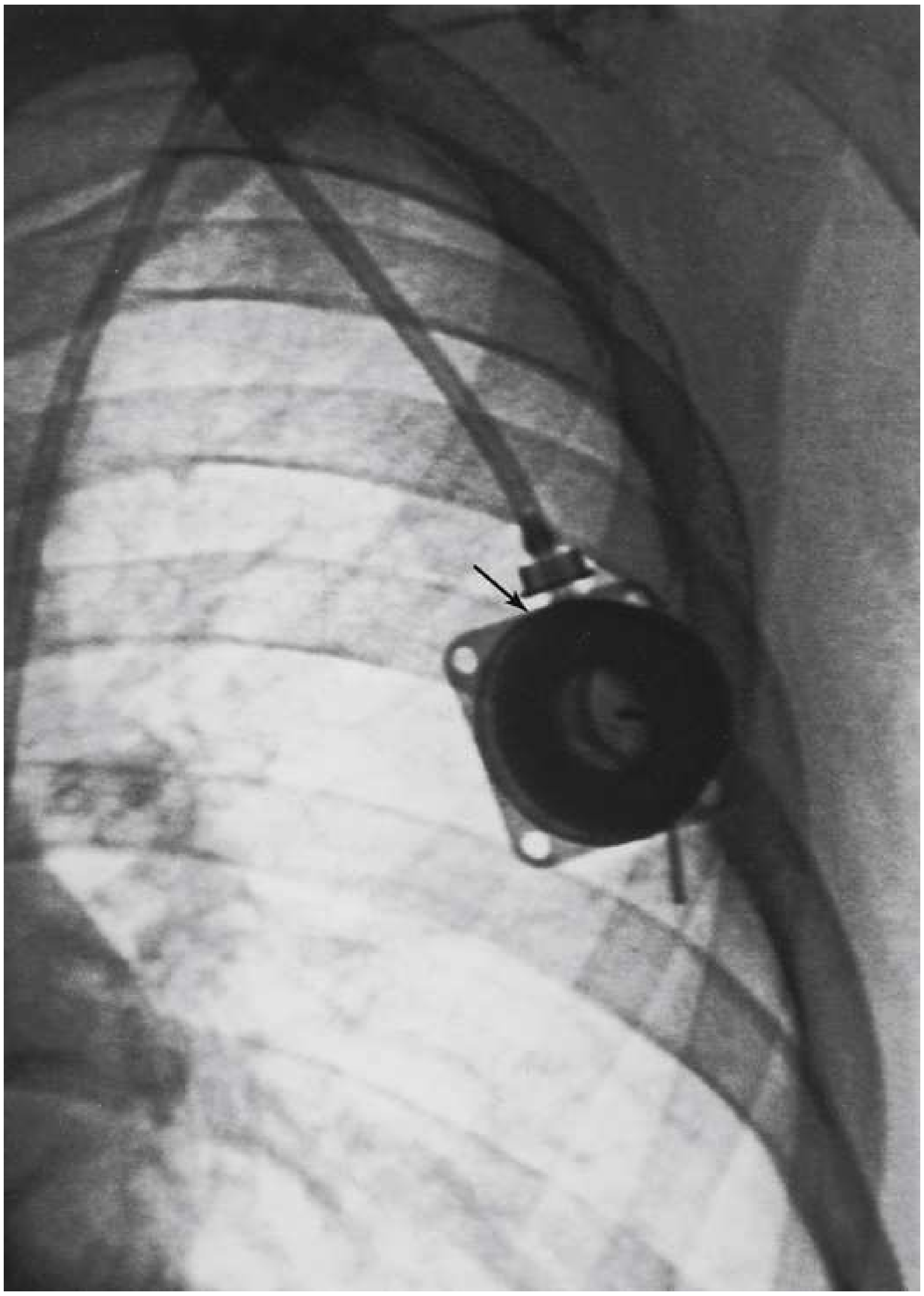

FIG. 22.79 Digital image of port *(arrow)*. Ports are vascular devices that must be accessed subcutaneously. They are preferred for active children and for aesthetic reasons.

Acknowledgments

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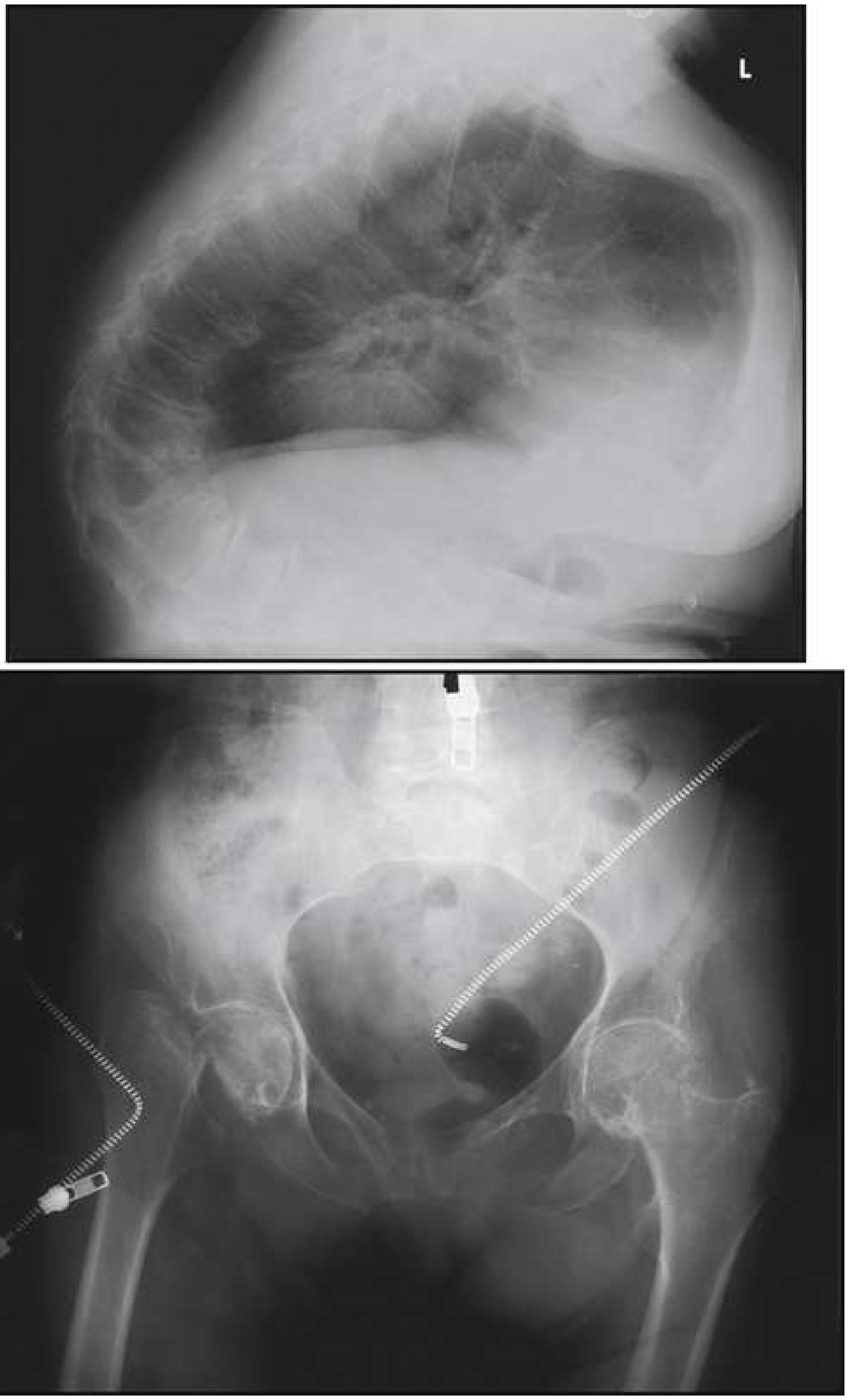
[a] Written by Jerry Tyree.

23: Geriatric Radiography



Cheryl Morgan-Duncan

OUTLINE

Geriatrics is the branch of medicine dealing with the aged and the problems of aging individuals. The field of *gerontology* includes illness prevention and management, health maintenance, and promotion of the quality of life for aging individuals. The ongoing increase in the number of people older than the age of 65 in the US population is well known. An even more dramatic aging trend exists among people older than 85 years. The number of people 100 years old is approximately 100,000 and increasing. Every aspect of the health care delivery system is affected by this shift in the general population. The 1993 Pew Health Commission Report noted that the "aging of the nation's society and the accompanying shift to chronic care that is occurring foretell major shifts in care needs in which allied health professionals are major providers of services." As members of the allied health professions, radiographers are an important component of the health care system. As the geriatric population increases, so does the number of medical imaging procedures performed on older adult patients. Students and practitioners must be prepared to meet the challenges that this shift in patient population represents. An understanding of geriatrics can foster a positive interaction between the radiographer and the older adult patient.

Demographics and Social Effects of Aging

The acceleration of the "gray" American population began when individuals born from 1946 to 1964 (known as the "baby boomers") began to turn age 50 in 1996. The number in the age 65 and older cohort is expected to reach 70.2 million by 2030 (Fig. 23.1). The US experience regarding the increase in the older adult population is not unique; it is a global one. As of 1990, 28 countries had more than 2 million persons older than 65, and 12 additional countries had more than 5 million people older than 65. The entire older adult population of the world has begun a predicted dramatic increase for the period 1995–2030.

Research on a wide variety of topics ranging from family aspects of aging, economic resources, and the delivery of long-term care states that gender, race, ethnicity, and social class have consistently influenced the quality of the experience of aging. The experience of aging results from the interaction of physical, mental, social, and cultural factors. Aging varies across cultures. Culturally, aging and the treatment of health problems in older adults are often determined by the values of an ethnic group. Culture may also determine the way the older person views the process of aging and the manner in which he or she adapts to growing older. The United States is a multicultural society in which a generalized view of aging would be difficult. Health care professionals need to know not only diseases and disorders common to a specific age group but also the disorders common to a particular ethnic group. An appreciation of diverse backgrounds can help the health care professional provide a personal approach when dealing with and meeting the needs of older adult patients. Many universities are incorporating cultural diversity into their curricula.

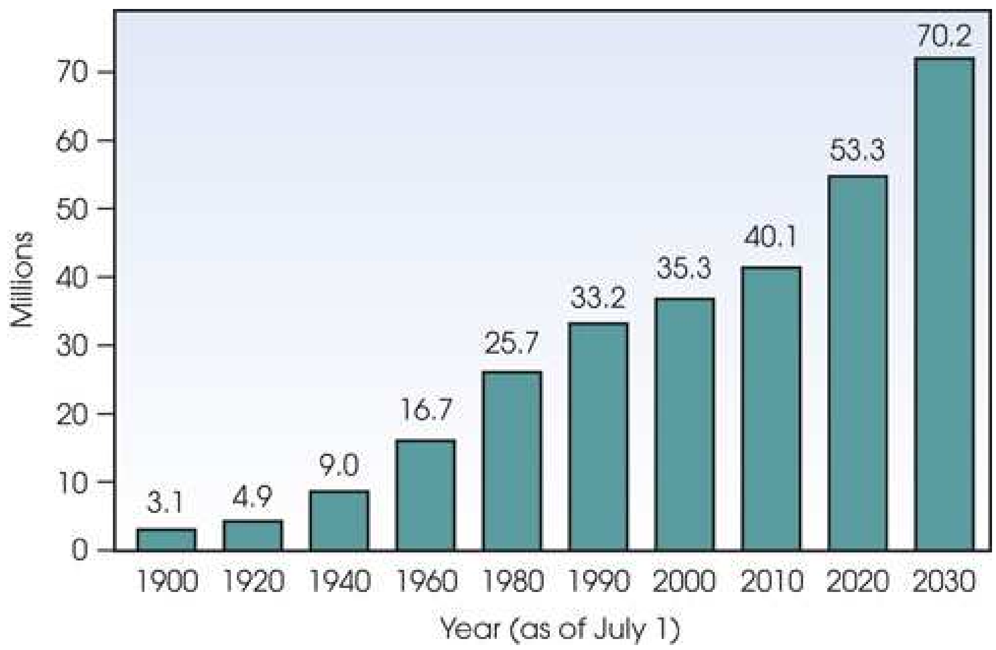


FIG. 23.1 Number of persons older than 65 years in millions, 1900–2030. Reprinted from U.S. Department of Commerce, Economics and Statistics Administration: 65+ in the United States. Washington, DC: U.S. Bureau of the Census; 1996.

A bar graph plots year (as of July) on the horizontal axis and millions on the vertical axis. The horizontal axis range from 19 00 to 20 30 with an interval of 20 years. The vertical axis range from 0 to 70 with an interval of 10. The values plotted on the graph are as follows: (19 00, 3.1), (19 20, 4.9), (19 40, 9.0), (19 60, 16.7), (19 80, 25.7), (19 90, 33.2), (20 00, 35.3), (20 20, 40.1), (20 20, 53.3), (20 30, 70.2). Note: All data is approximate.

The *economic status* of older adults varies and has an important influence on their health and well-being (Fig. 23.2). Most older adults have adequate income, but many minority patients do not. Single older adults are more likely to be below the poverty line. Economic hardships increase for single older adults, especially women. Of the population older than age 85, 60% is composed of women, making women twice as likely as men to be poor. By age 75, nearly two thirds of women are widows. Financial security is extremely important to an older adult. Many older adults are reluctant to spend money on what others may consider necessary for their well-being. A problem facing aging Americans is health care finances. Older adults often base decisions regarding their health care not on their needs but exclusively on the cost of health care services.

An increase in health care and the aging population go hand in hand. Heart disease, cancer, and stroke account for 7 of every 10 deaths among people older than 65. By 2025, an estimated two thirds of the US health care budget will be devoted to services for older adult patients.

FIG. 23.2 The economic status of older adults varies and is an important influence on their health and well-being.

Aging is a broad concept that includes physical changes in people's bodies over adult life; psychological changes in their minds and mental capacities; social psychological changes in what they think and believe; and social changes in how they are viewed, what they expect, and what is expected of them. Aging is a constantly evolving concept. Notions that biologic age is more critical than chronologic age when determining health status of the older adult are valid. Aging is an individual and extremely variable process. The functional capacity of major body organs varies with advancing age. Environmental and lifestyle factors affect the age-related functional changes in the body organs. Advancements in medical technology have extended the average life expectancy in the United States by nearly 20 years since the 1960s, which has allowed senior citizens to be actively involved in every aspect of American society. People are healthier longer today because of advanced technology; the results of health promotion and secondary disease prevention; and lifestyle factors, such as diet, exercise, and smoking cessation, which have been effective in reducing the risk of disease (Fig. 23.3). Most older adult patients seen in the health care setting have been diagnosed with at least one chronic condition. Individuals who in the 1970s would not have survived a debilitating illness such as cancer or a catastrophic health event such as a heart attack can now live for more extended periods, sometimes with various concurrent debilitating conditions. Although age is the most consistent and strongest predictor of risk for cancer and death from cancer, management of an older adult cancer patient becomes complex because of other chronic conditions, such as osteoarthritis, diabetes, chronic obstructive pulmonary disease, and heart disease. Box 23.1 lists the top 10 chronic conditions for people older than 65 years.

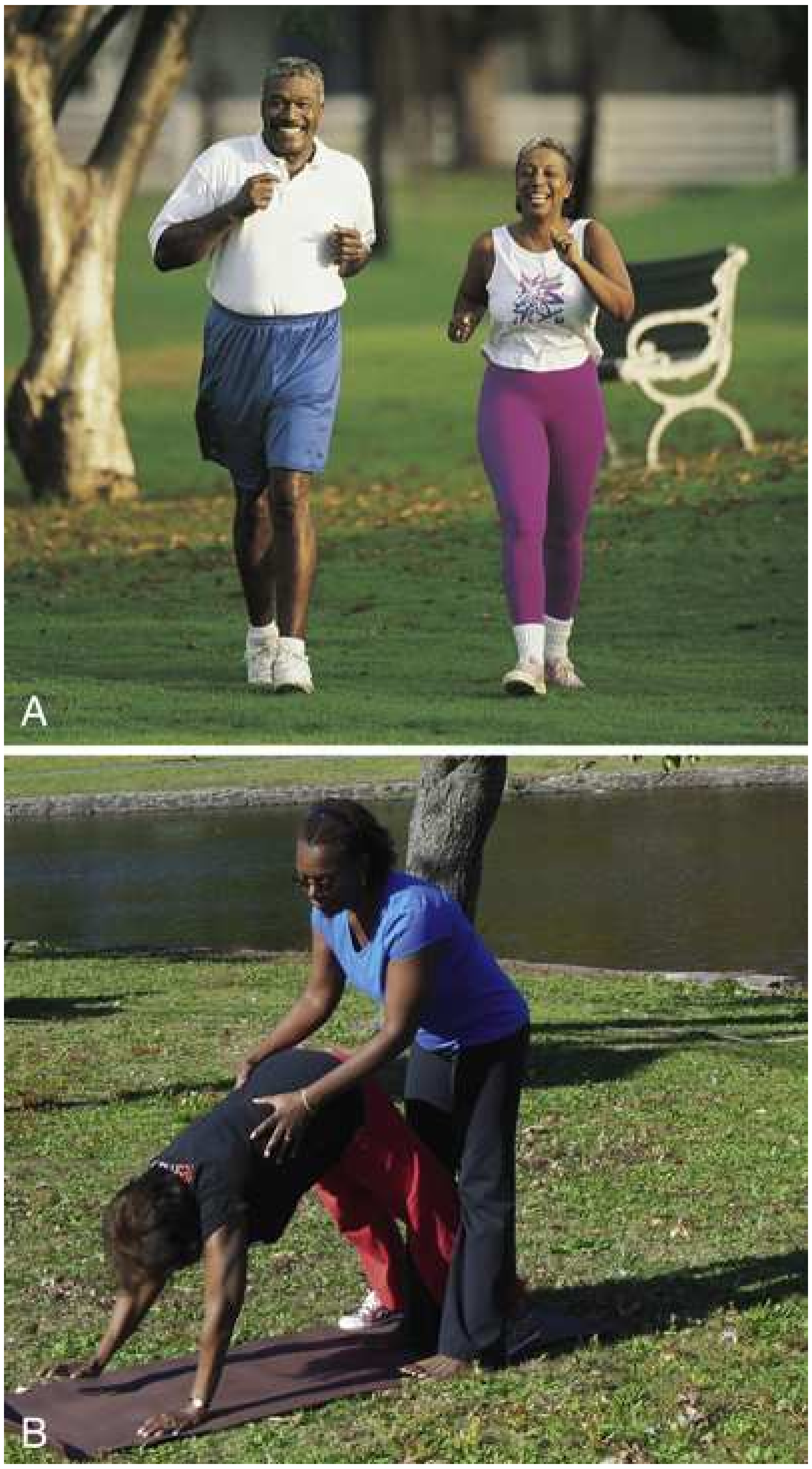


FIG. 23.3 (A) Lifestyle factors—such as diet, exercise, and smoking cessation—reduce the risk of disease and increase life span. (B) Yoga emphasizes breathing and slow, low-impact motion, which are good for those with arthritis.

BOX 23.1 Top 10 chronic conditions of people older than 65 years

- Arthritis
- Hypertension
- Hearing impairment
- Heart disease
- Cataracts
- Deformity or orthopedic impairment
- Chronic sinusitis
- Diabetes
- Visual impairment
- Varicose veins

Elder Abuse

Another emerging worldwide issue of older adults is elder abuse. It has been estimated that 2.1 million cases of elder abuse are reported each year. These numbers may be suspect, however, because studies estimate that only one in five cases is reported to the authorities. It is thought that elder abuse is approximately as common as child abuse. Elder abuse is defined as the knowing, intentional, or negligent act by a caregiver or any other person that causes harm or a serious risk of harm to a vulnerable adult. Box 23.2 lists the various types of abuse. The typical victim of abuse is older than 75 years. Most studies of elder abuse show the incidence to be gender neutral. Physical abuse is usually received from the victim's spouse (50%), less often from the victim's children (23%), and only in 17% of cases is the abuse from non-family caregivers.

The radiologic technologist should be aware that the presence of injury is not proof of abuse. It is important to be watchful for the warning signs of abuse or neglect listed in Box 23.3. The older adult is often embarrassed by the situation and may be hesitant to communicate his or her concerns for fear of retaliation. The technologist needs to employ excellent communication skills, accurate documentation, and quality radiographs, and the technologist should report any suspicions of neglect or abuse. Injuries sustained by older adult victims are typical to the head, face, and neck as well as defensive injuries.

Attitudes Toward the Older Adult

The attitudes of health care providers toward older adults affect their health care. Research indicates that health care professionals have significantly more negative attitudes toward older patients than younger ones. This attitude must change if health care providers are to have positive interactions with older adult patients. These attitudes seem to be related to the pervasive stereotyping of the older adult, which serves to justify avoiding care and contact with them, as well as the older adults being reminders of one's own mortality. *Ageism* is a term used to describe the stereotyping of and discrimination against older adults and is considered to be similar to that of racism and sexism. [1] Ageism emphasizes that frequently older adults are perceived to be repulsive and that distaste for the aging process itself exists. Ageism suggests that most older adults are senile, miserable most of the time, and dependent rather than independent individuals. For example, sometimes radiologic technologists and students assume that the elderly patient in their care is unable to raise his or her arms for the lateral chest x-ray and proceed to perform the examination with the arms partially raised. This results in the humeri and soft tissue superimposing the apices of the lungs. To avoid this, simply ask the patient to raise their arms, and offer assistance if necessary. The media have also influenced ongoing stereotypic notions about older adults. Commercials target older adults as consumers of laxatives and wrinkle creams, and other products that promise to prolong their condition of being younger, more attractive, and desirable. Television sitcoms portray the older adult as stubborn and eccentric. Health care providers must learn to appreciate the positive aspects of aging so that they can assist older adult patients in having positive experiences with imaging procedures. Education would enable health care providers to adapt imaging and therapeutic procedures to accommodate mental, emotional, and physiologic alterations associated with aging and to be sensitive to cultural, economic, and social influences in the provision of care for older adult patients.

BOX 23.2 Forms of elder abuse

Physical: inflicting physical pain or injury
Sexual: nonconsensual sexual contact of any kind
Neglect: failure by those responsible to provide food, shelter, health care, or protection
Exploitation: illegal taking, misuse, or concealment of funds, property, or assets of a senior
Emotional: inflicting mental pain, anguish, or distress through verbal or nonverbal acts
Abandonment: desertion of a vulnerable older adult by anyone who has assumed the responsibility for care or custody of that person
Self-neglect: failure of a person to perform essential, self-care tasks, which threatens his or her own health or safety

BOX 23.3 Warning signs of elder abuse

- Bruises, pressure marks, broken bones, abrasions, and burns may be an indication of physical abuse, neglect, or mistreatment
- Unexplained withdrawal from normal activities, sudden change in alertness, and unusual depression may be indicators of emotional abuse
- Bruises around the breasts or genital area may occur from sexual abuse
- Sudden changes in financial situations may be the result of exploitation
- Bedsores, unattended medical needs, poor hygiene, and unusual weight loss may be indicators of possible neglect
- Behavior such as belittling, threats, and other uses of power and control by a caregiver may be an indicator of verbal or emotional abuse
- Strained or tense relationships, frequent arguments between caregiver and older adult

Physical, Cognitive, and Psychosocial Effects of Aging

The human body undergoes a multiplicity of physiologic changes second by second. Little consideration is given regarding these changes unless they are brought on by sudden physical, psychological, or cognitive events. Each older adult is a unique individual with distinct characteristics. These individuals have experienced a life filled with memories and accomplishments.

Young or old, the definition of quality of life is an individual and personal one. Research has shown that health status is an excellent predictor of happiness. Greater social contact, health satisfaction, low vulnerable personality traits, and fewer stressful life events have been linked to successful aging. *Self-efficacy* can be defined as the level of control one has over one's future. Many older adults feel they have no control over medical emergencies and fixed incomes. Many have fewer choices about their personal living arrangements. These environmental factors can lead to depression and decreased self-efficacy. An increase in illness usually parallels a decrease in self-efficacy.

Older adults may experience changing roles from a life of independence to dependence. The family dynamic of a parent caring for children and grandchildren may evolve into the children caring for the aging parent. Older adulthood is also a time of loss. Losses may include the death of a spouse and friends and loss of income owing to retirement. Loss of health may be the reason for the health care visit. The overall loss of control may lead to isolation and depression in the older adult. Death and dying are also imminent facts of life.

A positive attitude is an important aspect of aging. Many older people have the same negative stereotypes about aging that young people do. [2] For them, feeling down and depressed becomes a common consequence of aging. One in five people older than age 65 in a community shows signs of clinical depression. Yet health care professionals know that depression can affect young and old. Research has shown most older adults rate their health status as good to excellent. How older adults perceive their health status depends largely on their successful adaptation to disabilities.

Radiographers need to be sensitive to the fact that an older adult may have had to deal with many social and physical losses in a short period. More importantly, they must recognize symptoms resulting from these losses to communicate and interact effectively with these patients. The radiographer must remember that each older adult is unique and deserves respect for his or her own opinions.

The aging process alone does not likely alter the essential core of the human being. Physical illness is not aging, and age-related changes in the body are often modest in magnitude. As one age, the tendencies to prefer slower-paced activities, take longer to learn new tasks, become more forgetful, and lose portions of sensory processing skills increase slowly but perceptibly. Health care professionals need to be reminded that *aging and disease are not synonymous.* The more closely a function is tied to physical capabilities, the more likely it is to decline with age, whereas the more a function depends on experience, the more likely it will increase with age. Box 23.4 lists the most common health complaints of older adults.

Joint stiffness, weight gain, fatigue, and loss of bone mass can be slowed through proper nutritional interventions and low-impact exercise. The importance of exercise cannot be overstated. Exercise has been shown to increase aerobic capacity and mental speed. Exercise programs designed for older adults should emphasize increased strength, flexibility, and endurance. One of the best predictors of good health in later years is the number and extent of healthy lifestyles that were established in earlier life.

BOX 23.4 Most common health complaints of older adults

- Weight gain
- Fatigue
- Loss of bone mass
- Joint stiffness
- Loneliness

An older adult may show decreases in attention skills during complex tasks. Balance, coordination, strength, and reaction time all decrease with age. Falls associated with balance problems are common in the older adult population, resulting in a need to concentrate on walking. *Not overwhelming older adults with instructions is helpful.* Their hesitation in following instructions may be a fear instilled from a previous fall. Sight, hearing, taste, and smell all are sensory modalities that decline with age. Older people have more difficulty with bright lights and tuning out background noise. Many older adults become adept at lip-reading to compensate for the loss of hearing. For radiographers to assume that all older adult patients are hard of hearing is not unusual, but they are not all hard of hearing. Talking in a normal tone, while making volume adjustments only if necessary, is a good rule of thumb. Speaking slowly, directly, and distinctly when giving instructions allows older adults an opportunity to sort through directions and improves their ability to follow them with better accuracy (Fig. 23.4).

Cognitive impairment in older adults can be caused by disease, aging, and disuse. *Dementia* is defined as a progressive cognitive impairment that eventually interferes with daily functioning. It includes cognitive, psychological, and functional deficits, including memory impairment. With normal aging comes a slowing down and a gradual wearing out of bodily systems, but normal aging does not include dementia. Yet the prevalence of dementia increases with age. Persistent disturbances in cognitive functioning, including memory and intellectual ability, accompany dementia. Fears of cognitive loss, especially Alzheimer disease, are widespread among older people.

Alzheimer disease is the most common form of dementia. Health care professionals are more likely to encounter people with this type. Most older adults work at maintaining and keeping their mental functions by staying active through mental games and exercises and keeping engaged in regular conversation. When caring for patients with any degree of dementia, verbal conversation should be inclusive and respectful. One should never discuss these patients as though they are not in the room or are not active participants in the procedure.

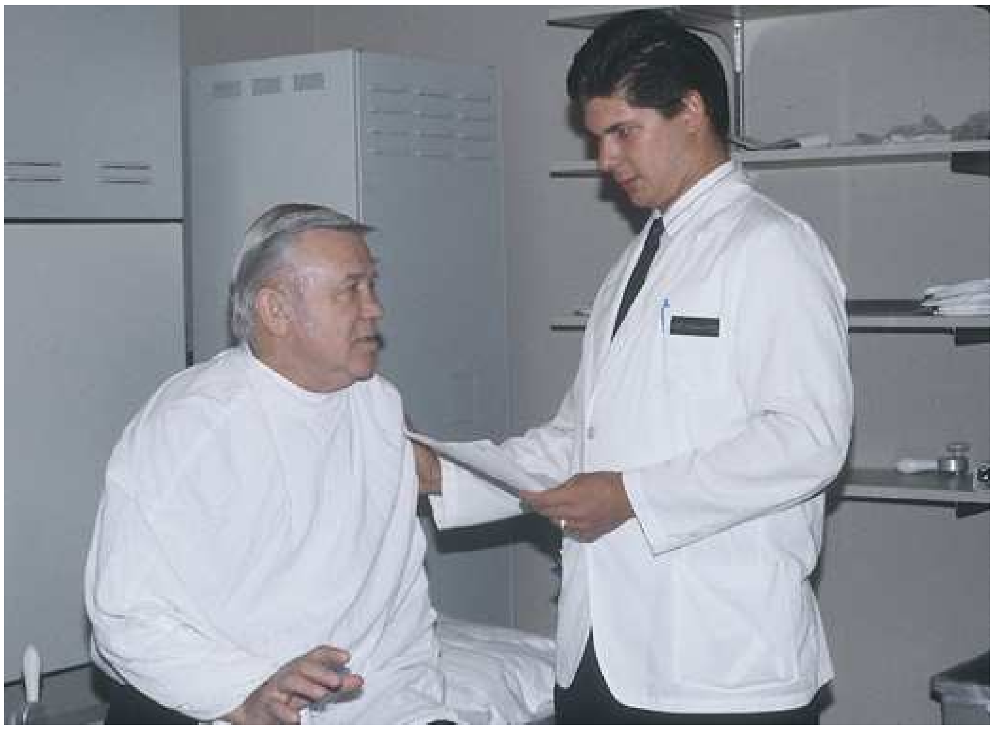


FIG. 23.4 Speaking slowly, directly, and distinctly when giving instructions allows older adults an opportunity to sort through directions and improves their ability to follow them with better accuracy.

One of the first questions asked of any patient entering a health care facility for emergency service is, "Do you know where you are and what day it is?" Health care providers need to know just how alert the patient is. Although memory does decline with age, this is experienced mostly with short-term memory tasks. Long-term memory or subconscious memory tasks show little change over time and with increasing age. There can be various reasons for confusion or disorientation. Medication, psychiatric disturbance, or retirement can confuse the individual. For some older people, retirement means creating a new set of routines and adjusting to them. Most older adults like structure in their lives and have familiar routines for approaching each day.

Physiology of Aging

Health and well-being depend largely on the degree to which organ systems can successfully work together to maintain internal stability. With age, there is apparently a gradual impairment of these homeostatic mechanisms. Older adults experience nonuniform, gradual, ongoing organ function failure in all systems. Many of the body organs gradually lose strength with advancing age. These changes place older adults at risk for disease or dysfunction, especially in the presence of stress. At some point, the likelihood of illness, disease, and death increases. Various physical diseases and disorders affect the mental and physical health of people of all ages. They are more profound among older adults because diseases and disorders among older people are more likely to be chronic in nature. Although aging is inevitable, the aging experience is highly individual and is affected by heredity, lifestyle choices, physical health, and attitude. A great portion of usual aging risks can be modified with positive shifts in lifestyle.

Aging OF The Organ Systems

Integumentary system disorders

Disorders of the integumentary system are among the first apparent signs of aging. The most common skin diseases among older adults are herpes zoster (shingles), malignant tumors, and decubitus ulcers. With age comes flattening of the skin membranes, making it vulnerable to abrasions and blisters. The number of melanocytes decreases, making ultraviolet light more dangerous, and the susceptibility to skin cancer increases. Wrinkling and thinning skin are noticeable among older adults; this is attributable to decreases in collagen and elastin in the dermis. A gradual loss of functioning sweat glands and skin receptors occurs, which increases the threshold for pain stimuli, making an older adult vulnerable to heat strokes. With age comes atrophy or thinning of the subcutaneous layer of skin in the face, back of the hands, and soles of the feet. Loss of this "fat pad" can cause many foot conditions in older adults.

The most striking age-related changes to the integumentary system are the graying, thinning, and loss of hair. As a person ages, the number of hair follicles decreases, and the follicles that remain grow at a slower rate with less concentration of melanin, causing the hair to become thin and white. A major problem with aging skin is chronic exposure to sunlight. The benefits of protecting one's skin with sunscreen and protective clothing cannot be overemphasized and become more evident as one grows older. The three most common skin tumors in older adults are basal cell carcinoma, malignant melanoma, and squamous cell carcinoma.

Nervous system disorders

The nervous system is the principal regulatory system of all other systems in the body. It is probably the least understood of all body systems. Central nervous system disorders are among the most common causes of disability in older adults, accounting for almost 50% of disability in individuals older than the age of 65. Loss of myelin in axons of the nervous system contributes to the decrease in nerve impulse velocity that is noted in aging. One such condition of the nervous system decline is Alzheimer disease, which is known to be the most common form of dementia. More than 5 million Americans currently suffer from the disease, and it is estimated that this number will rise to about 13 million by 2050. Although there exist drug remedies and therapies, and lifestyle modification to stifle its progress, there is no cure for the disease.

In the healthy brain, an intricate network of billions of nerve cells communicates using electrical signals that regulate thoughts, memories, sensory perception, and movement. In an Alzheimer patient, brain cells die when genes and other factors cause the formation of an amyloid protein, which eventually breaks up and forms plaques—the hallmark of Alzheimer disease (Fig. 23.5). These plaques ultimately lead to the destruction of brain cells. Once the brain cells are destroyed, neural connections are shut down, causing decreased cognitive functions. Other known risk factors of this disease are, of course, age and family history. The greatest risk factor for this disease is increasing age. After age 65, the risk doubles every 5 years. After age 85, the risk is nearly 50%.

Although family history increases the risk for getting the disease, there are a large number of Alzheimer patients with no family history, suggesting that there are other factors influencing the development of the disease. In addition to the Alzheimer gene, there is some evidence that some forms of the disease may be due to a "slow virus"; it is possible that the disorder is caused by an accumulation of toxic metals in the brain or by the absence of certain kinds of endogenous brain chemicals.

Health experts inarguably propose that as the baby boomers become closer to the age where they may contract the disease, Medicare will become burdened with an estimated $626 billion more in Alzheimer-related health care cost. There is also a considerable psychological burden that is attached to this debilitating disease: adults are becoming more concerned that the disease will affect them or someone they know.

Current attempts to detect Alzheimer disease include imaging procedures such as structural imaging with magnetic resonance imaging (MRI) or computed tomography (CT). These tests are used to rule out other conditions that may cause symptoms similar to Alzheimer but require different treatment options. As for functional imaging of Alzheimer disease, position emission tomography (PET) scans show diminished brain cell activity in the regions affected. Molecular imaging research studies are aggressively being pursued to detect biologic cues indicating the early stage of Alzheimer before it alters the brain's structure or function and causes irreversible loss of memory or the ability to reason and think.

Similar to any other organ system, the nervous system is vulnerable to the effects of atherosclerosis with advancing age. When blood flow to the brain is blocked, brain tissue is damaged. Repeated episodes of cerebral infarction can eventually lead to multi-infarct dementia. The changes in the blood flow and oxygenation to the brain slow down the time to carry out motor and sensory tasks requiring speed, coordination, balance, and fine motor hand movements. This decrease in the function of motor control puts the older adult at a higher risk for falls. Healthy changes in lifestyle can reduce the risk of disease. High blood pressure is a noted risk and can be decreased with medication, weight loss, proper nutritional diet, and exercise.

Sensory system disorders

All of the sensory systems undergo changes with age. Beginning around age 40, the ability to focus on near objects becomes increasingly difficult. The lens of the eye becomes less pliable, starts to yellow, and becomes cloudy, resulting in farsightedness *(presbyopia)*. Distorted color perception and cataracts also occur. Changes in the retina affect the ability to adapt to changes in lighting, and the ability to tolerate glare decreases, making night vision more difficult for older adults.

Hearing impairment is common in older adults. The gradual progressive hearing loss of tone discrimination is called *presbycusis*. Men are more often affected than women, and the degree of loss is more severe for high-frequency sounds. Speech discrimination is problematic when in noisy surroundings, such as a room full of talking people.

There is a decline in sensitivity to taste and smell with age. The decline in taste is consistent with a decreased number of taste buds on the tongue, decreased saliva, and dry mouth that accompany the aging process.

Hyposmia is the impairment of the ability to smell. It accounts for much of the decreased appetite and irregular eating habits that are noted consistently in older adults. Similar to taste, the degree of impairment varies with a particular odor, and the ability to identify odors in a mixture is gradually lost with age.

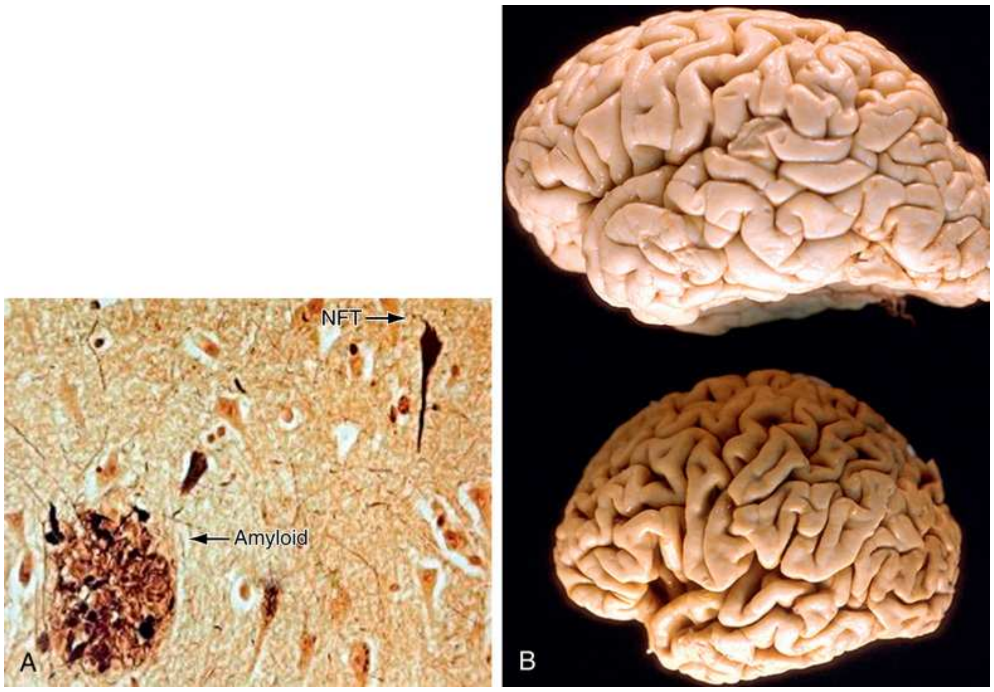


FIG. 23.5 Pathologic changes in Alzheimer disease (AD). (A) A mature plaque with central amyloid core next to a neurofibrillary tangle *(NFT)*. (B) Comparison of normal and AD brains. *Top,* normal brain. *Bottom,* brain of a patient with Alzheimer disease. The AD brain shows gyral atrophy and sulcal widening greater than that seen in a person with no cognitive impairment. From Naidich TP, Castillo M, Cha S, Smirniotopoulos J. *Imaging of the brain.* 7th ed. Philadelphia: Elsevier; 2013.

(A) A micrograph shows a cluster is brown colored tissues and a few black regions scattered on it. Amyloid and N F T are labeled on it. (B) The brain on top is shaped normally. The brain at the bottom is smaller and misshaped.

Musculoskeletal system disorders

Musculoskeletal dysfunction is the major cause of disability in older adults. Osteoporosis, the reduction in bone mass and density, is one of the most significant age-related changes. Women are four times as likely as men to develop this disease. Risk factors for osteoporosis include estrogen depletion, calcium deficiency, physical inactivity, testosterone depletion, alcoholism, and cigarette smoking. The rate of new bone resorption surpasses the rate of new bone formation at approximately age 40. This accounts for a subsequent loss of 40% of bone mass in women and 30% of bone mass in men over the course of the life span. Osteoporosis is associated with an increased risk of fractures. Common fracture sites are the vertebral bodies, distal radius, femoral neck, ribs, and pubis. Changes in the shape of the vertebral bodies can indicate the degree and severity of osteoporosis. Advanced cases may show complete compression fractures of the vertebral bodies. Compression fractures can result in severe kyphosis of the thoracic spine (Fig. 23.6).

The incidence of degenerative joint disease, osteoarthritis, increases with age. Osteoarthritis is the chronic deterioration of the joint cartilage, and the weight-bearing joints are the most commonly affected. Obesity is probably the most important risk factor. Osteoarthritis of the joint cartilage causes pain, swelling, and a decrease in range of motion in the affected joint. Osteoarthritis is the second most common cause of disability in the United States, affecting more than 50 million Americans. At age 40, most adults have osteoarthritic changes visible on radiographic images of the cervical spine. The most progressive changes occur in weight-bearing joints and hands as age increases (Fig. 23.7).

Total joint replacement or arthroplasty procedures are common among older adult patients. Joint replacement may offer pain relief and improve joint mobility. Joint replacements can be performed on any joint including the hip, knee, ankle, foot, shoulder, elbow, wrist, and fingers. Hip and knee replacements are the most common and the most effective (Fig. 23.8).

With age, women are more likely to store fat in their hips and thighs, whereas men store fat in their abdominal area. Without exercise, muscle mass declines, resulting in decreased strength and endurance, prolonged reaction time, and disturbed coordination. It cannot be overemphasized that regular physical training can improve muscle strength and endurance, along with cardiovascular fitness, even in the oldest individuals.

Cardiovascular system disorders

The cardiovascular system circulates the blood, which delivers oxygen and nutrients to all parts of the body and removes waste products. Damage to this system can have negative implications for the entire body. Decreased blood flow to the digestive tract, liver, and kidneys affects the absorption, distribution, and elimination of substances, such as medications and alcohol.

Cardiovascular disease is the most common cause of death worldwide. The maximum heart rate during exercise decreases with age; older adults become short of breath and tire quickly. Loss of arterial elasticity results in elevated systolic blood pressure, increasing the risk of heart disease and stroke. Another prevalent problem is postural hypertension, in which there is a decrease in systemic blood pressure when rising from a supine to a standing position. The predominant change that occurs in the blood vessels with age is atherosclerosis which is a development of fatty plaques in the walls of the arteries. These fatty plaques within the artery wall can lead to ulcerations of the artery wall, subsequently making the artery prone to the formation of blood clots. The plaques also cause destruction of the artery wall leading to a balloon and risk of an aneurysm. Complications can lead to an embolism, heart attack, or stroke.

FIG. 23.6 Lateral chest radiograph of a geriatric patient with kyphosis and compression fractures.

FIG. 23.7 Lateral knee radiograph showing severe arthritis.

Congestive heart failure is due to an inability of the heart to propel blood at a sufficient rate and volume. This pathology is more common in older adults, particularly individuals 75 to 85 years old. People who are most at risk for developing congestive heart failure include individuals who have been diagnosed with coronary artery disease, heart attack, cardiomyopathy, untreated hypertension, and chronic kidney disease.

Radiographically, the heart is enlarged, and the hilar region of the lungs is congested with increased vascular markings. Exposure factors must be adjusted to visualize the heart borders despite the pulmonary edema.

Preventive health measures, such as control of high blood pressure, diet, exercise, and smoking cessation, decrease the risk of cardiovascular disease. These interventions are more effective if initiated earlier in life.

Gastrointestinal system disorders

Gastrointestinal disorders in older adults include malignancies, peptic ulcer disease, gastrointestinal bleeding, pancreatitis, difficulty swallowing, diverticulitis, gastric outlet obstruction, esophageal foreign bodies, constipation, and fecal incontinence. Mouth and teeth pain, side effects of medication, decreased saliva, and dry mouth can lead to nutritional deficiencies, malnutrition, and dehydration problems. Most gastrointestinal disorders are related to an age-related decrease in the rate of gastric acid production and secretions and decreased motility of the smooth muscle in the large intestine. A decrease in acid production and secretion can lead to iron-deficiency anemia, peptic ulcers, and gastritis. Diverticulosis, a common problem in older adults, develops when the large intestine herniates through the muscle wall. Gallstone disease, hepatitis, and dehydration tend to be more common in older adults. Healthy lifestyle habits, such as smoking cessation, low alcohol intake, a high fiber–low sugar diet, and regular exercise, can decrease the risk of gastrointestinal problems. Gastrointestinal malignancies are second only to lung cancer as a cause of cancer mortality. Survival after colon and rectal cancer is increased with inexpensive early detection. Stool samples and rectal examinations are effective in detecting early cancer (Fig. 23.9).

FIG. 23.8 AP proximal femur radiograph showing a total hip arthroplasty procedure.

FIG. 23.9 Postoperative image of an older adult patient showing an AP abdomen with surgical staples and nasogastric tube.

Immune system decline

Age takes its toll on the immune system. To be immune to an infection implies protection from that infection. The ability of one's body to remain free of infections requires the immune system to distinguish healthy cells from invading microorganisms or altered cancer cells. The age-related decline of immune system function makes older adults more vulnerable to diabetes mellitus, pneumonia, and nosocomial infections. The incidence of infectious disease increases. Influenza, pneumonia, tuberculosis, meningitis, and urinary tract infections are prevalent among older adults. The three general categories of illness that preferentially affect older adults are infections, cancer, and autoimmune disease. [3]

Respiratory system disorders

Throughout the aging process, the lungs lose some of their elastic recoil, trapping air in the alveoli. This reduced elasticity decreases the rate of oxygen entering the bloodstream and the elimination of carbon dioxide. The muscles involved in breathing become a little more rigid, which can account for shortness of breath with physical stress. In the wall of the thorax, the rib cage stiffens, causing kyphotic curvature of the thoracic spine. Respiratory diseases that increase in frequency with aging include emphysema, chronic bronchitis, pneumonia, and lung cancer.

Chronic obstructive pulmonary disease refers to a variety of breathing disorders that cause a decreased ability of the lungs to perform ventilation. Emphysema is the permanent destruction and distention of the alveoli. Cigarette smoking is the most significant risk factor in the development of emphysema and is the leading cause of chronic bronchitis. Chronic bronchitis is an inflammation of the mucous membrane of the bronchial tubes. These two conditions are considered irreversible. Chest radiographs may show hyperinflation of the lungs (Fig. 23.10).

Pneumonia is the most frequent type of lung infection and among the leading causes of death in older adults. This population is also at an increased risk for aspiration pneumonia secondary to slower swallowing reflexes and other health conditions. Radiographically, pneumonia may appear as soft, patchy alveolar infiltrates or pulmonary densities (Fig. 23.11).

Lung cancer is the second most common cancer and the most common cause of cancer-related death in men and women. More Americans die each year from lung cancer than from breast, prostate, and colorectal cancers combined.

There is a strong association between low lung function and the future development of coronary heart disease. Research has shown that the total amount of air inhaled in one's deepest breath and the fastest rate at which one can exhale are powerful predictors of how many more years one will live. Sedentary lifestyle is the greatest risk factor in lung function, and lifestyle habits are the crucial factors over which one has control.

FIG. 23.10 PA chest radiograph showing emphysema.

FIG. 23.11 PA chest radiograph with right middle lobe pneumonia and accompanying abscess.

Hematologic system disorders

A major hematologic concern in older adults is the high prevalence of anemia. Individuals with anemia often have pale skin and shortness of breath, and they fatigue easily. As bone ages, the marrow of the bone has a harder time maintaining blood cell production than young bone marrow when the body is stressed. The high incidence of anemia in older adults is believed to be a result not of aging per se, but rather of the high frequency of other age-related illnesses that can cause anemia. Anemia is not a single disease but a syndrome that has several causes. Insufficient dietary intake and inflammation or destruction of the gastrointestinal lining leading to an inability to absorb vitamin B_{12} causes a type of anemia that affects older adults. Because of other physiologic stresses affecting marrow production, older adults have an increased incidence of various blood disorders.

Genitourinary system disorders

Familiar age-related genitourinary changes are those associated with incontinence. Changes in bladder capacity and muscle structure predispose older adults to this problem. Urinary and bowel incontinence can also lead to social and hygiene concerns. Along with structural changes in the genitourinary system, the number of nephrons in the kidneys decreases dramatically after the onset of adulthood. This decreased reserve capacity of the kidneys could cause what would otherwise be a regularly prescribed dose of medication to be an overdose in an older adult. The role of the kidneys to maintain the body's water balance and regulate the concentration according to the body's need diminishes with age. Acute and chronic renal failure affects many older adults.

Benign prostatic hyperplasia can affect 70% of men older than age 70. Benign prostatic hyperplasia is an enlargement of the prostate gland, which can cause obstruction of the flow of urine. Surgical resection of the prostate may be necessary. Prostate cancer is primarily a disease of later life, and more than 80% of tumors are found in men older than 65 years. Prostate cancer is the most common cancer in men and the third most common cause of cancer deaths in men. Radiographic imaging of the male reproductive system comprises ureterograms, intravenous urography, and CT. Ultrasound is commonly used to evaluate testicular masses and prostate nodules.

Endocrine system disorders

The endocrine system is another principal regulatory system of the body. Age-related changes in thyroid function result from inadequate responses of target cells to thyroid hormone. The most common age-related disease associated with the endocrine system is diabetes mellitus. Non–insulin-dependent diabetes mellitus increases in frequency with age and accounts for about 90% of all cases. Regular exercise and weight loss can significantly reduce the risk and delay the onset of non–insulin-dependent diabetes.

Summary

Aging is the one certainty in life. It starts at conception and continues throughout the life cycle. No two people age in the same way. As stated earlier, aging is individualized and is affected by heredity, lifestyle choices, physical health, and attitude. Despite the changes that occur in the body systems observed with aging, most older adults view themselves as healthy. They learn to adapt, adjust, and compensate for the disabilities secondary to aging. Older people are stereotyped into two groups: diseased and normal. The normal group is at high risk of disease but is just not there yet. By categorizing these older adults as normal, health professionals tend to underestimate their vulnerability. Modest increases in blood pressure, blood sugar, body weight, and low bone density are common among normal older adults. These risk factors promote disease, and yet they can be modified. They may be age-related in industrial societies, but they are not age-determined or harmless. Positive lifestyle changes, such as diet, exercise, and smoking cessation, reduce the risk of disease and improve the quality of life. Good health cannot be left to chance, and staying healthy depends to a large degree on lifestyle choices and attitude.

Summary OF Pathology: Geriatric Radiography

Condition	Definition
Alzheimer disease	Progressive, irreversible mental disorder with loss of memory, deterioration of intellectual functions, speech and gait disturbances, and disorientation
Atherosclerosis	Condition in which fibrous and fatty deposits on the luminal wall of an artery may cause obstruction of the vessel
Benign prostatic hyperplasia	Enlargement of prostate gland
Chronic obstructive	Chronic condition of persistent obstruction of bronchial airflow pulmonary disease
Compression fracture	Fracture that causes compaction of bone and decrease in length or width
Congestive heart failure	Heart is unable to propel blood at sufficient rate and volume
Contractures	Permanent contraction of a muscle because of spasm or paralysis
Dementia	Broad impairment of intellectual function that usually is progressive and interferes with normal social and occupational activities
Emphysema	Destructive and obstructive airway changes leading to increased volume of air in the lungs
Kyphosis	Abnormally increased convexity in the thoracic curvature
Osteoarthritis	Form of arthritis marked by progressive cartilage deterioration in synovial joints and vertebrae
Osteoporosis	Loss of bone density
Renal failure	Failure of the kidney to perform essential functions
Urinary incontinence	Absence of voluntary control of urination

Patient Care

Box 23.5 lists quick tips for working with older adult patients. These tips are discussed in the following pages.

Patient And Family Education

Educating all patients, especially older adult patients, about imaging procedures is crucial to obtain their confidence and compliance. More time with older adult patients may be necessary to accommodate their decreased ability to process information rapidly. Most older adults have been diagnosed with at least one chronic illness. They typically arrive at the clinical imaging environment with natural anxiety because they are likely to have little knowledge of the procedure or the highly technical modalities employed for their procedures. A fear concerning consequences resulting from the examination exacerbates their increased levels of anxiety. Taking time to educate patients and their families or significant caregivers in their support system about the procedures makes for a less stressful experience and improved patient compliance and satisfaction.

Communication

Good communication and listening skills create a connection between the radiographer and the patient. Older people are unique and should be treated with dignity and respect. Examples of appropriate communication may include addressing the patient by his or her title and last name. It is inappropriate to call someone "honey" or "dear." Each older adult is a wealth of cultural and historical knowledge that becomes a learning experience for the radiographer. If it is evident that the patient cannot hear or understand verbal directions, it is appropriate to speak lower and closer. Background noise can be disrupting to an older person and should be eliminated if possible when giving precise instructions. Giving individual instruction provides the older adult time to process a request. An empathetic, warm attitude and approach to a geriatric patient result in a trusting and compliant patient.

Transportation And Lifting

Balance and coordination of an older adult patient can be affected by normal aging changes. The patient's anxiety about falling can be diminished by assistance in and out of a wheelchair and to and from the examination table. Many older adult patients have decreased height perception resulting from some degree of vision impairment. Hesitation of the older adult patient may be due to previous falls. Assisting an older patient when there is a need to step up or down throughout the procedure is more than a reassuring gesture. Preventing opportunities for falls is the responsibility of the radiographer. The older adult patient often experiences vertigo and dizziness when moving from a recumbent position to a sitting position. Giving the patient time to rest between positions mitigates these disturbing, frightening, and uncomfortable sensations. The use of table handgrips and proper assistance from the radiographer create a sense of security for an older adult patient.

Skin Care

Acute age-related changes in the skin cause it to become thin and fragile. The skin becomes more susceptible to bruising, tears, abrasions, and blisters. All health care professionals should use caution in turning and holding an older adult patient. Excessive pressure on the skin causes it to break and tear. *Adhesive tape should be avoided because it can be irritating and can easily tear the skin of an older person.* The loss of fat pads makes it painful for an older adult patient to lie on a hard surface and can increase the possibility of developing ulcerations. Decubitus ulcers, or pressure sores, are commonly seen in bedridden people and people with decreased mobility. Bony areas such as the heels, ankles, elbow, and lateral hips are frequent sites for pressure sores. A decubitus ulcer can develop in 1 to 2 hours. Almost without exception, tables used for imaging procedures are hard surfaced and cannot be avoided. The use of a table pad can reduce the friction between the hard surface of the table and the patient's fragile skin. Sponges, blankets, and positioning aids make the procedure much more bearable and comfortable for the older adult patient.

BOX 23.5 Tips for working with older adult patients

Take time to educate the patient and the family.
Speak lower and closer.
Treat the patient with dignity and respect.
Give the patient time to rest between projections and procedures.
Avoid adhesive tape: older adult skin is thin and fragile.
Provide warm blankets in cold examination rooms.
Use table pads and handrails.
Always access the patient's medical history before contrast medium is administered.

Because skin plays a crucial role in maintaining body temperature, the thinning process associated with aging skin renders the patient less able to retain normal body heat. The regulation of body temperature of an older adult varies from that of a younger person. Older adult patients may need a blanket to prevent hypothermia, even in a room that is at comfortable temperature for the radiographer.

Contrast Agent Administration

Because of age-related changes in kidney and liver functions, the amount, but not the type, of contrast media is varied when performing radiographic procedures on an older adult patient. The number of functioning nephrons in the kidneys steadily decreases from middle age throughout the life span. Compromised kidney function contributes to the older adult patient being more prone to electrolyte and fluid imbalance, which can create life-threatening consequences. They are also more susceptible to the effects of dehydration because of diabetes and decreased renal or adrenal function. The decision of type and amount of contrast media used for the geriatric patient usually follows some sort of routine protocol. Assessment for contrast agent administration accomplished by the imaging technologist must include age; history of liver, kidney, or thyroid disease; history of hypersensitivity reactions and previous reactions to medications or contrast agents; sensitivity to aspirin; over-the-counter and prescription drug history including the use of acetaminophen (Tylenol); and history of diabetes and hypertension. [4]

The imaging technologist must be selective in locating an appropriate vein for contrast agent administration on the older adult patient. The technologist should consider the location and condition of the vein, decreased integrity of the skin, and duration of the therapy. Thin superficial veins, repeatedly used veins, and veins located in areas where the skin is bruised or scarred should be avoided. The patient should be assessed for any swallowing impairments, which could lead to difficulties with drinking liquid contrast agents. The patient should be instructed to drink slowly to avoid choking, and an upright position helps prevent aspiration.

Joint Commission Criteria

The Joint Commission is the accrediting and standards-setting body for hospitals, clinics, and other health care organizations in the United States. Employees in institutions accredited by the Joint Commission must demonstrate age-based communication competencies, which include the older adult. The standards were adopted as a means of demonstrating competence in meeting the physiologic and psychological needs of patients in special populations. These populations include infants, children, adolescents, and older adults.

Age-related competencies

Standard HR 01.05.03 of the Human Resources section of the Joint Commission manual states: "When appropriate, the hospital considers special needs and behaviors of specific age groups in defining qualifications, duties, and responsibilities of staff members who do not have clinical privileges but who have regular clinical contact with patients (e.g., radiologic technologists and mental health technicians)." The intent of the standard is to ensure age-specific competency in technical and clinical matters but is not limited to equipment and technical performance. Age-specific competencies address the different needs people have at different ages. Examples of age-specific care for older adults may include the following: assessing visual or hearing impairments; assessing digestive and esophageal problems, such as reflux, bladder, and bowel problems; addressing grief concerns; providing warmth; and providing safety aids. Being able to apply age-specific care also includes the use of age-appropriate communication skills. Clear communication with the patient can be the key to providing age-specific care. Knowledge of age-related changes and disease processes assists all health care professionals, including those in the radiation sciences, in providing care that meets the needs of the older adult patient.

Performing the Radiographic Procedure

Radiographer's Role

The role of the radiographer is no different than that of all other health professionals. The whole person must be treated, not just the manifested symptoms of an illness or injury. Medical imaging and therapeutic procedures reflect the impact of ongoing systemic aging in documentable and visual forms. Adapting procedures to accommodate disabilities and diseases of geriatric patients is a crucial responsibility and a challenge based almost exclusively on the radiographer's knowledge, abilities, and skills. An understanding of the physiology and pathology of aging and an awareness of the social, psychological, cognitive, and economic aspects of aging are required to meet the needs of older adult patients. Conditions typically associated with older adult patients invariably require adaptations or modifications of routine imaging procedures. The radiographer must be able to differentiate between age-related changes and disease processes. Production of diagnostic images requiring professional decision making to compensate for physiologic changes, while maintaining the compliance, safety, and comfort of the patient, is the foundation of the contract between the older adult patient and the radiographer.

To better care for individuals with Alzheimer disease, it is important to become familiar with some simple facts about the disease and behaviors that are associated with it. Alzheimer disease is a progressive disease with no known cure. There are five stages: preclinical stage, mild cognitive impairment, mild dementia, moderate dementia, and severe dementia. The disease is often diagnosed in the mild stage of dementia. Table 23.1 lists these stages and a brief description of each.

The rate of progression of Alzheimer disease varies widely. On average, people with this disease live 8 to 10 years after diagnosis; however, some will live as long as 25 years after diagnosis. Pneumonia is a common cause of death because impaired swallowing allows food or beverages to enter the lungs, where an infection can begin. Other common causes of death include complications from urinary tract infections and falls.

It is important that the radiologic technologist becomes aware of and understands the various types of physical and cognitive impairments associated with Alzheimer disease. It requires patience, compassion, and attentiveness when dealing with this patient group. Patients who are at risk of falling must never be left alone, whether in the radiology waiting room or the examination room. Caregivers should be encouraged to accompany the patient to appointments whenever possible. It may be more comforting for the patient to have a familiar person with them in an unfamiliar setting. In addition, depending on the stage of the disease, some patients may tend to wander, often wanting to go home. Home sometimes is their native town, state, or even country. Confused elderly patients can travel considerable distances before they are found. There have been cases where patients have wandered off, never to be found, or never to be found alive. For that reason, the patient should never be left alone. Whenever possible, and whenever a caregiver has not accompanied the patient, a two-technologist team should be available to care for the patient while in the diagnostic radiology suite—one acquiring the images and one in the role of companion to the patient while the images are being reviewed. The patient should be then handed off to the unit or responsible party upon completion of the exam.

It is not uncommon for the Alzheimer patients to ask repetitive questions or to become accusatory. The technologist should exercise a great deal of patience and use distraction techniques to eliminate the frustration this may cause. Simply changing the subject or asking an unrelated question may reduce the repetitive questioning or conversation. There may be occasions when the patient requires restraints to complete the exam. Note, however, that restraints should only be applied in cases where the patient can potentially cause harm to themself or to others.

Working quietly and smoothly around the patient and maintaining calm, relaxing, and noise-free surroundings is the preferred situation for the Alzheimer patient in the radiology department. The music, if any, should be soothing and relaxing. This will potentially benefit all types of patients.

Radiographic Positioning for Geriatric Patients

The preceding discussions and understanding of the physical, cognitive, and psychosocial effects of aging can help radiographers adapt to the positioning challenges of the geriatric patient. In some cases, routine examinations need to be modified to accommodate the limitations, safety, and comfort of the patient. Communicating clear instructions with the patient is important. The following discussion addresses positioning suggestions for various structures.

Chest

The position of choice for the chest radiograph is the upright position; however, an older adult patient may be unable to stand without assistance for this examination. When performing a PA projection of the lungs, the patient places the back of their hands on their hips. This may be difficult for someone with impaired balance and flexibility. The radiographer can allow the patient to wrap his or her arms around the wall bucky as a means of support and security (Fig. 23.12). The patient may not be able to maintain his or her arms over the head for the lateral projection of the chest. The radiographer should provide extra security and stability while the patient is moving the arms up and forward to grasp overhead handgrips or IV pole (Fig. 23.13).

TABLE 23.1

Stages and symptoms of Alzheimer disease

Stages of Alzheimer disease	Description of behaviors/symptoms
Preclinical stage	Symptoms usually go unnoticed during this stage. This stage of Alzheimer disease can last for years, possibly even decades. Diagnostic imaging technologies can now identify deposits of the amyloidal beta substance that have been associated with Alzheimer disease.
Mild cognitive impairment	Memory lapses, interrupted thought processes. Trouble with time management. Trouble making sound decisions.
Mild dementia	Memory loss of recent events. Difficulty with problem solving. Difficulty completing complex tasks and making sound judgments. Changes in personality—may become subdued, or withdraw from certain social situations. Difficulty organizing or expressing thoughts. Gets lost or wanders away from home. Misplaces belongings.
Moderate dementia	Displays increasingly poor judgment. Confusion deepens. Memory loss increases. Needs assistance with daily routine activities. Becomes suspicious or paranoid and accusatory to caregivers or family members. Rummaging, tapping feet, rubbing hands, banging. Outbursts of physical aggression.
Severe dementia (late stage)	Inability to hold coherent conversations. Inability to recognize some or all family members. Requires assistance with personal care. Decline in physical abilities—needs assistance walking or may experience uncontrollable bladder and bowel functions. Inability to swallow; rigid muscles; abnormal reflexes.

When the patient cannot stand, the examination may be performed AP with the patient seated in a wheelchair or stretcher, but some issues affect the radiographic quality. Hyperkyphosis can result in the lung apices being obscured. The abdomen may also obscure the lung bases. In a sitting position, respiration may be compromised, and the patient should be instructed on the importance of deep inspiration. Any alteration of the exam should be noted in the patient's recorded history.

Positioning of the image receptor (IR) for a kyphotic patient should be higher than normal because the shoulders and apices are in a higher position. Radiographic landmarks may change with age, and the centering may need to be lower if the patient is extremely kyphotic. When positioning the patient for the sitting lateral chest projection, the radiographer should place a large sponge behind the patient to lean him or her forward (Fig. 23.14).

Spine

Radiographic spine examinations may be painful for a patient with osteoporosis who is lying on the x-ray table. Positioning aids such as radiolucent sponges, sandbags, and a mattress may be used as long as the quality of the image is not compromised (Fig. 23.15). Performing upright radiographic examinations may also be appropriate if a patient can safely tolerate this position. The combination of cervical lordosis and thoracic kyphosis can make positioning and visualization of the cervical and thoracic spine difficult. Lateral cervical projections can be performed with the patient standing, sitting, or lying supine. The AP projection in the sitting position may not visualize the upper cervical vertebrae because the chin may obscure this anatomy. In the supine position, the head may not reach the table and result in magnification. The AP and open-mouth projections are difficult to do in a wheelchair.

FIG. 23.12 Radiographer positioning patient's arms around the chest stand for a PA chest radiograph. Having the patient hold on in this way provides stability.

FIG. 23.13 Radiographer placing the IR behind a patient who is unable to stand. With careful positioning of the IR and x-ray tube, a quality image of the chest can be obtained.

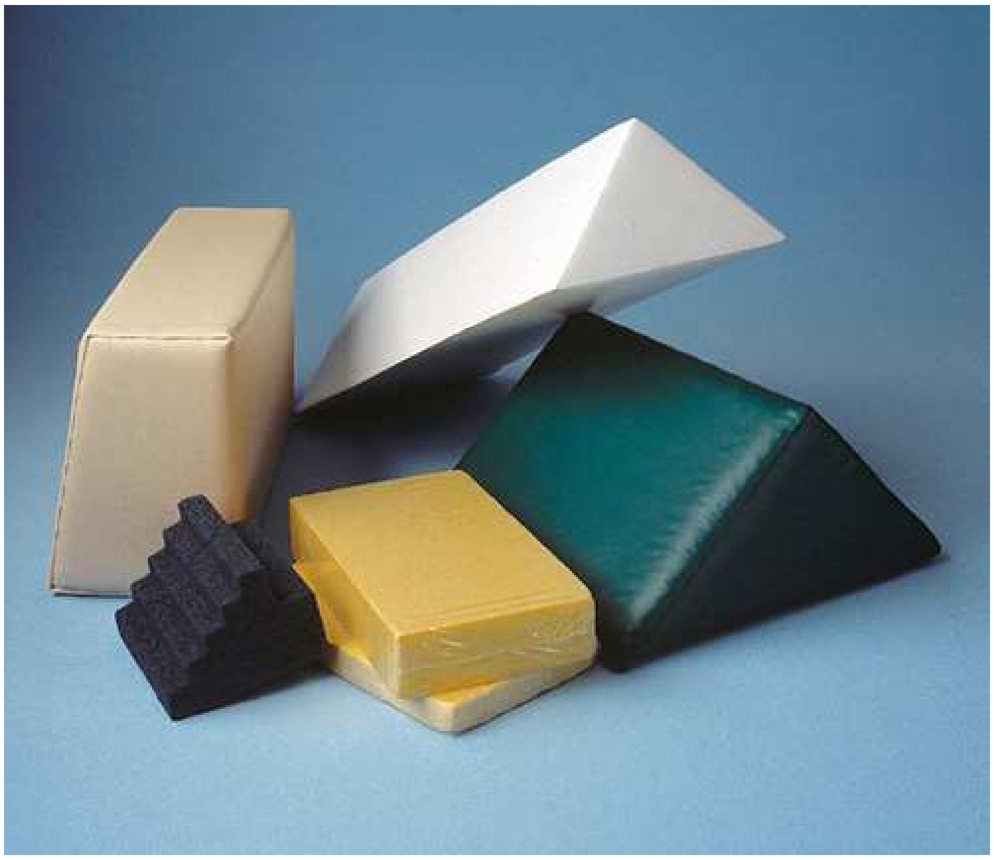


FIG. 23.14 Positioning sponges and sandbags are commonly used as immobilization devices.

A few radiolucent positioning sponges and sandbags of different shapes, sizes, and colors are next to each other. Two of them are triangular, two are rectangular, one of them is shaped like a pyramid with steps

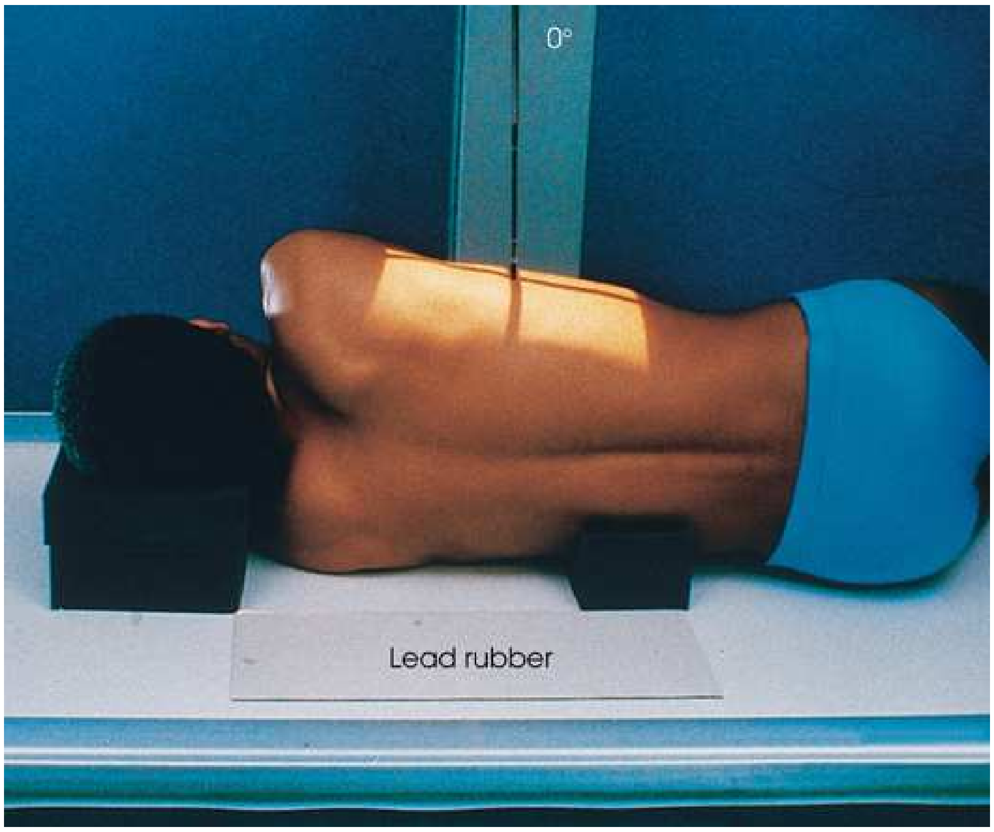


FIG. 23.15 Recumbent lateral thoracic spine. Support placed under lower thoracic region; perpendicular central ray.

FIG. 23.16 Legs inverted for AP projection of the pelvis. Wrapping flexible sandbags around the feet can help the geriatric patient hold his or her legs in this position.

FIG. 23.17 An older adult patient with Alzheimer disease was brought to the emergency department because he could not walk. The patient did not complain of pain. Note fracture of the right hip. Trauma radiograph was made with patient's pants on and the zipper is shown.

The thoracic and lumbar spines are sites for compression fractures. The use of positioning blocks may be necessary to help the patient remain in position. For the lateral projection, a lead blocker or shield behind the spine should be used to absorb as much scatter radiation as possible (see Fig. 23.15).

Pelvis And Hip

Osteoarthritis, osteoporosis, and injuries as the result of falls contribute to hip pathologies. A common fracture in older adults is to the femoral neck. An AP projection of the pelvis should be performed to examine the hip. If the indication is trauma, the radiographer should *not attempt to rotate the limbs*. The second view taken should be a cross-table lateral of the affected hip. If hip pain is the indication, assist the patient to internal rotation of the legs with the use of sandbags if necessary (Figs. 23.16 and 23.17).

Upper Extremity

Positioning the geriatric patient for projections of the upper extremities can present its own challenges. Often the upper extremities have limited flexibility and mobility. A cerebrovascular accident or stroke may cause contractures of the affected limb. Contracted limbs cannot be forced into position, and cross-table views may need to be done. The inability of the patient to move his or her limb should not be interpreted as a lack of cooperation. Supination is often a problem in patients with contractures, fractures, and paralysis. The routine AP and lateral projections can be supported with the use of sponges, sandbags, and blocks to raise and support the extremity being imaged. The shoulder is also a site of decreased mobility, dislocation, and fractures. The therapist should assess how much movement the patient can do before attempting to move the arm. The use of finger sponges may also help with the contractures of the fingers (Fig. 23.18).

FIG. 23.18 Most projections of the upper limb can be obtained with the patient in a wheelchair and with some creativity. (A) Patient being positioned for an AP hand radiograph. Note use of a 4-inch sponge to raise the IR. (B) Patient being positioned for a lateral wrist radiograph. A hospital food tray table provides a base for IR and for ease of positioning.

(A) An elderly man is sitting in a wheelchair next to a radiographic table. A 4-inch sponge is placed on the lap and the hand is placed on the I R on top of the sponge. A woman standing in front of him is positioning the I R and the x-ray tube. (B) An elderly man is sitting in a wheelchair next to a radiographic table. His forearm is placed on a hospital food tray table on top of the I R. A woman standing in front of him is positioning his hand on the I R.

Lower Extremity

The lower extremities may have limited flexibility and mobility. The ability to dorsiflex the ankle may be reduced as a result of neurologic disorders. Imaging on the x-ray table may need to be modified when a patient cannot turn on his or her side. Flexion of the knee may be impaired and require a cross-table lateral projection. If a tangential projection of the patella, such as the Settegast method, is necessary, and the patient can turn on his or her side, the radiographer can place the IR superior to the knee and direct the central ray perpendicular through the patellofemoral joint. Projections of the feet and ankles may be obtained with the patient sitting in the wheelchair. Positioning sponges and sandbags support and maintain the position of the body part being imaged (Fig. 23.19). Whenever possible, the technologist should keep the patient in the wheelchair or stretcher to perform upper and lower extremity exams. This will minimize the stress (to both patient and technologist) of transferring the patient to and from the examination table.

Technical Factors

Exposure factors also need to be taken into consideration when imaging the geriatric patient. The loss of bone mass and atrophy of tissues often require a lower kilovoltage (kVp) to maintain sufficient contrast. The kVp is also a factor in chest radiographs when there may be a large heart and pleural fluid to penetrate. Patients with emphysema require a reduction in technical factors to prevent overexposure of the lung field. Patient assessment can help with the appropriate exposure adjustments.

Time may also be a major factor. Geriatric patients may have problems maintaining the positions necessary for the examinations. A short exposure time helps reduce voluntary and involuntary motion and breathing. The radiographer needs to ensure that the geriatric patient clearly hears and understands the breathing instructions.

FIG. 23.19 Projections of the lower limb, especially from the knee and lower, can be obtained with the patient in a wheelchair. (A) AP projection of the ankle with the patient's leg and foot resting on a chair. (B) Lateral projection of the ankle performed by using a chair as a rest and a sponge to raise the IR.

(A) An elderly man is sitting in a wheelchair next to a radiographic table with the leg and foot resting on a chair. A woman wearing gloves standing in front of him is positioning his foot on the chair. (B) An elderly man is sitting in a wheelchair next to a radiographic table with his leg and foot resting on a chair. A woman wearing gloves is holding a sponge with the I R against it.

Best Practices in Geriatric Radiography

There is no cookie cutter approach to imaging the elderly patient. Each patient comes with his/her own set of challenges. Elderly patients of advanced age often present with some form of physical or cognitive impairment, and the radiographer must be able to mitigate those challenges by applying problem-solving skills to adapt routine procedures to the patients' condition while maintaining quality images. The following guidelines present how to image challenging elderly patients.

1. ***Communication:*** Radiologic technology is a people-oriented, hands-on profession that requires proficiency in a wide variety of communication techniques. [5] Establishing a good rapport with the elderly patient at the beginning of the exam is a good approach to a successful procedure. Verbal communication should be clear and concise. Instructions should be given slowly and systematically so that the patient will be able to process the information and carry out the instructions. The technologist should provide clear explanation of the procedure before the start of and during the radiographic exam. Effective communication will ascertain maximum cooperation from the patient.
2. ***Comfort:*** Comfort is at the top of the list of needs for elderly patients. It is imperative that the caregiver values unique situations and provides the appropriate care for the patient. To comfort the elderly patient, the technologist should maintain an attitude focused on the patient's desires, wishes, and needs. [6]
3. ***Safety:*** Falls can be devastating to elderly patients, not only the physical injuries but also the psychologic effect triggering the fear of falling. [7] Close attention must be paid to the patient's fall risk assessment, and care must be taken that every move is supervised. The radiographer must adhere to the falls precautions and protocols established by the health care facility.
4. ***Speed:*** Speed does not necessarily mean sacrificing image quality. The radiographer will plan and strategize the best approach to each projection, arranging the order so the patient is spared the discomfort caused by moving/turning them multiple times. All like projections should be grouped together (i.e., perform all anteroposterior projections first, then axials, then obliques, then laterals, etc.)
5. ***Positioning:*** The technologist must adhere to the cardinal radiographic rule of producing orthogonal and oblique projections. Deviation from the routine protocol will be necessary at times in order to adapt to the patient's condition and limitations.
6. *Accuracy/image quality:* Chest radiography remains the initial exam of choice for diagnosing respiratory symptoms. Pulmonary fibrosis, pneumonia, and lung cancer can be detected with reasonable sensitivity and specificity. Because it is readily available and requires low radiation dose, chest radiography is usually the first step in diagnosis. [8] The radiographer should adjust technical factors to compensate for pathological changes or the presence of prosthetic devices in the patient's anatomy.
7. ***Patience:*** The advanced elderly and patients with dementia are sometimes confused, combative, and disagreeable, especially in unfamiliar environments and around unfamiliar people. Radiographers often experience their verbal and/or physical abuse. Great patience must be exercised in these situations. The resilient radiographer will develop a "thick skin" as they advance in the profession.

Conclusion

Imaging professionals will continue to see a change in the health care delivery system with a shift in the population of people older than age 65. This shift in the general population is resulting in an ongoing increase in the number of medical imaging procedures performed on older adult patients. Demographic and social effects of aging determine the way in which older adults adapt to and view the process of aging. An individual's family size and perceptions of aging, economic resources, gender, race, ethnicity, social class, and availability and delivery of health care affect the quality of the aging experience. Biologic age is much more critical than chronologic age when determining the health status of the older adult.

Healthier lifestyles and advancements in medical treatment are creating a generation of successfully aging adults, which should decrease the negative stereotyping of older adults. Attitudes of all health care professionals, whether positive or negative, affect the care provided to the growing older adult population. Education about the mental and physiologic alterations associated with aging, along with the cultural, economic, and social influences accompanying aging, enables the radiographer to adapt imaging and therapeutic procedures to the older adult patient's disabilities resulting from age-related changes.

The human body undergoes a multiplicity of physiologic changes and failure in all organ systems. The aging experience is affected by heredity, lifestyle choices, physical health, and attitude, making it highly individualized. No individual's aging process is the same. Radiologic technologists must use their knowledge, abilities, and skills to adjust imaging procedures to accommodate for disabilities and diseases encountered with geriatric patients. Safety and comfort of the patient are essential in maintaining compliance throughout imaging procedures. Communication, listening, sensitivity, and empathy lead to patient compliance. The Joint Commission, recognizing the importance of age-based communication competencies for older adults, requires the employees of accredited health care organizations to document their achievement of these skills. Knowledge of age-related changes and disease processes enhances the radiographer's ability to provide care that meets the needs of the increasing older adult patient population.

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24: Sectional Anatomy for Radiographers

Rex T. Christensen

OUTLINE

Overview

Imaging modalities, such as computed tomography (CT), magnetic resonance imaging (MRI), and diagnostic medical sonography, require the technologist to look at anatomy images in a totally different way than they are used to with general radiographs. These technologies create cross-sectional imaging planes, in effect visualizing a slice through the body. The advantage of visualizing cross-sectional anatomic structures is that images can be viewed without the confusing superimposition of other anatomic parts. Images are generated in various orientations, such as axial, sagittal, coronal, and oblique planes. These planes make it crucial for the technologists working within these modalities to have a clear and complete understanding of general anatomic principles. Without a clear understanding of general anatomy, it is difficult to feel confident identifying normal and abnormal structures in cross section. This chapter provides the radiographer who possesses a background in general anatomy with an orientation to sectional anatomy and correlates that anatomy with structures shown on images from the various computer-generated imaging modalities.

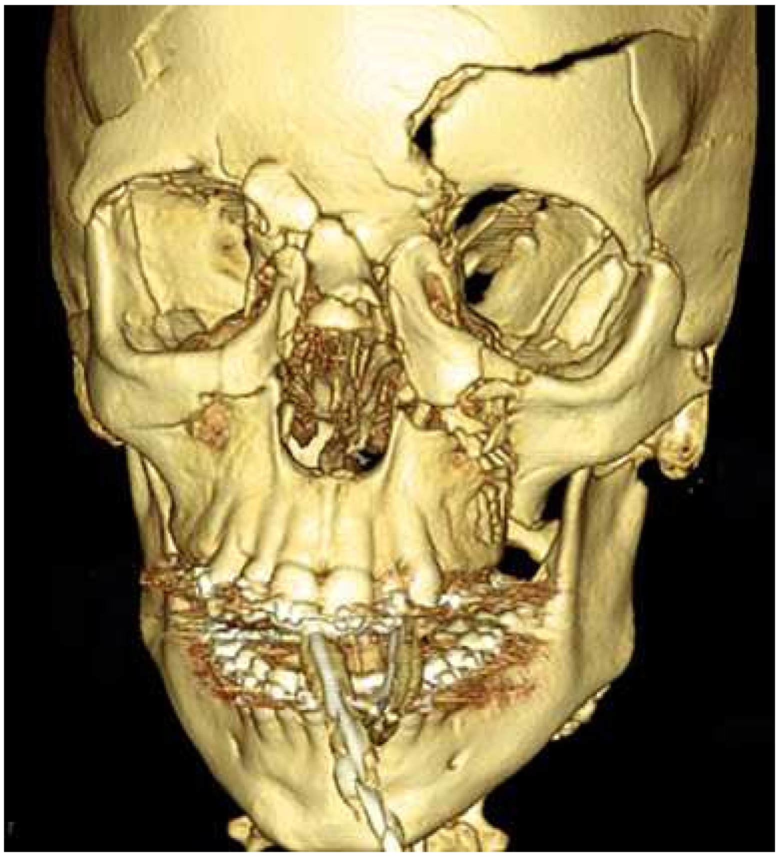


FIG. 24.1 Three-dimensional reconstructed CT image of the head.

There are three major imaging planes: axial, sagittal, and coronal. Images that are off-axis from these planes are termed *oblique*. Axial planes (sometimes referred to as *transverse planes* or *transaxial*) transect the body from anterior to posterior and from side to side. In effect, this type of horizontal plane divides the body into superior and inferior portions. Most images generated by CT are examples of axial or transverse planes. When looking at an axial image, it is helpful to imagine standing at the patient's feet and looking up toward the head. With this orientation, the patient's right side is to the viewer's left and vice versa. The anterior aspect of the patient is usually at the top of the image. Coronal planes divide the body into anterior and posterior portions. Coronal planes pass from superior to inferior and from side to side. Images viewed in the coronal plane are similar to radiographs in that the patient's right side is on the technologist's left (one can imagine facing the patient while viewing this type of image). Sagittal planes divide the body into right and left portions. These planes pass from superior to inferior and from anterior to posterior. MR images frequently use the coronal and sagittal planes to present the desired anatomy. CT images in the sagittal and coronal planes are reformatted data from axial images to display anatomy in these planes. Imaging planes that are generated from a single source are termed multiplanar reformat (MPR) images. Any plane that does not fit the previous descriptions is referred to as an *oblique plane*. Oblique planes are useful when imaging complicated structures, such as the heart. Source images obtained from the imaging modality can be compiled to produce not only MPR images but also three-dimensional images (Fig. 24.1). The CT three-dimensional images displayed in Fig. 24.1 help the physician with surgical and oncology treatment planning and patient instruction and education.

CT uses x-rays to generate images, so the various shades on the images correspond to the gray scale that radiographers are accustomed to seeing. Bones and other dense materials are white, whereas air and lower density materials are closer to black. Fat, muscle, and organs are represented with various shades of gray. Hounsfield units or CT numbers represent the scale of white to black that is used in CT imaging. Lower numbers represent anatomic structures that are more easily penetrated by the x-ray and appear closer to black on the image. Higher numbers are related to more radiopaque structures and are lighter gray or white on the image. Similar to routine radiographs, blood vessels and organs of the digestive system are not easily distinguishable from other structures. Tissue contrast limitations require these structures to be identified more accurately. Therefore, patients are frequently given a radiopaque contrast medium. Intravascular contrast medium highlights vessels, making them appear radiopaque and whiter on the image. To visualize the gastrointestinal system, patients may be given a contrast agent by mouth or via the rectum. A full description of CT fundamentals is presented in Chapter 25.

MRI uses magnetic fields and radiofrequencies to generate images. Anatomic structures are represented on the image regarding the signal generated from their protons. Structures that produce a strong signal are generally lighter gray or white on the image, and structures that do not generate a strong signal tend to be darker on the image. The signal generated by these structures depends on many things, including the strength of the magnetic fields, relaxation times of tissues, and the radiofrequency characteristics of anatomical structures. Contrast medium may also be used when performing MRI to change the signal intensity of particular anatomic structures. Gadolinium, air, and fluid may be used as contrast agents, depending on the organ of interest and the imaging sequences employed. MRI is discussed in depth in Chapter 26.

The cadaveric sections depicted in this chapter are representative of major organ structures for each of the body regions and *are depicted from the inferior surface to correspond to the images*. All relational terms are used in relation to the body in anatomic position. (When a structure is described as being to the right of something, this refers to the *patient's* right, not the *viewer's* right.) The major anatomic structures normally seen when using current imaging modalities are labeled. For each region of the body, a cadaveric section is presented, and representative images are included to provide an orientation to anatomic structures normally seen using the available imaging modalities. The cadaveric sections and diagnostic images do not match exactly; some structures are seen on only one of the illustrations for each body region. Major anatomic structures in each region of the body are reviewed in the following sections to make it easier to identify the images provided. Systematic review of the bones, vessels, major organs, and muscles begin each section. Selected images are presented in axial, sagittal, and coronal planes to show these structures. In practice, images should be examined collectively because the size, shape, and placement of these structures vary from slice to slice. Scrolling through the various slices of a structure is frequently the ideal way to identify the size and characteristics of that structure.

Cranial Region

Fig. 24.2 is a cadaveric image that can be used to distinguish bone, muscle, and other soft tissue structures. Referring to this image is helpful in identifying the sometimes-confusing shadows on the images. The head can be thought of systematically as being composed of the skull, central nervous system structures, various sensory organs, cranial blood supply, and associated cranial and facial muscles. The bones of the skull are categorized as the 8 cranial bones and the 14 facial bones. The cranial bones include the frontal, occipital, and two parietal bones that surround and protect the external surface of the brain. The other four cranial bones include the ethmoid, sphenoid, and two temporal bones. The frontal bone forms the anterior surface of the skull, with a vertical portion that corresponds to the forehead and a horizontal portion that forms the roof of the orbits. Between the inner and outer layers of the vertical portion of the frontal bone—just superior to the level of the eyes—are the paired frontal paranasal sinuses. The vertex is the most superior portion of the skull and is formed by the paired parietal bones. These roughly square-shaped bones articulate with the frontal bone at the coronal suture, with the temporal bones at the squamosal sutures, with the occipital bone at the lambdoidal suture, and with each other at the sagittal suture.

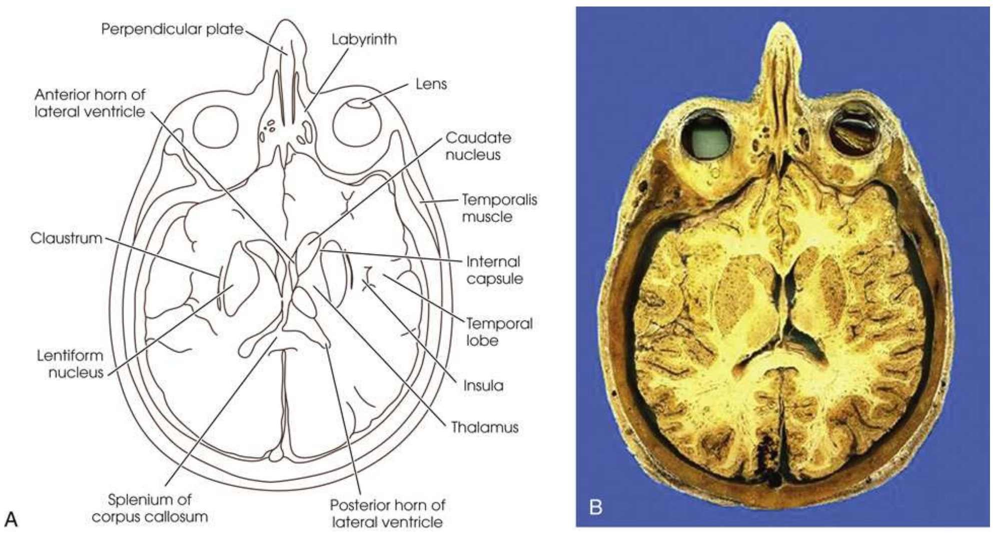


FIG. 24.2 (A) Line drawing of gross anatomic section. (B) Cadaveric image of skull.

Diagram (A) shows a line drawing of the anatomic section of the skull and its components. The parts labeled in the diagram are marked clockwise as follows: splenium of corpus callosum, lentiform nucleus, claustrum, anterior horn of lateral ventricle, perpendicular plate, labyrinth, lens, caudate nucleus, temporalis muscle, internal capsule, temporal lobe, insula, thalamus, posterior horn of lateral ventricle. (B) shows a cadaveric image of a skull. It appears yellow. There are two holes on either side of the perpendicular plate. The thalamus, and the caudate nucleus is black. The surface of the skull appears grainy.

The posterior aspect of the skull is formed by the occipital bone, which is composed of a squamous (vertical) portion and a basilar portion. The foramen magnum is a large opening within the squamous portion that allows passage of the spinal cord into the brain. The external occipital protuberance is a large prominence on the posterior surface of this bone. Roughly corresponding in position to this landmark is the internal occipital protuberance. The ethmoid bone is found within the cranium and forms the medial walls of the orbits and part of the lateral walls of the nasal cavity. The ethmoid bone is divided into a horizontal portion called the *cribriform plate* and vertical portions called the *perpendicular plate* and *two labyrinths* or *lateral masses.*

The cribriform plate lies between the orbital plates of the frontal bone and supports the olfactory bulbs (cranial nerve I). The cribriform plate is perforated by many small foramina, which transmit nerves from the nose to this cranial nerve. Projecting superiorly from the cribriform plate is a small ridge of bone called the *crista galli*, which serves as the anterior attachment for the falx cerebri. Projecting inferiorly from the center of the cribriform plate is the perpendicular plate. This thin strip of bone forms the superior part of the bony nasal septum. Extending inferiorly from the lateral edges of the cribriform plate are the labyrinths or lateral masses. These are perforated by multiple air spaces, which are collectively called the *ethmoidal paranasal sinuses.* From the medial surface of each labyrinth, two scroll-shaped ridges of bone project into the nasal cavity. These are the superior and middle nasal conchae.

In the center of the base of the skull is the sphenoid bone. This bone is sometimes referred to as the *anchor bone of the cranium* because it articulates with all the cranial bones. Thinking of this bone as being composed of a body, two sets of wings, and a pterygoid portion is helpful. The body is the central portion of the bone and contains the easily identifiable landmark known as the *sella turcica.* The sella turcica forms a cup-shaped depression that surrounds and protects the pituitary gland. The anterior surface of the sella is called the *tuberculum sellae*, and the posterior portion is called the *dorsum sellae.* Two posterior clinoid processes project from the superior edge of the dorsum sellae and are attachments for dura mater partitions. Within the body of the sphenoid and inferior to the sella turcica are the paired sphenoidal paranasal sinuses. The lesser wings of the sphenoid are triangular ridges of bone found posterior to the orbital plates of the frontal bone. Directly inferior to the medial edge of each lesser wing is the optic canal, which transmits the optic nerve (cranial nerve II). The larger, greater wings support the temporal lobes of the cerebrum and extend from the body to the external surface of the skull. The pterygoid processes project inferiorly from the body of the sphenoid and form the posterior walls of the nasal cavity.

The temporal bones form part of the lateral walls of the cranium and extend internally to meet the sphenoid and the basilar portion of the occipital bone. Parts of the temporal bone include the squamous, tympanic, mastoid, and petrous portions. The squamous portion is the thin, fan-shaped external part of the bone superior to the external ear. It articulates with the parietal and several other cranial bones. Its articulation with the parietal bone is called the *squamous suture.* The tympanic portion is the area of the bone surrounding the external ear canal. The zygomatic process arches anteriorly from just superior to the external ear canal. Just inferior to the origin of the zygomatic process is the mandibular fossa, in which the condyle of the mandible is found. On the inferior surface of the tympanic portion of the bone is the styloid process, which serves as an attachment for muscles. Posterior to the ear is the mastoid portion, which is perforated by many small, air-filled cavities. The mastoid portion extends inferiorly to form the cone-shaped mastoid process. The petrous portion of the bone lies within the cranium, normally forming an angle of approximately 45 degrees to the median sagittal plane. This dense ridge of bone surrounds and protects the organs of hearing and balance, the facial and vestibulocochlear nerves, and the internal carotid artery.

The organs associated with the face are surrounded and protected by 14 bones. Each of these bones is paired, with the exception of the vomer and the mandible. The lacrimal bones are about the size of a fingernail and are found in the medial wall of the orbit between the maxilla and the labyrinth of the ethmoid bones. The nasal bones form the bridge of the nose and articulate superiorly with the frontal bone, laterally with the maxilla, and with each other in the midline. The zygomatic bones form the inferolateral walls of the orbits. Each of these bones articulates superiorly with the frontal bone, medially with the maxilla, and laterally with the zygomatic process of the temporal bone. The maxilla originates as two separate bones, which ultimately fuse along the midsagittal plane. This large bone forms the inferior surface of each orbit, the lateral walls of the nasal cavity, and the anterior portion of the roof of the mouth. On either side of the nasal cavity, large air-filled maxillary paranasal sinuses are embedded within the bone. The upper teeth are rooted within the alveolar process at the anteroinferior surface of the bone. The maxilla articulates with the nasal bones, the lacrimal bones, the frontal bone, the zygomatic bones, and the palatine bones. The inferior nasal conchae are scroll-shaped facial bones found in the nasal cavity, just inferior to the middle nasal conchae of the ethmoid bone. The L-shaped palatine bones form the posterior portion of the hard palate. The vertical portions of the palatines extend superiorly along the posterior nasal cavity to form a small part of the posterior orbit.

The vomer is an unpaired facial bone that rests on the hard palate and articulates with the inferior surface of the perpendicular plate of the ethmoid. It forms the inferior portion of the bony nasal septum. The mandible, which is also an unpaired facial bone, is formed by a body and two rami. The body comprises the anterior portion of the bone and presents an alveolar ridge in which the lower teeth are embedded. The rami extend superiorly from the body and end in anterior and posterior bony processes. The anterior process at the superior end of the ramus is the coronoid process, where muscles of mastication attach. The posterior process is the condyloid process, which rests in the mandibular fossa of the temporal bone. This articulation—the temporomandibular joint—is the only movable articulation associated with the skull. (Refer to Chapter 11 for review of skull anatomy.)

The brain is surrounded by three layers of protective membranes called the *meninges.* From internal to external, they are the pia mater, arachnoid, and dura mater. The pia mater adheres directly to the brain and is composed of a fine network of capillaries and supporting tissue. The arachnoid is a delicate membrane that resembles a cobweb. The subarachnoid space lies between the arachnoid and pia mater. Cerebrospinal fluid (CSF) circulates in this space. The arachnoid does not closely adhere to cerebral structures. As it bridges the gap between various parts of the brain, enlarged regions—or cisterns—are formed in the subarachnoid space. Some of the more crucial cisterns include the cisterna magna, pontine, interpeduncular, and superior or *quadrigeminal cistern.* The cisterna magna is the largest of these and is found just inside the foramen magnum, between the cerebellum and the medulla oblongata. This cistern receives CSF from the fourth ventricle. The pontine cistern lies anterior to the pons and contains the basilar artery. The interpeduncular cistern is anterior to the midbrain. The infundibulum (stalk) of the pituitary and the vessels of the circle of Willis are seen here. The cistern found posterior to the midbrain is the superior cistern. It surrounds the pineal gland and the great cerebral vein. Ambient cisterns communicate with the superior cistern and extend laterally around the midbrain. The most external of the meninges is the double-layered dura mater. The outer layer of dura is attached to the inner surface of the cranial bones. The inner layer can be seen between cerebral structures and in large fissures. Dural sinuses are venous drainage channels formed where the inner dural layers separate from the outer layer. One of the largest dural flaps, the falx cerebri, is found in the longitudinal fissure between the cerebral hemispheres. It extends from the crista galli of the ethmoid to the occipital bone. The tentorium cerebelli extends between the cerebrum and the cerebellum. It attaches to the sella turcica and the internal surface of the occipital bones.

The structures of the central nervous system within the skull include the cerebrum, brain stem, and cerebellum. The cerebrum is the largest of these structures and is divided by the longitudinal fissure into two hemispheres. The hemispheres are connected to each other via a white matter tract called the *corpus callosum.* This arch-shaped structure is divided into the anterior genu, central body, and posterior splenium. Each cerebral hemisphere is divided into lobes that are named for the most adjacent cranial bone: frontal, parietal, temporal, and occipital. An additional lobe called the insula is located deep within the lateral sulcus of each hemisphere, below the frontal, parietal, and temporal lobes. The cerebrum is thrown into numerous folds called *gyri*, which are separated by small fissures called *sulci.* The outer surface of the cerebrum consists of a thin layer of gray matter. The central portion of this part of the brain is mainly white matter (formed by myelinated nerve fibers). These fibers, referred to as the *corona radiata*, connect the gray matter of the cortex to deeper gray matter nuclei deep within each hemisphere. The buried gray matter centers are called *basal nuclei* or *basal ganglia* and include the claustrum, putamen, globus pallidus, and caudate nucleus. White matter tracts—or capsules—are found between these gray matter structures. Other gray matter structures found within the central cerebrum include the thalamus and hypothalamus. The medial aspects of the thalamus and the hypothalamus form the lateral walls of the third ventricle. Many of these gray and white matter structures are seen on the cadaveric section in Fig. 24.2.

The brain stem is formed by the midbrain, pons, and medulla oblongata. It lies between the cerebrum and cerebellum and serves as a relay for nerve impulses between the spinal cord and these two structures. The midbrain is the most superior of the three. White matter tracts called the cerebral peduncles extend from the anterior midbrain to the cerebrum. Toward the posterior aspect of the midbrain are the corpora quadrigemina, which are formed by two superior and two inferior colliculi that lie just inferior to the splenium of the corpus callosum. The cerebral aqueduct drains CSF from the third ventricle to the fourth ventricle and passes through the posterior portion of the midbrain. The central portion of the brain stem is formed by the pons. It communicates with the medulla, with the midbrain, and via white matter cerebellar peduncles to the cerebellum. The most inferior of the brain stem structures is the medulla oblongata, which is continuous with the spinal cord as it passes through the foramen magnum.

The cerebellum lies in the posteroinferior region of the cranium. Although smaller in size, it is similar in composition to the cerebrum. A midline fissure divides the cerebellum into hemispheres that are connected by a midline vermis. It is also thrown into numerous small folds, here called folia, which are separated by numerous small fissures. The outer surface of the cerebellum is composed of gray matter, with white matter constituting most of the central portion of this part of the brain. Gray matter nuclei can be found here also, although they are difficult to distinguish on images and are not discussed in this chapter.

Four large cavities called *ventricles* are found in the brain. The ventricles' major function is to produce and store CSF; this is accomplished as blood is filtered through capillary networks called *choroid plexuses* in each of the ventricles. The largest of these chambers are the lateral ventricles, one of which is found in each cerebral hemisphere. The lateral ventricles are divided into a body and anterior, posterior, and inferior horns. CSF from these chambers passes into the midline third ventricle through the interventricular foramina. The third ventricle is found between the cerebral hemispheres inferior to the lateral ventricles. The cerebral aqueduct drains CSF from the third ventricle to the fourth ventricle. The fourth ventricle is found between the cerebellum and the brain stem. Its walls are formed by white matter tracts called *cerebellar peduncles*, which connect the brain stem and cerebellum. A central aperture and two lateral apertures allow CSF to pass from the fourth ventricle into the subarachnoid space.

The brain is a highly metabolic organ and needs a rich blood supply to function well. Four major arteries supply the brain and its related structures: the two internal carotid arteries and the two vertebral arteries. The internal carotid arteries supply the anterior structures of the brain. After passing superiorly through the neck, these arteries enter the skull via the carotid canals in the petrous portion of the temporal bones. After exiting the petrous portion, the internal carotid arteries pass along the lateral aspect of the sella turcica, ultimately dividing into the anterior and middle cerebral arteries. The posterior communicating artery arises from the internal carotid just before this bifurcation. The anterior cerebral arteries pass anteriorly and superiorly to the longitudinal fissure, where they curl around the external aspect of the corpus callosum and supply the anterior portion of the brain. The middle cerebral arteries pass laterally to the lateral fissures, where their branches supply the middle portion of the brain. The posterior communicating arteries pass posteriorly to join with the branches from the vertebrobasilar arterial system. The vertebral arteries traverse the neck in the transverse foramina of the cervical spine and enter the posterior skull via the foramen magnum. These arteries pass superiorly along the anterior aspect of the medulla and at the base of the pons join to form the basilar artery. At the superior aspect of the pons, the basilar artery splits to form the posterior cerebral arteries. A unique arterial anastomosis exists in the brain to protect it from sudden loss of blood supply. This vascular connection is called the *circle of Willis.* The blood supply to the anterior brain is connected to the blood supply for the posterior brain as the posterior communicating arteries extend from the internal carotid arteries to the posterior cerebral arteries. This communication lies in the interpeduncular cistern, just anterior to the midbrain.

Venous drainage in the cranium is accomplished by two systems: cerebral veins and dural venous sinuses. The dural sinuses are created by gaps formed between the inner and outer layers of the dura mater. These gaps are found in the areas where the dura invaginates between the various structures of the brain. The superior sagittal sinus is found in the superior border of the falx cerebri, and the inferior sagittal sinus is found in its inferior margin. The channel formed where the falx cerebri meets the tentorium cerebelli is the straight sinus (Fig. 24.3). This sinus is a continuation of the inferior sagittal sinus as it joins with the great cerebral vein. The great cerebral vein, also known as the vein of Galen, continues under the corpus callosum to form the internal cerebral vein. The transverse or lateral sinuses are found along the lateral aspect of the tentorium cerebelli as it meets the occipital bone. At the level of the petrous portions of the temporal bones, the transverse sinuses curl medially and inferiorly and become known as the *sigmoid sinuses.* As the sigmoid sinuses pass out of the cranium via the jugular foramina, these vessels change names again and become the internal jugular veins. One of the major veins within the skull is the great cerebral vein. This large venous structure is found in the superior cistern, and there it joins the inferior sagittal sinus to form the straight sinus.

Many muscles are associated with the face, only a few of which are referred to in the following sections. The temporalis muscle is found on the external surface of the squamous portion of the temporal bone. Its inferior attachment is to the coronoid process of the mandible. On the external surface of the mandibular rami are the masseter muscles, and on the internal surface of the rami are the pterygoid muscles. These muscles are associated with moving the mandible and with swallowing (Fig. 24.4).

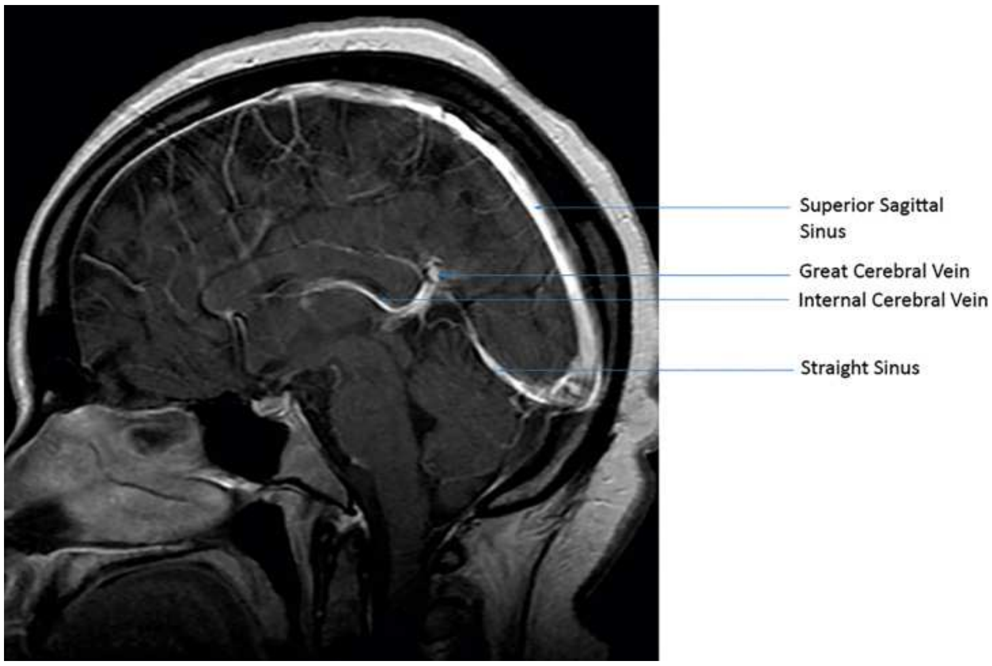


FIG. 24.3 Midsagittal contrast-enhanced MR image of the brain.

A M R I image of the brain shows the falx cerebri meeting the tentorium cerebelli. They appear radiopaque. The superior sagittal sinus is a white border around the skull. The parts labeled are marked from top to bottom as follows: superior sagittal sinus, great cerebral vein, internal cerebral vein, straight sinus.

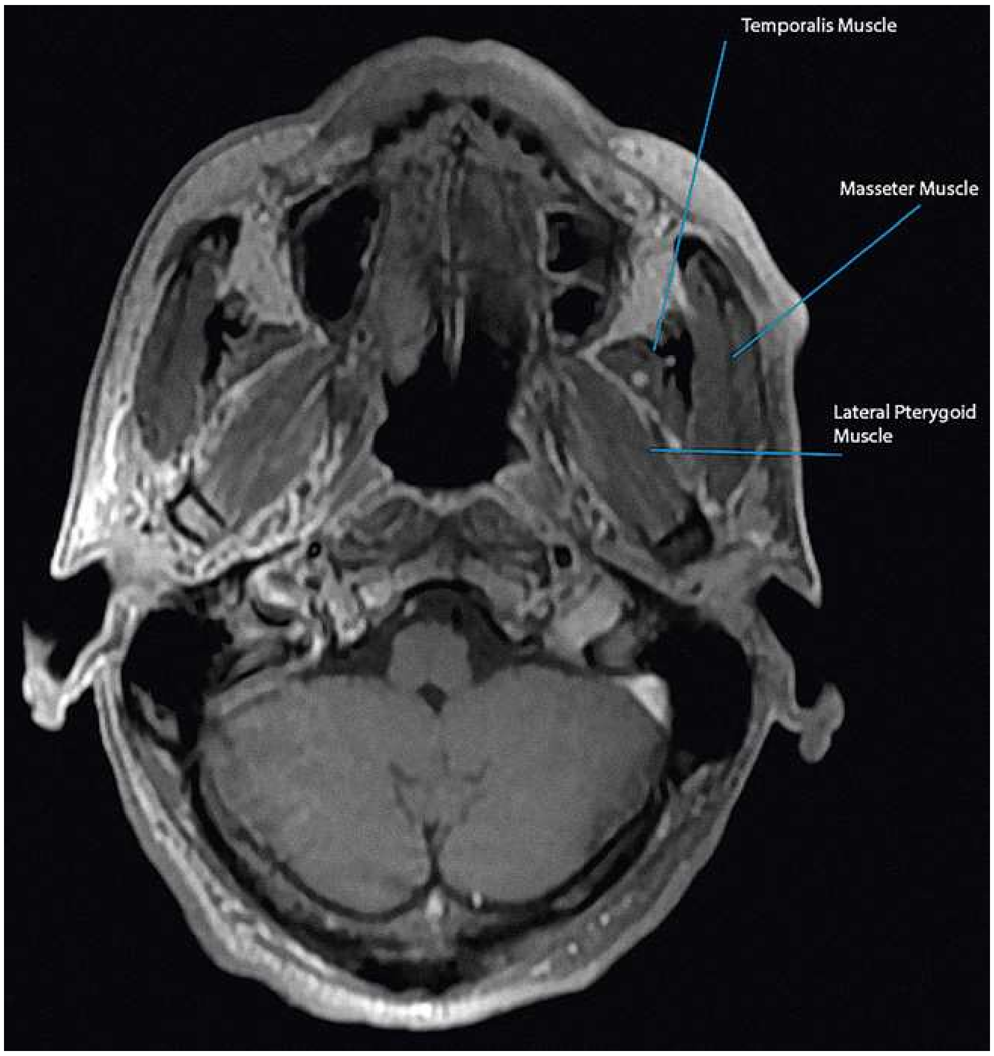


FIG. 24.4 Axial T1-weighted MR image of the brain.

A axial M R I of the brain shows the muscles associated with moving the mandible and with swallowing. They appear grey. The parts labeled are marked from top to bottom as follows: temporalis muscle, masseter muscle, lateral pterygoid muscle.

A lateral skull radiograph is used here for localization of the imaging plane in this section (Fig. 24.5A), and a sagittal MR image (see Fig. 24.5B) is used for localization of MRI cross sections of the brain. CT imaging for the cranium may be performed with the gantry parallel to or angled 15 to 20 degrees to the orbitomeatal line. Angling the gantry of the CT scanner allows for imaging of the brain without excess radiation to the eyes. MRI of the cranium generally results in images that are parallel to the orbitomeatal or infraorbitomeatal plane. More details on patient positioning for CT are provided in Chapter 25, and information on patient positioning for MRI is provided in Chapter 26. Because the imaging planes may be different for CT and MRI, some variation exists in the anatomic structures visualized on corresponding illustrations in this section. Seven identifying lines represent the approximate levels for each of the labeled images for this region.

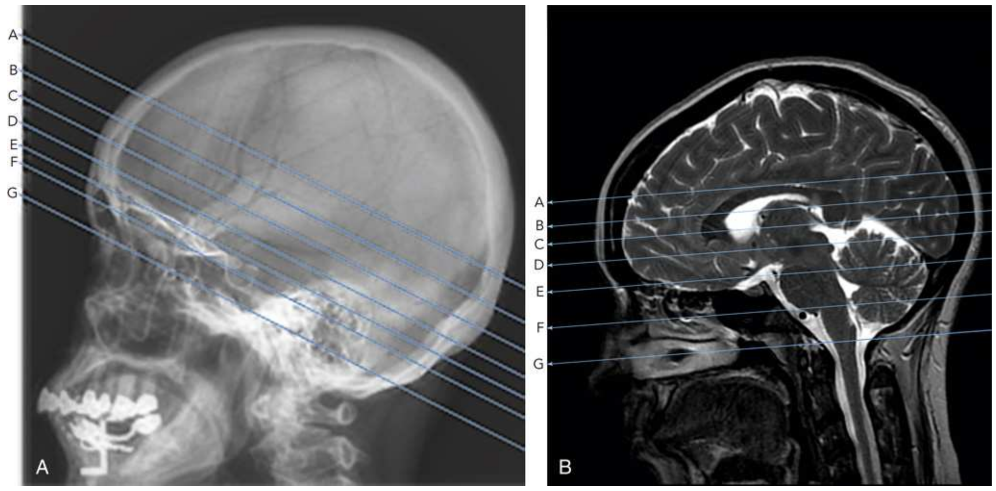


FIG. 24.5 (A) CT localizer (scout) image of skull. (B) Sagittal localizer for MRI of the brain.

(A) shows a C T image of the lateral skull. Seven lines labeled A, B, C, D, E, F, and G are angled 15 to 20 degrees to the orbitomeatal line. (B) shows a M R I of the lateral brain. Seven horizontal lines labeled A, B, C, D, E, F, and G are parallel to one another.

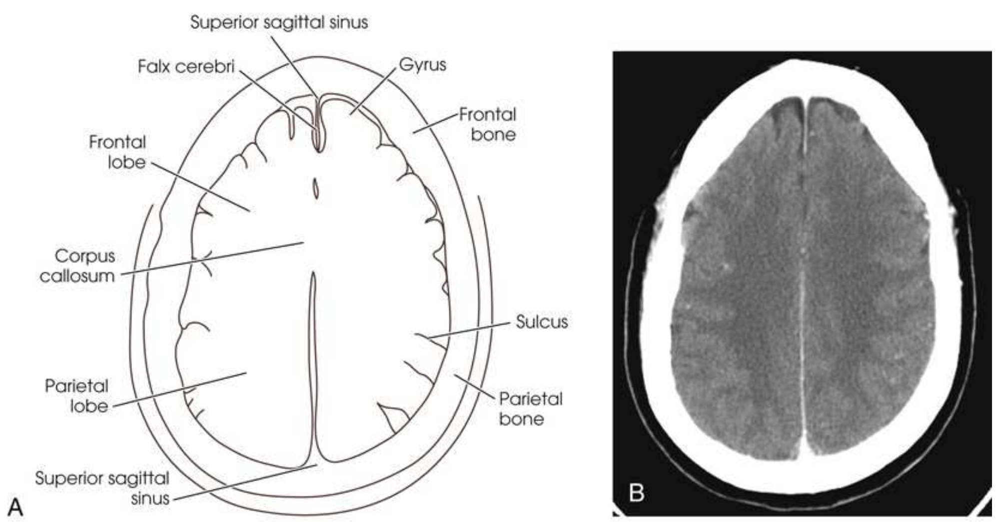


FIG. 24.6 (A) Line drawing of CT section. (B) CT image representing anatomic structures located at level *A* in Fig. 24.5A.

Diagram (A) shows a line drawing of the C T section of the brain. The parts labeled in the diagram are marked clockwise as follows: superior sagittal sinus, parietal lobe, corpus callosum, frontal lobe, falx cerebri, superior sagittal sinus, gyrus, frontal bone, sulcus, parietal bone. (B) A C T image shows the brain. The outer covering of the brain appears radiopaque and the inner region appears grey and grainy.

The cranial CT image seen in Fig. 24.6 represents a CT slice obtained through the frontal and parietal bones, and Fig. 24.7 is a corresponding T1-weighted MR image. The *cortex*—or outer layer of gray matter—can be differentiated from the deeper *white matter*. The numerous *gyri*—or *convolutions*—and *sulci* are shown and are surrounded by the darker appearing CSF in the subarachnoid space. The *cerebral hemispheres* are separated by the *longitudinal cerebral fissure*. Invaginated in this fissure is a fold of *dura mater* called the *falx cerebri*. The *superior sagittal sinus*, which passes through the superior margin of the falx cerebri, follows the contour of the superior skull margin. In cross section, the anterior and posterior aspects of this sinus can normally be seen in the midline deep to the bony plates when the patient has been given an intravenous contrast agent and appear as triangular expansions near the bones on both CT and MR images. Two of the five *cerebral lobes* are seen (frontal and parietal). The *corona radiata* is the central tract of white matter in the cerebrum and is darker than the cortex on the CT image; the white matter is lighter than the gray matter on the MR image. These sections were obtained at a level that passes through the superiormost portion of the *corpus callosum*, which separates the anterior and posterior portions of the falx cerebri.

Fig. 24.8 is an axial CT slice through the superior portions of the lateral ventricles; Fig. 24.9 is the corresponding T1-weighted MR image. Visualized bony structures on the CT scan include the *frontal bone* and the two *parietal bones*. The falx cerebri is seen within the *longitudinal fissure*. The *frontal lobes* and *parietal lobes* of the cerebrum are shown. In the center of each image, the *lateral ventricles* are easily seen because of the dark appearance of the CSF circulating within each. In the posterior portions of the ventricles, the contrast-filled capillary network of the *choroid plexuses* also is visualized. A thin membrane called the *septum pellucidum* can be seen separating the ventricles. The corpus callosum is an arch-shaped structure; in cross section at this level, only the anterior *genu* and the posterior *splenium* can be seen. The *caudate nuclei* lie along the lateral surfaces of the ventricles and tend to follow their curves. Because these nuclei are composed of gray matter, they are the same shade of gray as the cortex on MR images (see Fig. 24.9). Several contrast-filled vascular structures are visible. The *anterior cerebral arteries* lie within the longitudinal fissure just anterior to the genu of the corpus callosum. A few branches of the *middle cerebral arteries* are seen near the lateral aspect of the skull on the CT scan. The anterior and posterior portions of the superior sagittal sinus are seen in the periphery of the falx cerebri. The *inferior sagittal sinus* lies in the internal edges of the falx. The thin strips of muscle seen on the external surface of the frontal bone correspond to the superior edges of the *temporalis muscles*.

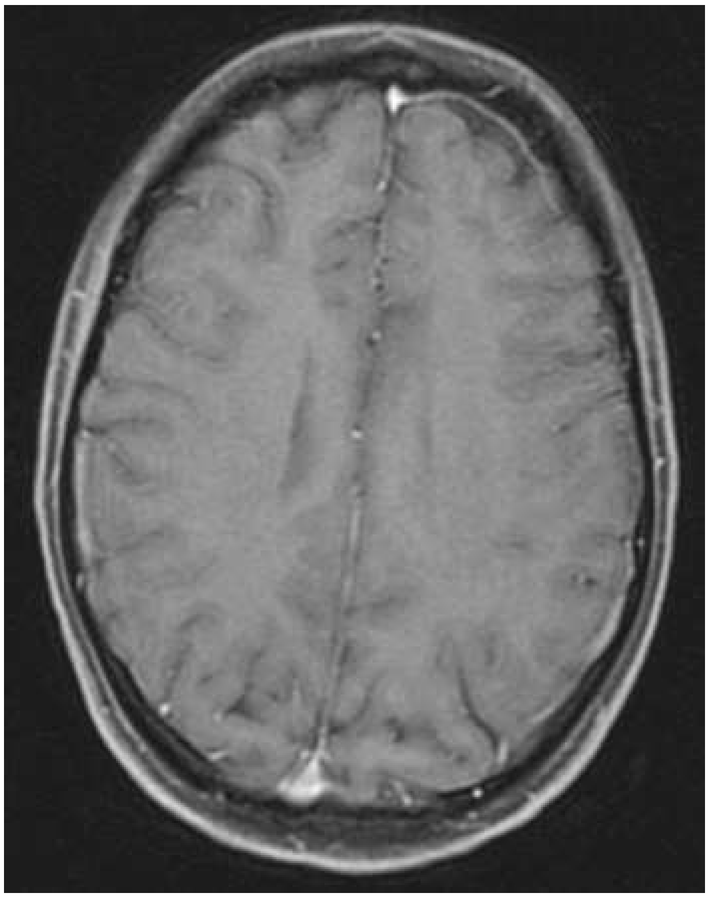


FIG. 24.7 MRI corresponding to level *A* in Fig. 24.5B.

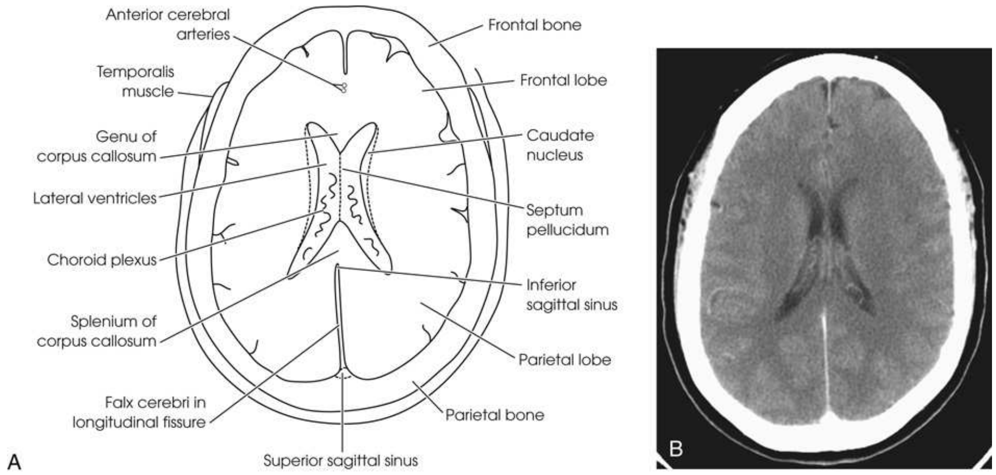


FIG. 24.8 (A) Line drawing of CT section. (B) CT image representing structures located at level *B* in Fig. 24.5A.

Diagram (A) shows a line drawing of the C T section of the brain. The parts labeled in the diagram are marked clockwise as follows: falx cerebri in longitudinal fissure, splenium of corpus callosum, choroid plexus, lateral ventricles, genu of corpus callosum, temporalis muscle, anterior cerebral arteries, frontal bone, frontal lobe, caudate nucleus, septum pellucidum, inferior sagittal sinus, parietal lobe, parietal bone, superior sagittal sinus. (B) A C T slice of the brain through the superior portions of the lateral ventricles shows the outer covering of the brain appearing radiopaque and the inner region appearing grey and grainy. A dark grey colored concave region is seen on either side in the middle.

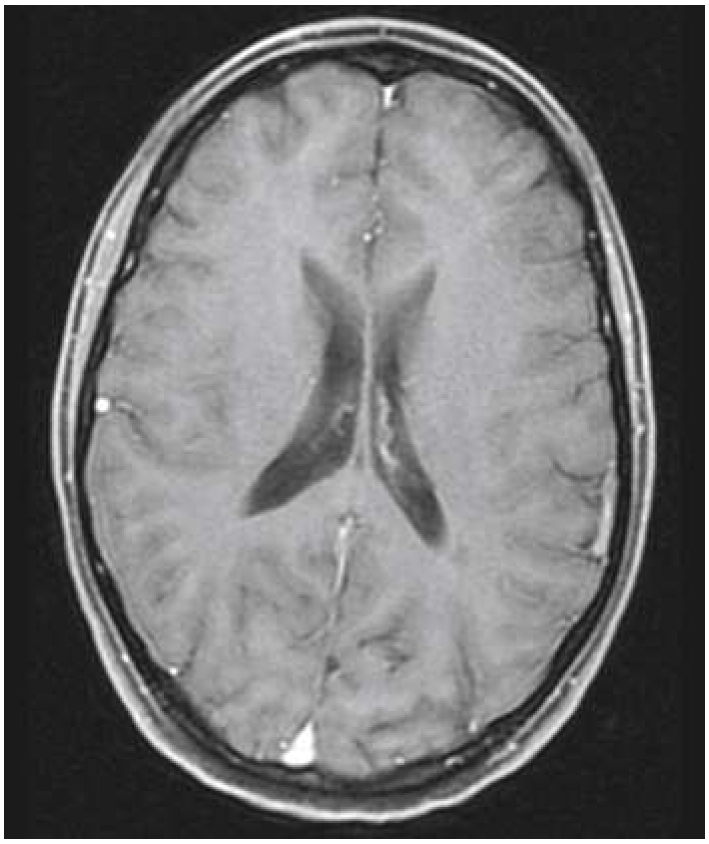


FIG. 24.9 MRI corresponding to level *B* in Fig. 24.5B.

A C T slice of the brain through the superior portions of the lateral ventricles shows several black and grey layers. The inner region appears grey and grainy. The folds of the brain appears black. A dark grey colored concave region is seen on either side in the middle.

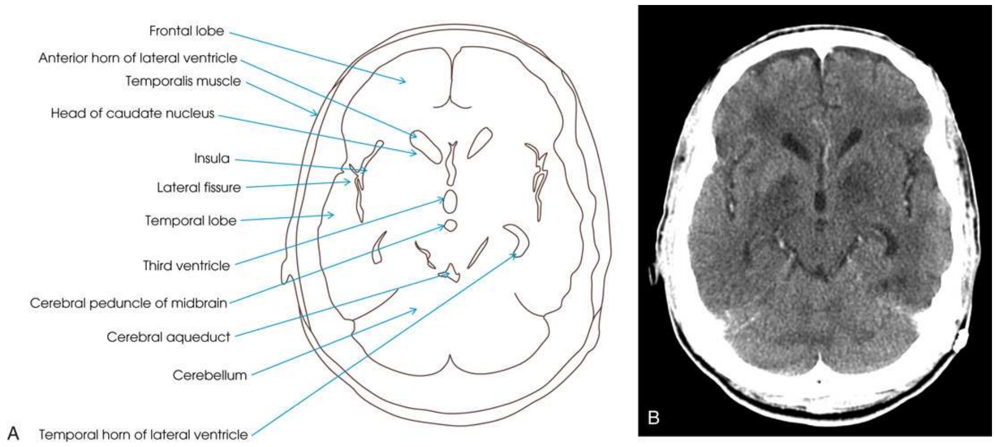


FIG. 24.10 (A) Line drawing of CT section. (B) CT image representing anatomic structures located at level *C* in Fig. 24.5A.

Diagram (A) shows a line drawing of the C T section of the brain. The parts labeled are marked from top to bottom as follows: frontal lobe, anterior horn of lateral ventricle, temporalis muscle, head of caudate nucleus, insula, lateral fissure, temporal lobe, third ventricle, cerebral peduncle of midbrain, cerebral aqueduct cerebellum. (B) A C T image of the brain shows the irregular outer covering of the brain appearing radiopaque and the inner region appearing grey and grainy. There are symmetrically identical dark grey colored regions in the middle. It appears grey and grainy.

The axial sections through the midportion of the cerebrum show many of the central structures of the cerebral hemispheres. (Fig. 24.10 is a CT image, and Fig. 24.11 is a T1-weighted image with contrast). Images at this level pass through the frontal bone, greater wing of the *sphenoid*, and squamous portion of the *temporal bones*. The posterior portion of the skull comprises the top portion (squamous portion) of the *occipital bone* at this level. The falx cerebri is shown within the longitudinal fissure, with the superior sagittal sinus best shown in the midline of the anterior and posterior margins of this membrane. In the CT image, the genu of the corpus callosum is found between the anterior horns of the lateral ventricles; however, the posterior portion of this slice is inferior to the level of the splenium. The MR image shows the genu and the splenium. At this level, the MR image shows the *frontal*, *temporal*, and *occipital lobes* along with the *insula* (fifth lobe or island of Reil), which is deep to the temporal lobe at the lateral fissure. Because of its orientation, the CT image shows the insula, frontal, and temporal lobes; the cerebellum occupies the posterior aspect of the skull in this image.

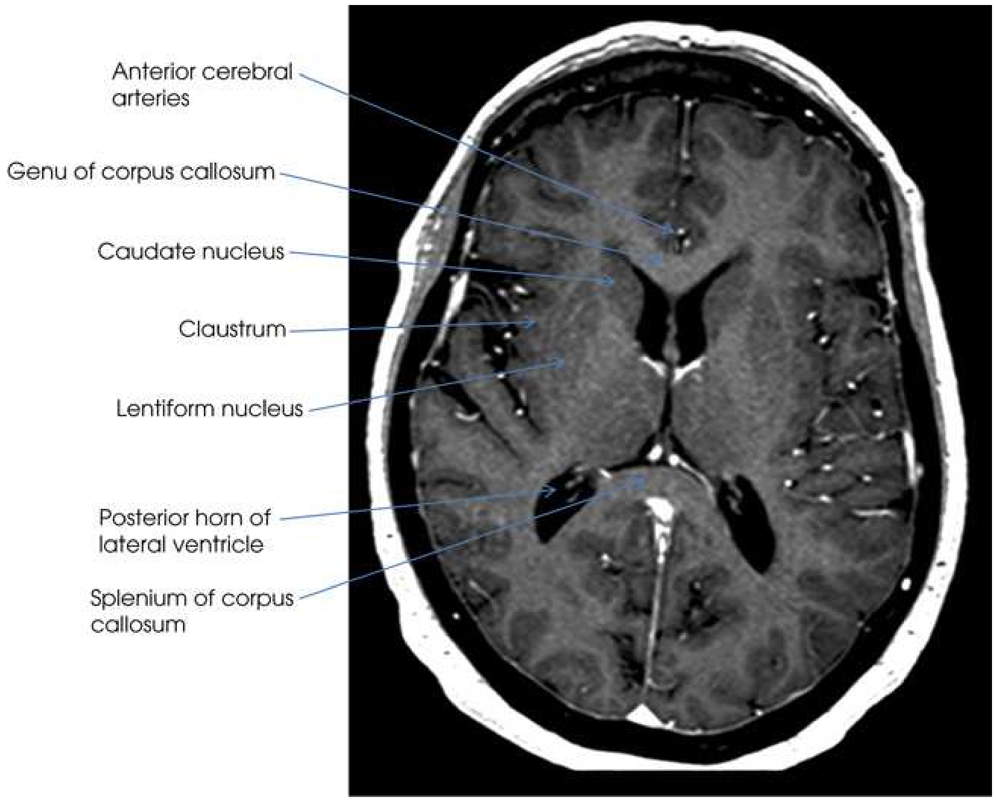


FIG. 24.11 MRI representing anatomic structures located at level *C* in Fig. 24.5B.

A M R I of the brain shows the irregular outer covering of the brain appearing radiopaque and the inner region appearing grey and grainy. The parts labeled are marked from top to bottom as follows: anterior cerebral arteries, genu of corpus callosum, caudate nucleus, claustrum, lentiform nucleus, posterior horn of lateral ventricle, splenium of corpus callosum.

The anterior and temporal horns of the lateral ventricles are seen on the CT scan, whereas the anterior and posterior horns are visible on the MR image. Within each posterior horn is a portion of the choroid plexus, which appears bright due to the presence of contrast medium in the capillaries. The heads of the caudate nuclei lie along the external surfaces of the anterior horns of each lateral ventricle. Several areas of gray matter can be seen faintly on the CT image deep within the white matter of the cerebrum and constitute the basal nuclei. The MR image contrast has been enhanced so that the deep gray matter structures can be seen. The major components of the basal nuclei seen at this level are (from lateral to medial) the *claustrum*, *lentiform nucleus* (composed of the putamen and globus pallidus), and *caudate nucleus*. The lentiform nucleus is separated from the caudate nucleus and thalamus by a tract of white matter known as the *internal capsule*. These sections pass through the superior portion of the midline *third ventricle*. The *thalamus*, which serves as a central relay station for sensory impulses to the cerebral cortex, forms its lateral walls. The plane of the CT image passes through the structures of the midbrain. The anterior portions of the midbrain include the cerebral peduncles (white matter tracts that connect the cerebrum and the midbrain). The dark circular area at the posterior edge of the midbrain is the CSF-filled cerebral aqueduct. This passage connects the third and fourth ventricles and allows the circulation of CSF. A contrast-enhanced vessel, the great cerebral vein, is found just posterior to the third ventricle and the splenium of the corpus callosum on the MR image. It passes through the upper portion of the *superior cistern*. The pineal gland is also found in this cistern but is not clearly visualized in either image. This is an important radiographic landmark because of its tendency to calcify in adults. Branches of the middle cerebral artery are visible within the lateral fissures, and the anterior cerebral arteries can be seen in the anterior portion of the longitudinal fissure on the MR image.

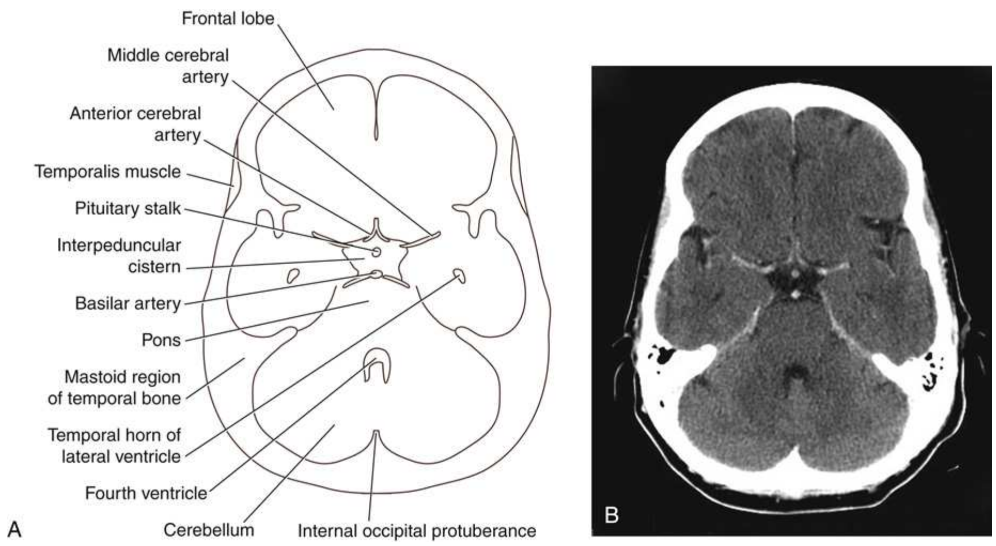


FIG. 24.12 (A) Line drawing of CT section. (B) CT image representing anatomic structures located at level *D* in Fig. 24.5A.

Diagram (A) shows a line drawing of the C T section of the brain. The parts labeled are marked from top to bottom as follows: frontal lobe, middle cerebral artery, anterior cerebral artery, temporalis muscle, pituitary stalk, interpeduncular cistern, basilar artery, pons, mastoid region of temporal bone, temporal horn of lateral ventricle, fourth ventricle, cerebellum, internal occipital protuberance. (B) A C T image of the brain passes through the frontal lobe, pons, and cerebellum. The outer covering has small peaks that reaches into the inner region. It appears radiopaque. The inner region appears grey and grainy. A dark grey colored region is in the middle and in the area below it.

FIG. 24.13 MRI through circle of Willis, corresponding to level *D* in Fig. 24.5B.

Fig. 24.12 is a CT image that passes through the frontal lobe, pons, and cerebellum. Fig. 24.13 is the T2-weighted MR image, which passes through the orbits, the midbrain, and the occipital lobes. Bony structures visible in the CT image include the frontal bone, the temporal bones, and the occipital bone. Within the temporal bones, the black air-filled structures represent the mastoid air cells. The internal protrusion of bone in the center of the occipital bone is the internal occipital protuberance. The darker area between the eyes on the MR image corresponds to the lower portion of the frontal sinuses. Frontal and temporal lobes of the cerebrum are shown on the CT image, whereas the frontal, temporal, and occipital lobes of the cerebrum are shown on the MR image. The CT scan passes just inferior to the midbrain, and the MR image passes through the level of the midbrain. The large dark area in the center of the CT image is the interpeduncular cistern. This is an enlarged area in the subarachnoid space containing CSF. The optic chiasm and the circle of Willis normally lie within the interpeduncular cistern. The pituitary stalk and some of the vessels that contribute to the circle of Willis are visible on this image. The pons lies posterior to the cistern. The cerebellum lies within the posterior fossa of the skull between the pons and the occipital bone. The large dark region between the pons and cerebellum is the CSF-filled fourth ventricle. The temporalis muscles are seen on the external surfaces on either side of the cranium. On the MR image, the *cerebral peduncles* form the anterior portions of the midbrain, and the *corpora quadrigemina* forms the posterior portion. The small light gray circle anterior to the colliculi is the CSF-filled *cerebral aqueduct*. Posterior to the midbrain is the *cerebellum*, which is surrounded by the *tentorium cerebelli*. The dark region anterior to the midbrain is the *interpeduncular cistern*, and the region posterior to the midbrain is the superior cistern. On the MR image, within and around the interpeduncular cistern the *optic tracts* are visualized along with the *hypothalamus*, the inferior portion of the third ventricle, and *mammillary bodies*.

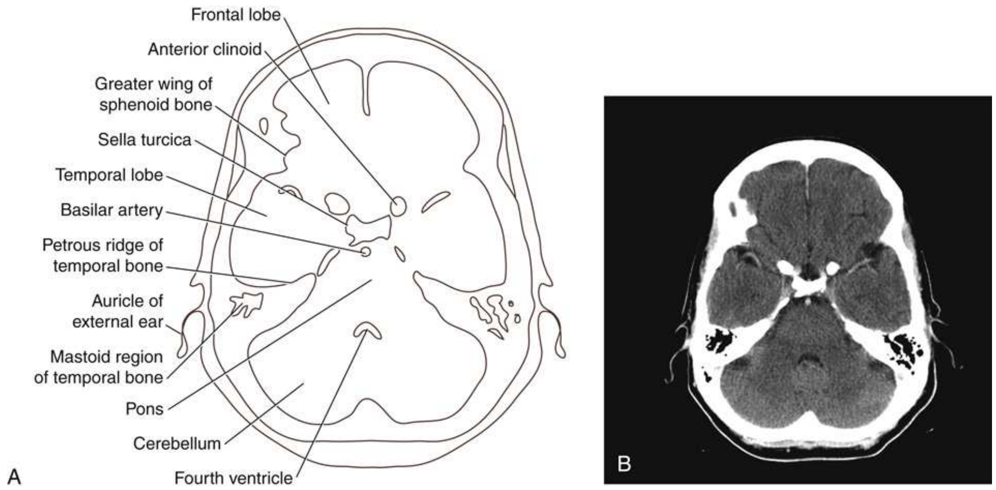


FIG. 24.14 (A) Line drawing of CT section. (B) CT image representing anatomic structures located at level *E* in Fig. 24.5A.

Diagram (A) shows a line drawing of the C T section of the brain. The parts labeled in the diagram are marked clockwise as follows: frontal lobe, anterior clinoid, greater wing of sphenoid bone, sella turcica, temporal lobe, basilar artery, petrous ridge of temporal bone, auricle of external ear, mastoid region of temporal bone, pons, cerebellum, fourth ventricle. (B) A C T image of the brain shows the sella turcica and the posterior fossa. The outer covering has small peaks that reaches into the inner region. It appears radiopaque. The inner region appears grey and grainy. The centermost region also appear radiopaque.

The CT image is just superior to the internal carotid arteries and shows the origins of the left anterior and middle cerebral arteries, at the anterior edge of the interpeduncular cistern. The anterior cerebral arteries pass from their origin toward the longitudinal fissure in the midline of the brain, and the middle cerebral arteries course from their origins toward the lateral fissures. The CT image also shows the bifurcation of the basilar artery into the two posterior cerebral arteries. These vessels can be seen just anterior to the pons. The MR image shows the posterior portion of the superior sagittal sinus located near the internal occipital protuberance; the *straight sinus* can be seen in the edge of the tentorium cerebelli, just posterior to the cerebellum on the MR image.

Fig. 24.14 is a CT image through the sella turcica and the posterior fossa. The T2-weighted MR image (Fig. 24.15) passes through the center of the orbits, the tops of the ears, the pituitary and center of the sella turcica, and the cerebellum. The MR image shows the *nasal bones*, visible in the anterior skull. Between the eyes, the *ethmoidal sinuses* and the *cribriform plate* of the ethmoid bone are seen. The *sphenoidal sinuses* lie posterior to the ethmoidal sinuses. The *sella turcica* and *dorsum sellae* are seen surrounding the *pituitary gland*. Several cranial bones are visible on the CT scan. The anterior clinoids of the sella turcica and the greater wings of the sphenoid are seen. The roof of the sella is formed by the lesser wings, anterior clinoids, and posterior clinoids. The temporal bone constitutes most of the lateral portions of the skull, and the *petrous ridges* can be seen on the CT image extending toward the median sagittal plane. The black air spaces near the lateral aspect of the petrous portions of these bones correspond to *mastoid air cells*, and the air spaces farther medial are associated with the internal structures of the ear. On the CT image, the frontal and temporal lobes of the cerebrum are visible, along with the pons and cerebellum. The dark region between the sella turcica and the pons is the pontine cistern, filled with CSF. The lower region of the fourth ventricle is seen between the pons and the cerebellum. On the MR image, both *globes* are visible within the orbits. Rectus muscles lie along the medial and lateral walls of each. The *optic nerves* are seen in the centers of the posterior orbits passing from the eyes toward the brain via the optic canal. The temporal lobes are found lateral to the sella turcica, resting in the middle cranial fossa. The *pons* lies posterior to the sella, and the cerebellum is seen filling the posterior cranial fossa. The edges of the tentorium cerebelli can be seen faintly between the temporal lobes and the cerebellum. The dark region anterior to the pons corresponds to the CSF-filled *pontine cistern* in which the contrast-filled *basilar artery* is easily visualized on both the CT and MR images. The dark region between the pons and the cerebellum is the superior region of the *fourth ventricle*. On the CT image, the contrast-filled basilar artery lies between the sella and the pons. At this level in the MR image, the *internal carotid arteries* lie lateral to the body of the sphenoid bone in an almost horizontal orientation. The *confluence of sinuses* can be seen just anterior to the internal occipital protuberance on the MR image. The confluence is the region where the superior sagittal sinus and the straight sinus meet the transverse sinuses. The *transverse sinuses* are seen on the MR image at this level lying just internal to the occipital bone. On the external surface of the skull in both images, the temporalis muscles lie along the temporal bones. The *auricle*—or cartilaginous portion of each ear—lies external to the temporal bone.

FIG. 24.15 T2-weighted MRI corresponding to the level of *E* in Fig. 24.5B.

A M R I shows the center of the orbits, the tops of the ears, the pituitary and center of the sella turcica, and the cerebellum. The nasal bones are visible in the anterior skull and they appear radiopaque. The lens on either side of the perpendicular plate also appears radiopaque.

The sectional images through the lower cranium show the inferior portions of the cerebrum, brain stem, cerebellum, and associated major skeletal structures. (Fig. 24.16 is a CT image, and Fig. 24.17 is a T1-weighted MR image). The CT image shows the frontal sinuses and the roofs of the orbits. The greater and lesser wings of the sphenoid bone are shown. The optic foramina (canals) can be seen between the greater and lesser wings. The optic chiasm and cavernous sinus can be seen posterior to the optic foramen. The petrous and mastoid portions of the temporal bones are shown dividing the middle and posterior cranial fossae. The maxilla, *maxillary sinuses*, and nasal bones are seen in the anterior skull on the MR image (note the mass within the right maxillary sinus). The *zygomatic bones* form the lateral walls of the orbits, and the *maxillae* form the medial walls. The *perpendicular plate* and *vomer* form the bony nasal septum seen in the center of the nasal cavity. Posterior to the nasal cavity, the sphenoidal sinuses are seen between the lower aspects of the greater wings. Both petrous ridges extend toward the midline; these are seen as dark areas on the MR image because of the lack of signal from this dense region of bone. Extending into the right petrous ridge is the *external auditory canal*. Just anterior to the canal is the *condyle of the mandible* resting in the mandibular fossa. Mastoid air cells lie posterior to the external acoustic meatus.

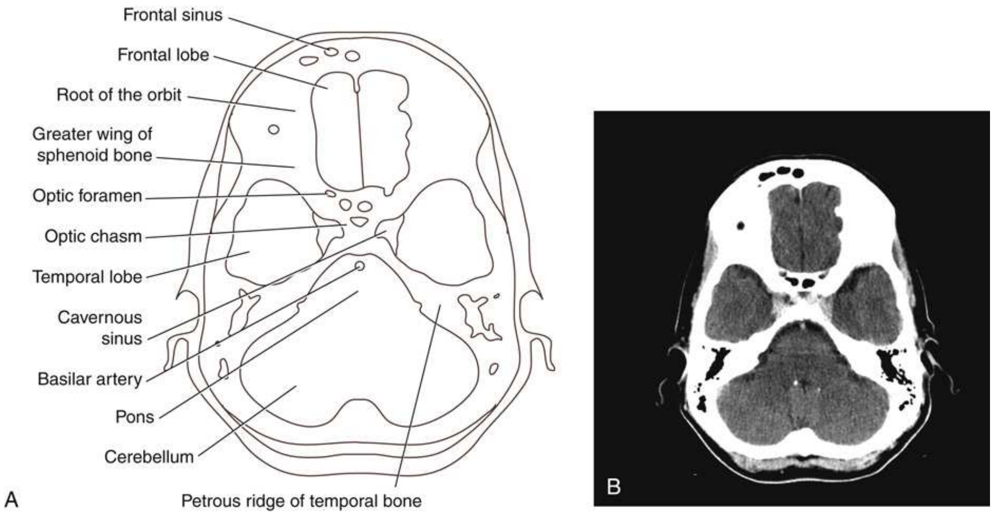


FIG. 24.16 (A) Line drawing of CT section. (B) CT image representing anatomic structures located at level *F* in Fig. 24.5A.

Diagram (A) shows a line drawing of the C T section of the brain. The parts labeled in the diagram are marked clockwise as follows: frontal sinus, frontal lobe, root of the orbit, greater wing of sphenoid bone, optic foramen, optic chasm, temporal lobe, cavernous sinus, basilar artery, pons, cerebellum, petrous ridge of temporal bone. (B) A C T image of the brain shows the frontal sinuses and the roofs of the orbits. The outer covering has small peaks that reaches into the inner region and fuses in the middle. The greater and lesser wings of the sphenoid bone ae also visible and they appear radiolucent.

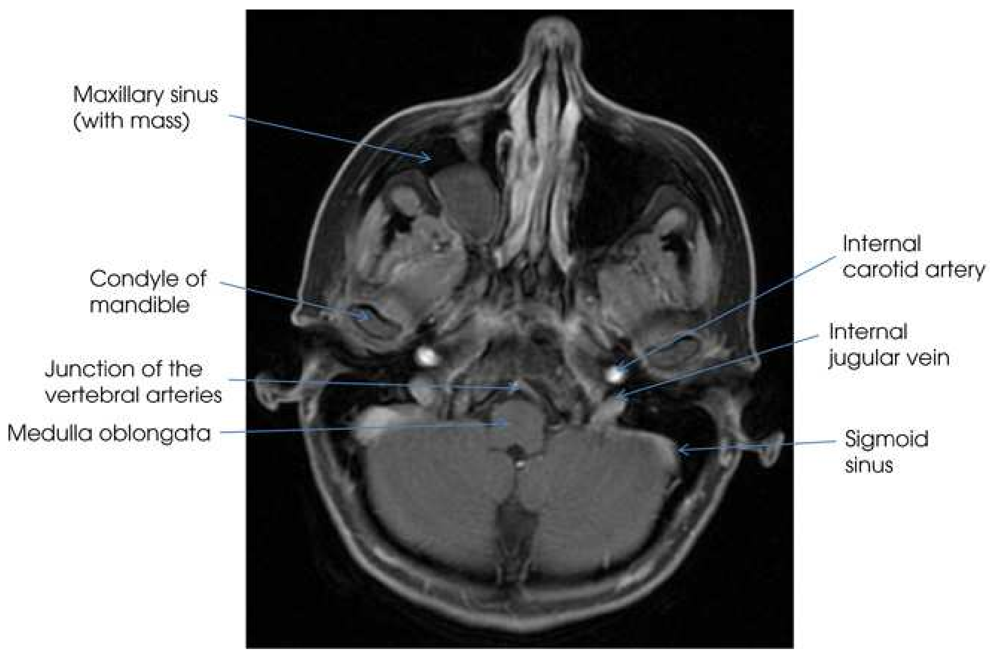


FIG. 24.17 MRI representing anatomic structures located at level *F* in Fig. 24.5B.

A M R I shows the frontal sinuses and the roofs of the orbits. The outer border appears white. The internal carotid artery appears as a small white circular region on either side. The parts labeled in the diagram are marked clockwise as follows: medulla oblongata, junction of the vertebral arteries, condyle of mandible, maxillary sinus (with mass), internal carotid artery, internal jugular vein, sigmoid sinus.

In the center of the skull, the greater wings of the sphenoid, petrous ridges, and basilar portion of the occipital bone meet. The CT image shows the lower portions of the frontal lobes and temporal lobes, along with the lower margin of the pons and the cerebellum. On the MR image, the most inferior folds of the temporal lobes are found in the middle cranial fossae resting on the greater wings of the sphenoid. The *medulla oblongata* lies posterior to the basilar portion of the occipital bone. The cerebellum is seen within the posterior fossa. The small, dark space between the medulla and the cerebellum is the lower extent of the fourth ventricle. CSF in the *cisterna magna* circulates around the anterior and lateral reaches of the medulla. At the level of this image, the internal carotid arteries are found just posterior to the optic foramina, within the cavernous sinuses, on the CT scan. Both are clearly visible as bright circles on the MR image. The *internal jugular veins* can also be seen on the MR image just posterior to the internal carotid arteries. The two *vertebral arteries* join and lie anterior to the medulla on the MR image. The CT image is just superior to the junction of the vertebral arteries and shows the lower part of the basilar artery. The transverse venous sinuses have passed anteriorly to the level of the petrous ridges and are seen on the MR image. At this point, they change position and change names to become the *sigmoid sinuses*.

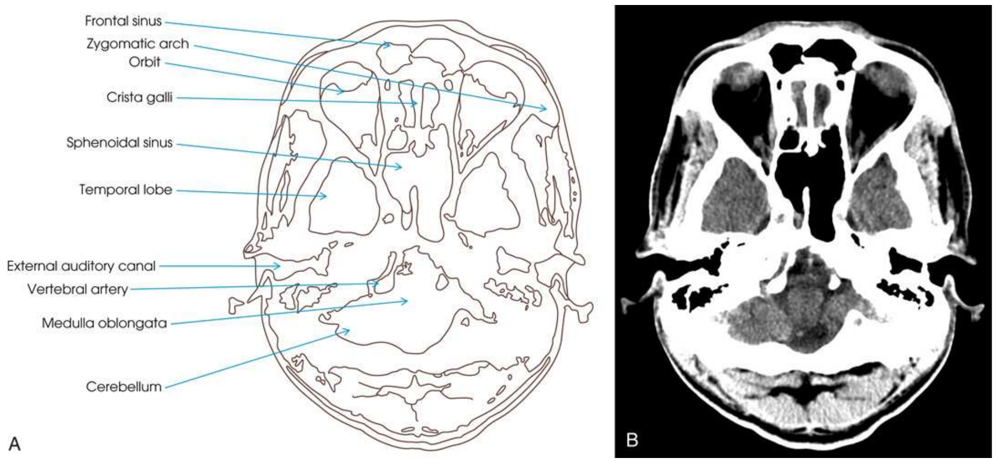


FIG. 24.18 (A) Line drawing of CT section. (B) CT image representing anatomic structures located at level *G* in Fig. 24.5A.

Diagram (A) shows a line drawing of the C T section of the brain. The parts labeled are marked from top to bottom as follows: frontal sinus, zygomatic arch, orbit, crista galli, sphenoidal sinus, temporal lobe, external auditory canal, vertebral artery, medulla oblongata, cerebellum. (B) A C T image of the brain shows the upper orbit, the sphenoidal sinuses, and the lower portion of the occipital bone. these regions appear radiolucent. The surrounding region appear radiopaque.

Fig. 24.18 is a CT image, and Fig. 24.19 is a T1-weighted MR image through the lower part of the skull. The plane of the CT image passes through the upper orbit, the sphenoidal sinuses, and the lower portion of the occipital bone. The frontal sinuses lie along the anterior skull. The crista galli is just posterior to these sinuses. This structure is a superior projection of bone from the cribriform plate of the ethmoid bone; it functions as an attachment for the falx cerebri. On either side of the crista galli, the lowermost portions of the frontal lobes can be seen resting on the cribriform plate. The sphenoidal sinuses lie posterior to the crista galli, and the greater wings of the sphenoid extend laterally from the region of the sinuses. The external auditory canals extend into the petrous portions of the temporal bones, and mastoid air cells are visible posterior to the canals. The lower portion of the occipital bone forms the most posterior region of the skull on this image.

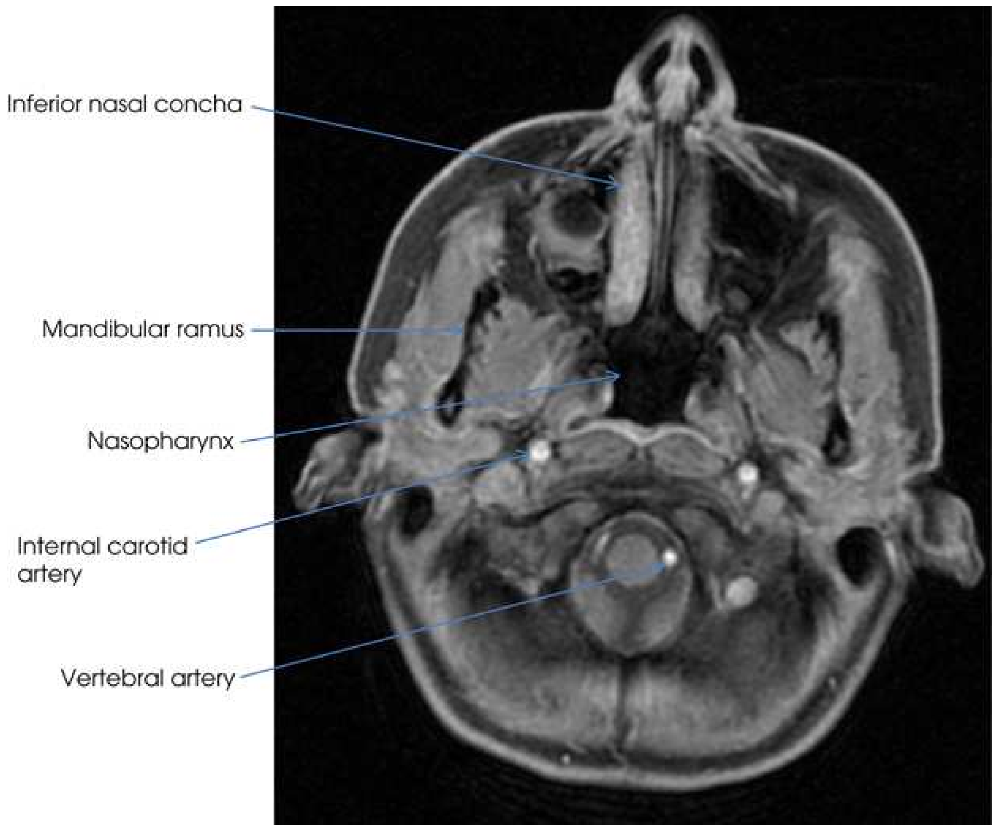


FIG. 24.19 MRI corresponding to level *G* in Fig. 24.5B.

The MR image plane passes through the nose and the base of the skull. On the MR image, the large, air-filled maxillary sinuses lie on either side of the nose. The *inferior nasal conchae* and the vomer are seen within the nasal cavity. Posterior to the nasal cavity, the nasopharynx is seen on the MR image. Portions of the zygomatic arches are seen extending posteriorly from the sides of the sinuses on CT. The MR image is slightly inferior to the mandibular condyles and shows the rami of the mandible. The MR image passes through the mastoid processes and the top of the vertebral column. The CT shows the lower temporal lobes of the cerebrum, the *cerebellar tonsils*, and the medulla oblongata. The MR image shows the spinal cord because the structures in this image lie inferior to the foramen magnum. The contrast-filled internal carotid arteries lie anterior and lateral to the foramen magnum and spinal cord on the MR image but are not visible on the CT image. As the sigmoid venous sinuses pass through the jugular foramina, they become the internal jugular veins. These veins are visible on the MR image posterior and lateral to the internal carotid arteries. The contrast-filled vertebral arteries are seen along the anterolateral aspects of the medulla and spinal cord. Muscular structures on the external surface of the mandible are the *masseters*, and the structures on the internal surface are the *pterygoids*.

FIG. 24.20 PA projection of skull for localization of sagittal images.

Images in sagittal, coronal, and oblique planes are becoming increasingly more common. CT scanners have the capability to generate images in the axial and coronal planes and to reconstruct the information in alternate planes. Magnetic resonance is capable of direct axial, sagittal, oblique, and coronal imaging. Representative images have been selected in the sagittal and coronal planes to help interpret the anatomy shown.

Fig. 24.20 is a PA skull (Caldwell method) image used to represent the locations of the following sagittal images of the brain. Fig. 24.21 is a midsagittal T1-weighted MR image of the cranium. The relationship among the cerebral hemisphere, cerebellum, and brain stem is shown. In this image, the frontal, parietal, and occipital lobes of the cerebrum are seen and correspond to the cranial bones. The corpus callosum is a white matter tract that connects the hemispheres and is found at the inferior aspect of the frontal and parietal lobes. CSF appears dark on this T1-weighted image, making it easy to trace the ventricular system. The anterior horn of the lateral ventricle is inferior to the genu of the corpus callosum. The third ventricle lies in the midline between the two lateral ventricles. The lateral ventricles produce a great deal of CSF, which is transported to the third ventricle by way of the *intraventricular foramina (of Monro)*. The third ventricle is not optimally visualized in this image. What is seen is the thalamus, which forms the lateral wall of the third ventricle. CSF drains from the third ventricle via the *cerebral aqueduct (of Sylvius)*, which can be found within the midbrain (between the *corpora quadrigemina* and the *cerebral peduncles*). The *fourth ventricle* is also a triangular-shaped midline structure that is situated between the pons and cerebellum. The large air-filled sphenoidal sinus is located anterior to the pons. Superior to this sinus, the pituitary gland rests within hypophyseal fossa formed by the sella turcica. Directly superior to the pituitary gland is the optic chiasm.

Several vascular structures are well shown in Fig. 24.21. The basilar artery appears between the clivus and pons. Portions of the superior sagittal sinus can be seen between the cerebrum and the cranial bones. Between the cerebrum and cerebellum, the *straight sinus* (one of the dural venous sinuses) is noted within the tentorium cerebelli. This vessel is formed by the junction of the inferior sagittal sinus and the great cerebral vein (of Galen).

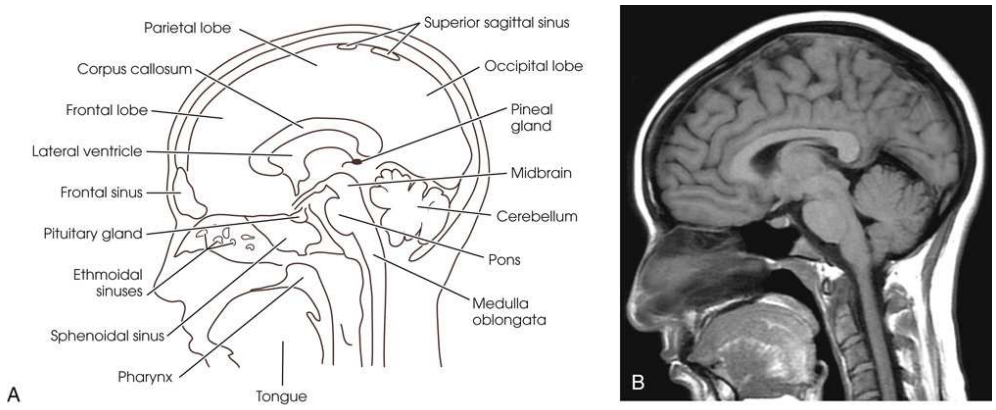


FIG. 24.21 (A) Line drawing of MRI section. (B) MRI through midsagittal plane, corresponding to level *A* in Fig. 24.20.

Diagram (A) shows a line drawing of the M R I section of the head. The parts labeled in the diagram are marked clockwise as follows: pharynx, sphenoidal sinus, ethmoidal sinuses, pituitary gland, frontal sinus, lateral ventricle, frontal lobe, corpus callosum, parietal lobe, superior sagittal sinus, occipital lobe, pineal gland, midbrain, cerebellum, pons, medulla oblongata, tongue. (B) An M R I shows the lateral view of the head showing the brain. The brain appears grey.

Fig. 24.22 is a sagittal T2-weighted MR image through the medial wall of the orbit. The bright, fluid-filled lateral ventricle is seen in the center of the cerebral hemisphere. Just inferior to it are the caudate nucleus and the thalamus. Because this image was obtained in a plane lateral to the midline, one of the cerebral peduncles is seen at the inferior border of the thalamus, and one of the cerebellar peduncles can be seen connecting the pons to the cerebellum. At the floor of the cranium, a dark circle is seen that represents the internal carotid artery. Cerebral vertebral bodies and arches can be seen in the neck on either side of the vertebral canal. In the face, the ethmoid sinus and tongue can be easily identified.

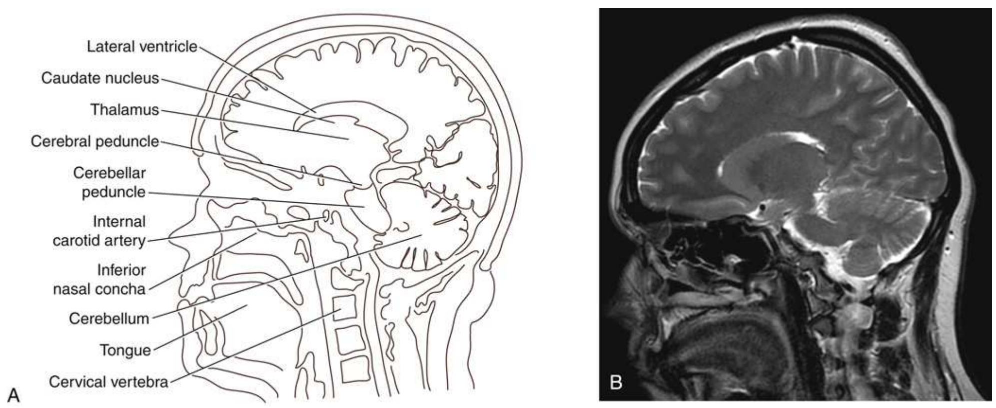
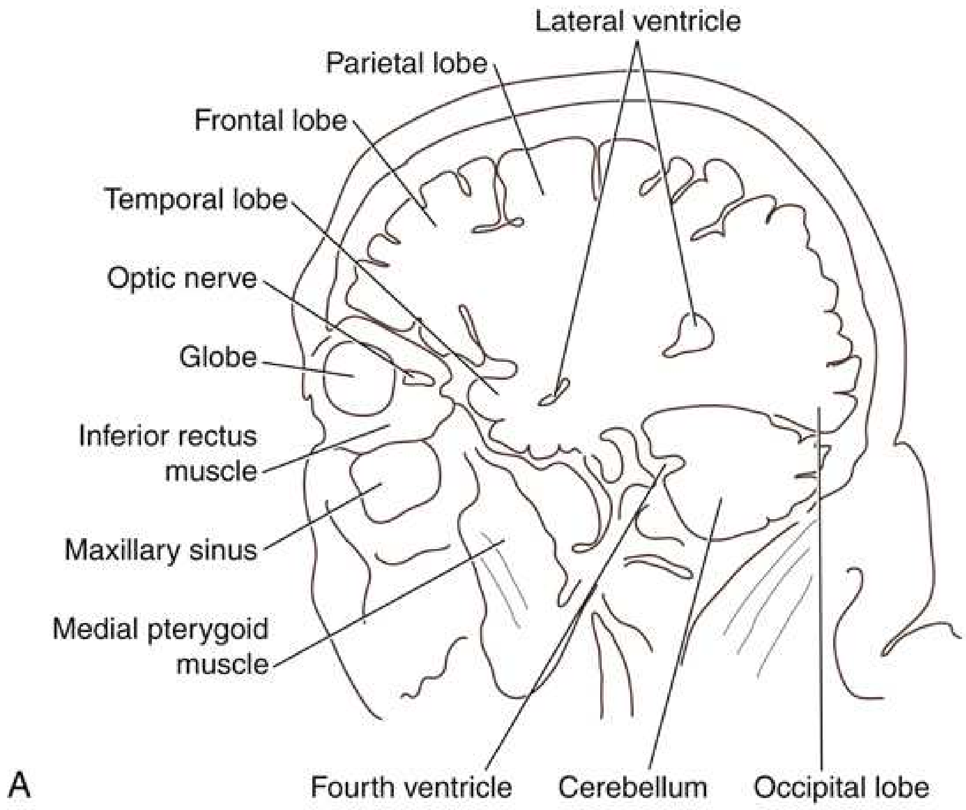


FIG. 24.22 (A) Line drawing of MRI section. (B) Sagittal MRI through medial wall of orbit corresponding to level *B* in Fig. 24.20.

Diagram (A) shows a line drawing of the M R I section of the head. The parts labeled are marked from top to bottom as follows: lateral ventricle, caudate nucleus, thalamus, cerebral peduncle, cerebellar peduncle, internal carotid artery, inferior nasal concha, cerebellum, tongue, cervical vertebra. (B) An M R I shows the lateral view of the head showing the brain. The brain appears dark and the folds are less visible.

The sagittal T2-weighted MR image in Fig. 24.23 is sectioned through the center of the orbit. The frontal, parietal, occipital, and temporal lobes of the cerebrum all are visible. Within the cerebrum, CSF is seen within the temporal and posterior horns of the lateral ventricle (the fluid appears bright on this T2-weighted image). The cerebellum lies within the posterior fossa and is separated from the cerebrum by the tentorium cerebelli. Anterior to the cerebellum, the lateral aspect of the fourth ventricle can be seen. Within the orbit, several structures associated with the eye can be seen: the globe and the inferior rectus muscle. The dark area inferior to the orbit is the air-filled maxillary sinus. The medial pterygoid muscle, which lies on the internal aspect of the mandibular ramus, is visible inferior and posterior to the maxillary sinus.



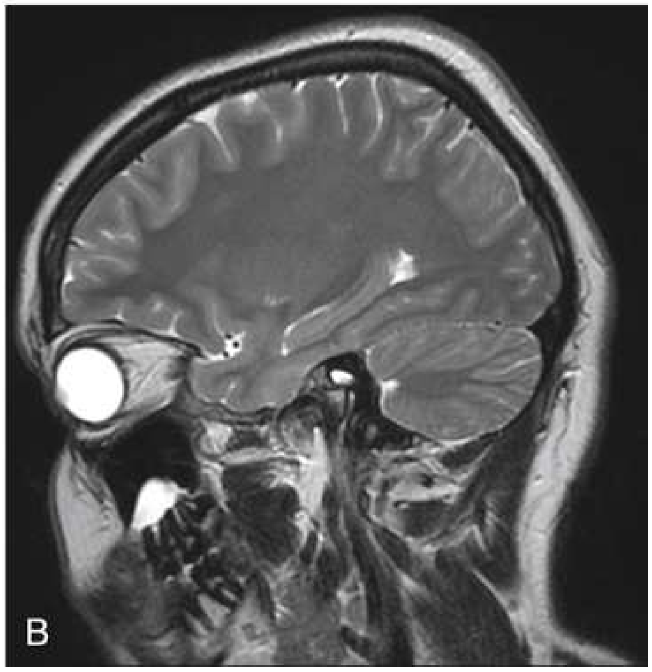


FIG. 24.23 (A) Line drawing of MRI section. (B) Sagittal MRI through midorbit corresponding to level *C* in Fig. 24.20.

Diagram (A) shows a line drawing of the M R I section of the head. The parts labeled in the diagram are marked clockwise as follows: medial pterygoid muscle, maxillary sinus, inferior rectus muscle, globe, optic nerve, temporal lobe, frontal lobe, parietal lobe, lateral ventricle, occipital lobe, cerebellum, fourth ventricle. (B) An M R I shows the frontal, parietal, occipital, and temporal lobes of the cerebrum. A white circular region is on the left side.

A CT localizer—or scout—image (Fig. 24.24) is included as a reference for the next three coronal images. Fig. 24.25 is a coronal T2-weighted MR image through the anterior horns of the lateral ventricles and the pharyngeal structures. The anterior portions of the cerebral hemispheres are joined by the corpus callosum, which is immediately superior to the lateral ventricles. The membrane between the anterior horns of the lateral ventricles is the *septum pellucidum*. On the lateral aspect of each cerebral hemisphere is the *lateral fissure*, which divides the frontal lobe from the temporal lobe. The insula lies deep to this fissure.

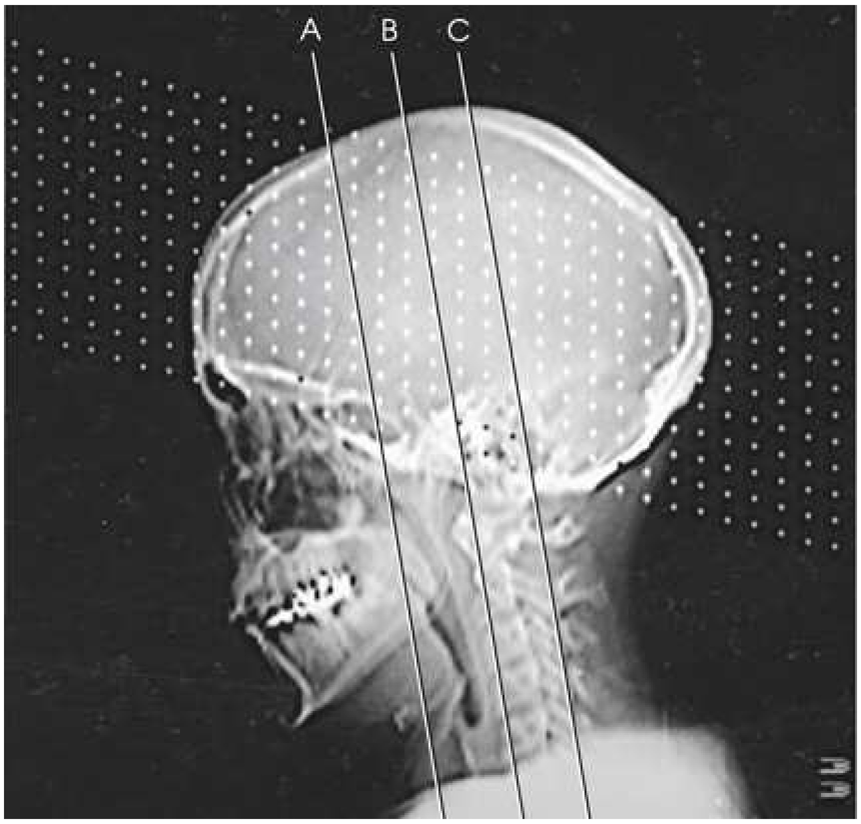


FIG. 24.24 CT localizer (scout) image of skull.

Structures of the basal nuclei can be faintly identified. The caudate nucleus is lateral to the anterior horns. Inferolateral to the caudate nuclei are the internal capsules—white matter tracts that connect the cortex to deeper gray matter structures. The anterior portion of the third ventricle is found in the midline inferior to the lateral ventricles. Inferior to the third ventricle are the optic chiasm and pituitary gland (hypophysis cerebri). The *superior* and *inferior sagittal sinuses* occupy the margins of the falx cerebri in the longitudinal fissure between the hemispheres of the cerebrum. The internal carotid arteries occupy the *cavernous sinuses* along with several cranial nerves and are found lateral to the pituitary gland and sella turcica. Branches of the middle cerebral arteries occupy the lateral fissures of the cerebrum. Fig. 24.26 is a coronal T2-weighted MR image through the bodies of the lateral ventricles, brain stem, and bodies of the cervical vertebrae. The third ventricle is well shown and bordered laterally by the thalamus. The dark region (low signal return) medial to the external acoustic canal corresponds to the *petrous portion of the temporal bone*. The first two cervical vertebrae are detailed in this section with the *dens* of the *axis* (C2) seen between the lateral masses of the *atlas* (C1). The large, intermediate gray masses inferior to the external acoustic canals are the *parotid glands*.

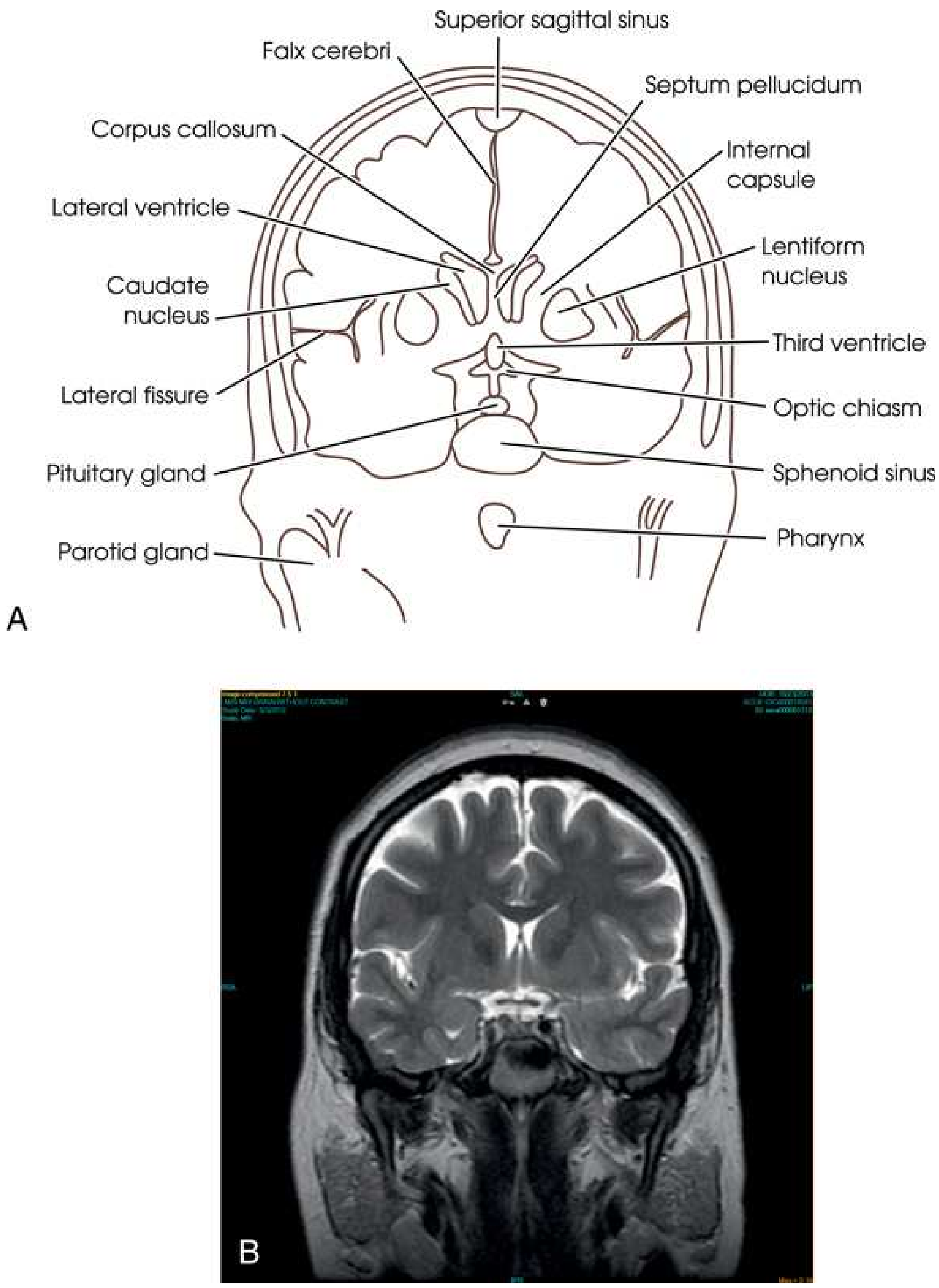


FIG. 24.25 (A) Line drawing of MRI section. (B) Coronal MRI corresponding to level *A* in Fig. 24.24.

Diagram (A) shows a line drawing of the M R I section of the posterior head. The parts labeled in the diagram are marked clockwise as follows: parotid gland, pituitary gland, lateral fissure, caudate nucleus, lateral ventricle, corpus callosum, falx cerebri, superior sagittal sinus, septum pellucidum, internal nucleus, lentiform nucleus, third ventricle, optic chiasm, sphenoid sinus, pharynx. (B) An M R I shows the anterior horns of the lateral ventricles and the pharyngeal structures.

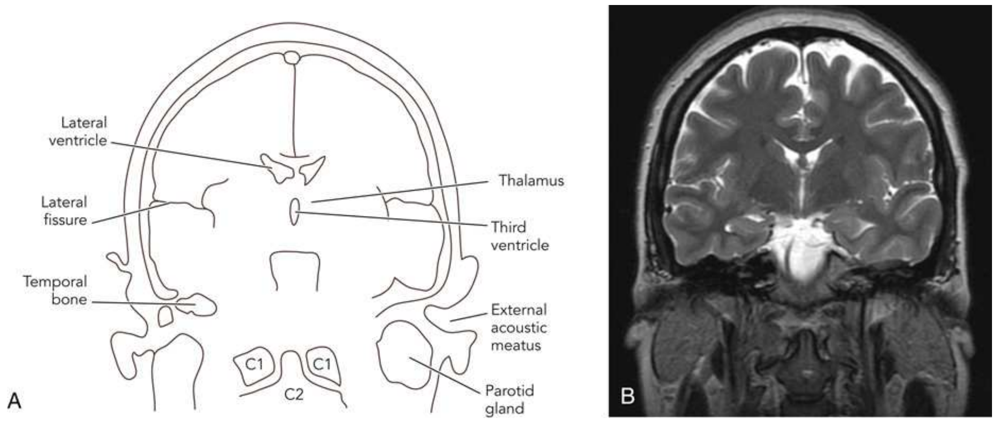
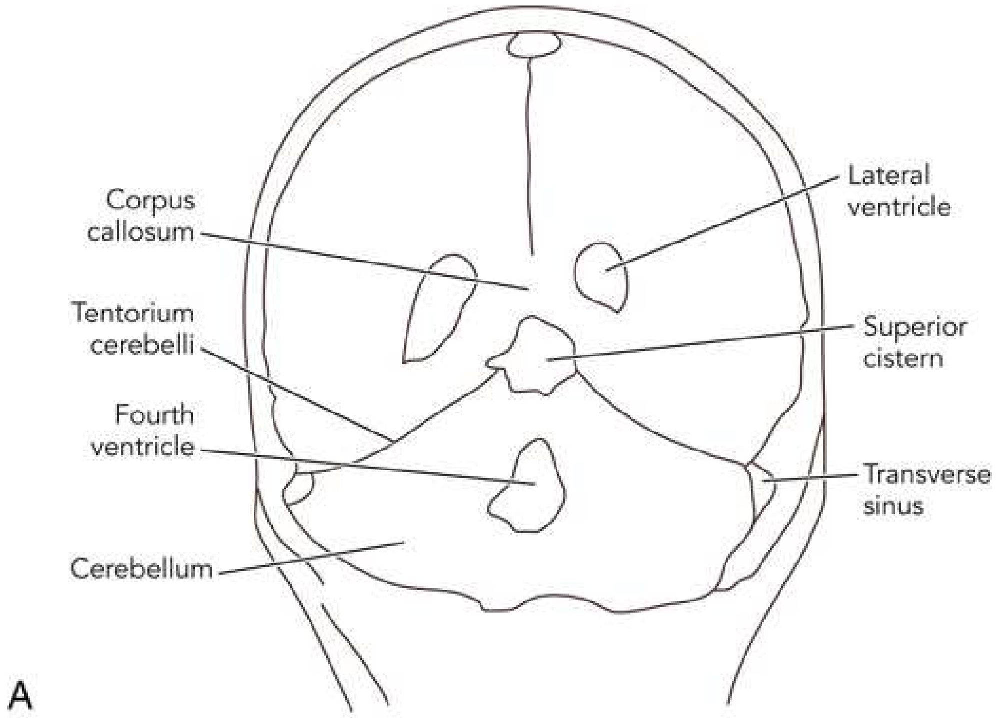


FIG. 24.26 MR corresponding to bodies of the lateral ventricles, brain stem, and cervical vertebrae.

Diagram (A) shows a line drawing of the M R I section of the posterior head. The parts labeled in the diagram are marked clockwise as follows: temporal bone, lateral fissure, lateral ventricle, thalamus, third ventricle, external acoustic meatus, parotid gland. (B) An M R I shows the lateral ventricles, brain stem, and bodies of the cervical vertebrae. A radiopaque region is in the middle and on the top.



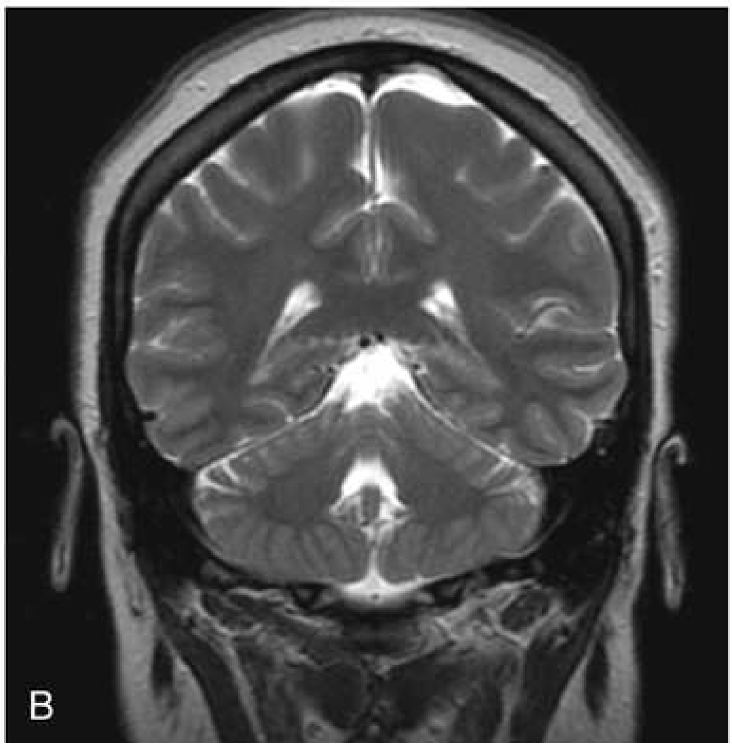


FIG. 24.27 MR corresponding to lateral ventricles and cerebellum.

Diagram (A) shows a line drawing of the M R I section of the brain. The parts labeled in the diagram are marked clockwise as follows: cerebellum, fourth ventricle, tentorium cerebelli, corpus callosum, lateral ventricle, superior cistern, transverse sinus. (B) An M R I shows the lateral ventricles and cerebellum. A radiopaque region is in the middle.

Fig. 24.27 shows a coronal T2-weighted MR image through the lateral ventricles and cerebellum. The splenium of the corpus callosum is found between the lateral ventricles. Inferior to the splenium is the superior cistern. Portions of the cerebellum are visualized superior and inferior to the middle cerebellar peduncles. The large, bright area near the center of the cerebellum is the fourth ventricle. The bright line between the cerebellum and cerebrum represents the tentorium cerebelli. The large, dark areas (low signal) lateral to the cerebellum correspond to the bony mastoid portions of the temporal bone.

Thoracic Region

The thorax extends from the thoracic inlet to the diaphragm. The inlet is an imaginary plane through the first thoracic vertebra and the top of the manubrium. Sectional images of the thorax are obtained to include all structures between these boundaries. Two cadaveric images are included to assist in identifying some of the structures of the thorax. Fig. 24.28 is a cadaveric image that corresponds to a level just superior to the sternoclavicular joints. Fig. 24.33 (presented later in the chapter) lies near the level of the sixth thoracic vertebra and shows the chambers of the heart and other surrounding structures.

The bones of the thorax include the thoracic vertebrae, ribs, sternum, clavicles, and scapulae. Each of the 12 thoracic vertebrae is subdivided into a body and a vertebral arch. The opening formed between these divisions is the vertebral foramen, through which the spinal cord travels. Two pedicles, two laminae, two transverse processes, and one spinous process constitute the arch. The pedicles are more anterior and unite with the body of the vertebra; the laminae form the posterior part of the arch and unite to give rise to the spinous process. Transverse processes arise from the lateral arch where pedicles and laminae meet. Two superior articular processes arise from the superior arch, and two inferior articular processes arise from the inferior arch. Superior and inferior articular processes from adjacent vertebrae articulate to form zygapophyseal joints. Notches between succeeding arches form the intervertebral foramina. These foramina transmit spinal nerves. Articular disks are found between the vertebral bodies. These disks are composed of a dense cartilaginous outer rim called the *annulus fibrosus* and a gelatinous central core called the *nucleus pulposus*. Twelve pairs of ribs curl around the lateral thorax to protect the lungs and heart. The head of each rib is posterior and articulates with the body of a thoracic vertebra. These joints are called *costovertebral joints*. Tubercles of the ribs are lateral to the heads and articulate with transverse processes of the vertebrae, forming costotransverse joints. Anteriorly, the first 10 pairs of ribs articulate with the sternum either directly or indirectly via costal cartilage. The sternum lies in the midline of the anterior chest wall. From superior to inferior, the parts are the manubrium, body, and xiphoid process. An indentation at the superior edge of the sternum, the jugular or sternal notch, lies at the level of the interspace between the second and third thoracic vertebrae. The manubrium joins the body of the sternum at the sternal angle, which corresponds to the interspace between the fourth and fifth thoracic vertebrae. The xiphoid process lies at approximately the level of the 10th thoracic vertebra. Familiarity with these vertebral levels can be helpful in orienting oneself when looking at thoracic sectional images.

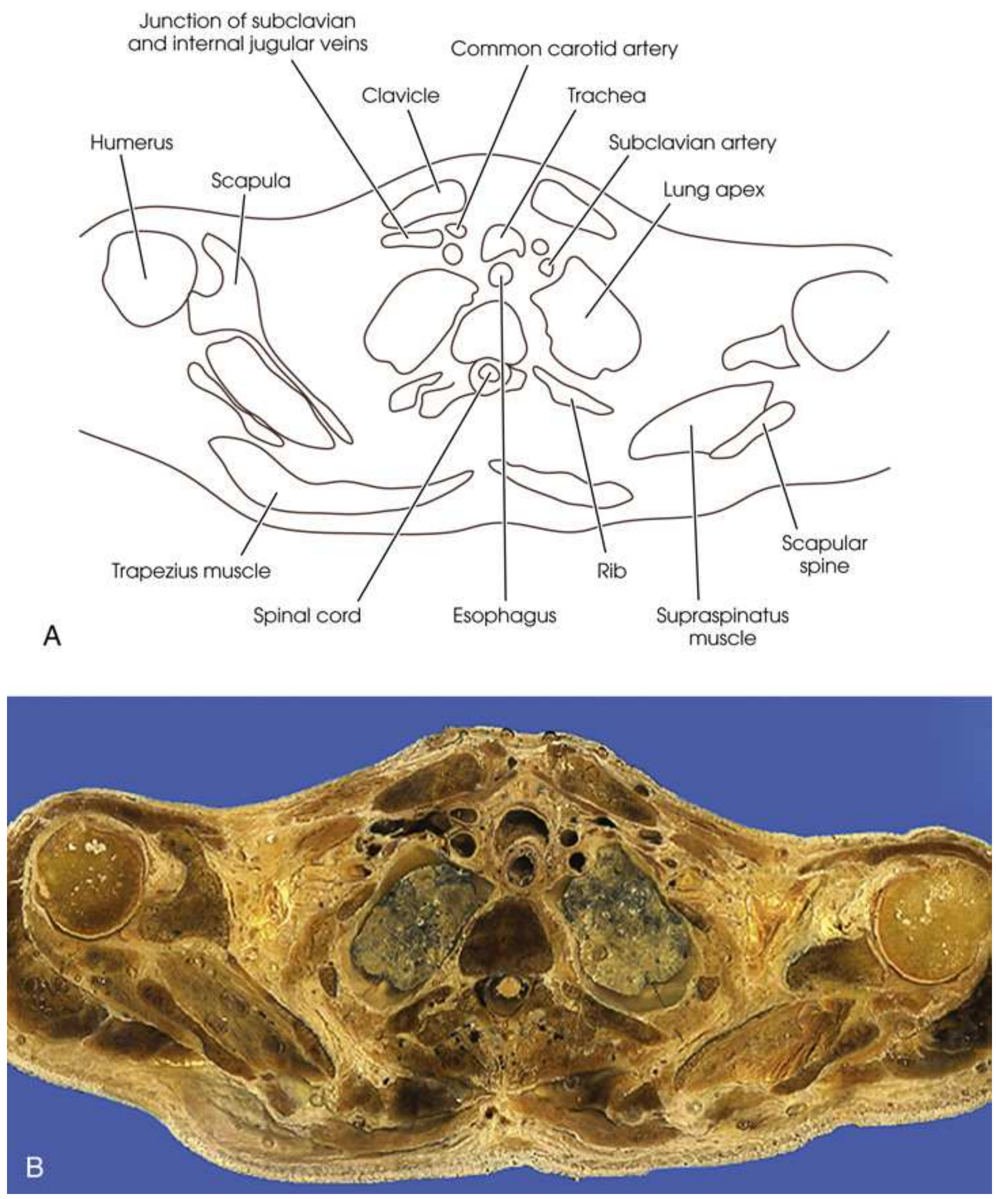


FIG. 24.28 (A) Line drawing of gross anatomic section. (B) Cadaveric image of superior thorax.

Diagram (A) shows a line drawing of the gross anatomic section. The parts labeled in the diagram are marked clockwise as follows: spinal cord, trapezius muscle, humerus, scapula, junction of subclavian and internal jugular veins, clavicle, common carotid artery, trachea, subclavian artery, lung apex, scapular spine, supraspinatus muscle, rib, esophagus. (B) shows a cadaveric image of superior thorax. It appears yellow and brown. Some regions appear black.

The clavicles are slender, S-shaped bones that extend across the upper anterior thorax. The medial end of each clavicle articulates with the superolateral edge of the manubrium to form sternoclavicular joints. Acromioclavicular joints are formed where the lateral extremity of the clavicle articulates with the acromion process of the scapula. The scapulae are triangular bones in the superior posterior thorax. Thinking of the scapula as having two surfaces (anterior and posterior), three borders (superior, medial, and lateral), and three angles (superior, lateral, and inferior) is helpful. The posterior surface is divided into a superior fossa and an inferior fossa by the scapular spine. This bony ridge extends laterally and superiorly to end as the acromion process. The coracoid process projects from the superoanterior surface near the glenoid. The lateral angle is formed by the glenoid cavity, which articulates with the humeral head. Many of these bony structures are identifiable in Fig. 24.28.

Major components of the respiratory system are seen in the thorax. The trachea originates at the level of the sixth cervical vertebra (near the bottom of the thyroid cartilage). The trachea is formed by incomplete cartilage rings, which are open along its posterior surface. The trachea passes into the thorax and bifurcates into the right and left main bronchi near the level of the sternal angle (T4–5). The carina is the last cartilage ring of the trachea. The main bronchi pass through the hila of the lungs and branch to secondary bronchi, one for each lobe. The lungs are triangular organs enclosed in the thoracic cavity by the double-walled pleural membrane. The portion of the lung that lies superior to the clavicle is the apex; the part that rests on the diaphragm is the base. The most inferior and posterior reaches of the base constitute a region called the *costophrenic angle*. The bronchi and vascular structures enter and exit the center of the medial aspect of the lung at the hilum. Each lung is divided into superior and inferior lobes by an oblique fissure. The upper lobe of the right lung is divided further by a horizontal fissure to form a middle lobe that lies lateral to the heart. The portion of the left lung that corresponds in position to the right middle lobe is called the *lingula*.

The area between the lungs is the mediastinum. Within this cavity are the heart, trachea and bronchi, esophagus, major blood vessels, nerves, and lymphatic structures. The heart lies obliquely oriented in the lower mediastinum, surrounded by a double-walled fibrous sac called the *pericardium*. It rests on the diaphragm between the sternum and the thoracic spine. The superior surface is the base, and the inferior portion is the apex. The heart is divided into four chambers: two atria and two ventricles. The atria receive blood, and the ventricles pump blood away from the heart. The right atrium forms the right border of the heart and receives blood from the superior vena cava, inferior vena cava, and coronary sinus (the venous drainage channel for the heart muscle). Blood passes from here through the tricuspid (right atrioventricular) valve into the right ventricle. This chamber forms most of the anterior surface of the heart. As this ventricle contracts, blood passes through the right ventricular outflow tract, through the pulmonary semilunar valve, and into the main pulmonary artery toward the lungs. The left atrium forms the posterior border of the heart and receives blood from four pulmonary veins. Blood passes through the mitral (bicuspid or left atrioventricular) valve into the left ventricle. The most muscular of the chambers—the left ventricle—forms the left side and inferior-most portion of the heart. Blood is pumped out of the left ventricle through the left ventricular outflow tract through the aortic semilunar valve and into the aorta. A muscular wall—the interventricular septum—can be seen between the ventricles. Chambers of the heart are seen in Fig. 24.29.

One portion of the digestive system is typically found in the thorax. The esophagus originates at the level of the sixth cervical vertebra as the posterior continuation of the pharynx. It continues into the thorax, at first posterior to the trachea, and then posterior to the left atrium and ventricle of the heart. At the lower thorax, the esophagus pierces the diaphragm to continue into the abdomen.

The vascular system in the upper thorax can be confusing. To identify these structures, one must clearly understand the vascular anatomy. Tracing the paths of vessels through the scan can help alleviate some of the confusion. This discussion follows the path of circulation through the vessels. The discussion of arterial structures starts at the heart and follows the vessels toward the periphery. Veins are discussed from their peripheral origins and followed as they travel toward the heart.

The aorta originates from the left ventricle of the heart. Just distal to the aortic semilunar valve are the origins of the right and left coronary arteries, which supply the heart muscle. The aorta ascends along the posterior sternum, arches posterior and toward the left behind the sternal angle, and turns inferiorly to become the descending aorta. The descending aorta passes down the posterior thorax, resting against the left anterolateral surfaces of the vertebral bodies. The major vessels that supply the head and upper limbs arise from the aortic arch. From anterior to posterior, these are the brachiocephalic, left common carotid, and left subclavian arteries. The brachiocephalic artery passes superiorly and bifurcates into the right subclavian and right common carotid arteries posterior to the sternoclavicular joint. The right and left common carotid arteries ascend the neck along the lateral surface of the trachea. At approximately the level of the third cervical vertebra, each common carotid artery exhibits a dilation called the *carotid sinus* just proximal to bifurcating into internal and external carotid arteries. The subclavian arteries pass laterally across the upper thorax, just deep to the clavicles. At the outer edges of the first ribs, the subclavian arteries become the axillary arteries.

Venous drainage from the head is mainly through the jugular veins. The internal jugular veins accompany the carotid arteries down through the neck, lateral to the trachea. The subclavian veins are continuations of the axillary veins draining the upper limbs. These veins pass toward the midline, deep to the clavicles. At the sternoclavicular joints, the internal jugular veins and the subclavian veins unite to form the brachiocephalic veins. The right brachiocephalic vein passes vertically downward; the left passes obliquely down, posterior to the manubrium. These two vessels unite to form the superior vena cava. The superior vena cava lies posterior to the right border of the sternum and enters the right atrium just below the level of the sternal angle. Venous drainage from the lower body is via the inferior vena cava. This vessel is found along the right anterior surface of the vertebral bodies and empties into the inferior aspect of the right atrium. The azygos vein is a small vessel that passes up the posterior thorax along the right anterior aspect of the vertebral bodies. It arches anteriorly (near the level of the aortic arch) to drain into the superior vena cava.

The pulmonary vascular system transports blood between the lungs and heart. The main pulmonary artery receives deoxygenated blood from the right ventricle. At the level of the sternal angle, this vessel gives rise to the right and left pulmonary arteries, which pass laterally toward the hila of the lungs. The bifurcation of the main pulmonary artery is just inferior to the aortic arch. Four pulmonary veins exit the hila, two from each lung, and pass medially to enter the superolateral aspect of the left atrium.

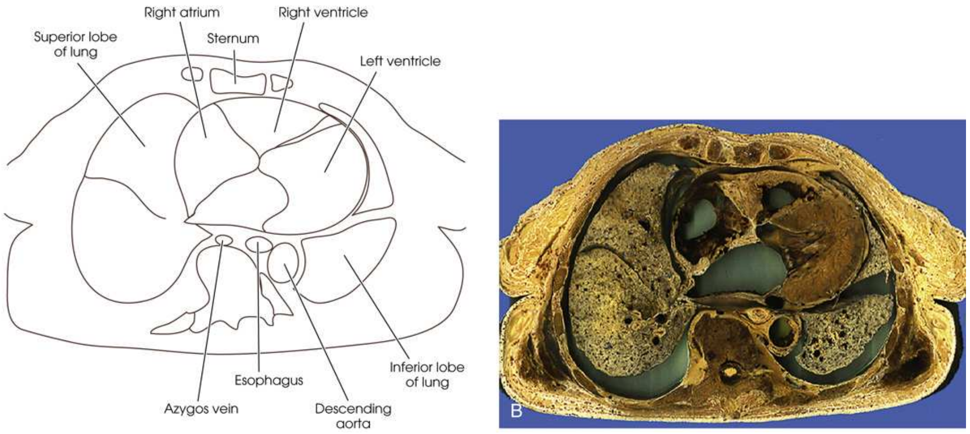


FIG. 24.29 (A) Line drawing of gross anatomic section. (B) Cadaveric image of central thorax.

Diagram (A) shows a line drawing of the gross anatomic section. The parts labeled in the diagram are marked clockwise as follows: superior lobe of lung, right atrium, sternum, right ventricle, left ventricle, inferior lobe of lung, descending aorta, esophagus, azygos vein. (B) shows a cadaveric image of central thorax. It appears yellow and a few regions in it appear green.

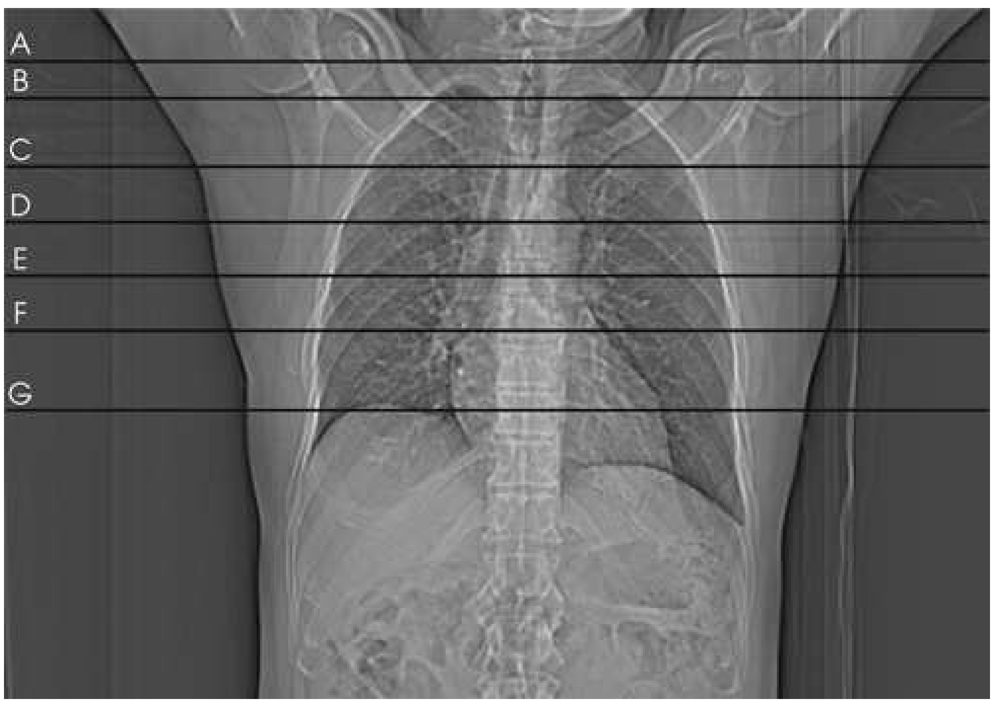


FIG. 24.30 CT localizer (scout) image of thorax.

Many muscles can be seen in the thorax, especially in the shoulder region. The pectoralis major is a large, fan-shaped muscle superficially located along the anterior chest wall. The pectoralis minor lies just deep to the pectoralis major. The trapezius is the most superficial of the posterior thoracic muscles. The rhomboid major and minor muscles are deep to the trapezius and lie between the medial scapular borders and the spinous processes of the upper thoracic spine. The serratus anterior muscles attach to the medial side of the anterior scapula and blanket the external surface of the rib cage. Several muscles are associated with the scapula; many of these also attach to the humerus. The subscapularis muscle lines the anterior surface. Supraspinatus and infraspinatus muscles lie in the supraspinous and infraspinous fossae. The teres major and teres minor also lie along the infraspinous fossa. Four of these muscles are collectively known as the rotator cuff: subscapularis, supraspinatus, infraspinatus, and teres minor.

The CT localizer—or scout—image represents an AP projection of the thoracic region with identifying lines (Fig. 24.30). These lines show the approximate levels for each of the labeled images for this region. Most of the images for this region are CT scans. When performing scans of the thorax, the patient's arms are extended above the head. This fact must be kept in mind when looking at upper thoracic scans because some anatomic structures do not correspond to the normal anatomic position. MR images are frequently degraded by motion artifact in the thorax, so only a few representative images are included.

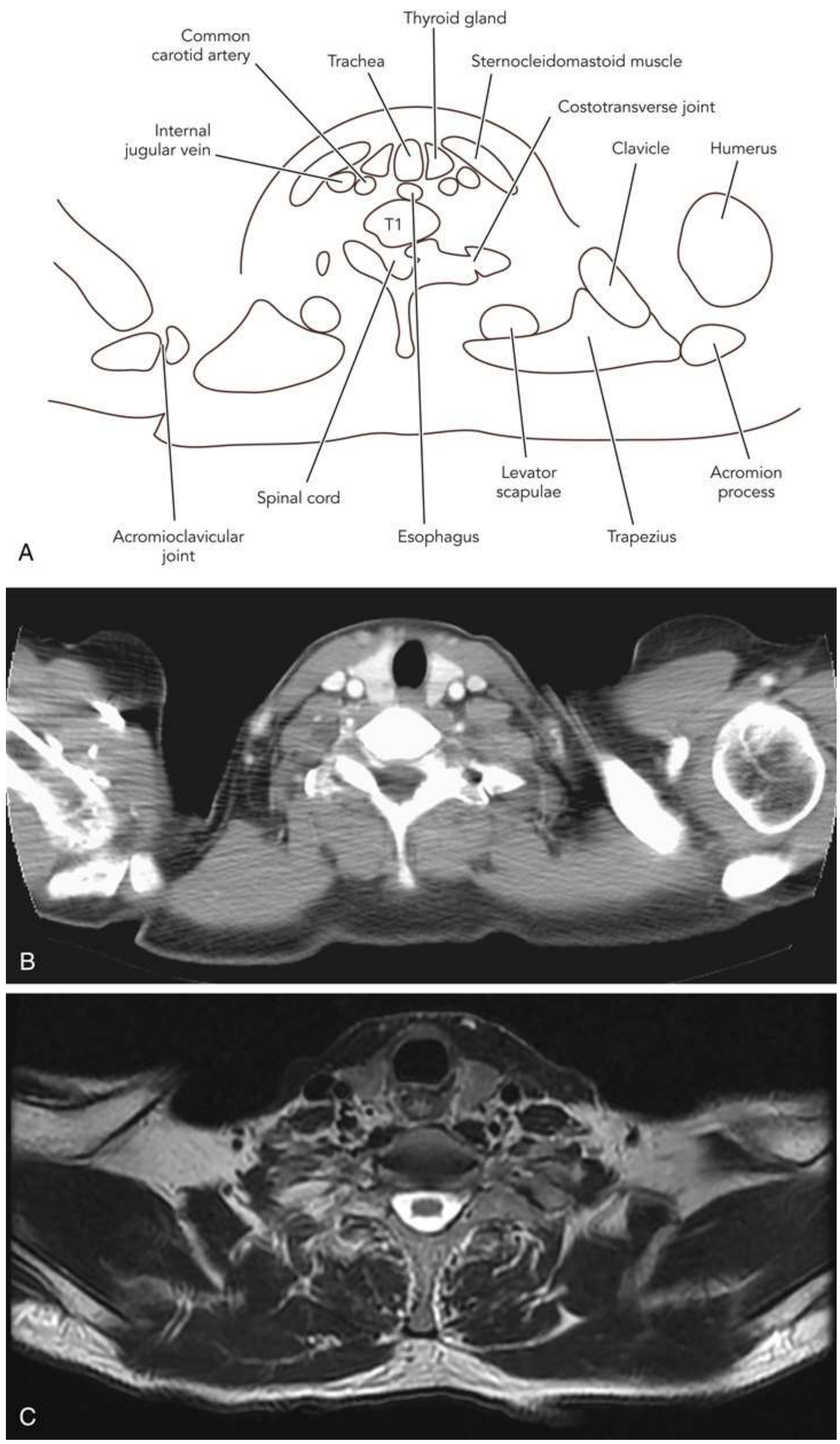


FIG. 24.31 (A) Line drawing of CT section. (B) CT image, and (C) MR image corresponding to level *A* in Fig. 24.30 through first thoracic vertebra.

Diagram (A) shows a line drawing of the C T section of the thoracic vertebra. The parts labeled in the diagram are marked clockwise as follows: spinal cord, acromioclavicular joint, internal jugular vein, common carotid artery, trachea, thyroid gland, sternocleidomastoid muscle, costotransverse join, clavicle, humerus, acromion process, trapezius, levator scapulae, esophagus. (B) A C T image shows several radiopaque areas in the thoracic vertebra. (C) A C T image shows several a radiopaque spot in the middle with a dark region in the middle of it.

Fig. 24.31B shows a CT and T2-weighted MR images at the level of T1 and show the relationship between the vertebral column, esophagus, and trachea. The body and *vertebral arch* of the first thoracic vertebra can be identified, and the spinal cord is seen in the vertebral foramen. The *costotransverse joint* between the first rib and the transverse process of the first thoracic vertebra is seen on the patient's left. Because the patient's arms are raised on the CT image, the scan passes through the surgical neck of the humerus. The inferior portion of the *thyroid gland*, which extends from C6 to T1, is positioned lateral to the *trachea*. The soft tissue shadow immediately posterior to the trachea is the *esophagus*. The outer esophageal lining is well demonstrated on the MR image. The *vertebral arteries* are positioned lateral to the vertebral column, and the *common carotid arteries* are found lateral to the trachea. At this level, the *internal jugular veins* are positioned to the lateral aspect of the carotid arteries. The CT image demonstrates the contrast-filled axillary arteries in the medial aspect of the arms. The *sternocleidomastoid muscles* are found lateral to the thyroid gland. The *trapezius* is the most superficial muscle of the posterior thorax, with the levator scapulae muscles lying just anterior.

Fig. 24.32 shows a CT and T2-weighted MR images through the lower edge of T2. These scans pass through the *jugular notch* of the sternum and are just superior to the sternoclavicular joints. The CT image demonstrates the costovertebral and costotransverse joints that are seen between the ribs and the spine. On the right, the glenoid portion and the acromion process of the scapula are seen. The humerus is visible where it articulates with the glenoid cavity. On the left, the spine and the body of the scapula are seen. Both images demonstrate the *trachea* and esophagus located anterior to the vertebral body. The major vessels of the superior thorax are visualized posterior to the clavicles. The right and left *brachiocephalic veins* are formed by the junction of the *subclavian veins* and the internal jugular veins. Because contrast medium was injected for the CT scan, the axillary and most of the right subclavian vein are filled with contrast medium. Posterior to the right clavicle, the right subclavian vein and internal jugular vein have joined. Because the CT image is slightly more inferior on the left, the image plane passes through the left brachiocephalic vein (below the junction of these two vessels). The brachiocephalic veins unite and form the *superior vena cava* at a more inferior level. The arterial branches to the head and upper limb are also well visualized on the CT image. From the patient's right to left, they are situated as the *right subclavian artery*, *right common carotid artery*, *left common carotid artery*, and *left subclavian artery*. The brachiocephalic artery gives rise to the right subclavian and right common carotid arteries and is inferior to this level. The *pectoralis major* and *pectoralis minor* lie along the anterior thoracic wall. The trapezius is the most superficial of the posterior muscles and is seen between the scapula and the spine on each side. The *subscapularis muscle* lines the left anterior scapula, the *infraspinatus* and *teres minor* line the posterior portion of this bone, and the *supraspinatus* is seen between the body and the scapular spine.

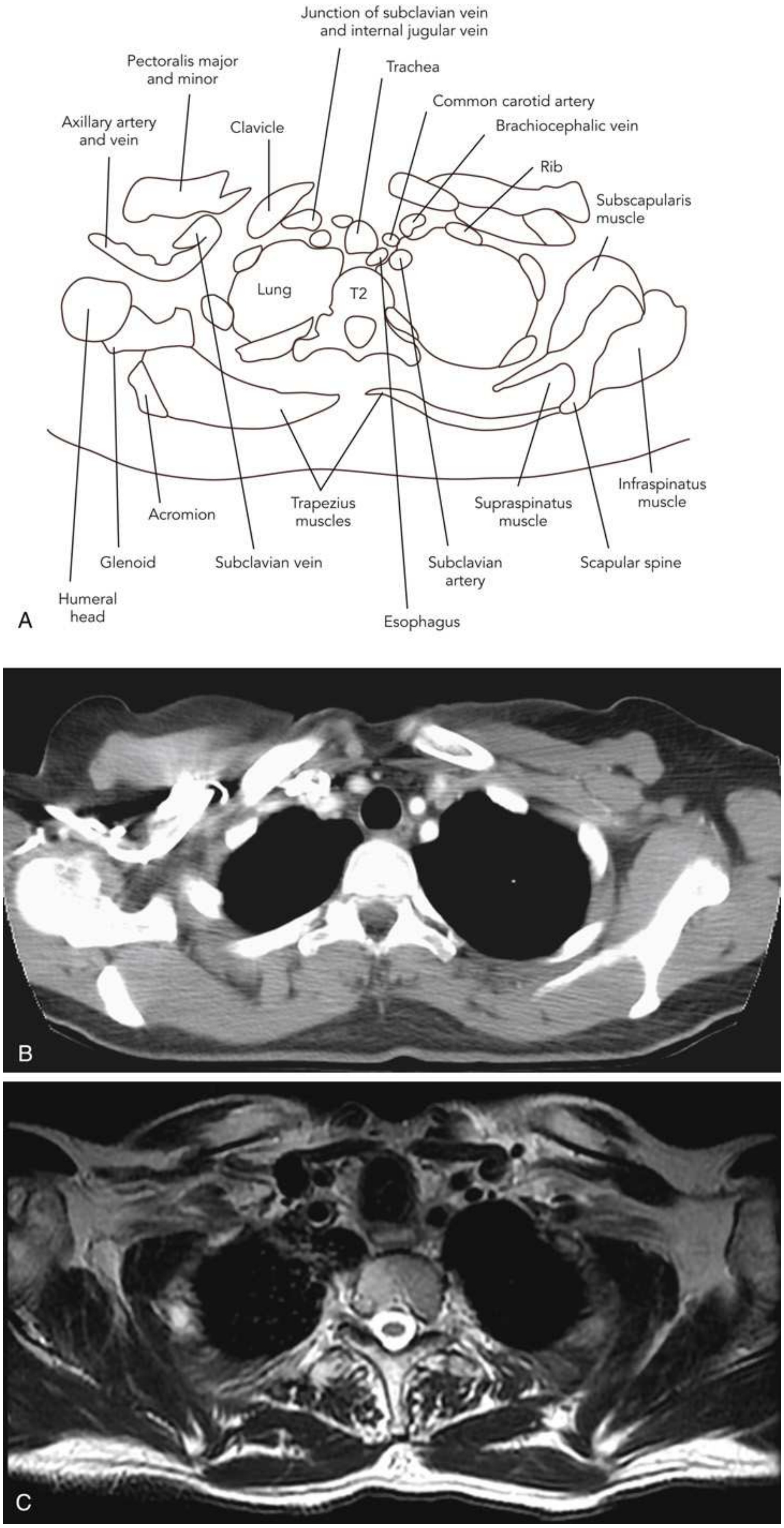


FIG. 24.32 (A) Line drawing of CT section. (B) CT image, and (C) MR image corresponding to level *B* in Fig. 24.30 through jugular notch.

Diagram (A) shows a line drawing of the C T section. The parts labeled in the diagram are marked clockwise as follows: trapezius muscles, subclavian vein, acromion, glenoid, humeral head, axillary artery and vein, pectoralis major and minor, clavicle, junction of subclavian vein and internal jugular vein, trachea, common carotid artery, brachiocephalic vein, rib, subscapularis muscle, infraspinatus muscle, scapular spine, supraspinatus muscle, subclavian artery, esophagus. (B) A C T image shows two circular radiolucent region on either side of the image followed by several radiopaque areas. (C) A C T image shows two circular radiolucent region on either side of the image. A radiopaque region is at the bottom.

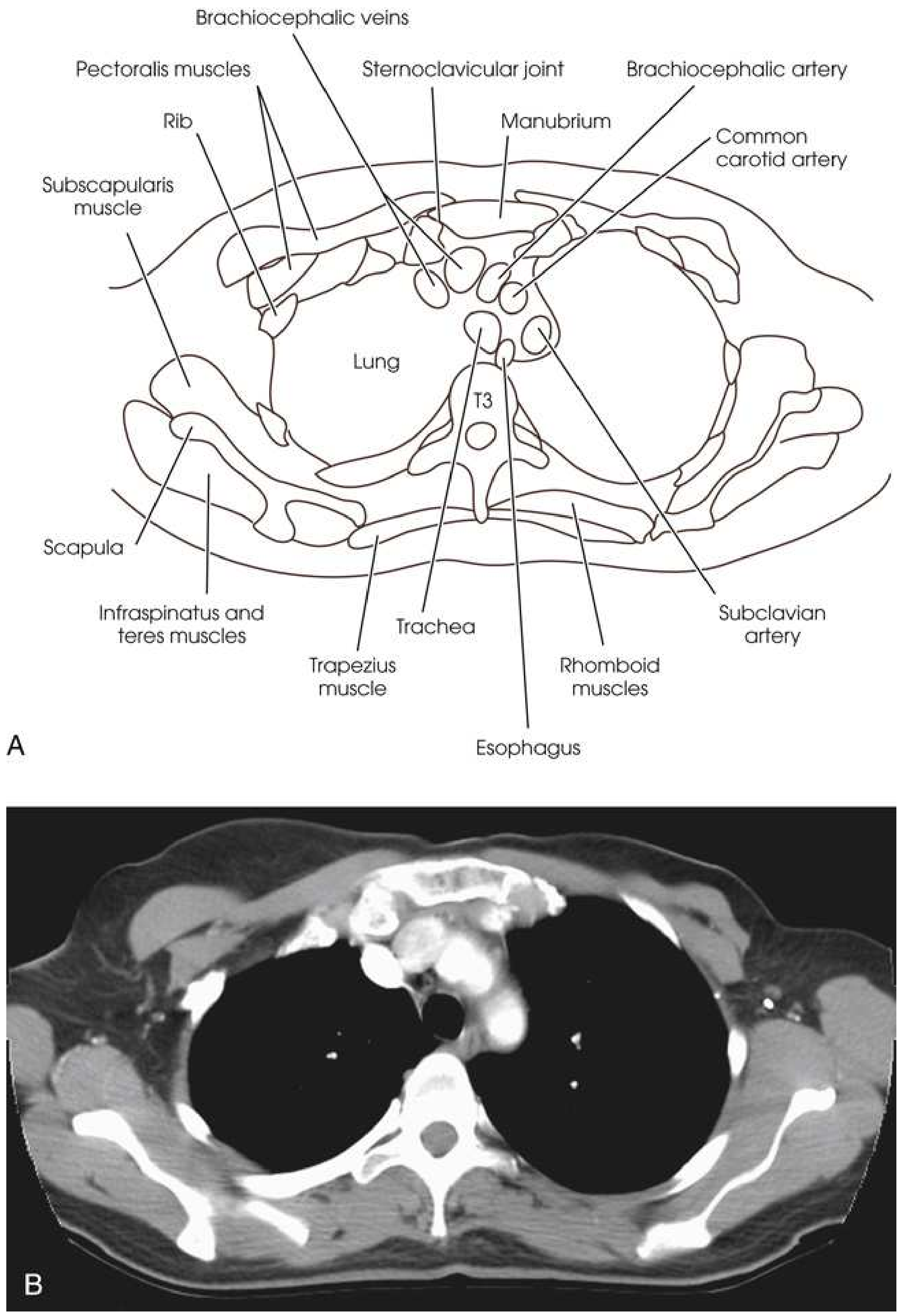


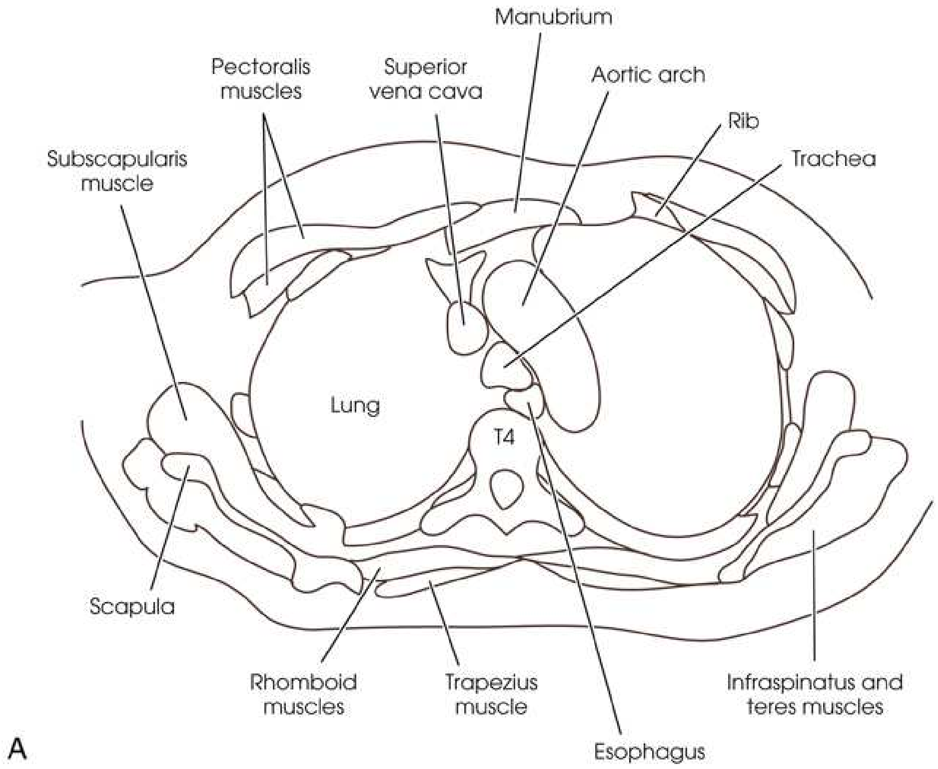
FIG. 24.33 (A) Line drawing of CT section. (B) CT image corresponding to level *C* in Fig. 24.30 just superior to aortic arch.

Diagram (A) shows a line drawing of the C T section. The parts labeled in the diagram are marked clockwise as follows: trachea, trapezius muscle, infraspinatus and teres muscles, scapula, subscapularis muscle, rib, pectoralis muscles, brachiocephalic veins, sternoclavicular joint, manubrium, brachiocephalic artery, common carotid artery, subclavian artery, rhomboid muscles, esophagus. (B) A C T image shows two circular radiolucent region on either side followed by several radiopaque areas.

Fig. 24.33 is a CT image through the level of T3. Bony structures depicted in this image include the *manubrium* and sternoclavicular joints anteriorly, the ribs laterally, and the scapulae and vertebra posteriorly. The spine and the body of the right scapula are visible at this level. Costovertebral and costotransverse joints are noted along the right side of the vertebra. Several vascular structures, highlighted with contrast medium, are visible posterior to the manubrium. The right and left brachiocephalic veins are seen just posterior to the right sternoclavicular joint. This level is just superior to where the vessels join to form the superior vena cava. The brachiocephalic artery, left common carotid artery, and left subclavian artery curl around the left side of the trachea. This scan is just superior to the arch of the aorta and visualizes the origins of these three vessels. Posterior to the vessels are the trachea and esophagus. The upper lobes of each lung lie lateral to the mediastinal structures. The pectoralis major and pectoralis minor lie external to the anterior ribs. Rotator cuff muscles (subscapularis, infraspinatus, and teres minor) are shown anterior and posterior to the scapulae. The trapezius and *rhomboid muscles* lie between the scapulae and the spinous process of the vertebra in this image.

Fig. 24.34 is a CT scan obtained through the lower edge of T4. At this level, the brachiocephalic veins have joined to form the *superior vena cava*. The large contrast-filled structure in the left anterolateral mediastinum is the *aortic arch*.

Fig. 24.35 is a CT image at the level of T5 and shows the great vessels superior to the heart. (The heart is normally positioned between T7 and T11, with most of the organ lying left of the midline). The *ascending aorta* is found anteriorly in the midline; the *descending aorta* is related to the left anterolateral surface of the vertebral bodies. (This relationship between the descending aorta and vertebral column is continuous through the thorax and abdomen.) Note the normal difference in caliber between the ascending and descending aorta. The superior vena cava is located to the right of the ascending aorta, and the pulmonary trunk and left and right pulmonary arteries are located to the left of the ascending aorta at this level. The *pulmonary trunk* originates from the right ventricle of the heart and divides into the right and left *pulmonary arteries*, which carry deoxygenated blood to the lungs. The left pulmonary artery is seen bifurcating into the two lobar branches at the hilum of the left lung. Near the T5 level, the trachea divides into the left and right *primary bronchi*. The esophagus (in which a small amount of air is seen) is found just posterior to the left main bronchus. Fig. 24.36 is a T2-weighted MR image that corresponds in position to the previous CT image. The main pulmonary artery and the left pulmonary artery are seen on this image, although the right pulmonary artery is not visible. Muscular structures are easily differentiated. The spinal cord is seen within the vertebral canal, where it is surrounded by CSF.



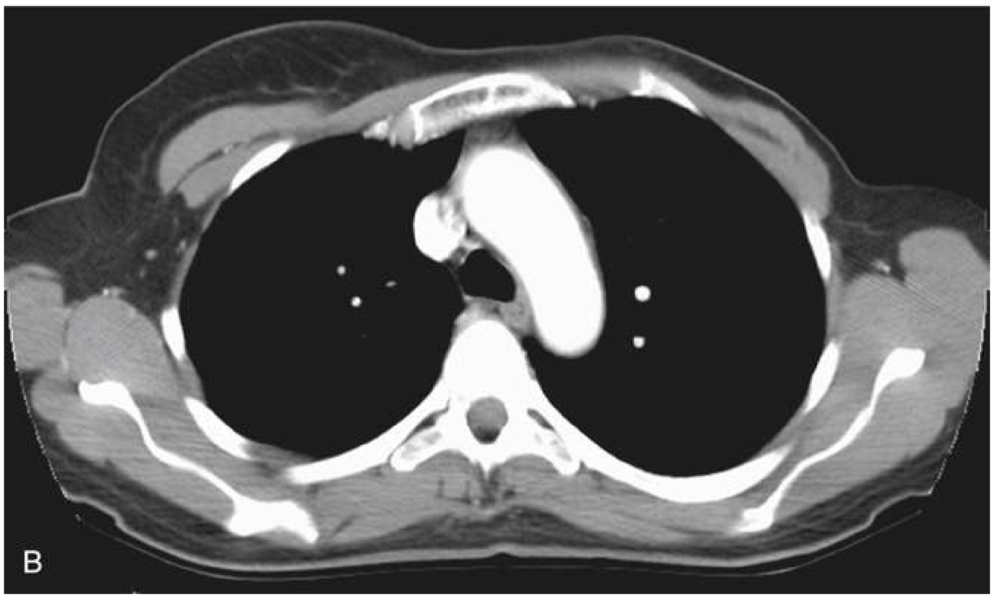


FIG. 24.34 (A) Line drawing of CT section. (B) CT image corresponding to level *D* in Fig. 24.30 through aortic arch.

Diagram (A) shows a line drawing of the C T section. The parts labeled in the diagram are marked clockwise as follows: trapezius muscle, rhomboid muscles, scapula, subscapularis muscle, pectoralis muscles, superior vena cava, manubrium, aortic arch, rib, trachea, infraspinatus and teres muscles, esophagus. (B) A C T image shows two circular radiolucent region on either side and a radiopaque region in the right side. There are a few white spots on the radiolucent region.

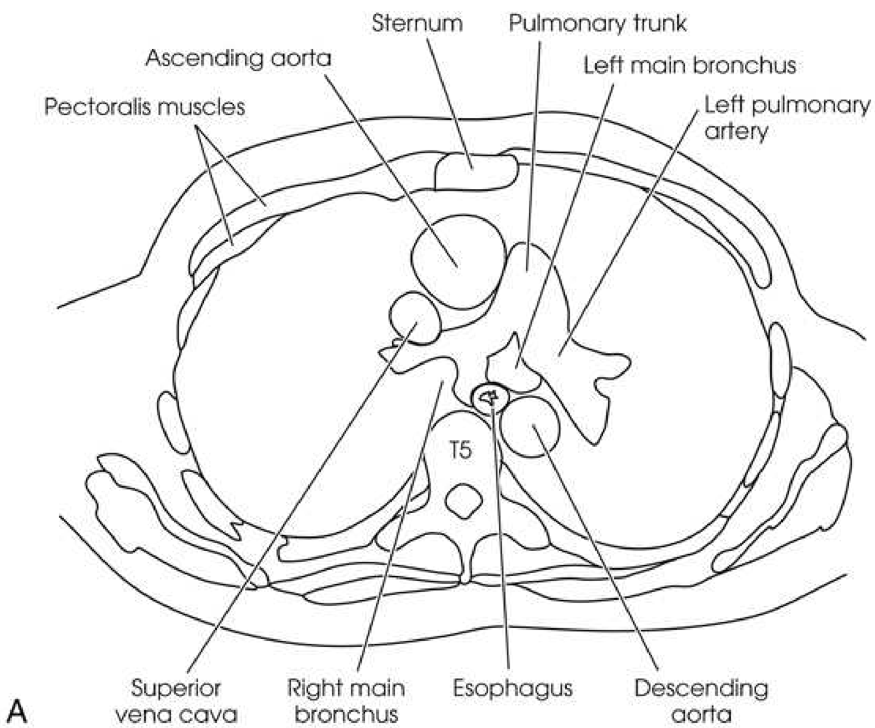


FIG. 24.35 (A) Line drawing of CT section. (B) CT image corresponding to level *E* in Fig. 24.30 through pulmonary trunk.

Diagram (A) shows a line drawing of the C T section. The parts labeled in the diagram are marked clockwise as follows: right main bronchus, superior vena cava, pectoralis muscles, ascending aorta, sternum, pulmonary trunk, left main bronchus, left pulmonary artery, descending aorta, esophagus. (B) A C T image shows two circular radiolucent region on either side and a radiopaque region in the middle.

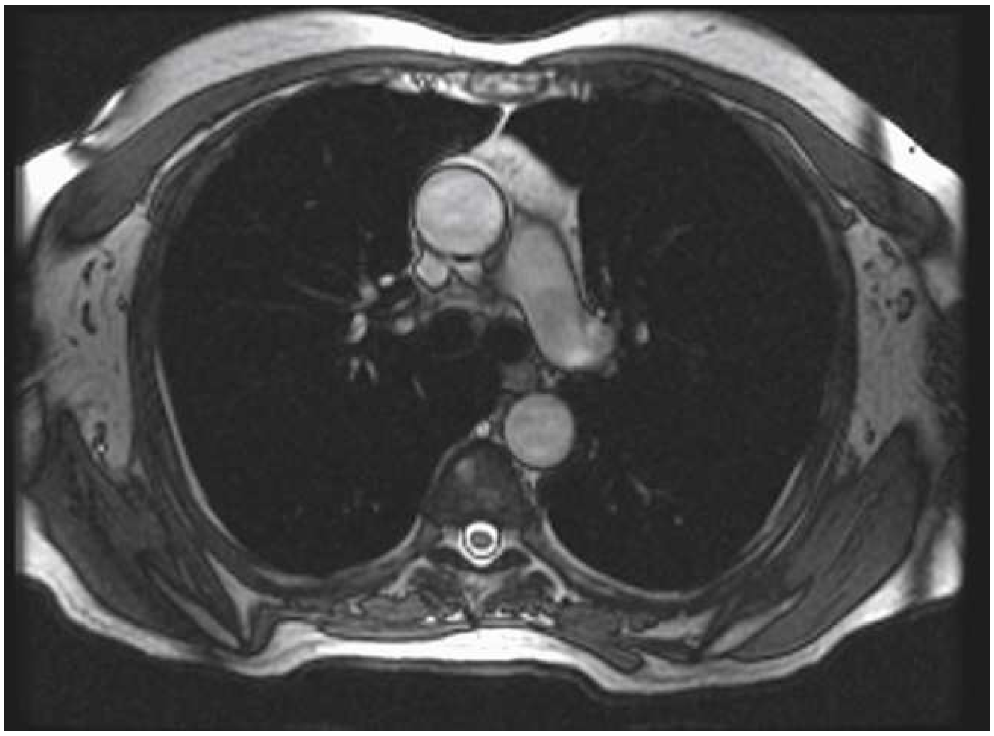


FIG. 24.36 MRI corresponding to level *E* in Fig. 24.30.

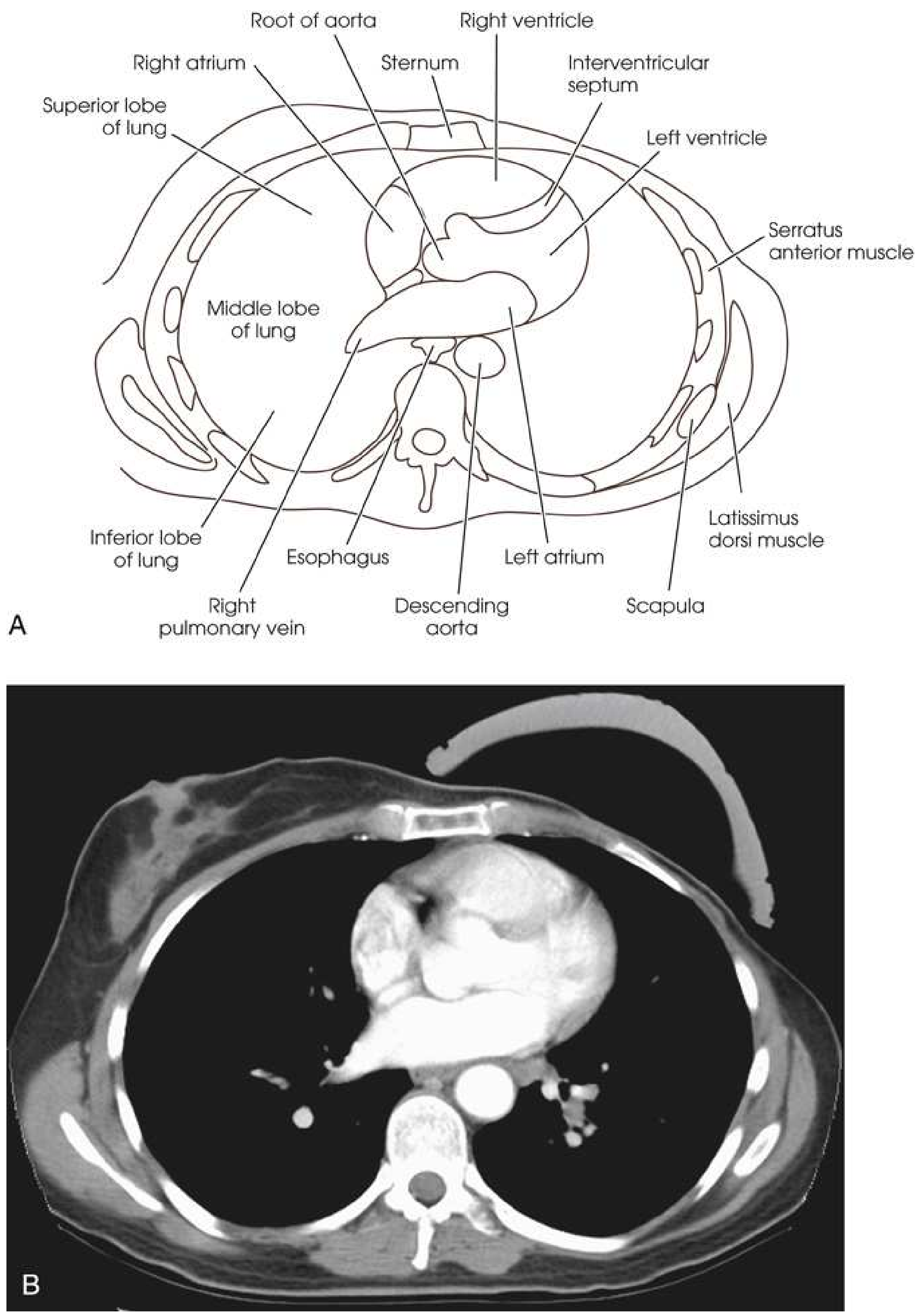


FIG. 24.37 (A) Line drawing of CT section. (B) CT image corresponding to level *F* in Fig. 24.30 through base of the heart.

Diagram (A) shows a line drawing of the C T section. The parts labeled in the diagram are marked clockwise as follows: esophagus, right pulmonary vein, inferior lobe of lung, superior lobe of lung, right atrium, root of aorta, sternum, right ventricle, interventricular septum, left ventricle, serratus anterior muscle, latissimus dorsi muscle, scapula, left atrium, descending aorta. (B) A C T image shows two circular radiolucent region on either side and a huge radiopaque region in the middle.

The CT image depicted in Fig. 24.37 shows the *lungs* and the base of the *heart*. In general, when the heart is imaged in cross section, the *left atrium* is the superiormost structure encountered, and the *pulmonary veins* are seen emptying into it (one of the right pulmonary veins can be seen here). The *right atrium* is seen lying the farthest toward the right side of the body, anterior and inferior to the left atrium. The superior vena cava may be seen at this level as it enters the right atrium. The *right ventricle* lies to the left of the right atrium and anterior to the more muscular *left ventricle*. Contrast-enhanced blood is seen here as blood exits the left ventricle to enter the root of the aorta. The *interventricular septum* can be seen between the ventricles.

The lungs are divided into superior and inferior lobes by the diagonally oriented *oblique fissure*. The *superior lobes* lie superior and anterior to the inferior lobes. The *superior lobe* of the right lung is divided further by the *horizontal fissure*, with the lower portion termed the *middle lobe*. The left lung has no horizontal fissure. The inferior and anterior portion of the left lung (corresponding to the right middle lobe) is termed the *lingula*. Although the fissures are not seen, the approximate locations of these lobes are identified here.

Muscular structures that can be seen at this level include the inferior insertions of the trapezius, the *latissimus dorsi*, and the *serratus anterior muscles*. The esophagus lies between the left atrium and the vertebral column at this level.

The CT image depicted in Fig. 24.38 lies at approximately T9 and shows the lower sternum and ribs. The descending aorta normally lies along the left anterolateral surface of the vertebral column, and the *azygos vein* is normally on the right anterolateral surface. Because this scan is inferior to the right ventricle, the *inferior vena cava* is seen between the heart and the liver. The superior portion of the liver is bulging against the base of the right lung, and the superiormost portion of the left hemidiaphragm is seen at the base of the left lung. The right and left ventricles of the heart and the interventricular septum can be seen surrounded by pericardium. The major muscle structures that are visible are the serratus anterior, latissimus dorsi, and the deep back muscles.

Fig. 24.39 is a frontal CT localizer image representing the sagittal levels of the thorax presented here. Fig. 24.40 is a CT image located near the median sagittal plane of the chest. In this image, the central portion of the manubrium can be seen in the anterior thorax. The sternal angle is represented as a dark line separating the manubrium and the body of the sternum. Thoracic vertebral bodies, spinous processes, zygapophyseal joints, and intervertebral foramina border the posterior thorax. Because the body has a slight degree of curvature in the spine, different structures are seen in the spinal column at different levels. Within the upper thorax, the cartilage rings of the trachea can be observed. The soft tissue structure posterior to the trachea is the esophagus. The heart and great vessels lie near the center of the thorax. In this image, the superiormost vascular structure is the arch of the aorta. At this level, the origin of the left common carotid artery is present. The left ventricle is the largest chamber of the heart and is seen here filled with contrast medium. It also empties into the aorta. The origin and ascending aorta can be seen just superior to the left ventricle. The left pulmonary artery lies immediately inferior to the aortic arch. This vessel is a branch of the pulmonary artery and originates from the right ventricle of the heart, which is anterior to the left ventricle. The left atrium of the heart is the most posterior chamber and is seen here posterior to the pulmonary trunk and left ventricle. The diaphragm is located inferior to the heart and separates the thoracic cavity from the abdomen.

Fig. 24.41 is a CT image that passes just medial to the left sternoclavicular joint. In this image, the entire aorta is present, from the root, through the arch, and continuing as the descending portion. The origins of the left common carotid and the left subclavian arteries are seen at the superior border of the arch. The left common carotid artery courses from its origin superiorly into the neck near the trachea. The upper portion of the esophagus is posterior to the trachea. The left pulmonary artery is visible just inferior to the arch, and the air-filled structure posterior to this vessel is the left main bronchus.

The CT image depicted in Fig. 24.42 represents a sagittal section through the left sternoclavicular joint. Anteriorly, the bony structures include the clavicle, the upper-outer corner of the manubrium, and the costosternal articulations. The posterior bony anatomy includes the thoracic spine and the upper ribs. Within the thorax, the arch and descending aorta are present. The left subclavian artery is the third branch from the aortic arch. This vessel passes superiorly to arch over the apex of the left lung. In this image, the proximal portion of this vessel is seen just superior to the aortic arch. In the anterior mediastinum, the contrast-filled right ventricle is pumping blood into the main pulmonary artery. The left pulmonary veins return blood from the lungs to the left atrium. The left ventricle lies between the right ventricle and the left atrium in this image.

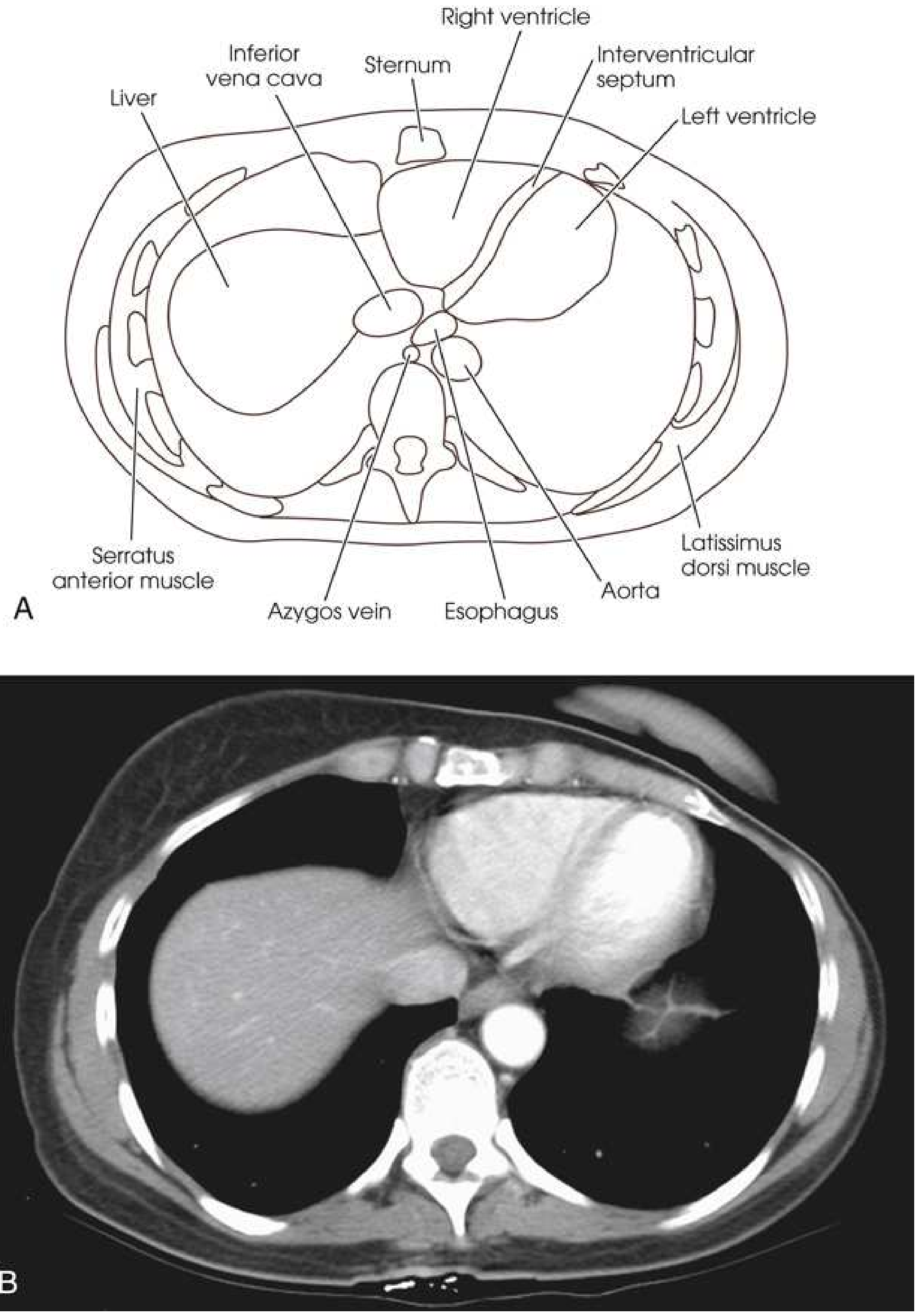


FIG. 24.38 (A) Line drawing of CT section. (B) CT image corresponding to level *G* in Fig. 24.30 through right hemidiaphragm.

Diagram (A) shows a line drawing of the C T section. The parts labeled in the diagram are marked clockwise as follows: azygos vein, serratus anterior muscle, liver, inferior vena cava, sternum, right ventricle, interventricular septum, left ventricle, latissimus dorsi muscle, aorta, esophagus. (B) A C T image shows two circular radiolucent region on either side and a huge radiopaque region at peak projected in the middle.

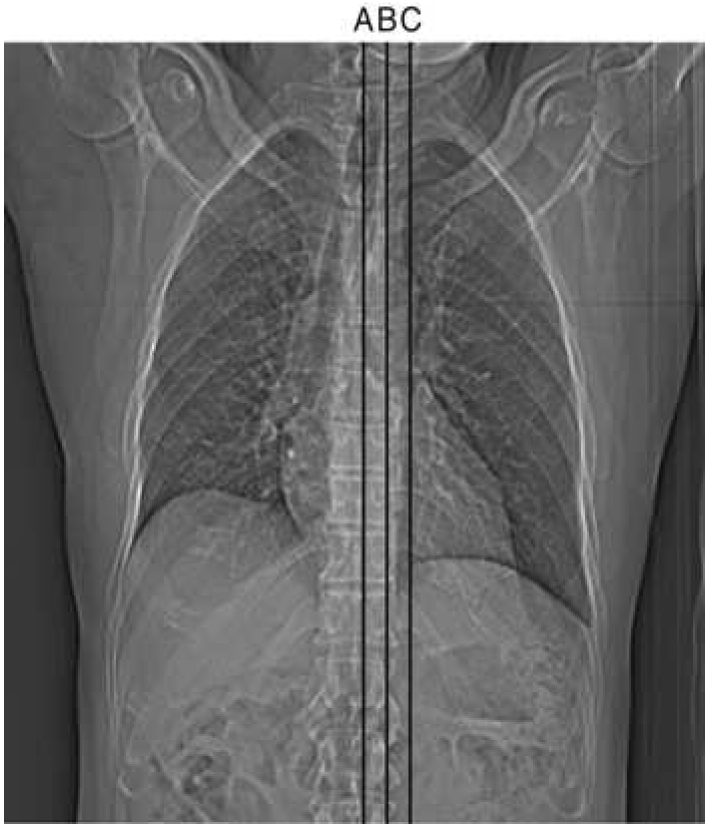


FIG. 24.39 CT localizer image representing levels of sagittal sections through thorax.

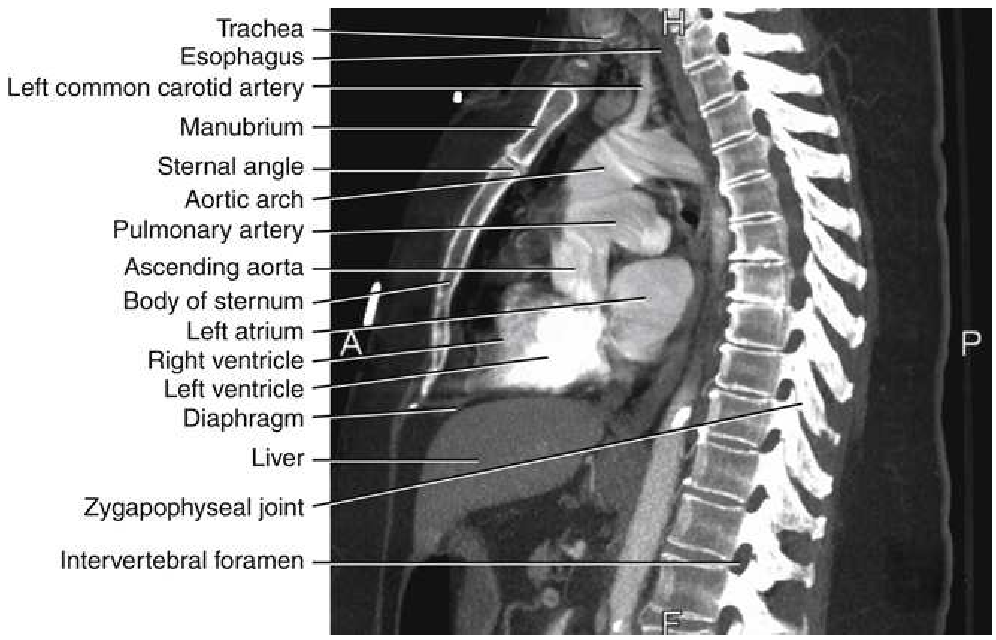


FIG. 24.40 Sagittal CT image of thorax corresponding to level *A* in Fig. 24.39.

A C T image shows the vertebra and the heart. The parts labeled are marked from top to bottom as follows: trachea, esophagus, left common carotid artery, manubrium, sternal angle, aortic arch, pulmonary artery, ascending aorta, body of sternum, left atrium, right ventricle, left ventricle, diaphragm, liver, zygapophyseal joint, intervertebral foramen.

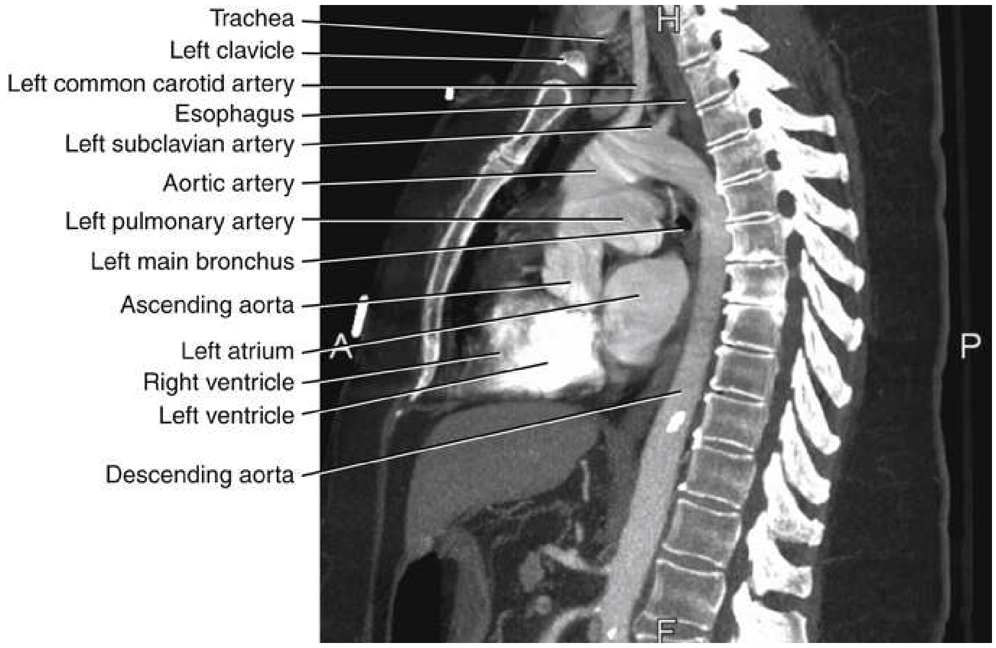


FIG. 24.41 Sagittal CT image of thorax corresponding to level *B* in Fig. 24.39.

A C T image shows the vertebra and the heart. The parts labeled are marked from top to bottom as follows: trachea, left clavicle, left common carotid artery, esophagus, left subclavian artery, aortic artery, left pulmonary artery, left main bronchus, ascending aorta, left atrium, right ventricle, left ventricle, descending aorta.

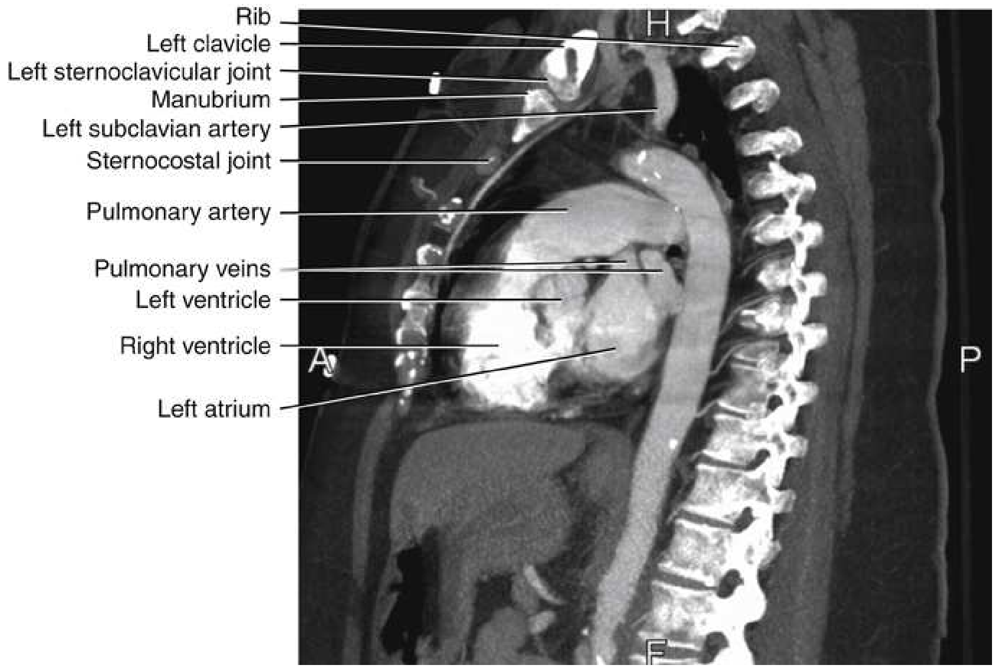


FIG. 24.42 Sagittal CT image of thorax corresponding to level *C* in Fig. 24.39.

A C T image shows the vertebra and the heart. The parts labeled are marked from top to bottom as follows: rib, left clavicle, left sternoclavicular joint, manubrium, left subclavian artery, sternocostal joint, pulmonary artery, pulmonary veins, left ventricle, right ventricle, left atrium.

Fig. 24.43 is a lateral chest x-ray to be used to localize the coronal sections of the thorax presented here. The CT image depicted in Fig. 24.44 is a coronal image passing through the anterior mediastinum. The clavicles, manubrium, and sternoclavicular joints are visible at the entrance into the thorax. Sections through the ribs line both lateral walls of the thoracic cavity. The setting for this image shows the lungs as black structures with a few vascular shadows visible within each. The mediastinum in the center of the thoracic cavity is occupied by the heart and great vessels. This scan passes through the anterior mediastinum, so the ascending portion of the aorta is visible. It lies between the pulmonary artery and the superior vena cava. In this slice, the superior vena cava is discernible at its entrance into the right atrium. The right ventricle is the most anterior chamber of the heart and is seen here lateral to the right atrium.

The CT coronal thoracic section seen in Fig. 24.45 passes through a plane near the median coronal plane of the thorax. Clavicles and ribs can be seen surrounding the superior and lateral thorax. The cartilage rings of the trachea lie in the median sagittal plane at the superior end of the thorax. The left lung is specked with several light gray vascular structures. The right lung shows infiltrates and central scar tissue from an old resection. This scan was performed with contrast enhancement, and the right axillary vein and superior vena cava are visible as bright white. The aortic arch gives rise to the vessels that supply the head and neck. In this image, the brachiocephalic artery and the origin of the left common carotid artery can be seen. The brachiocephalic veins are formed by the internal jugular and subclavian veins. The left brachiocephalic vein is located just to the left of the brachiocephalic artery and superior to the origin of the common carotid artery in this image. The main pulmonary artery is visible inferior to the aorta. A small portion of the left atrium and the right atrium and ventricle can be seen.

Fig. 24.46 shows anatomy in a posterior plane through the mediastinum. Because of the curve of the spine, the lower cervical and thoracic vertebrae are visible, but most of the thoracic spine is posterior to this imaging plane. Near the level of the fourth or fifth thoracic vertebrae, the trachea bifurcates into the right and left main bronchi. In this image, the lower trachea, its bifurcation, and the main bronchi are visible. On the right, the main bronchus is dividing into lobar bronchi. The soft tissue structure detectable near the top of the visible portion of the trachea is the esophagus. On the left side of the esophagus, the left subclavian artery, filled with contrast medium, is seen as it starts its arch over the apex of the lung. The round contrast-filled vessels that lie on the left side of the trachea are the aortic arch (superior) and the left pulmonary artery (inferior). Inferior to the trachea, the left atrium is detectable, filled with contrast medium. One of the four pulmonary veins is visible, filled with contrast medium and to the right of the left atrium. Because this image is relatively posterior in the mediastinum, no other chambers of the heart can be seen; however, a section of the descending aorta, filled with contrast medium, lies inferior to the left atrium.

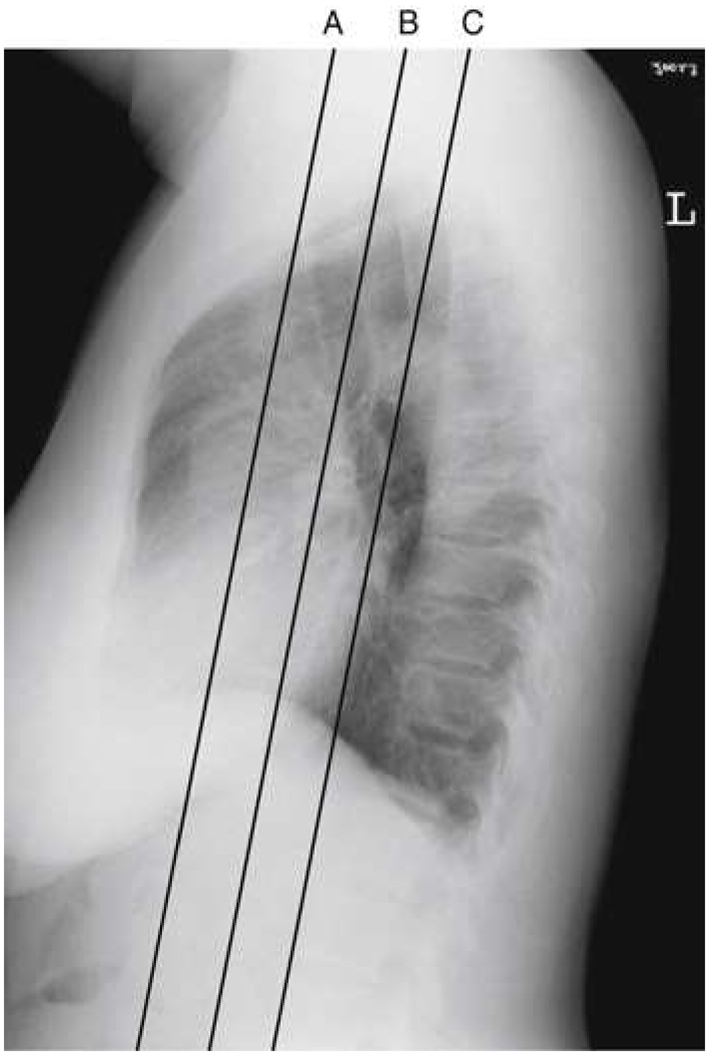


FIG. 24.43 Lateral chest x-ray representing levels of coronal sections through thorax.

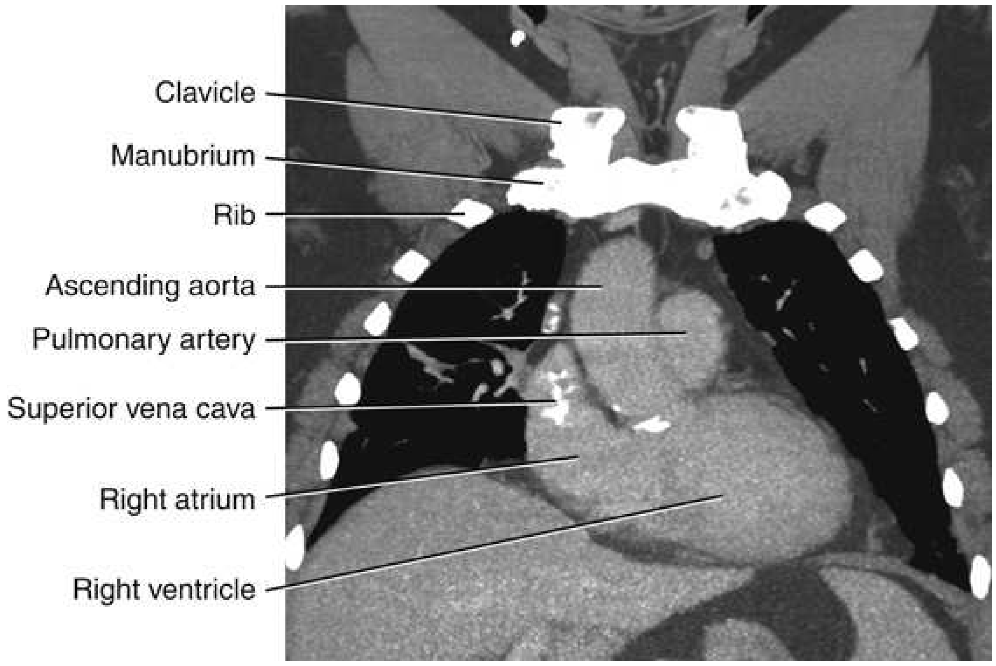


FIG. 24.44 Coronal CT image of thorax corresponding to level *A* in Fig. 24.43.

A C T image shows the heart. The parts labeled are marked from top to bottom as follows: clavicle, manubrium, rib, ascending aorta, pulmonary artery, superior vena cava, right atrium, right ventricle.

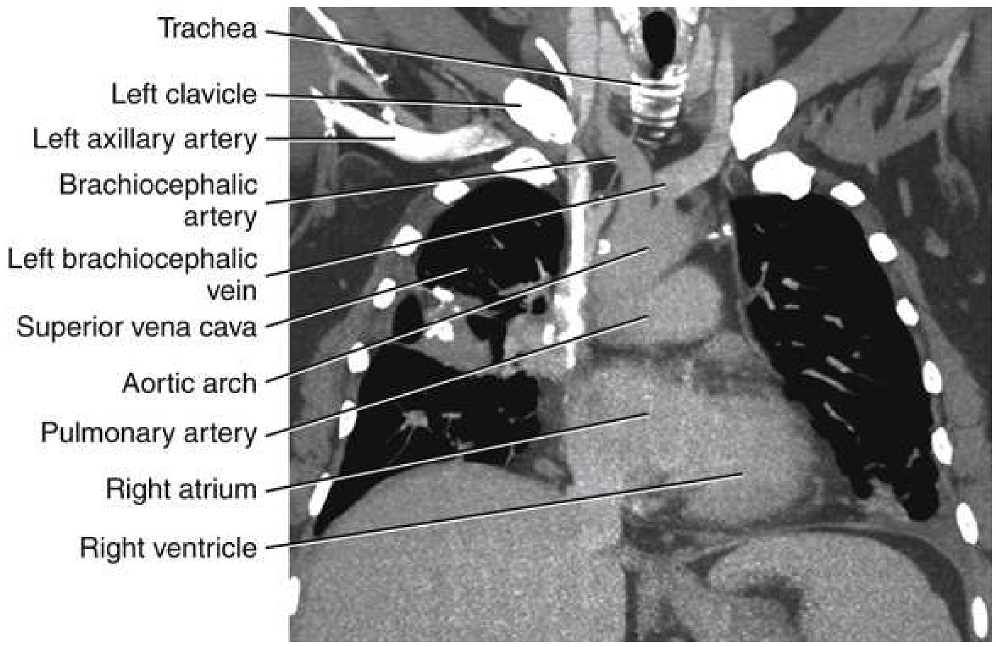


FIG. 24.45 Coronal CT image of thorax corresponding to level *B* in Fig. 24.43.

A C T image shows the heart. The parts labeled are marked from top to bottom as follows: trachea, left clavicle, left axillary artery, brachiocephalic artery, left brachiocephalic vein, superior vena cava, aortic arch, pulmonary artery, right atrium, right ventricle.

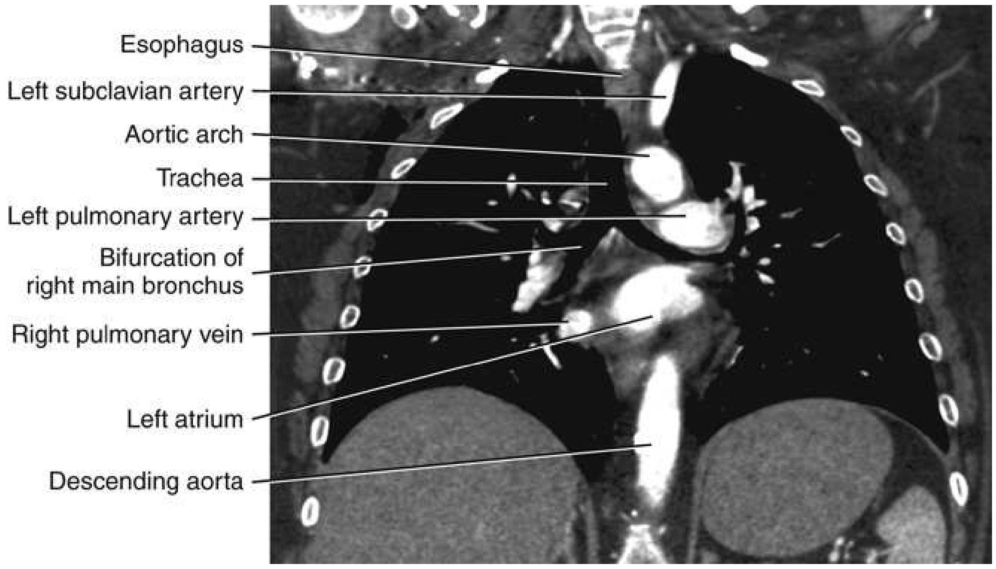


FIG. 24.46 Coronal CT image of thorax corresponding to level *C* in Fig. 24.43.

A C T image shows the heart. The parts labeled are marked from top to bottom as follows: esophagus, left subclavian artery, aortic arch, trachea, left pulmonary artery, bifurcation of right main bronchus, right pulmonary vein, left atrium, descending aorta.

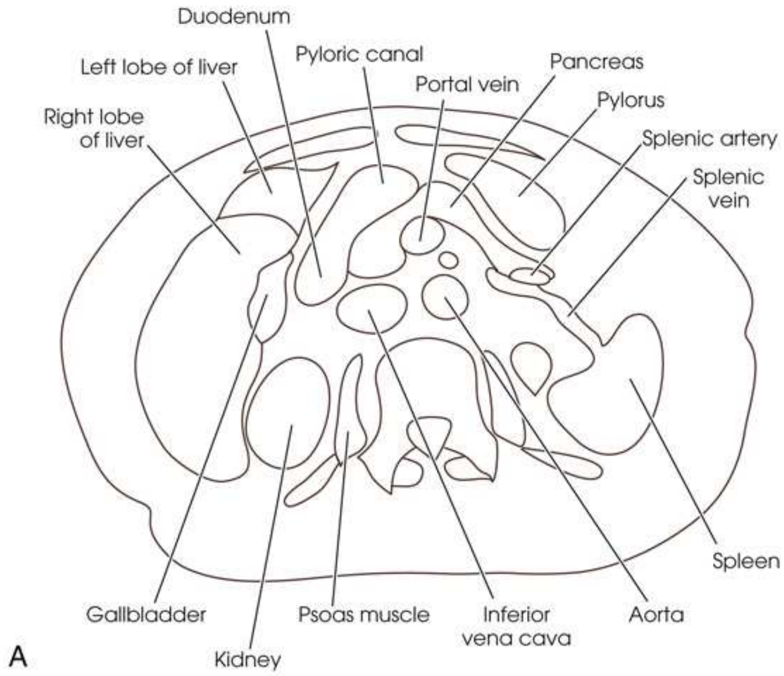


FIG. 24.47 (A) Line drawing of gross anatomic section. (B) Cadaveric section through central abdomen at the level of L2.

Diagram (A) shows a line drawing of the gross anatomic section. The parts labeled in the diagram are marked clockwise as follows: psoas muscle, kidney, right lobe of liver, left lobe of liver, duodenum, pyloric canal, portal vein, pancreas, pylorus, splenic artery, splenic vein, spleen, aorta, inferior vena cava. (B) shows a section through central abdomen. It appears yellow. The internal structures appear brown and green.

Abdominopelvic Region

The abdominopelvic region includes the diaphragm and everything inferior to it. Fig. 24.47 is a cadaveric image at the level of the second lumbar vertebra. Major abdominal organs and vascular structures can be identified in this image. In the abdomen, five lumbar vertebrae are visible. Although these vertebrae are slightly larger than the vertebrae in the thorax, the anatomic components are roughly the same. In the pelvis, the lower spine and hip bones (os coxae or innominate) form an attachment for the lower limbs and support for the trunk. The lower spine comprises the sacrum and coccyx. These are triangular bones with their broad bases oriented superiorly. Each os coxae lies obliquely situated in the pelvis, articulating with the sacrum (sacroiliac joint) posteriorly and with the opposite os coxae anteriorly (symphysis pubis). At birth, this bone consists of three components: the ilium, ischium, and pubis. These three ultimately fuse at the acetabulum. The superior, wing-shaped portion of the os coxae is the ilium. The superior edge is the crest, which lies at the level of the lower fourth lumbar vertebra. The anterior superior and anterior inferior iliac spines lie along the anterior surface of the ilium. At the posterior ilium, posterior superior, and posterior inferior, iliac spines are found at the top and bottom of the sacral articular surface. Below the posterior inferior iliac spine, the greater sciatic notch curves sharply toward the front of the bone. The inferior and anterior os coxae are composed of the pubis. The pubic bone extends from the acetabulum toward the midline and then curves inferiorly. The pubic bones articulate with each other at the symphysis pubis. The posterior inferior os coxae is formed by the ischium. This portion extends inferiorly from the acetabulum, and then curls forward to meet the lower part of the pubis. The obturator foramen is a circular opening formed by the junction of the pubis and ischium.

The abdominal cavity is lined by a double-walled membrane called the *peritoneum.* Some organs develop posterior to the peritoneum and are referred to as *retroperitoneal.* Others invaginate into the peritoneum and are referred to as *intraperitoneal.* Several large folds of the peritoneum are identifiable on sectional images because of the large amount of fat found within it. The greater omentum extends from the greater curvature of the stomach and the transverse colon to blanket the anterior surface of the abdominal organs, especially the digestive organs. The small intestines invaginate into the peritoneum as they develop, and a large flap of peritoneum—the mesentery—anchors this part of the digestive system to the posterior abdominal wall.

The spleen is an organ belonging to the lymphatic system. It lies inferior to the left hemidiaphragm and posterior to the fundus of the stomach. On the medial surface of the spleen, blood vessels enter and exit at the hilum.

The organs of the alimentary tract include the esophagus, stomach, small intestine, and large intestine. The esophagus lies anterior to the spine and passes through the diaphragm to enter the abdomen at about the level of T10. In the abdomen, the esophagus passes toward the left to enter the stomach. The opening into the stomach is the cardiac orifice, and the junction is the esophagogastric junction. The stomach is a J-shaped pouch in the left upper quadrant. The region above the level of the esophagogastric junction is the fundus, the central region is the body, and the distal part is the pyloric antrum. This last portion normally lies at about the level of the second lumbar vertebra. The medial and lateral borders are referred to as the *lesser and greater curvatures.* Internally, the stomach is thrown into multiple folds termed *rugae.* Food passes from the distal stomach through the pyloric canal into the small intestine. A muscle called the *pyloric sphincter* controls passage through the canal. The small intestine consists of the duodenum, jejunum, and ileum. The first portion or duodenum extends from the stomach laterally to the liver, where the remainder curls inferiorly and medially to form a C-shaped loop around the head of the pancreas. The duodenum is approximately 10 to 12 inches (24 to 30 cm) long, and at the ligament of Treitz it continues as the jejunum. The jejunum is approximately 8 ft (2.4 m) long and mainly occupies the left upper abdomen. It continues as the ileum. This distalmost part of the small bowel is about 10 ft (3 m) long and occupies the right inferior abdominal cavity and the pelvis. The large intestine is about 6 ft (1.8 m) long. It frames the periphery of the abdominal cavity and comprises the cecum, colon (ascending, transverse, descending, and sigmoid portions), rectum, and anus. The ileum empties into the saclike cecum in the right lower quadrant via the ileocecal valve. The vermiform appendix can frequently be seen projecting off the cecum. From the cecum, the ascending portion of the colon passes superiorly. Just below the liver, this portion curves anteriorly and medially at the hepatic (right colic) flexure. The transverse portion passes from here across the anterior abdomen. This portion dips inferiorly into the abdomen to a variable degree depending on the body habitus of the patient. As the colon reaches the spleen, it turns posteriorly and inferiorly at the splenic (left colic) flexure to become the descending colon. This portion passes down the posterior aspect of the left side of the abdomen toward the pelvis, where it continues as the sigmoid colon. The sigmoid colon curls medially and posteriorly in the pelvis, and at the mid-sacrum it curves inferiorly as the rectum. The rectum lies anterior to and follows the curve of the sacrum to become the anal canal as the large intestine exits the pelvis.

Several accessory organs of the digestive system are located in the upper abdomen. The liver occupies most of the right upper quadrant. This triangular organ is divided anatomically into a large right lobe and a much smaller left lobe. The falciform ligament is located along the division between these lobes on the anterior surface, and the ligamentum venosum and ligamentum teres are found along the division on the posterior surface of the liver. On the posteroinferior surface of the right lobe are two smaller lobes: the caudate (superior) and the quadrate (inferior). These two lobes are separated by the porta hepatis (hilum) of the liver. The hepatic artery, portal vein, and hepatic bile ducts enter and exit the liver here. The gallbladder rests against the undersurface of the liver. This organ functions as a storage vessel for bile, which is produced in the liver. Bile drains from the liver through the right and left hepatic ducts. These ducts unite to form the common hepatic duct, which meets the cystic duct from the gallbladder. Distal to this junction, the continuation of this duct is known as the *common bile duct*. Bile passes through this duct to empty into the second part of the duodenum at the hepatopancreatic ampulla (ampulla of Vater). The pancreas, which functions as an endocrine and exocrine gland, lies transversely across the abdomen near the level of the second lumbar vertebra. The divisions of this retroperitoneal organ, from right to left, are the head, neck, body, and tail. The head is the most inferior portion and is encircled by the duodenum. The tail is located near the hilum of the spleen. The pancreatic duct traverses the length of the organ and enters the second part of the duodenum at or near the common bile duct.

The urinary system includes the two kidneys and ureters, the bladder, and the urethra. The kidneys are retroperitoneal and lie between the 12th thoracic and 3rd lumbar vertebrae. The center or hilar region is normally near the interspace between L1 and L2. Suprarenal (adrenal) glands are perched on the upper surface of each kidney. The right adrenal gland can be seen between the liver and the right diaphragmatic crus, and the left lies between the left crus and the pancreatic tail and spleen. Each kidney is surrounded by a dense membrane—the renal fasciae—and a layer of fat—the perirenal fat. Urine is formed in the parenchyma of the kidney and collects in the calyceal system. The calyces unite to form the renal pelvis, which is continuous with the ureter. The ureters are musculomembranous tubes that extend down the posterior abdomen, resting along the anterior surface of the psoas muscles. They are difficult to visualize unless filled with radiopaque contrast medium. In the pelvis, the ureters empty into the posteroinferior region of the bladder. The bladder is a collapsible muscular sac that serves as a reservoir for urine until it is expelled from the body. The bladder rests on or near the pelvic floor, posterior to the symphysis pubis and anterior to the rectum in males or the vagina in females. The urethra is the muscular passageway that originates from the apex (inferior surface) of the bladder and by which urine is expelled. The urethra is relatively short in females, passing through the floor of the pelvis. The urethra is much longer in males because it passes through the prostate gland and the membranous and cavernous portions of the penis.

The internal organs of the male reproductive system include the ductus deferens, seminal vesicles, and prostate. Internal and external reproductive structures are connected by the spermatic cord, which includes the ductus deferens, testicular vessels, nerves, and lymphatic structures. The spermatic cord is seen anterior and medial to the femoral artery and vein and anterior and lateral to the pubis. The ductus deferens enters the pelvis through the spermatic cord and then arches over the anterior and lateral aspect of the bladder. It passes down the posterior surface of the bladder and enters the superior prostate. The seminal vesicles are found on the posterior and inferior surface of the bladder near the insertion of the ureters. The prostate gland lies inferior to the bladder, between the symphysis pubis and the rectum. The prostatic portion of the urethra passes through the prostate.

The organs of the female reproductive system include the uterus, uterine (fallopian) tubes, ovaries, and vagina. The uterus, which normally lays superior and posterior to the urinary bladder, is divided into a fundus, body, isthmus, and cervix. The fundus is the upper, rounded portion of the organ, superior to the orifices of the uterine tubes. The central portion is the body, which narrows at its lower end to become the isthmus. The narrowed lower ¾ inch (2 cm) of the uterus is the cervix, which is continuous with the vagina. The uterus is suspended in the pelvis by folds of peritoneum called the *broad ligaments*. The ovaries lie lateral to the body of the uterus within the broad ligament. They are normally found near the lateral pelvic wall at or slightly below the level of the anterior superior iliac spine. Extending between the ovaries and uterus, in the superior rim of the broad ligament, are the uterine tubes. The medial ends open into the upper body of the uterus. The lateral end of each tube—the infundibulum—is expanded and terminates in multiple fingerlike projections called *fimbriae*. This end of the tube is superior to the ovary but not attached. The inferior-most part of the internal female reproductive system is the vagina. This muscular tube lies between the rectum and the bladder and opens to the external body surface posterior to the urethral meatus.

Three vascular systems can be described in the abdomen: arterial, venous, and portal. The descending—or abdominal—aorta is the main conduit for arterial blood and passes through the diaphragm at approximately the level of T11 and extends to the pelvis along the left anterolateral surface of the vertebral bodies. Just below the diaphragm, at approximately the level of the 12th thoracic vertebra, the celiac artery originates from the anterior aorta. This fairly short vessel divides into the splenic, common hepatic, and left gastric arteries. The splenic artery passes toward the left to enter the hilum of the spleen. The common hepatic artery extends to the right to the porta hepatis. The superior mesenteric artery arises from the left anterior aorta near the first lumbar vertebra. The origin of this vessel is posterior to the neck of the pancreas. It extends anteriorly for a short distance and then turns inferiorly as it sends its branches to supply the small intestine and the proximal half of the large intestine. Near the level of the second lumbar vertebra, the renal arteries arise from the lateral surface of the aorta. The renal arteries pass laterally to enter the hila of the kidneys. The right renal artery is longer than the left because it must cross the spine to reach the right kidney. The inferior mesenteric artery arises from the abdominal aorta at L3 and supplies the distal half of the large bowel. At the fourth lumbar vertebra, the abdominal aorta bifurcates to form the right and left common iliac arteries. Each common iliac artery divides into internal and external iliac arteries near the top of the sacrum. Internal iliac arteries divide rapidly and send branches to various structures within the pelvis. The external iliac arteries pass anteriorly and inferiorly through the pelvis. These vessels pass deep to the inguinal ligaments and become the femoral arteries.

The femoral veins carry venous blood from the lower limbs toward the pelvis. The femoral vein becomes the external iliac vein as it passes deep to the inguinal ligament. It is joined within the pelvis by the internal iliac vein to form the common iliac vein. The two common iliac veins unite at the level of the fifth lumbar vertebra to form the inferior vena cava. The inferior vena cava passes up the right anterolateral surface of the vertebral bodies, pierces the diaphragm, and empties into the inferior surface of the right atrium. The major tributaries of the inferior vena cava are the renal veins and the hepatic veins. The renal veins enter the lateral inferior vena cava near L2; the three hepatic veins enter near the top of the liver.

The vessels that drain the spleen and digestive system form the portal venous system. The major tributaries of this system are the superior and inferior mesenteric veins and the splenic vein. The inferior mesenteric vein empties into the splenic vein, which meets the superior mesenteric vein just posterior to the head of the pancreas. The junction of these two vessels forms the portal vein. These vessels extend superiorly to enter the porta hepatis of the liver.

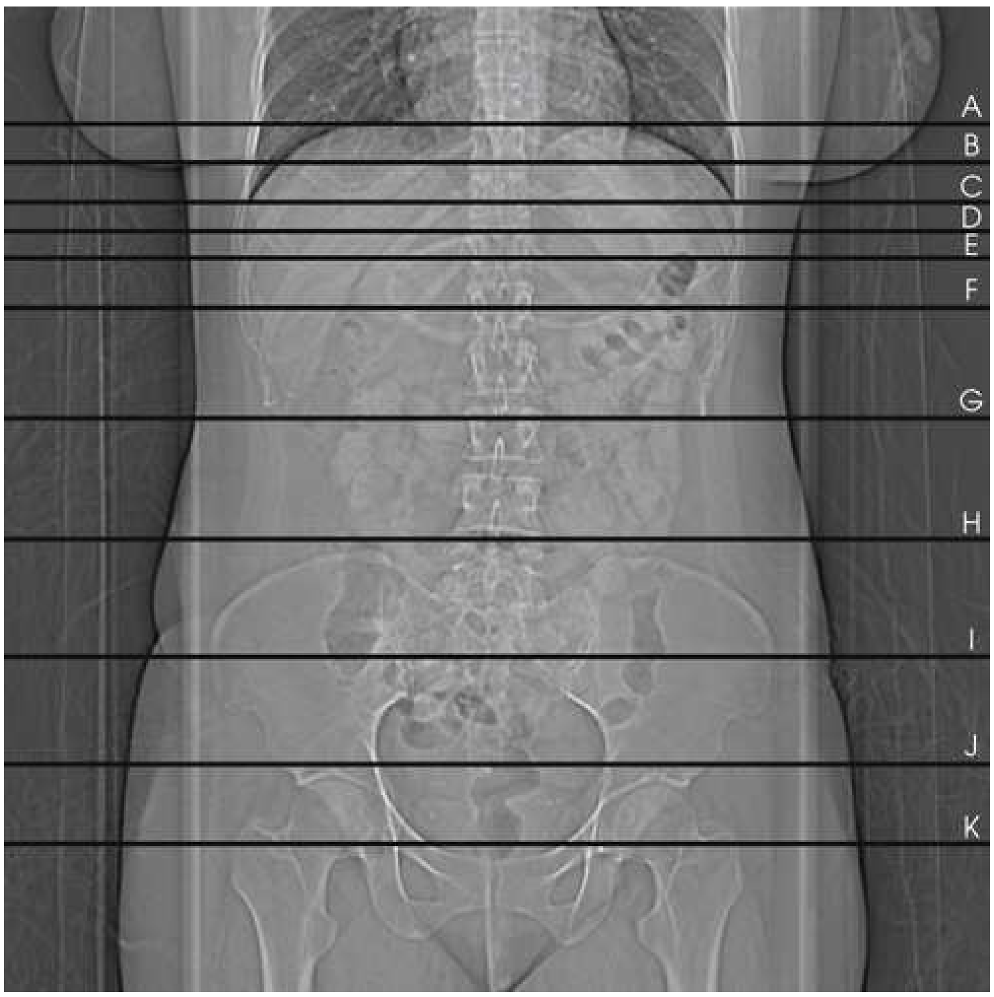


FIG. 24.48 CT localizer (scout) image of abdominopelvic region.

Fig. 24.48 is a CT localizer—or scout—image representing an AP projection of the abdominopelvic region. See Fig. 24.48 has 11 identifying lines showing the levels for each of the labeled images for this region.

Fig. 24.49 represents structures seen at the T9 level. The tip of the xiphoid process and lower ribs are seen. The image shows the *right hemidiaphragm* surrounding the superior portion of the *liver* and the *left hemidiaphragm* encircling the pericardial fat surrounding the apex of the heart and the *fundus* of the stomach. A small amount of oral contrast agent can be seen in the dependent portion of the stomach in this image. The *esophagus*, posterior to the liver, has migrated toward the patient's left as it nears its entrance into the stomach. The lower lobes of each lung are seen external to the diaphragm. The *aorta* is in its normal position, anterior and slightly left of the vertebral body; the azygos vein lies to the right of the aorta. The inferior vena cava appears embedded within the liver. Three *hepatic veins* drain into the inferior vena cava at this level. Serratus anterior muscles are seen external to the lateral aspects of the ribs; latissimus dorsi muscles extend superficially across the posterior abdomen.

Fig. 24.50 is a CT image at the level of the 10th thoracic vertebra. It shows the aorta and inferior vena cava and contrast-enhanced vessels within the liver. These represent branches of the hepatic and portal venous circulation. The right, left, and *caudate lobes* of the liver are visible. On the patient's left, the contrast-filled body of the stomach and the *spleen* can be identified. This is normally the level at which the esophagus enters the cardiac portion of the stomach. The *greater omentum* (a large fold of peritoneum) lies along the greater curvature of the stomach. Fig. 24.50 shows the greater omentum anterior and lateral to the stomach. The inferior lobes of the lungs are seen posterior to the liver and the spleen. The *crura of the diaphragm* are the lower tendinous insertions of this muscle. They can be seen extending around the anterior aorta and the posterior liver and spleen. This scan shows the latissimus dorsi and the lower reaches of the serratus anterior. The upper portions of the anterior abdominal muscles (rectus abdominis, external oblique) can also be seen.

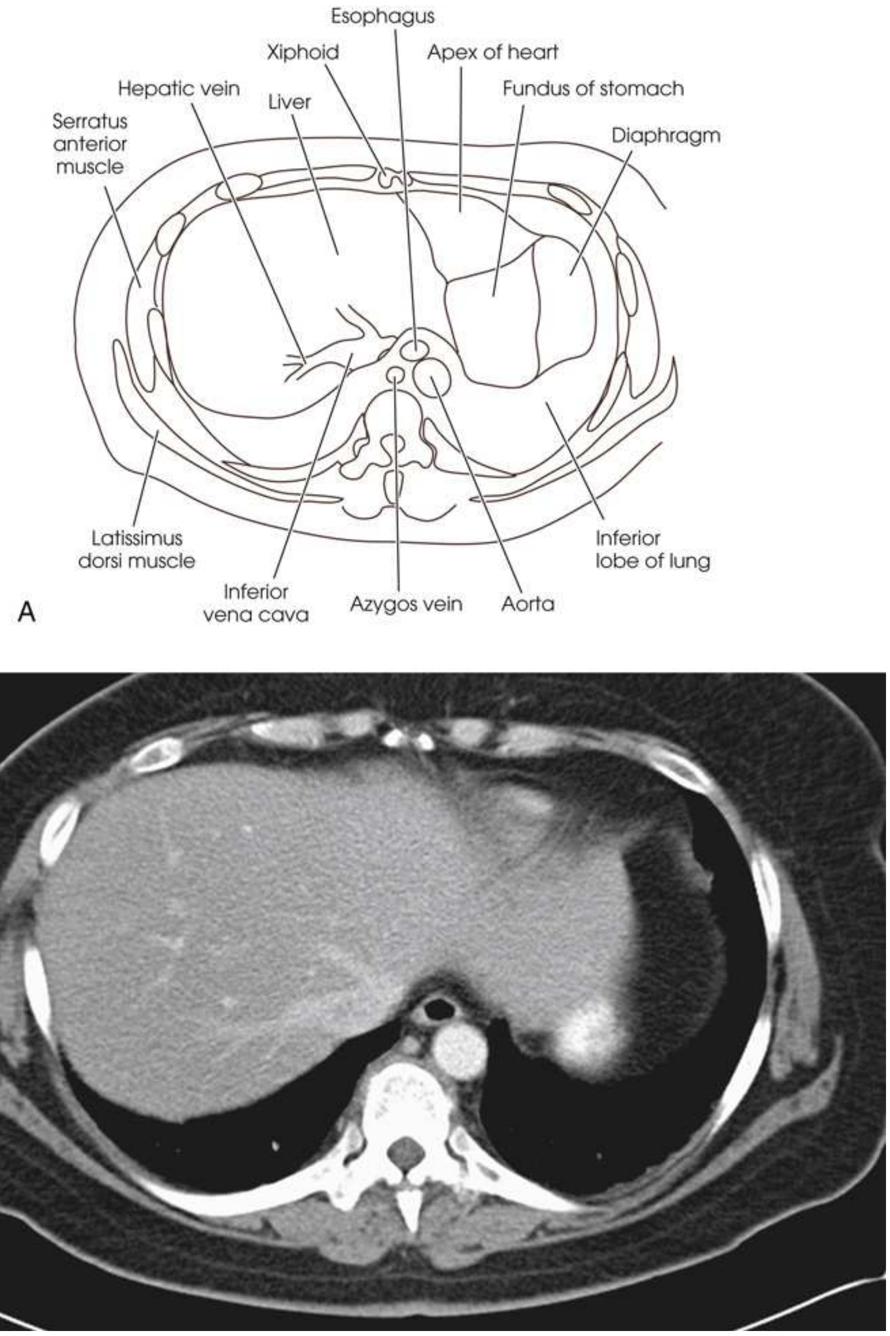


FIG. 24.49 (A) Line drawing of CT section. (B) CT image corresponding to level *A* in Fig. 24.48.

Diagram (A) shows a line drawing of the C T section. The parts labeled in the diagram are marked clockwise as follows: inferior vena cava, latissimus dorsi muscle, serratus anterior muscle, hepatic vein, liver, xiphoid, esophagus, apex of heart, fundus of stomach, diaphragm, inferior lobe of lung, aorta, azygos vein. (B) A C T image shows a grey region in the middle. It appears grainy.

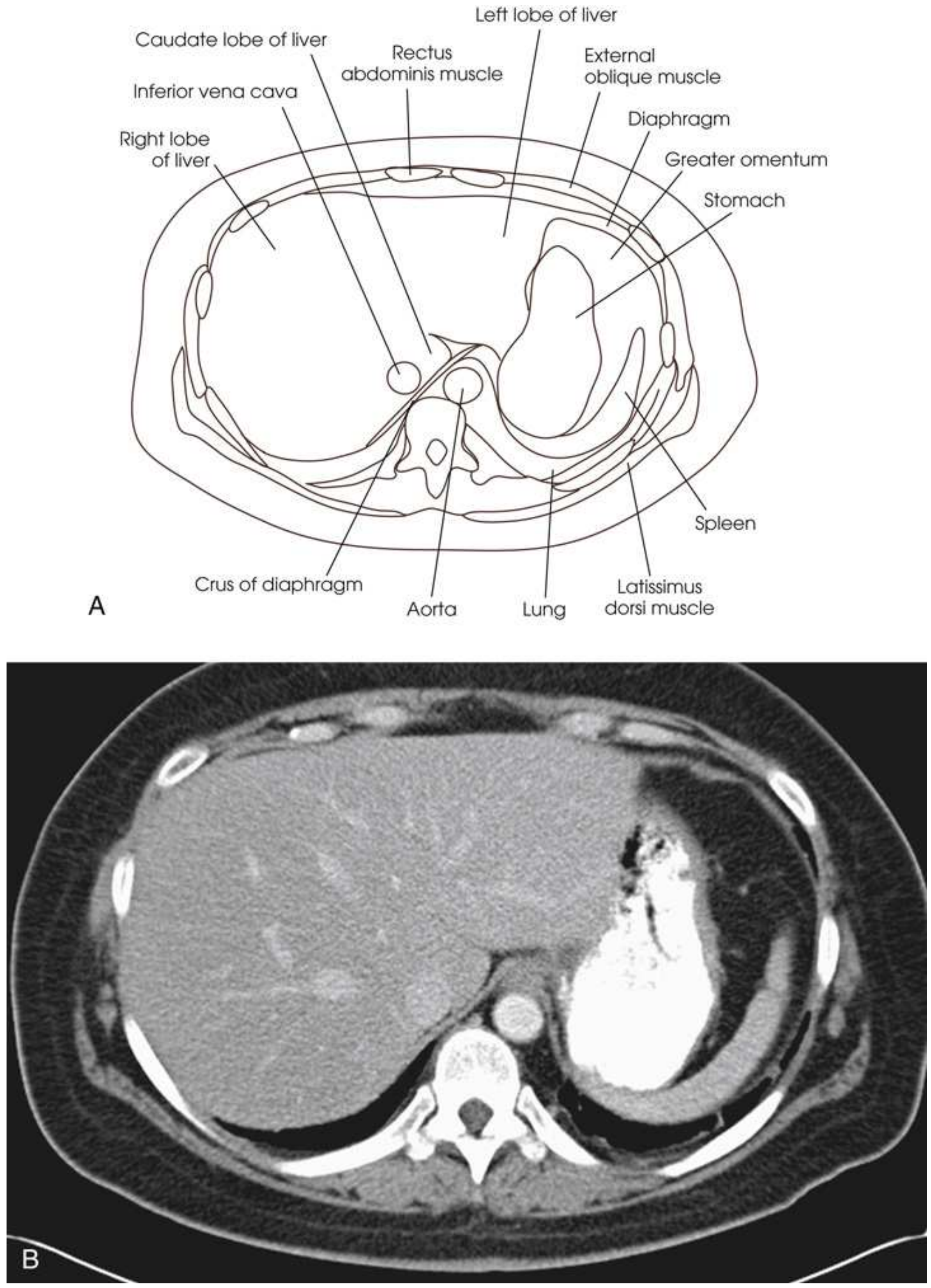


FIG. 24.50 (A) Line drawing of CT section. (B) CT image corresponding to level *B* in Fig. 24.48.

Diagram (A) shows a line drawing of the C T section. The parts labeled in the diagram are marked clockwise as follows: crus of diaphragm, right lobe of liver, inferior vena cava, caudate lobe of liver, rectus abdominis muscle, left lobe of liver, external oblique muscle, diaphragm, greater omentum, stomach, spleen, latissimus dorsi muscle, lung, aorta. (B) A C T image shows a grey region in the left and in the middle. A radiopaque region is on the right.

A CT image at the level of T11 (Fig. 24.51) shows the relationships among the liver, stomach, and spleen. The cardiac portion of the stomach is located at approximately the T10–11 level in the anterior aspect of the left upper quadrant, and the *pyloric portion* normally lies anterior to L2. This scan passes through the center or body of the stomach. An air-fluid level exists between the gas in the anterior stomach and the contrast medium in the posterior stomach. The spleen, located between the levels of T12 and L1, is in the posterolateral aspect of the left upper quadrant posterior to the fundus and body of the stomach. Contrast medium in the patient's colon is seen at the *splenic flexure*, seen here between the body of the stomach and the spleen. The liver is generally found between T11 and L3 and occupies the entire right upper quadrant. The right lobe of the liver has two small subdivisions, the caudate and *quadrate lobes*, which are bounded by the *gallbladder*, *ligamentum teres*, and inferior vena cava. The left lobe of the liver stretches across the midline and into the left upper quadrant. The *porta hepatis*, or hilum of the liver, is visible between the right and left lobes at this level. The inferior vena cava is found between the right and caudate lobes of the liver. In this image, it is nearly isodense with liver tissue. Large branches of the portal vein are seen at the porta hepatis.

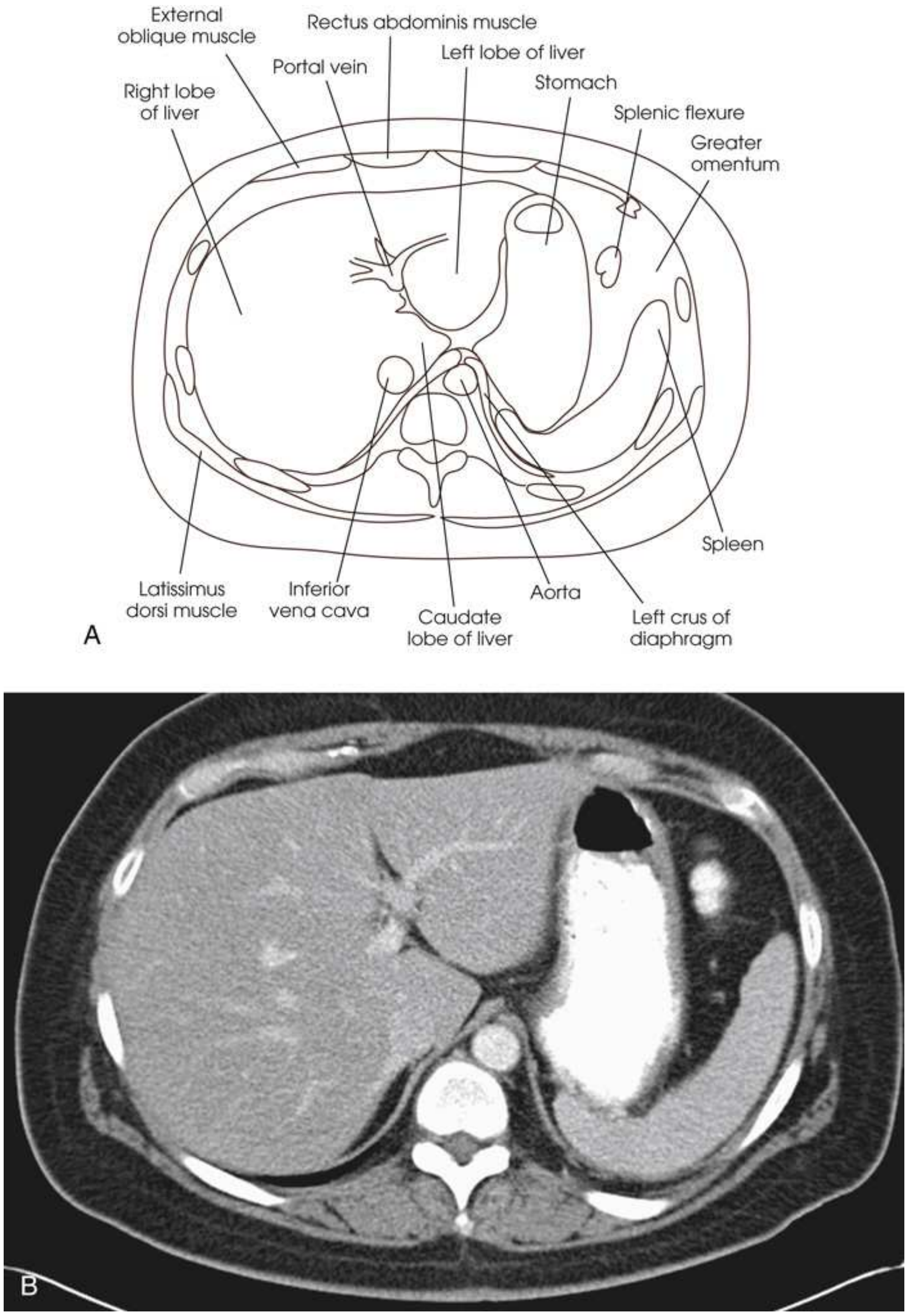
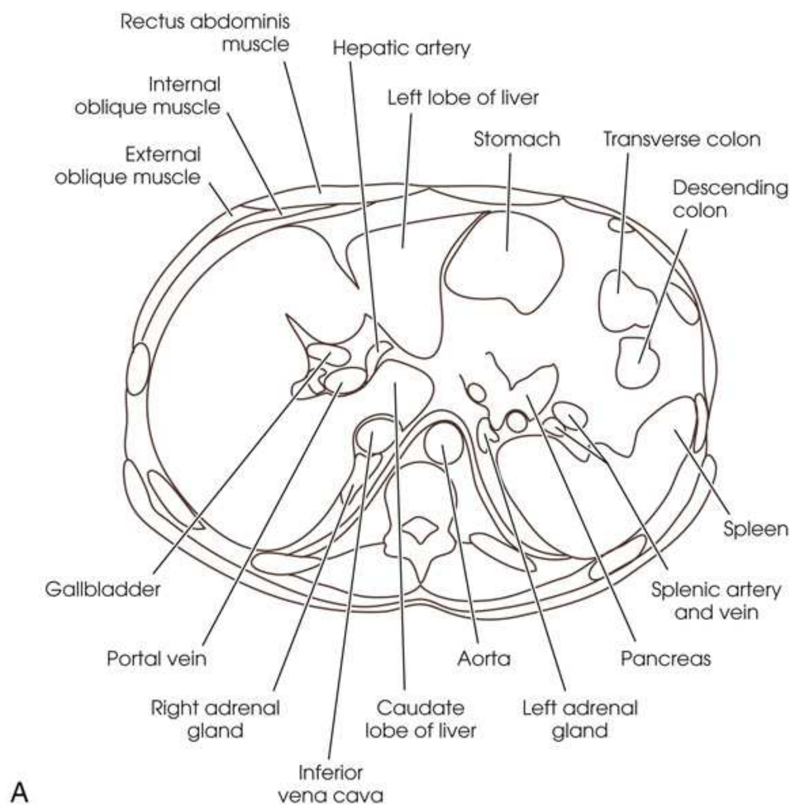


FIG. 24.51 (A) Line drawing of CT section. (B) CT image corresponding to level *C* in Fig. 24.48.

Diagram (A) shows a line drawing of the C T section. The parts labeled in the diagram are marked clockwise as follows: inferior vena cava, aorta latissimus dorsi muscle, right lobe of liver, external oblique muscle, portal vein, rectus abdominis muscle, left lobe of liver, stomach, splenic flexure, greater omentum, spleen, left crus of diaphragm, aorta, caudate lobe of liver. (B) A C T image shows a grey region in the left and in the middle. A radiopaque region is on the right.



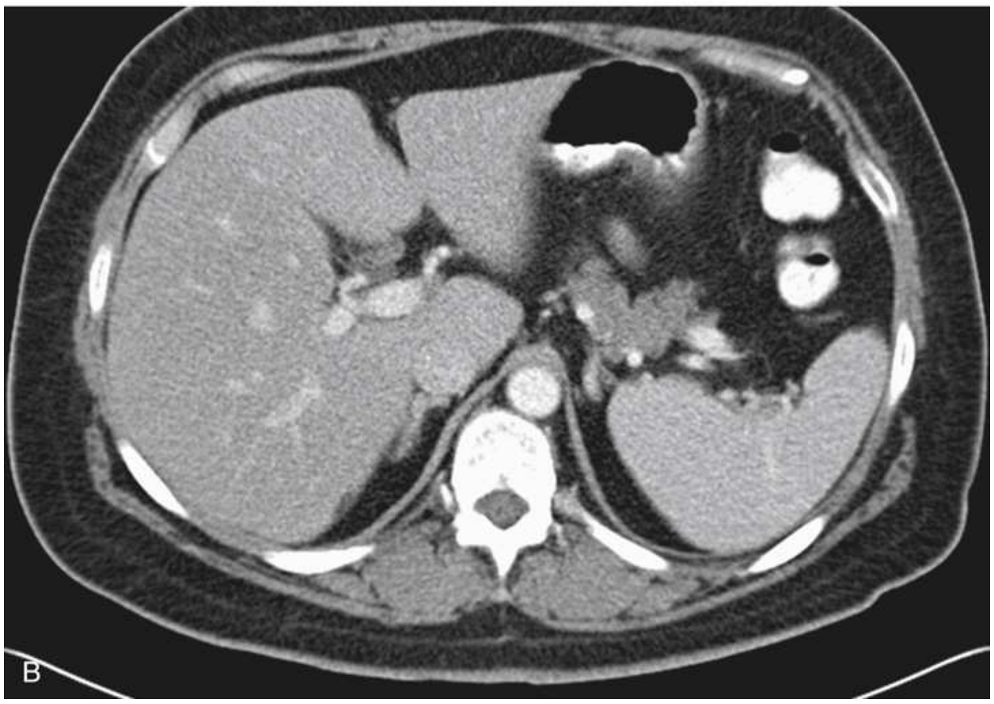


FIG. 24.52 (A) Line drawing of CT section. (B) CT image corresponding to level *D* in Fig. 24.48.

Diagram (A) shows a line drawing of the C T section. The parts labeled in the diagram are marked clockwise as follows: inferior vena cava, right adrenal gland, portal vein, gallbladder, external oblique muscle, internal oblique muscle, rectus abdominis muscle, hepatic artery, left lobe of liver, stomach, transverse colon, descending colon, spleen, splenic artery and vein, pancreas, left adrenal gland, aorta, caudate lobe of liver. (B) A C T image shows a grey region in the left and in the middle. There are a few radiopaque region is on the right.

Fig. 24.52 lies at the inferior edge of T11. It shows the right, left, and caudate lobes of the liver and the porta hepatis. Anteriorly, the falciform ligament lies near the fissure between the right and left lobes (not seen on this image). The pyloric antrum of the stomach lies near the left lobe of the liver. This scan is inferior to the splenic flexure, so the *transverse and descending portions of the colon* can be differentiated. The spleen lies along the left posterior abdominal wall. This scan lies near the hilum, and vascular structures are seen in this region. The tail of the pancreas normally lies near the spleen and can be seen here between the stomach and spleen. The *suprarenal glands* are normally located superior to the kidney. The right suprarenal gland is found at this level between the liver and the right diaphragmatic crus. The left suprarenal gland is medial to the pancreas and spleen. The abdominal aorta is positioned anterior and to the left of the vertebral column; the inferior vena cava is between the right and caudate lobes of the liver. The portal vein is seen within the porta hepatis, along with branches of the hepatic artery. The splenic artery is normally tortuous and not seen in its entirety. At this level, the bright circles along the posterior pancreas most likely represent portions of the contrast-filled *splenic artery.*

The CT scan in Fig. 24.53 passes through the upper portion of T12. The difference in density between the liver tissue and the bile-filled *gallbladder* makes these organs easy to differentiate. The antrum of the stomach, pyloric canal, and bulb (first portion) of the *duodenum* are seen in the anterior abdomen. The neck of the pancreas is posterior to the pyloric canal of the stomach in this image. The transverse and descending colon lie in the anterior left abdomen. The spleen is posterior to the descending colon. Loops of *jejunum*—the second part of the small bowel—are posterior to the antrum of the stomach. The left adrenal gland is lateral to the aorta and left diaphragmatic crus. The right adrenal gland is posterior to the IVC. The three branches of the *celiac trunk* (hepatic, splenic, left gastric arteries) supply the liver, spleen, pancreas, and stomach with oxygen-rich blood. In this image, the celiac trunk is seen as it divides into the *common hepatic artery* and the splenic artery. The left gastric artery is not seen. The splenic artery runs a tortuous course and normally cannot be visualized in its entirety in axial sections. Here, branches of the splenic artery and vein lie in close proximity and are difficult to differentiate. The inferior vena cava can be seen in its normal position anterior and to the right of the vertebral column. The main portion of the portal vein is just posterior to the duodenal bulb.

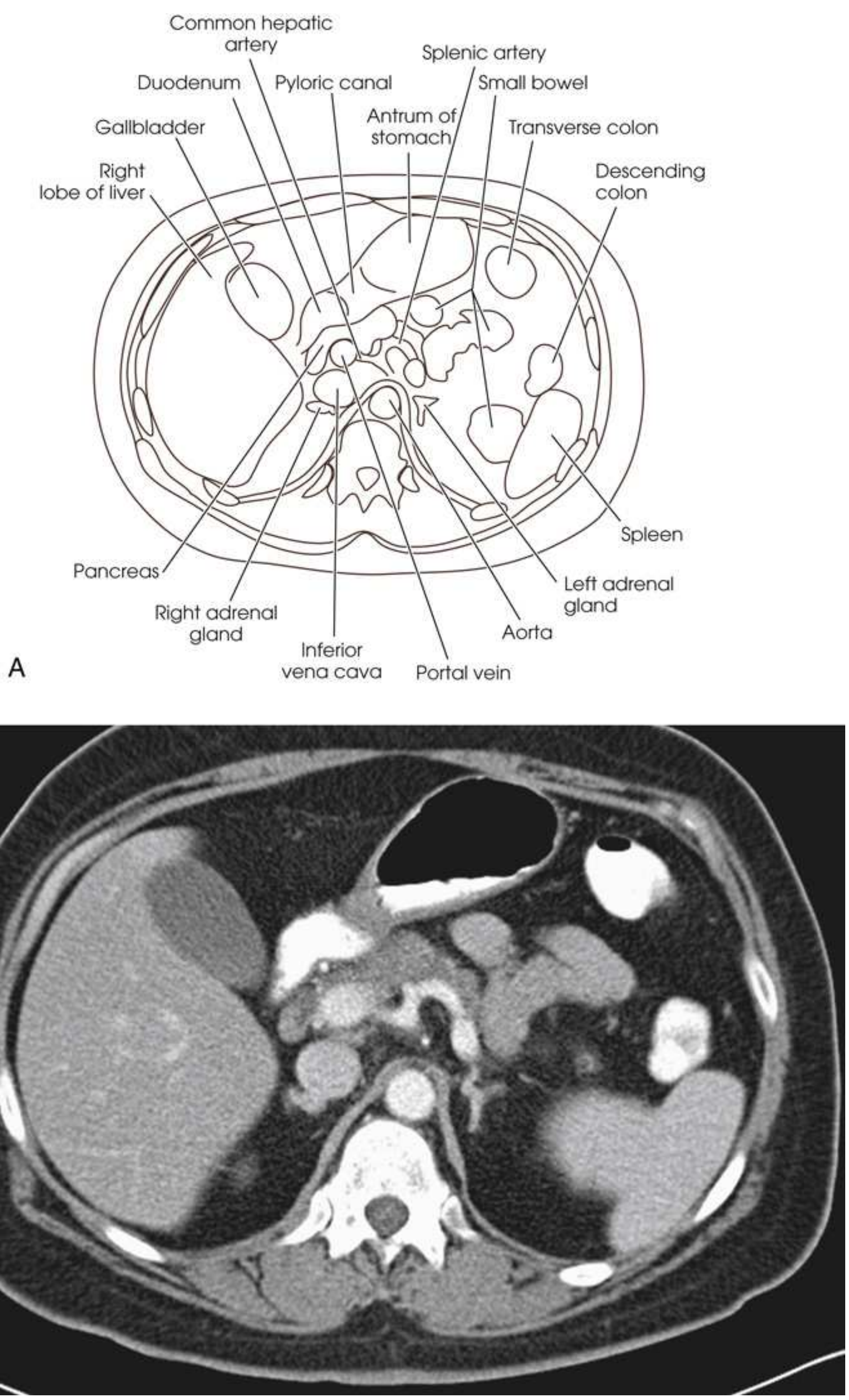


FIG. 24.53 (A) Line drawing of CT section. (B) CT image corresponding to level *E* in Fig. 24.48.

Diagram (A) shows a line drawing of the C T section. The parts labeled in the diagram are marked clockwise as follows: right adrenal gland, pancreas, right lobe of liver, gallbladder, duodenum, common hepatic artery, pyloric canal, antrum of stomach, splenic artery, small bowel, transverse colon, descending colon, spleen, left adrenal gland, aorta, portal vein. (B) A C T image shows a grey region in the left, a radiopaque region in the middle and a radiolucent region on top.

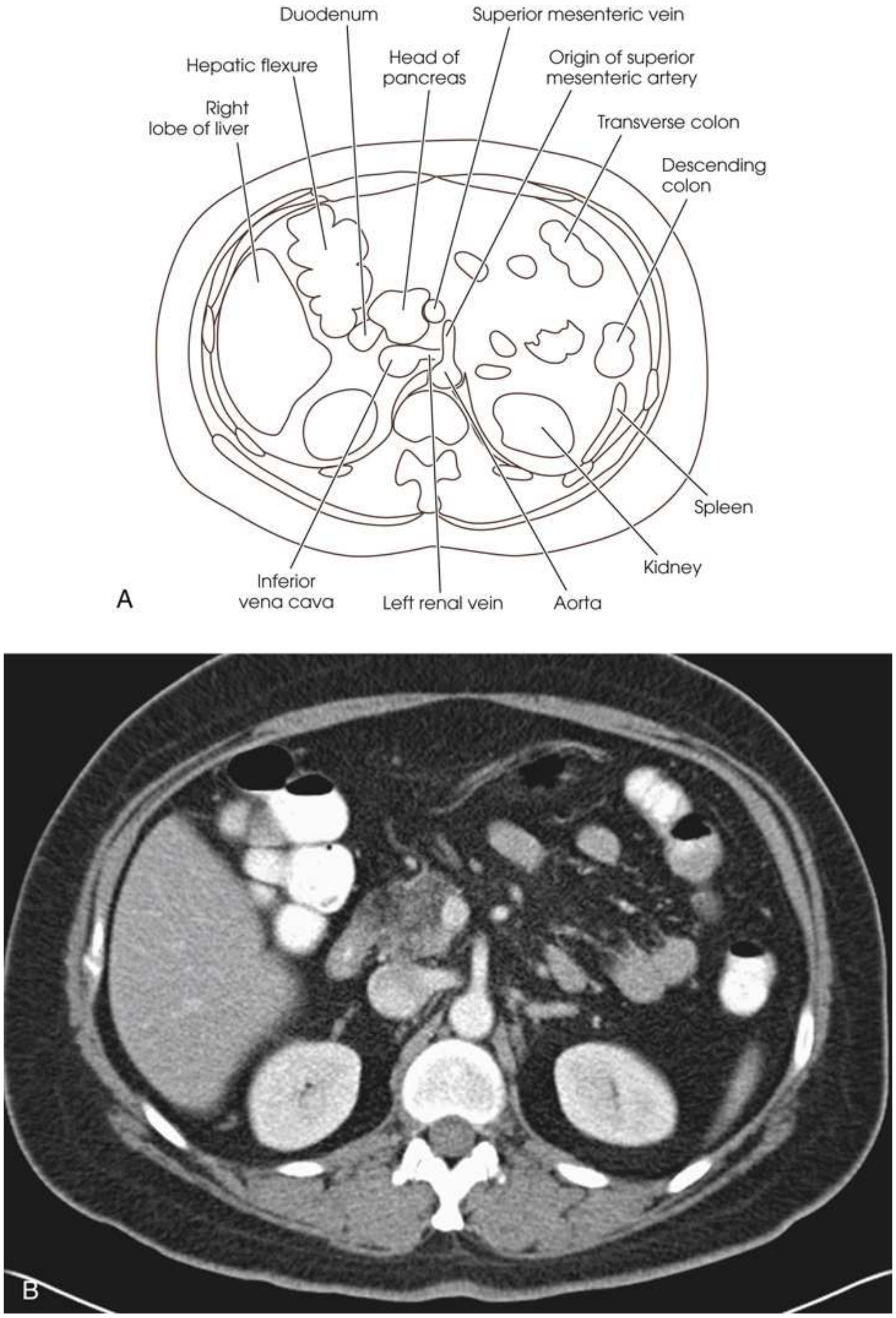


FIG. 24.54 (A) Line drawing of CT section. (B) CT image corresponding to level *F* in Fig. 24.48.

Diagram (A) shows a line drawing of the C T section. The parts labeled in the diagram are marked clockwise as follows: inferior vena cava, right lobe of liver, hepatic flexure, duodenum, head of pancreas, superior mesenteric vein, origin of superior mesenteric artery, transverse colon, descending colon. spleen, kidney, aorta, left renal vein. (B) A C T image shows a grey region in the left, a few radiopaque region scattered around the sides and a radiolucent region on top.

The muscles of the abdomen are located between the lower rib cage and the iliac crests. This group of muscles includes the *external oblique*, *internal oblique*, and *transverse abdominal muscles*. The two *rectus abdominis muscles* are located on the anterior aspect of the abdomen on either side of the midline and extend from the *pubic symphysis* to the xiphoid process.

The CT image in Fig. 24.54 is through the level of the first lumbar vertebra. The lower right lobe of the liver lies along the right side of the abdomen. The hepatic (right colic) flexure lies just medial to the liver. The duodenum forms a C-shaped loop around the head of the pancreas. In this scan, the head of the pancreas is seen between the duodenum (second portion) and the superior mesenteric vein. On the left side of the abdomen, loops of small bowel and the transverse and descending colon are seen. Folds of *mesentery* can be seen connecting some of the small bowel loops. The most inferior edge of the spleen lies along the left posterior abdomen. The upper poles of the kidneys appear on either side of the vertebral body. At this level, the *superior mesenteric artery* is seen as it originates from the anterior aorta. The *left renal vein* can also be seen as it empties into the lateral aspect of the inferior vena cava.

Fig. 24.55 is a CT scan through the third lumbar vertebra. The ascending colon is found on the right side of the abdomen. In this image, most of the transverse colon can be seen across the anterior abdomen. The descending colon lies along the posterior left abdomen. Loops of small bowel are found in the central portion of the abdomen. Ileal loops are filled with contrast medium that has refluxed through the ileocecal valve from the colon. This level is just below the hila of the kidneys, and some of the central collecting system can be observed. The inferior vena cava and contrast-filled aorta lie anterior to the vertebral body. The rectus abdominis muscles lie on either side of the midline in the anterior abdomen. The three layers of the lateral abdominal muscles (external oblique, internal oblique, and transverse abdominis) are separated by fat and can plainly be seen in this scan. The *psoas muscles* originate from the body of T12 and the transverse processes of the lumbar vertebrae and descend the abdomen lateral to the vertebral bodies. The *quadratus lumborum muscles* are located posterolateral to the psoas muscles through the abdomen. These muscles can be seen on either side of the vertebra. The *spinal cord* normally terminates at the level of L1. Inferior to L1, the *spinal nerves*—known as *cauda equina*—are seen within the spinal canal.

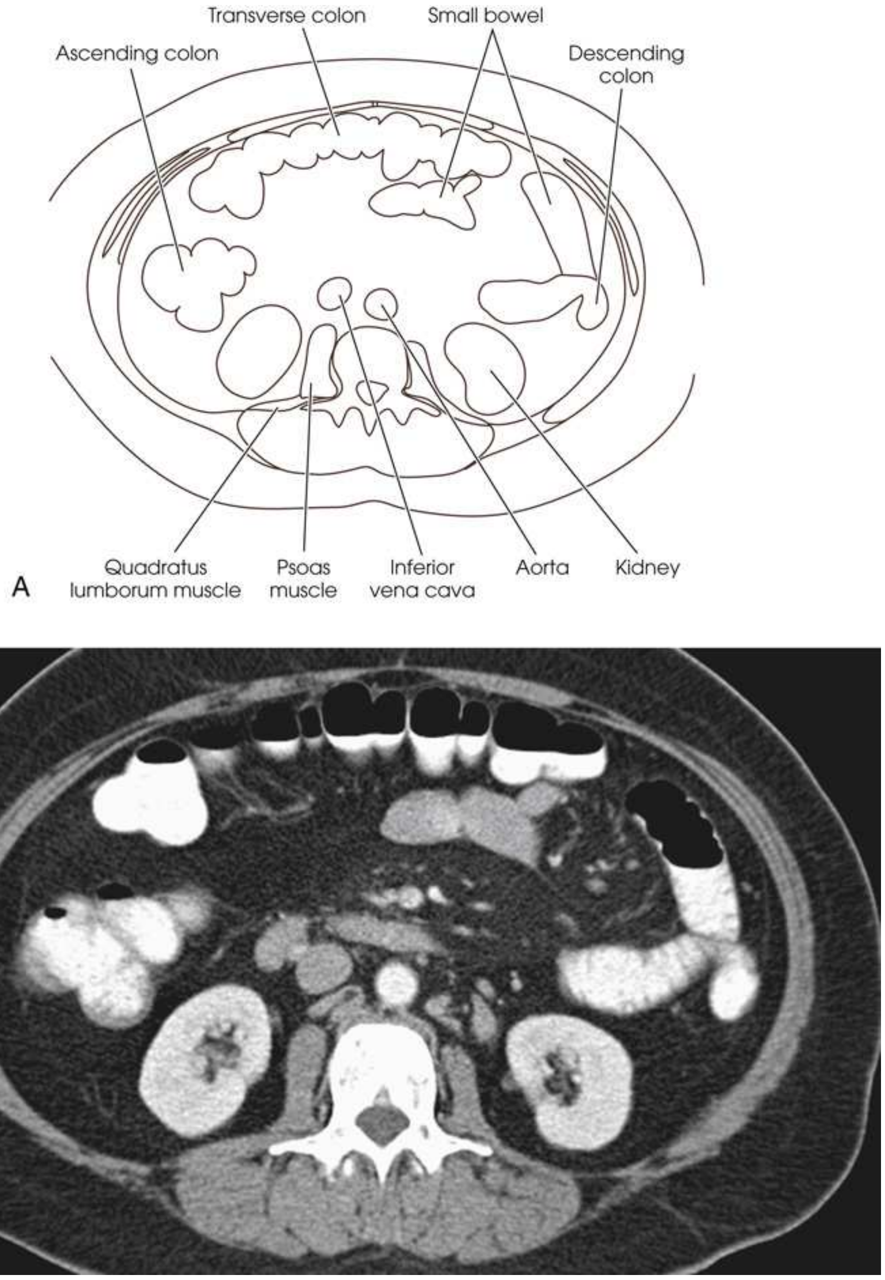


FIG. 24.55 (A) Line drawing of CT section. (B) CT image corresponding to level *G* in Fig. 24.48.

Diagram (A) shows a line drawing of the C T section. The parts labeled in the diagram are marked clockwise as follows: quadratus lumborum muscle, ascending colon, transverse colon, small bowel, descending colon, kidney, aorta, inferior vena cava, psoas muscle. (B) A C T image shows a few circular radiopaque region scattered around the sides and in the middle.

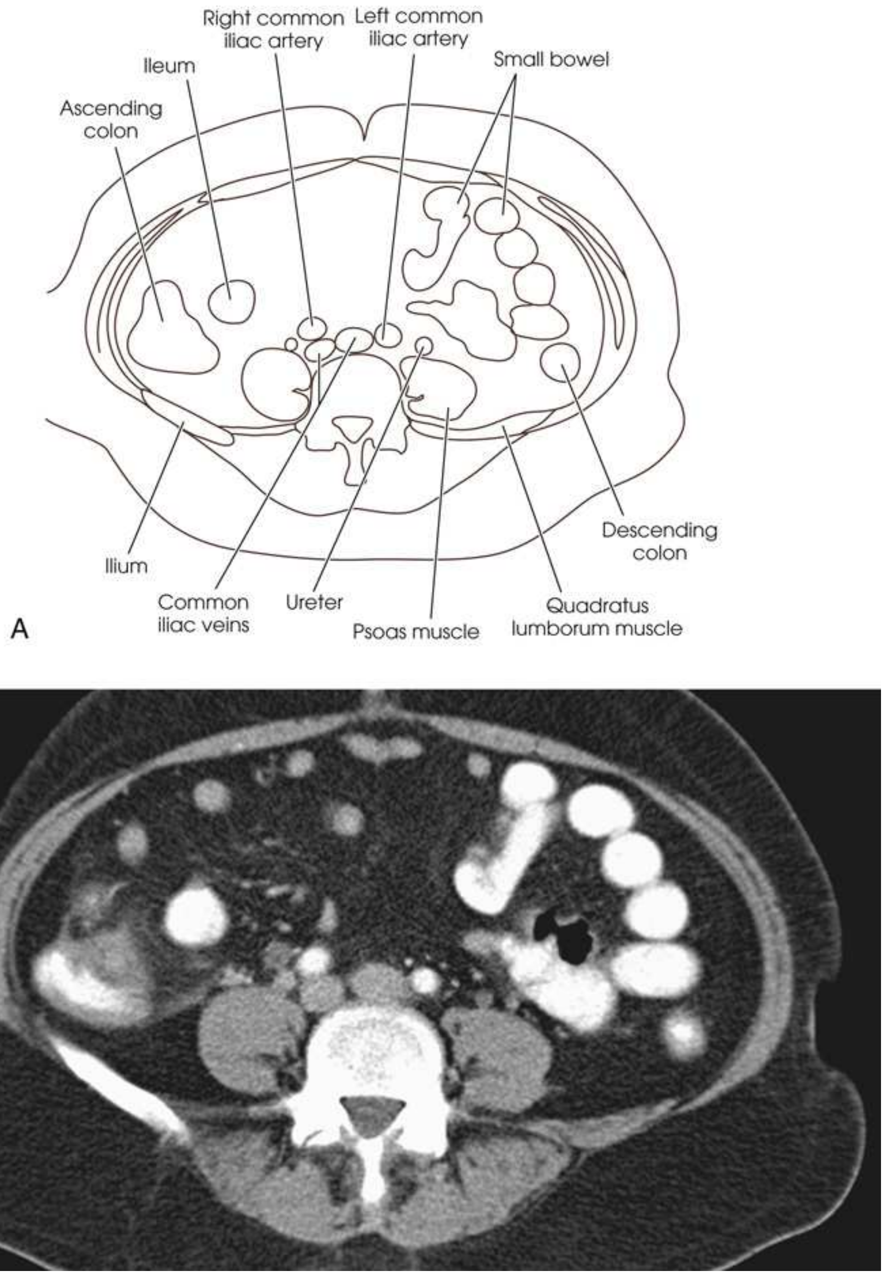
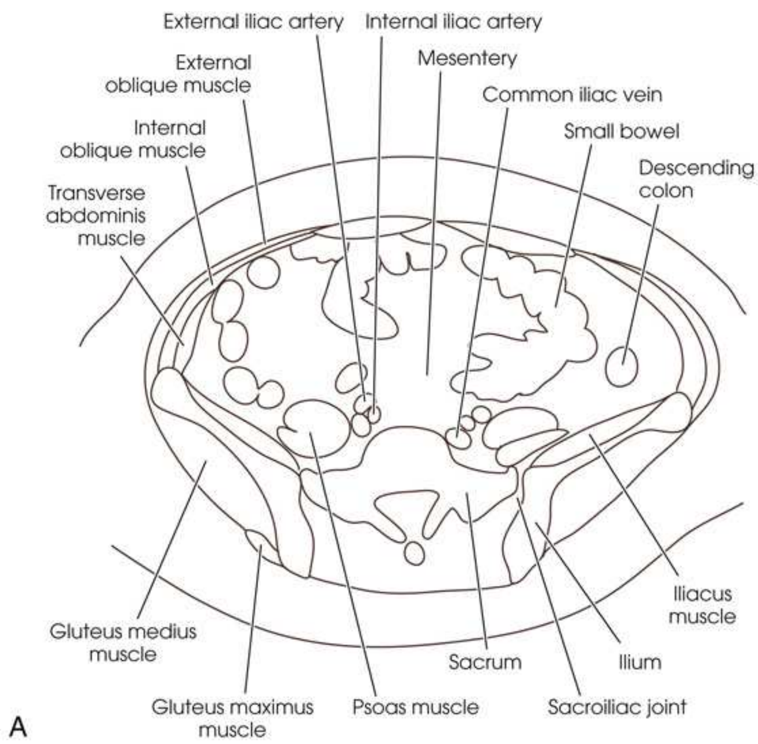


FIG. 24.56 (A) Line drawing of CT section. (B) CT image corresponding to level *H* in Fig. 24.48.

Diagram (A) shows a line drawing of the C T section. The parts labeled in the diagram are marked clockwise as follows: ureter, common iliac veins, ilium, ascending colon, ileum, right common iliac artery, left common iliac artery, small bowel, descending colon, quadratus lumborum muscle, psoas muscle. (B) A C T image shows a few circular radiopaque region on top of each other on the right and a few are on the left and in the middle.

The CT scan in Fig. 24.56 lies near the interspace between the fourth and fifth lumbar vertebrae. The superior edge of the right *iliac crest* is visible in this image. The inferior portion of the cecum and the descending colon lie in the posterior abdomen on the right and left sides. Loops of small bowel are seen more anteriorly in the abdomen. The ureters normally lie just anterior to the psoas muscles. Because of peristalsis, no contrast medium is seen in the ureters on this image. At this level, the aorta has bifurcated to form the right and left *common iliac vessels.* The common iliac veins are fairly close to each other, indicating this scan is just inferior to their junction (which forms the inferior vena cava).

The CT image seen in Fig. 24.57 is of a female patient and was obtained at the upper sacral level. It shows the *wings* of the *ilia*, the right *anterior superior iliac spine*, and the *sacroiliac joints.* The descending colon is seen at the left lateral aspect of the pelvis, and multiple loops of *small intestine* are found throughout this level in the images. Three muscles lie posterior to the wings of the ilia: the gluteus minimus, gluteus medius, and gluteus maximus. The gluteus medius normally extends the farthest superiorly and is the first muscle visible as scans progress down through the pelvis. At the posterolateral aspect of the right ilium, two of the three *gluteal muscles* are visible—the gluteus medius and a small amount of the gluteus maximus—whereas on the left, only the gluteus medius is visible. The *iliacus muscle* is seen lining the internal aspect of the iliac wings near the psoas muscles. The two rectus abdominis muscles are found in the anterior abdomen on both sides of the midline. The external oblique, internal oblique, and transverse abdominis are seen extending anteriorly from the ilium on each side. The abdominal aorta bifurcates at L4 into the *common iliac arteries.* Each common iliac artery divides at the level of the anterior superior iliac spine into *internal* and *external iliac arteries.* The *internal iliac arteries* tend to be located in the posterior pelvis and branch to feed the pelvic structures. The *external iliac vessels* are found progressively anterior in succeeding inferior sections to become the femoral vessels at the superior aspect of the thigh. The internal and external iliac veins unite inferior to the anterior superior iliac spine to form the common iliac veins, and the inferior vena cava is formed anterior to L5 by the junction of the common iliac veins. This scan shows the internal and external iliac arteries. At this level, the internal and external iliac veins have joined to form the common iliac veins. The common iliac veins are positioned at the anterior aspects of the sacrum with the internal and external iliac arteries anterior and medial to the veins in these images.



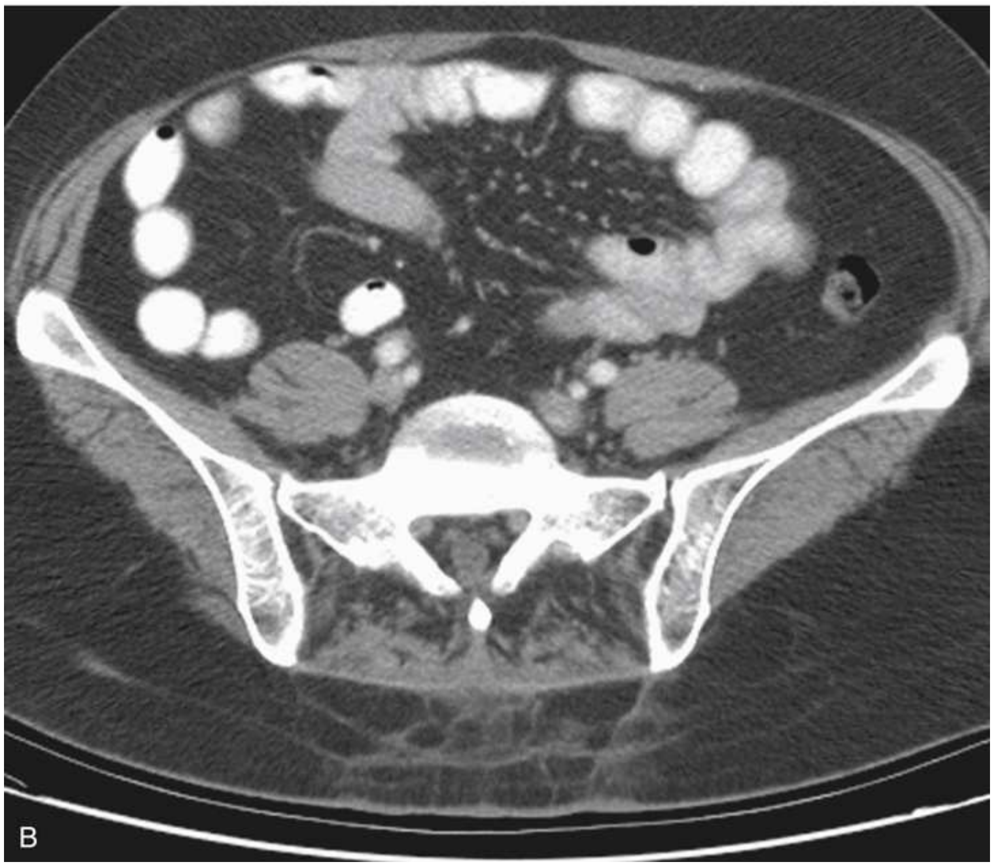


FIG. 24.57 (A) Line drawing of CT section. (B) CT image corresponding to level *I* in Fig. 24.48.

Diagram (A) shows a line drawing of the C T section. The parts labeled in the diagram are marked clockwise as follows: gluteus maximus muscle, gluteus medius muscle, transverse abdominis muscle, internal oblique muscle, external oblique muscle, external iliac artery, internal iliac artery, mesentery, common iliac vein, small bowel, descending colon, iliacus muscle, ilium, sacroiliac joint, sacrum, psoas muscle. (B) A C T image shows a horn like structure on the sides. It appears radiopaque. A few circular radiopaque regions are at the top.

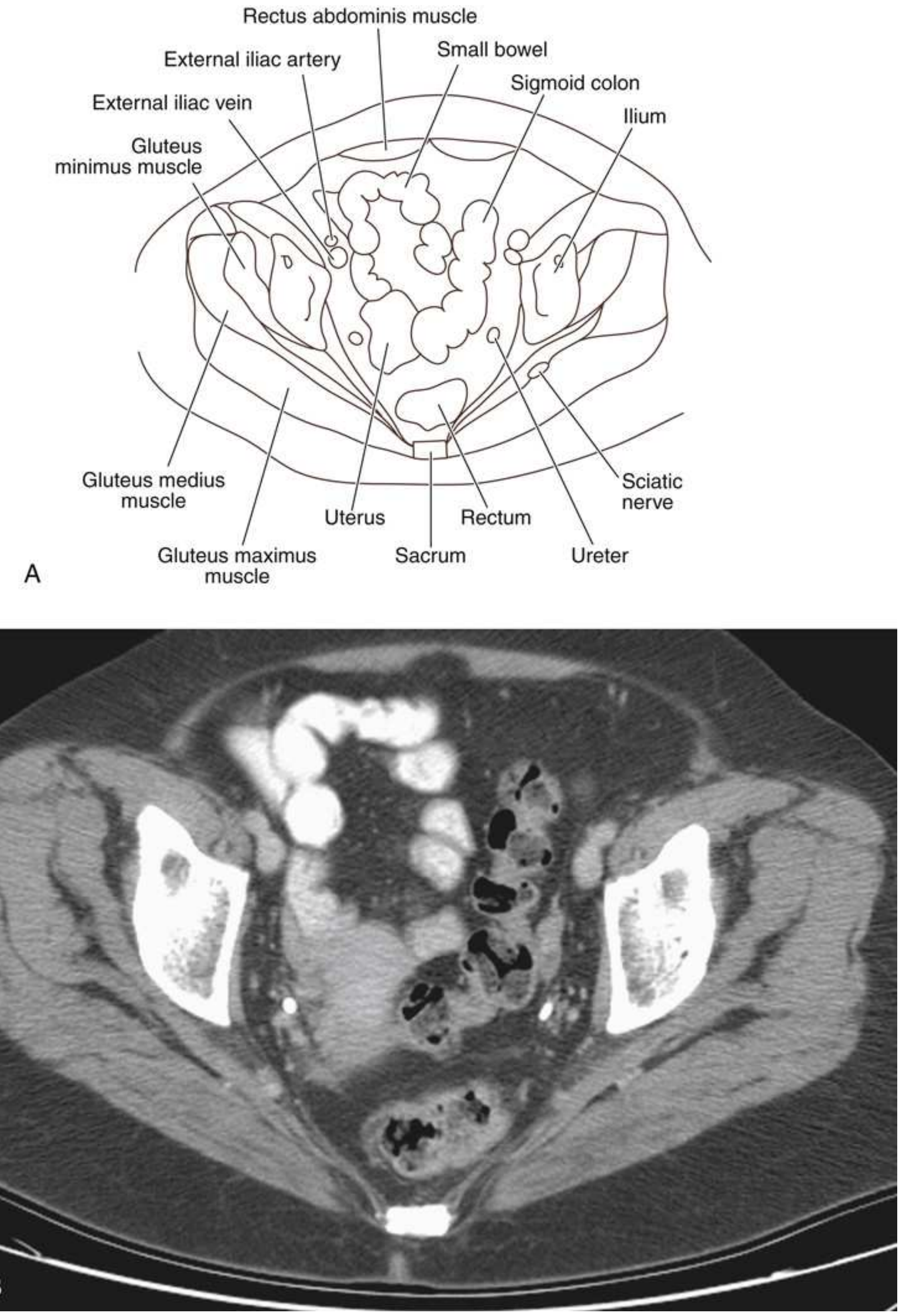


FIG. 24.58 (A) Line drawing of CT section. (B) CT image of female pelvis corresponding to level *J* in Fig. 24.48.

Diagram (A) shows a line drawing of the C T section. The parts labeled in the diagram are marked clockwise as follows: uterus , gluteus maximus muscle, gluteus medius muscle, gluteus minimus muscle, external iliac vein, external iliac artery, rectus abdominis muscle, small bowel, sigmoid colon, ilium, sciatic nerve, ureter, rectum, sacrum. (B) A C T image shows a few circular radiopaque region on top of each other on the right and a few are on the left and in the middle.

Fig. 24.58 is a CT image obtained just superior to the level of the *acetabulum*. In this image, the inferior sacrum is visible, and the junction of the *ilium*, *ischium*, and *pubis* lies near the upper part of the acetabulum. Loops of ileum filled with contrast medium are seen in the anterior right pelvis. The *haustral folds* of the *sigmoid colon* are found in the center of the pelvis as this part of the large intestine curls toward the sacrum. A portion of the rectum is seen just anterior to the sacrum in this image. The fundus of the *uterus* lies medial to the right acetabulum and posterior to the ileal folds. The ureters are filled with contrast medium in this image and are easily identifiable in the posterior and lateral regions of the pelvic cavity. The external iliac arteries and veins run a diagonal course through the pelvis, lying near the sacrum in the upper part of the pelvis and passing anteriorly as they pass down through the pelvis toward the lower extremities. In this scan, the external iliac vessels are seen just medial to the anterior edges of the acetabula. Multiple muscular structures are found at this level. The rectus abdominis muscles lie on either side of the midline in the anterior abdomen. The gluteal muscles (maximus, medius, and minimus) lie along the external surface of the posterior pelvis. Other muscles of the lower limbs are found just anterior to the acetabula. The large sciatic nerve can be plainly seen on the left between the gluteus maximus and medius muscles.

The CT scan in Fig. 24.59 is of a female patient and is at a level just superior to the pubic symphysis. The pubic bones, *ischia*, *acetabula*, *femoral heads*, and *greater trochanters* are visualized. The relationship between the *rectum*, *cervix*, and wall of the *bladder* is shown from posterior to anterior in the pelvic region. The ureters entered the bladder just superior to this scan and so are no longer visible. The external iliac vessels are now referred to as the *femoral vessels*, with the name change occurring at the inguinal ligament, which is found between the pubic symphysis and the anterior superior iliac spine. The *iliopsoas muscles* (formed by the junction of the psoas and iliacus muscles) are found anterior to the femoral heads; the *obturator internus muscle*, with its characteristic right-angle bend, is found medial to the acetabulum.

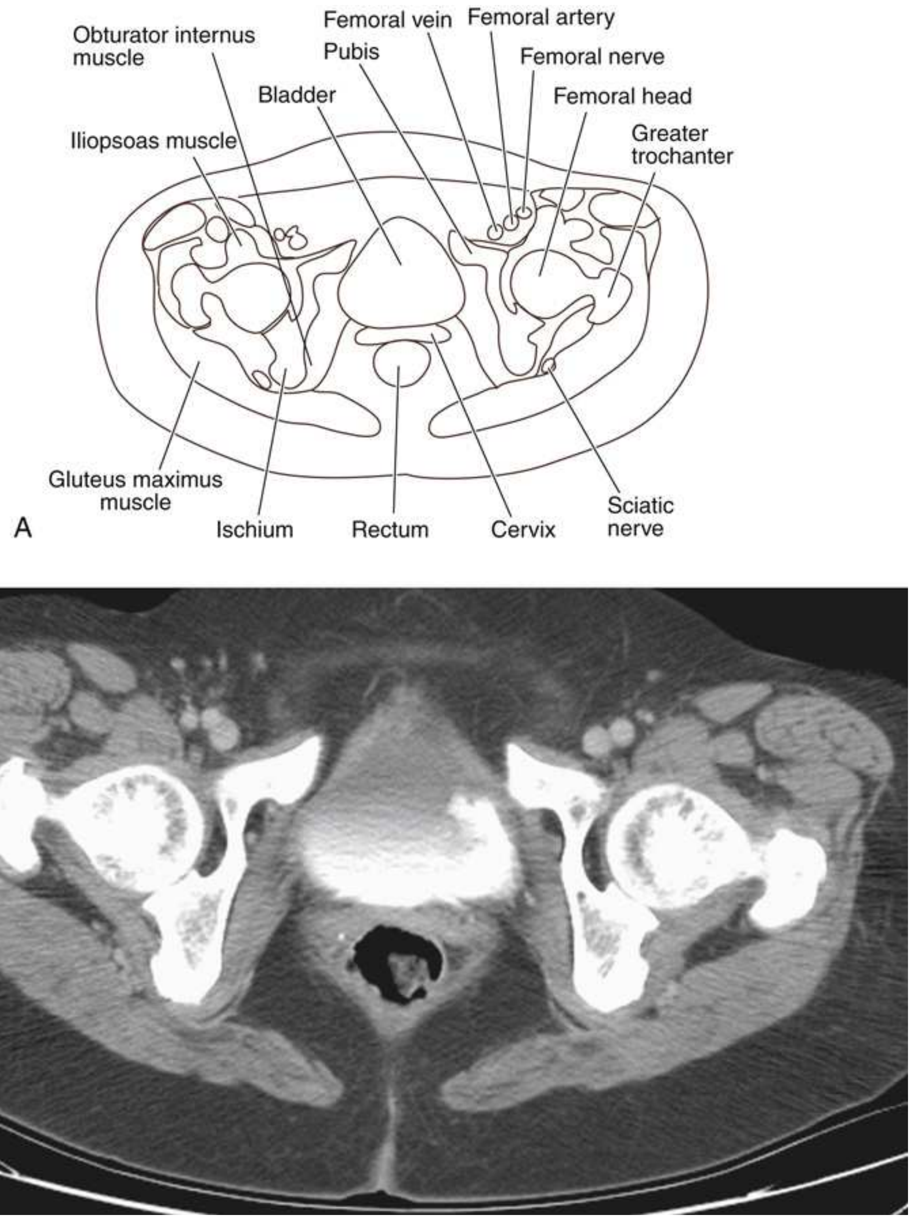


FIG. 24.59 (A) Line drawing of CT section. (B) CT image of female pelvis corresponding to level *K* in Fig. 24.48.

Diagram (A) shows a line drawing of the C T section. The parts labeled in the diagram are marked clockwise as follows: ischium, gluteus maximus muscle, iliopsoas muscle, obturator internus muscle, bladder, pubis, femoral vein, femoral artery, femoral nerve, femoral head, greater trochanter, sciatic nerve, cervix, rectum. (B) A C T image shows a few circular radiopaque region on top of each other on the right and two are on the left and in the middle.

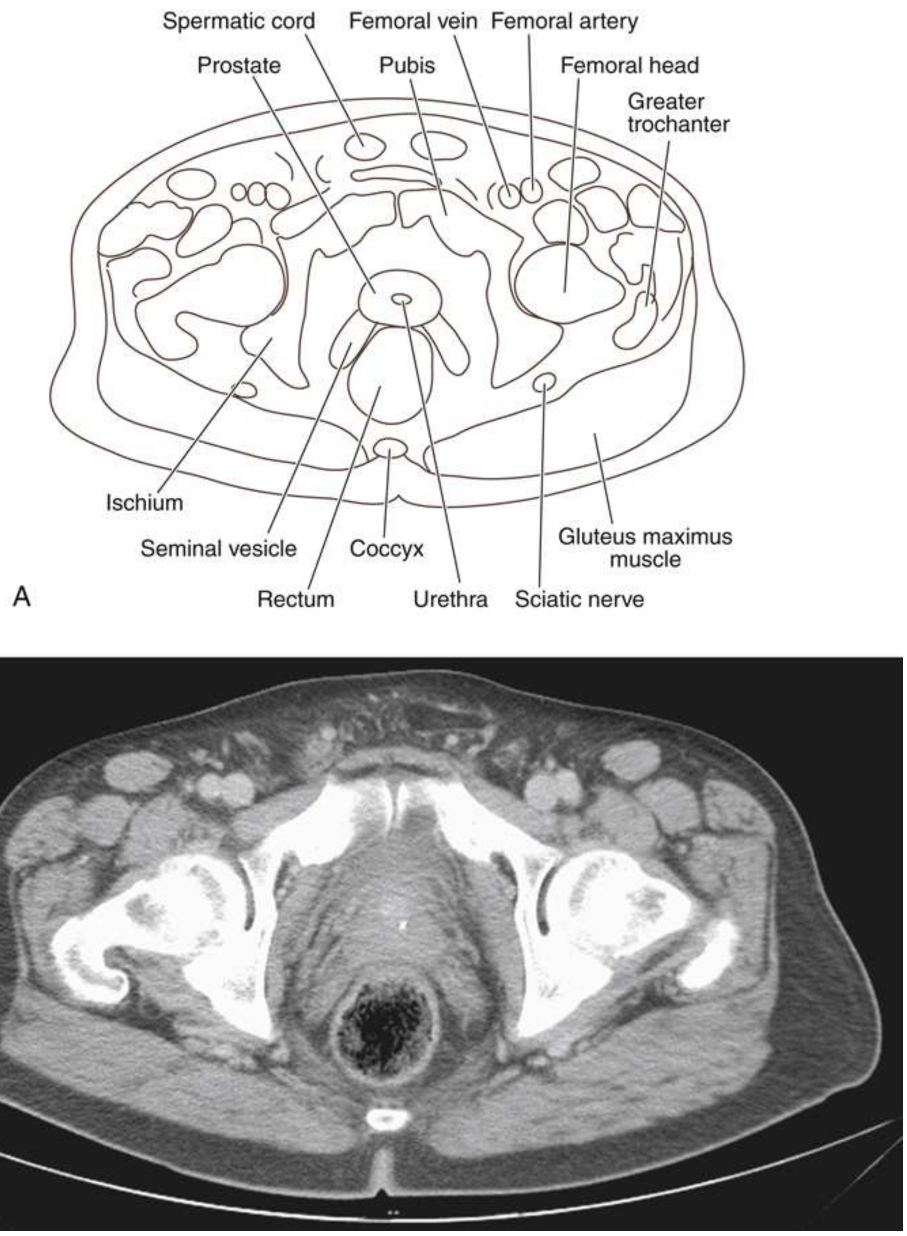


FIG. 24.60 (A) Line drawing of CT section. (B) CT image of male pelvis corresponding to level *K* in Fig. 24.48.

Diagram (A) shows a line drawing of the C T section. parts labeled in the diagram are marked clockwise as follows: rectum, seminal vesicle, ischium, prostate, spermatic cord, pubis, femoral vein, femoral artery, femoral head, greater trochanter, gluteus maximus muscle, sciatic nerve, urethra, coccyx. (B) A C T image shows a grey region on the sides and radiopaque region on either side of a dark region. (B) A C T image shows the female abdominopelvic region. The vertebra appears dark and the segments appear darker.

Fig. 24.60 is a CT scan through the lower pelvis of a male patient. This scan is at a slightly more inferior level than the previous scan. The symphysis pubis is seen here, along with the acetabula, *ischial spines*, and *femoral heads* and *greater trochanters*. The tip of the *coccyx* is visible in the posterior pelvis. In the male pelvis, the prostate gland lies inferior to the bladder and is traversed by the *urethra*. In this image, the prostate gland, seminal vesicles, and rectum occupy the pelvic cavity from anterior to posterior. The bright spot within the prostate gland is the contrast-filled urethra. The *spermatic cords* transmit the ductus deferens and vascular structures between the pelvis and the testicular structures and are found on either side of the midline just anterior to the symphysis pubis.

Fig. 24.61 is a sagittal T2-weighted MR image of the female pelvis near the midline. The fourth and fifth lumbar vertebrae, the sacrum, and the coccyx are visualized. The cauda equina is seen descending the spinal canal. The areas of signal void anterior to the sacrum represent the rectum. The musculature and cavity of the uterus are visible anterior to the rectum. In the anterior pelvis, the bladder is seen posterior and superior to the symphysis pubis. Multiple loops of small bowel fill the upper anterior region of the pelvis but are blurry owing to peristaltic motion. The rectus abdominis muscle extends superiorly from the pubis in the anterior abdominal wall. Fig. 24.62 is a sagittal T1-weighted MR image of a male patient. Note the prostate gland lying inferior to the bladder. A portion of the urethra can be seen passing through the prostate in this image.

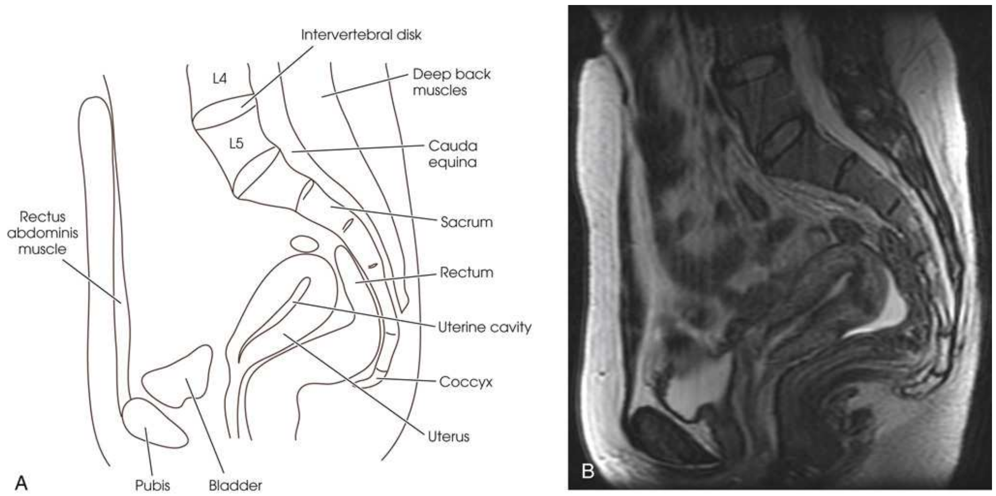


FIG. 24.61 (A) Line drawing of MRI section. (B) MRI of female abdominopelvic region at midsagittal plane.

Diagram (A) shows a line drawing of the C T section. The parts labeled in the diagram are marked clockwise as follows: rectus abdominis muscle, intervertebral disk, deep back muscles, cauda equine, sacrum, rectum, uterine cavity, coccyx, uterus, bladder, pubis. (B) A C T image shows the female abdominopelvic region. The vertebra appears dark and the segments appear darker.

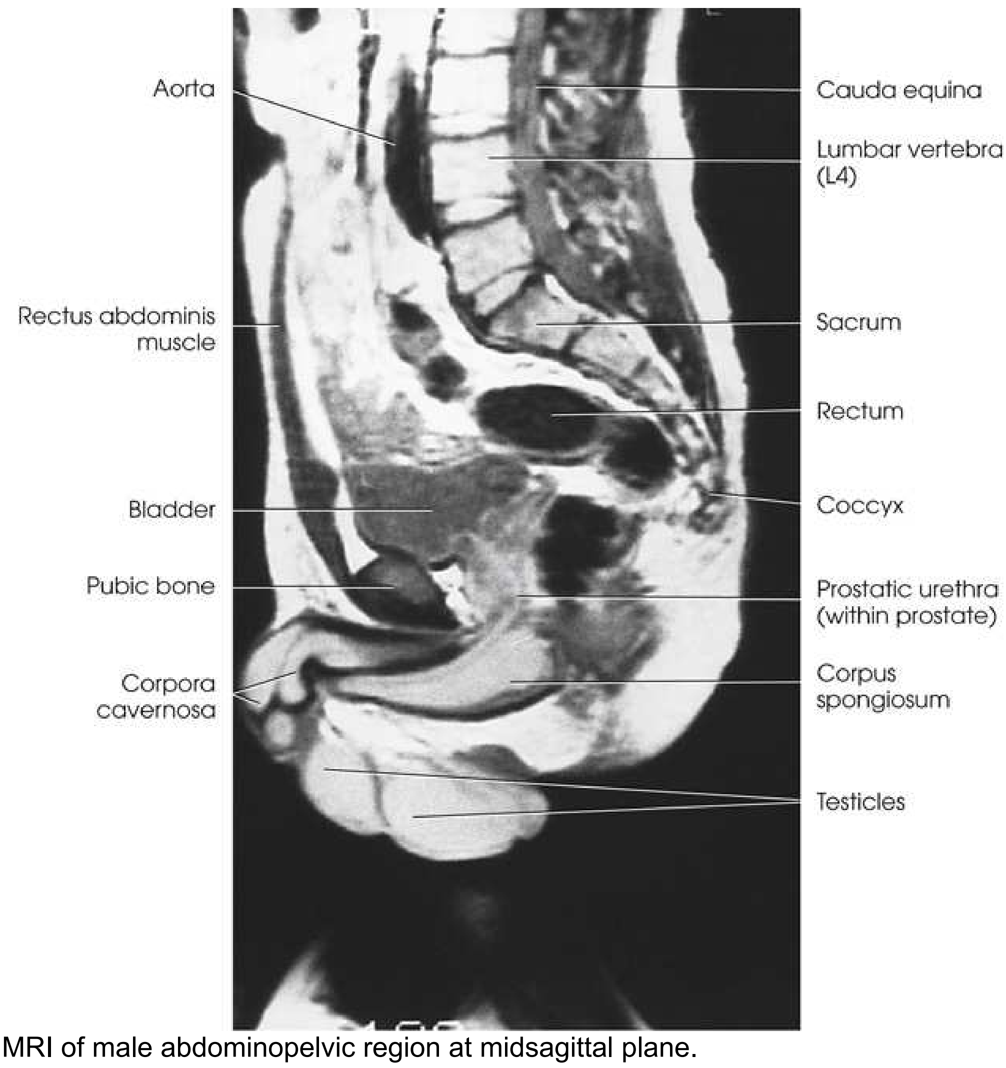


FIG. 24.62 MRI of male abdominopelvic region at midsagittal plane.

A m R I shows the male abdominopelvic region. The parts labeled in the diagram are marked clockwise as follows: corpora cavernosa, pubic bone, bladder, rectus abdominis muscle, aorta, cauda equine, lumbar vertebra (L 4), sacrum, rectum, coccyx, prostatic urethra (within prostate), corpus spongiosum, testicles.

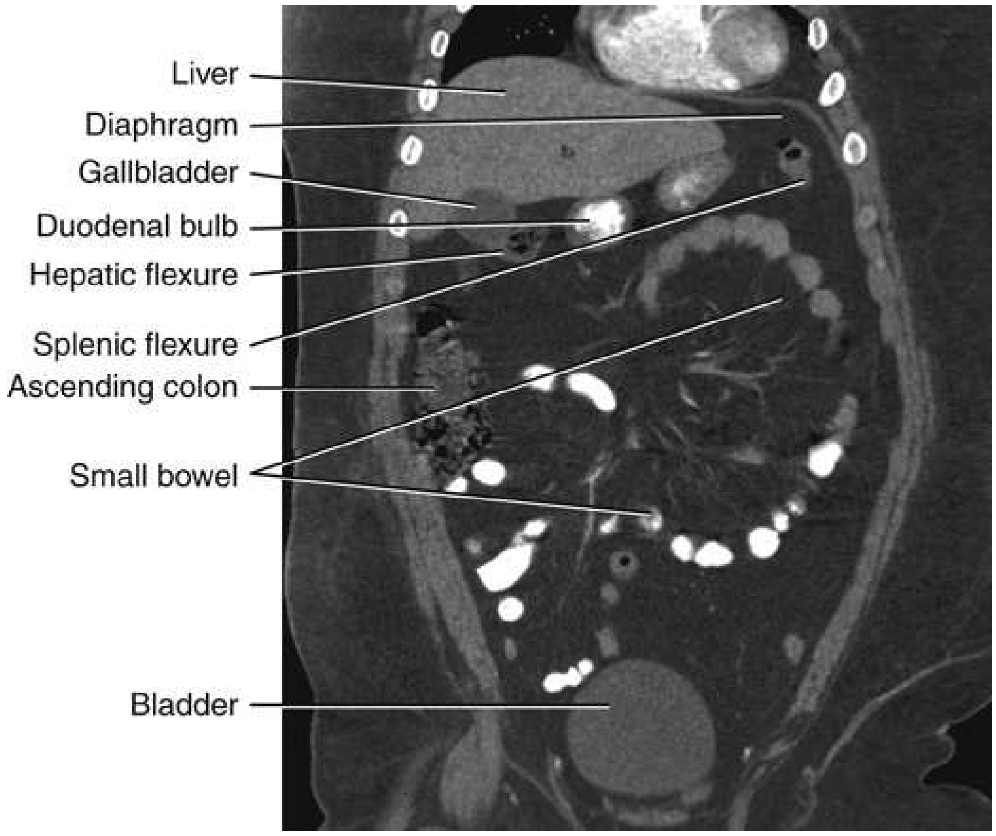


FIG. 24.63 Coronal CT image through anterior abdomen.

A C T image shows the anterior abdomen. There are many white regions scattered on it. The parts labeled are marked from top to bottom as follows: liver, diaphragm, gallbladder, duodenal bulb, hepatic flexure, splenic flexure, ascending colon, small bowel, bladder.

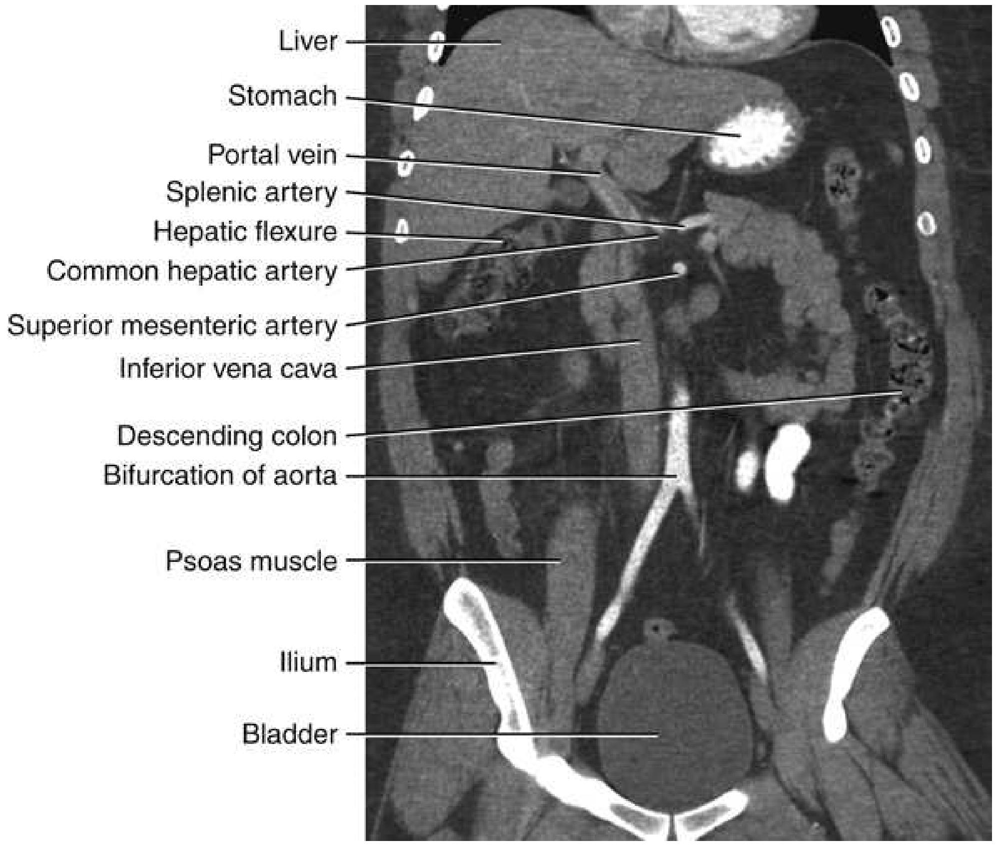


FIG. 24.64 Coronal CT image through central abdomen.

A C T image shows the central abdomen. The parts labeled are marked from top to bottom as follows: liver, stomach, portal vein, splenic artery, hepatic flexure, common hepatic artery, superior mesenteric artery, inferior vena cava, descending colon, bifurcation of aorta, psoas muscle, ilium, bladder.

Fig. 24.63 is a coronal CT image through the abdomen and pelvis. The only bony structures visible are the lower ribs. At the top of the abdomen, the diaphragm separates the heart and lungs from the liver and gastrointestinal structures. The right lobe of the liver occupies most of the right upper quadrant. On the inferolateral surface of the liver is a fluid-filled circle, which represents the gallbladder. Several structures of the gastrointestinal system are visible in this image. Near the midline, inferior to the liver, are contrast-filled structures, which represent the proximal duodenum and the stomach. The right (hepatic) and left (splenic) flexures of the large intestine are visible. The hepatic flexure is just inferior to the liver and gallbladder; the splenic flexure is just inferior to the left hemidiaphragm. The ascending colon lies along the right lateral abdominal wall, and multiple loops of small bowel with and without contrast enhancement can be seen within the central portion of the abdomen. The urinary bladder occupies the center of the pelvis.

Fig. 24.64 lies near the median coronal plane. At this level, the right and left lobes of the liver and a small portion of the gallbladder are apparent. The porta hepatis is the region of the liver where vascular structures enter and leave the organ. It is sometimes referred to as the hilum of the liver and is seen here on the inferior surface near the center. The contrast-filled body of the stomach lies near the left lobe of the liver. Several loops of small bowel are visible in the central abdomen, and the hepatic flexure and descending portion of the colon are along the lateral walls. The aorta and inferior vena cava are found anterior to the vertebral column within the abdomen. The aorta lies on the left, and the vena cava lies on the right. Major visceral branches of the abdominal aorta are (from superior to inferior) the celiac artery (sometimes called the celiac trunk), which originates from the anterior aorta near the level of T12; the superior mesenteric artery, which originates from the anterior aorta near the level of L1; the right and left renal arteries, which originate from the lateral aorta near the level of L2; the inferior mesenteric artery, which originates between the lateral and anterior surface of the aorta near the level of L3; and the common iliac arteries, which result when the aorta bifurcates near the level of L4. In this image, the aorta is bright because of contrast enhancement. The celiac trunk is a short vessel that almost immediately bifurcates into the common hepatic, splenic, and left gastric arteries. This image shows the common hepatic artery, which passes right to supply the liver, and the splenic artery, which branches toward the left to supply the spleen. Just below these vessels, the origin of the superior mesenteric artery is also apparent. The image clearly shows the lower abdominal aorta, its bifurcation, and the common iliac arteries. The portal system drains blood from the digestive system and carries nutrients to the liver. The portal vein is formed by the junction of the superior mesenteric vein and the splenic vein and can be seen within the porta hepatis.

Fig. 24.65 is a coronal CT image that represents a plane just posterior to the median coronal plane. Ribs are seen on the superior lateral aspect of the lower thorax and upper abdomen. Several lumbar vertebral bodies are visible in the center of the abdomen, and the iliac wings, acetabuli, femoral heads, and symphysis pubis are discernible in the pelvis. The right lobe of the liver lies in the right upper quadrant, and the spleen is found in the left upper quadrant where it is positioned lateral to the stomach and inferior to the diaphragm. The pancreas is a long, thin organ that lies horizontally across the center of the abdomen. In this scan, the tail of the pancreas can be found near the hilum of the spleen. The stomach, filled with contrast medium, rests inferior to the left hemidiaphragm, superior to the pancreatic tail, and between the liver and spleen. The right and left kidneys are retroperitoneal organs. Most of the right kidney is visible on this image; the anterior surface of the left kidney can also be seen. The central abdominal portions of the aorta and inferior vena cava are present in the center of the abdomen. The aorta is brighter, owing to contrast enhancement. The left renal artery is visible at its origin from the aorta, and a small segment of the right renal artery is seen near the hilum of the right kidney.

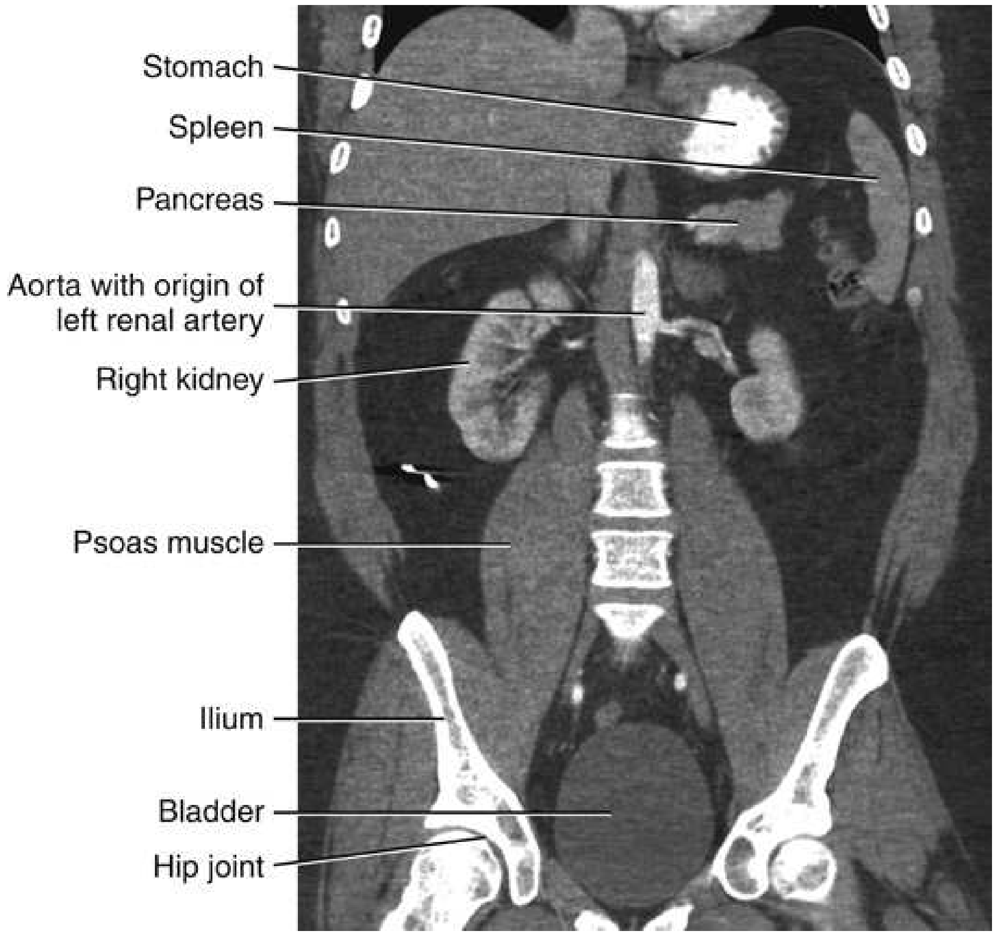


FIG. 24.65 Coronal CT image of abdomen posterior to midcoronal plane.

A C T image shows the abdomen. The hip joint and the vertebrae appear radiopaque. The parts labeled are marked from top to bottom as follows: stomach, spleen, pancreas, aorta with origin of left renal artery, right kidney, psoas muscle, ilium, bladder, hip joint.

Advanced Visualization

The discussion of sectional anatomy in medical imaging would be incomplete without including three-dimensional (3D) advanced visualization. This section will discuss three-dimensional imaging related particularly to CT and MR imaging.

In the early years of radiology there was a need for 3D imaging; however, there was no advanced software and computers to support the technology. Instead, there were special stereotactic devices which displayed two images, one for each eye. The two images had a minimal change of 5 degrees in the view angles between the two studies. The radiologist would use a handheld stereotactic viewer to bring the two images together to make one three-dimensional image.

The introduction of spiral CT created a change in the way three-dimensional images were viewed. In 1993, Elscint Inc. introduced the first multi-detector row CT (MDRCT) which allowed for two spiral slices to be acquired simultaneously. Other manufactures soon followed, introducing 4 rows of detectors, which evolved to 8, 16, 40, 64, and 128 rows. This number will continue to increase as technology advances and becomes more sophisticated.

The acquisition of multiple slices over a shorter period of time helped in the evolution of three-dimensional imaging. A series of CT images creates a volumetric data set, or a more simple "data set" that can be manipulated by the computer to produce additional images in different planes or three-dimensional images. The thickness of these individual slices and the associated matrix size contributes to the size of the volume element or voxel. The voxel is like a pixel but with a third-dimensional element, thus creating a 3D "box" or "volume." The matrix is the number of voxels in each slice. A larger number matrix (e.g., 512 × 512) results in smaller voxels, while a smaller matrix (e.g., 256 × 256) results in larger voxels. The shape of each individual voxel is important in the 3D reconstruction process. Voxels that are symmetrical in all three dimensions are considered to be isotropic. Voxels that are not symmetrical in all three dimensions are considered to be anisotropic. Having isotropic voxels, thin slices, and a large matrix size are key in the successful reconstruction of multiplanar reformatting (MPR) and 3D images. This is because the volumetric data set, when post-processed, provides the radiologist better spatial resolution in the reconstructed planes. As mentioned previously in this chapter, source images obtained from the imaging modalities can be compiled to produce MPR images and 3D images. Three-dimensional and MPR images provide the clinician a more detailed look at complex anatomy.

The following are some of the 3D reconstruction techniques.

Multiplanar Reformatting (MPR)

The MPR technique enables the clinician to see other planes that were not acquired directly during the acquisition stage of the imaging study. The post-processing of the acquired volumetric data set (usually in the axial plane in CT) can be reformatted into sagittal, coronal, and oblique cross-sectional images (Fig. 24.66). This post-processing technique might be useful to adjust a particular slice to the orientation that may be relevant to a specific anatomical structure. Some vendors provide software that automatically reconstructs MPR slices after the data set has been acquired. For example, in CT a number of axial images are acquired of the abdomen/pelvis and then automatically reconstructed in the sagittal and coronal planes. Curved MPR can be used for analysis of patients with scoliosis or to visualize blood vessels by cutting the plane parallel to the spine or blood vessel. MPR is one of the most widely used post-processing three-dimensional imaging techniques used today.

Cine Mode

The cine mode technique is often used when the data set has anisotropic voxels. The cine visualization is mostly used along the slice orientation; the clinician is able to view individual slices in a continuous movie loop. This provides better visualization of adjacent anatomical structures. The cine mode technique can be slowed down or speed up depending on the individual user.

Maximum Intensity Projection (Mip) And Minimum Intensity Projection (MinIP)

The MIP technique is frequently used in order to see voxels with maximum intensity (bright), or to put it another way, voxels that have a hyperintense signal in MR and a high CT number in CT. Higher CT numbers are related to more radiopaque structures and are lighter gray or white on the image. The MIP technique is particularly helpful in the assessment and diagnosis of vascular structures (Fig. 24.67). The MIP reconstruction method is also used in positron emission tomography (PET) exams to provide greater visibility of lesions. The MinIP technique is used to show voxels with a minimum intensity (dark), or to put it another way, voxels that have a hypointense signal in MR and a low CT number in CT. Lower CT numbers represent anatomic structures that are more easily penetrated by x-ray and appear closer to black on the image. This type of post-processing is used to demonstrate organs filled with air in CT examinations, such as the trachea, lungs, and sinuses.

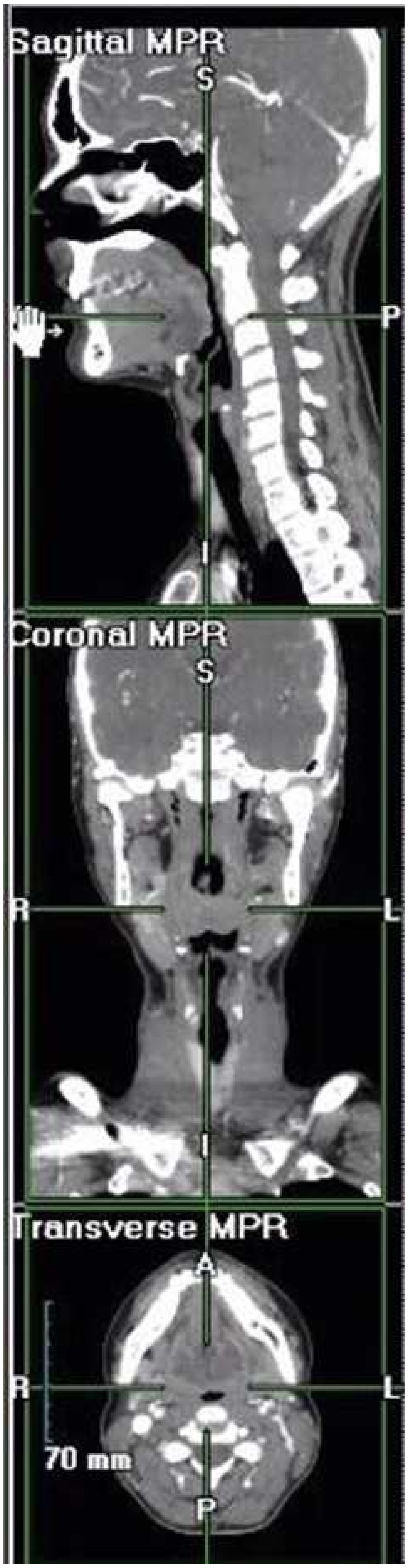


FIG. 24.66 CT multiplanar reformat (MPR) of the head and neck. From Weber State University, School of Radiologic Sciences.

Shaded Surface Display (SSD)

SSD is an indirect post-processing technique by which surfaces of the object are determined within a volumetric data set, and the resulting surface is displayed. The SSD technique is generated by applying a boundary of voxels that have the same or similar intensity values. The surface on these voxels is called an isosurface. The SSD technique applies a threshold to the data set. Surface contours are created by generating polygonal meshes that connect adjacent voxels within the given threshold value. The user can apply a virtual lighting source in different orientations to produce shaded visualizations, which helps display depth relations (Fig. 24.68).

Volume Rendering (VR)

Volume rendering (VR) is a direct post-processing technique that takes the entire data set and calculates the contributions of each voxel along a line from the viewer's eye through the data set, displaying the resulting value for each pixel of the display. In other words, volume rendering involves the formation of a red green blue alpha (RGBA) volumetric image from the data set. The RGB represents the colors of the image, while the A (alpha) represents the opacity of the image. The opacity values range from 0 to 1. Zero is represented as totally transparent, while 1 is represented as totally opaque. The surfaces of the image can be improved by using shading techniques, which form the RGB mapping. Adjusting the opacity is helpful to see the interior structures of the data set. Volume rendering is widely used to visualize vascular structures as well as applications in cardiac and orthopedic imaging (Fig. 24.69).

FIG. 24.67 MRI maximum intensity projection (MIP) of the circle of Willis (COW). From Weber State University, School of Radiologic Sciences.

Virtual Colonoscopy

Virtual colonoscopy is a post-processing function similar to SSD. This post-processing method visualizes internal organs, vessels, and gastrointestinal structures using data sets from MRI and CT. The method is similar to an endoscopy exam. The post-processing technique allows a virtual journey along the path in a vessel or specific organ such as the stomach, small intestine, or the colon. A predefined camera path through the respective anatomical structure uses a software feature known as planned navigation. This camera path specifies camera positions and view directions (orientations) of the virtual camera. A fly-through movie is then created based on this predetermined path.

3D Printing

In 1984, Charles Hull was the first to introduce 3D printing technology. Three-dimensional printing is widely known by other terms such as additive manufacturing (AM), layered manufacturing, solid free form fabrication, or rapid prototyping (RP). Traditional manufacturing techniques, known as subtractive manufacturing, involve the removal of material from a solid block using a milling technique to produce the final physical object. Three-dimensional printing adds different materials to the build platform until a 3D object is completed. The basic components of 3D printing can be divided into three groups: (1) hardware (the 3D printer); (2) software (communicates instructions to the hardware; and (3) the physical materials used to print objects. The materials selected for 3D printing include plastic, silicone, nylon, metal, and biomaterials. They are also divided into rigid versus soft rubber-like materials, single-color versus multi-color, and opaque versus transparent. The workflow for 3D printing comprises 5 steps: (1) 3D data acquisition, (2) segmentation, (3) conversion of a Digital Imaging and Communication in Medicine (DICOM) file to a 3D mesh file format, (4) computer-aided design (CAD), and (5) 3D printing.

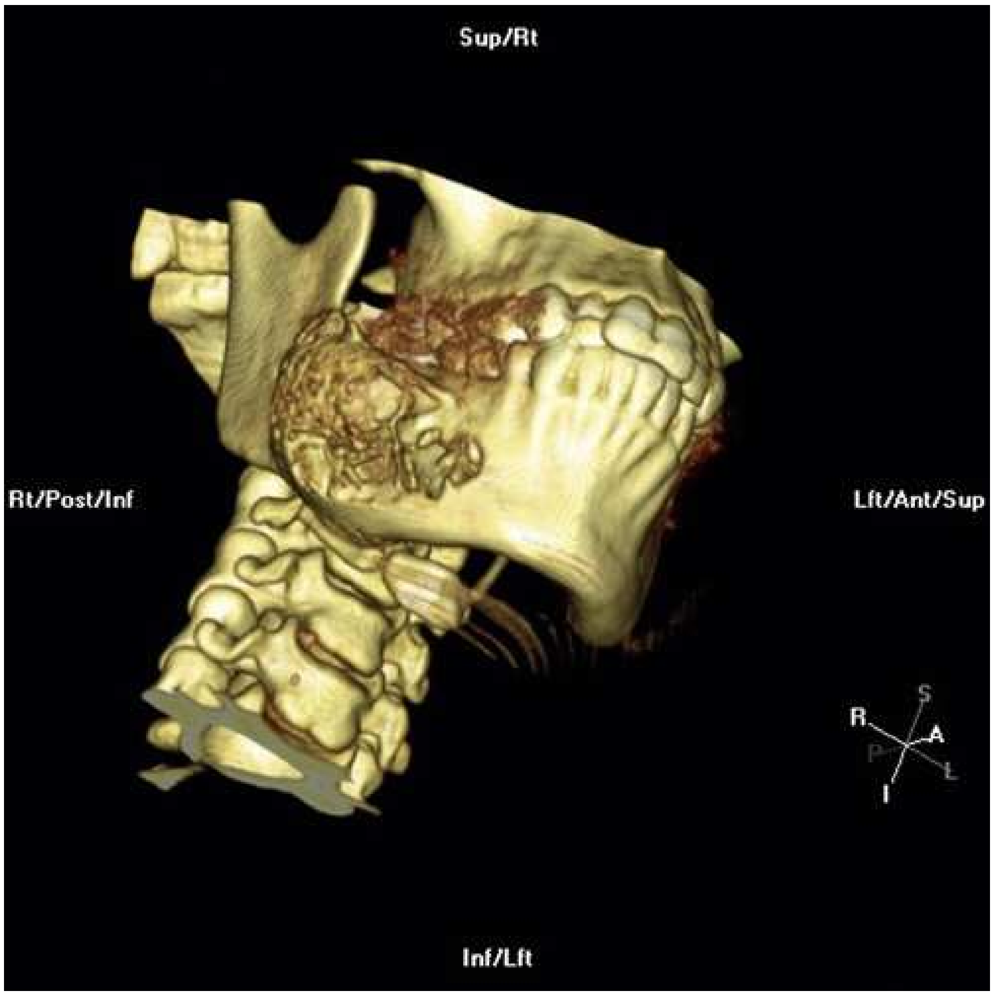


FIG. 24.68 CT shaded surface display (SSD) with anterior lighting effects. From Weber State University, School of Radiologic Sciences.

A C T surface shaded display of the jaw and the cervical vertebrae is shaded in gold. Right or posterior or inferior is labeled on the right, superior or right is labeled on top, left or anterior or superior is labeled on the left, and inferior or left is labeled below.

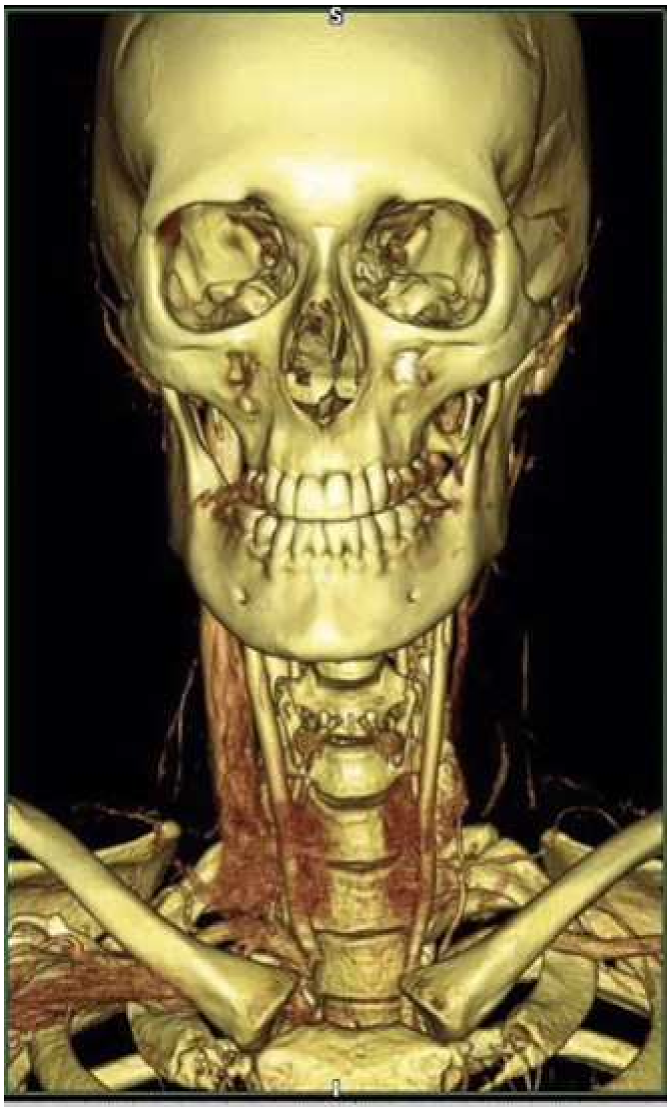


FIG. 24.69 CT 3D volume rendered study of the head and neck. From Weber State University, School of Radiologic Sciences.

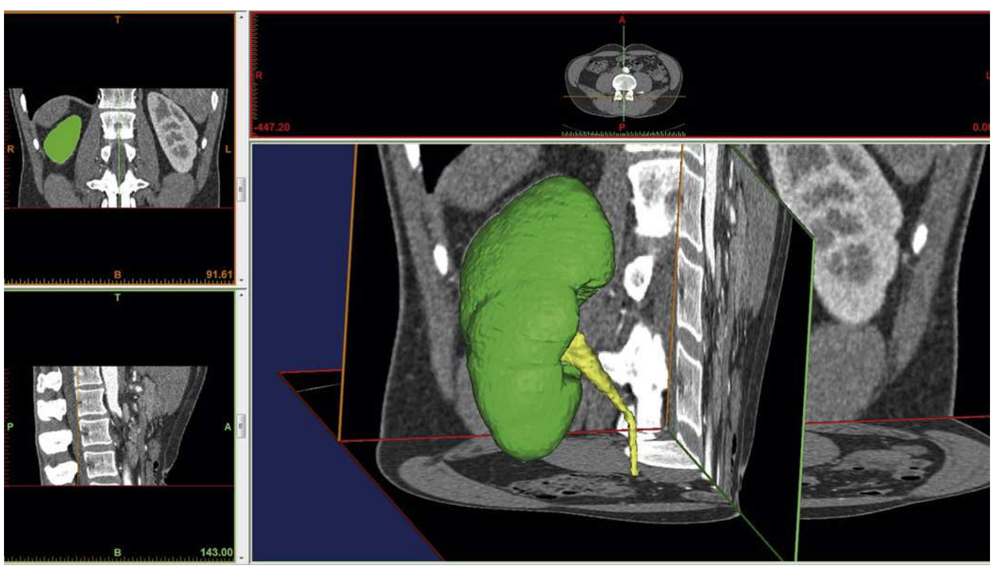


FIG. 24.70 CT structural segmentation of the right kidney. From Weber State University, School of Radiologic Sciences.

A C T image on the top left side shows a green colored oval structure on the left. The vertebra is appears white. A C T image at the bottom left shows the vertebral segments and the interspinous process. A C T image on the top right shows a sagittal view of the vertebra divided into four quadrants. A C T image at the bottom right shows the kidney highlighted in green. The ureter is highlighted in yellow. The vertebra appears white.

Data Acquisition

The acquisition of images, usually from CT and MRI, is the first step in the 3D printing process. This is the most crucial step due to the fact that poor acquisition quality can lead to a poor 3D printed model. Therefore, the acquisition of high-resolution isotropic 3D volumetric data sets with excellent image quality is a prerequisite for creating a high-quality 3D printed model. The volumetric data should also contain sufficient signal intensity and contrast to differentiate the anatomy of interest from other surrounding structures. Acquisition protocols with different imaging modalities should be adjusted to provide the best volumetric data set for 3D printing. In CT imaging, the risk vs. benefit of the increased radiation dose and the quality of the volumetric data set must be considered.

Segmentation

DICOM is the most common medical imaging format. DICOM is a standard for distributing and viewing any kind of medical image. The process of transforming DICOM images into a 3D model is referred to as segmentation. The process of segmentation separates anatomical structures from adjacent structures (Fig. 24.70). Thresholding, region growing, and other manual operations are used to segment (cut) the anatomical structure of interest away from adjacent anatomical structures.

Dicom File Conversion to 3D Mesh File

The conversion of a DICOM file to a 3D mesh file can be accomplished by a wide range of different software. Some of the software is open source (free), while others are purchased from specific venders. The software converts the DICOM image into a Standard Tessellation Language (STL) or various alternate file types such as 3D manufacturing format (3FM), object file (OBJ), and virtual reality modeling language (VRML). The most common file types that are converted from DICOM are STL and OBJ. In addition to converting DICOM files into a different file type, the software divides the surface of the image into small triangles that compose it into a mesh.

Computer-Aided Design (CAD)

The CAD is the final step before sending the completed file to the 3D printer. Some of the most commonly used CAD software products are listed in the following: MIMICS (Materialise), 3Matic (Materialise), SolidWorks (Dassault Systemes), and Pro/Engineer (PTC). Most CAD software combines the DICOM conversion and mesh formation together with the CAD functions. These two functions are listed as separate steps in this chapter, but they are usually combined with the CAD software. The CAD software performs an additional step of mesh post-processing. This step refines the triangulated surfaces to repair any edges or structures that may affect the final result of the printed object. The process basically “wraps” the 3D object to repair any holes and makes the surface smooth and even. The CAD process involves design processes such as local smoothing, cuts, change of spatial orientation, and adding additional parts to the object so other anatomical structures can be attached. Adjustments can be made to the wall thickness that provides structural integrity to the printed object.

3D Printers

Printers come in various shapes and sizes. The cost can range from hundreds to thousands of dollars. Different 3D printer types can help facilitate the speed, resolution, choice of colors, and material composition of the 3D printed object. Three-dimensional printers fall into four different types: (1) liquid-based, (2) powder-based, (3) solid-based, and (4) paper-based. The following are the various types of 3D printers.

Stereolithography (SLA)

In 1988, 3D Systems Inc. introduced the first rapid prototype of the SLA 3D printer based on the work by inventor Charles Hull. SLA is a liquid-based 3D printer that builds a plastic 3D object one layer at a time by tracing a laser beam on the surface of a vat filled with a liquid photopolymer. The photopolymer solidifies when the laser beam strikes the surface of the liquid. The platform is then lowered to a distance equal to the layer thickness (typically 0.003 to 0.002 inch), and a subsequent layer is formed on top of each previous layer. The photopolymer has self-adhesive properties that allow the previous layer to bond to subsequent layers. The 3D printed object is a result of all of these combined layers. Complex 3D objects add structural supports to provide stability to the object (see Fig. 24.71). When the object is completed, it is cleaned and cured to harden the object before structural supports are removed and the object is sanded and polished.

Fused deposition modeling (FDM)

FDM was developed by Stratasys in Eden Prairie, Minnesota, and is considered a solid-based printer. The FDM process uses a solid plastic or wax material that is extruded through a nozzle to form a three-dimensional object layer by layer. The heated plastic or wax hardens very rapidly after it has left the printer nozzle. A second extrusion nozzle is used for support material. The object is built on a mechanical platform which moves vertically downward as each layer is formed. The entire object is contained in a chamber that has a temperature just below the melting point of the plastic. The FDM printer can use a wide range of materials, including ABS, polycarbonate, polypropylene, polyamide, polyethylene, and investment casting wax.

Selective laser sintering

Carl Deckard and colleagues at the University of Texas in Austin developed the selective laser sintering (SLS) technique. The SLS printer is a powder-based 3D printer that uses a thermoplastic powder that is spread over the top of the build platform. A laser beam moves over the surface of the tightly compacted powder to selectively melt and fuse the powder together to form one layer of the object. The build platform moves down one object layer thickness to accommodate the next layer of powder, and the process repeats itself. Different types of thermoplastic powder materials are used, including nylon, polyamide, polystyrene, elastomers, and composites. One of the unique things about the SLS technique is that no building supports are required. The overhangs and complex geometric shapes are supported by the residual solid powder bed surrounding the object. This process does require a considerable amount of time for the object to cool down before it can be removed from the machine.

Direct metal laser sintering (DMLS)

The DMLS technique was developed jointly by Rapid Product Innovations (RPI) and EOS GmbH starting in 1994. The DMLS printer is a powder-based process that is similar to the SLS method. However, in the DMLS process, there is no binder or fluxing agents included in the metal powder. This results in a 95% density steel final object compared to a 70% density to the SLS final object. The metal powder used in the DMLS process is 20 microns in diameter. The metal powder is completely melted by a high-power laser beam. The size of the metal powder and the hardening of the metal powder using a high-power laser creates thinner layers resulting in higher detail resolution. Higher detail resolution results in more intricate part shapes. Material options for this process include alloy steel, stainless steel, tool steel, aluminum, bronze, cobalt-chrome, and titanium.

FIG. 24.71 3D printed model of the knee with structural supports still in place. From Weber State University, School of Radiologic Sciences.

Inkjet printing

The inkjet 3D printing process uses liquid plastic for the build material and wax for the support material. The liquids are held in reservoirs until they are fed to the individual jet heads. The liquids are squirted in tiny droplets onto the build platform to form a layer of the 3D object. The liquid hardens by the rapidly dropping temperature as it moves along the build platform. Once the droplets have been deposited and hardened, a sharp blade is passed over the layer to make the thickness uniform. The excess particles are vacuumed away and captured in a filter. After the 3D object is completed, the wax for the support material is dissolved or melted away. The inkjet printing process produces extremely high resolution (0.0005 inch) and excellent surface finishes. The downside is that it is rather slow for large 3D objects.

Polyjet printing

In early 2000, the first polyjet technology was introduced by Objet Geometries Ltd., an Israeli company. The polyjet technology is similar to the inkjet 3D printing technique in that it has individual jet heads. However, the polyjet printer squirts layers of a liquid photopolymer onto a tray that is then hardened by an ultraviolet (UV) ray to cure the model. The hardening of the photopolymer is similar to the SLA printing technique. The UV flood lamp is mounted onto the print head. The process continues layer after layer until the 3D object is complete. The support material is also made of a photopolymer and washed away with pressurized water. The advantage of the polyjet over the SLA printer is that the photopolymers come in a cartridge rather than stored in a vat, and multiple colors can be used. Polyjet printers are also very clean and quiet, with less post-processing cleanup on parts.

Laminated object manufacturing (LOM)

LOM was developed by Helisys of Torrance California. Three-dimensional objects are created by stacking, bonding, and cutting layers of adhesive-coated sheet material on top of each other. The outline of each sheet layer is cut by a laser. After the laser cuts the outline of the layer, another sheet is advanced on top of the previously deposited layers. A heated roller applies pressure to bond the new layer, and the process repeats until the final 3D object is complete. The LOM process can use a variety of different colors. The sheets are composed of paper and various types of plastics.

Uses of 3D Printing In Medicine

Interactive 3D advanced visualization and 3D printing have many applications in medicine. These post-processing techniques aid clinicians in visualizing anatomical and pathological structures that can be beneficial in the planning of radiation therapy treatment planning, surgical procedures, and minimally invasive interventions. Advanced post-processing imaging using these techniques provides a clearer view of anatomical structures and pathology, which aids the radiologist in making a diagnosis. Advanced visualization and the use of 3D printable models and cutting guides can help surgeons in pretreatment planning, which can result in reduced time for surgical procedures. Clinicians can use 3D models to educate patients regarding pathology, treatment options, and surgical approaches, thus giving the patient a better understanding of their disease, surgical approaches, and therapeutic options. Three-dimensional printers continue to find novel ways to improve patient outcomes and provide better continuity of care for the patient. In the future, as the cost of 3D printers declines and more physicians and technologists become familiar with using this technology, there may likely be an increase in the use of this technology in the health care marketplace. The future looks bright for these advanced post-processing techniques.

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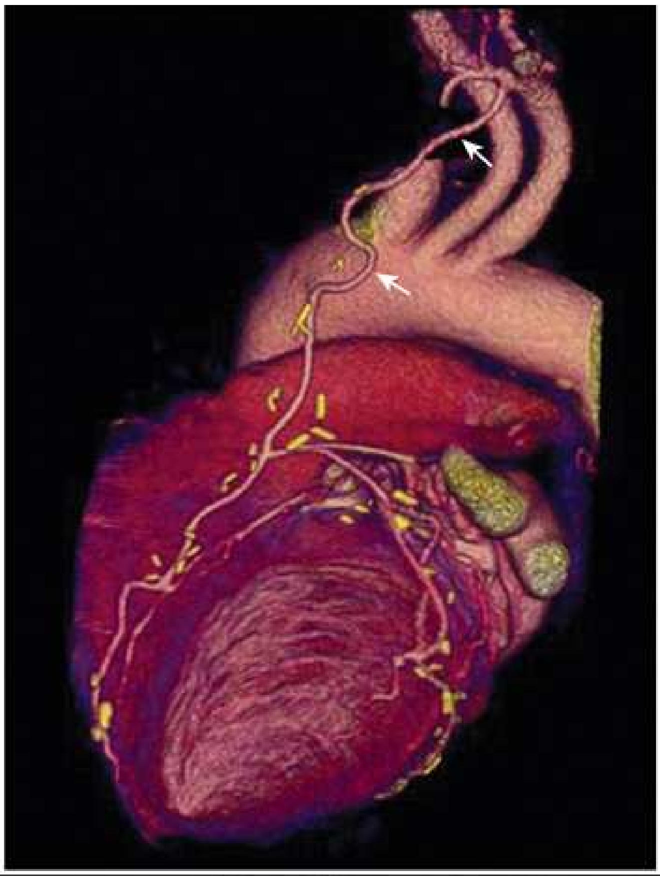
25: Computed Tomography



Carolyn Palazzolo

OUTLINE

Fundamentals of Computed Tomography

Computed tomography (CT) is the process of creating a cross-sectional tomographic plane of any part of the body (Fig. 25.1). For CT, a patient is scanned by an x-ray tube rotating around the body part being examined. A detector assembly measures the radiation exiting the patient and feeds back the information, referred to as primary data, to the host computer. After the computer has compiled and calculated the data according to a preselected *algorithm*, it assembles the data in a *matrix* to form an *axial* image. Each image, or *slice*, is displayed in a cross-sectional format.

In the early 1970s, CT scanning was used clinically only for imaging of the brain. The first CT scanners were capable of producing only axial images and were called *computed axial tomography (CAT)* units by the public; this term is no longer accurate because images can now be created in multiple planes. Dramatic technical advancements have led to the development of CT scanners that can be used to image virtually every structure within the human body. Improvements in scanner design and computer science have produced CT units with new imaging capabilities and reconstruction techniques. Three-dimensional reconstructions of images of the internal structures are used for surgical planning, CT angiography (CTA), radiation therapy planning, and virtual reality imaging.

Interventional procedures such as CT-guided biopsies and fluid drainage offer an alternative to surgery for some patients. Although these procedures are considered invasive, they offer shorter recovery periods and lower risk of infection.

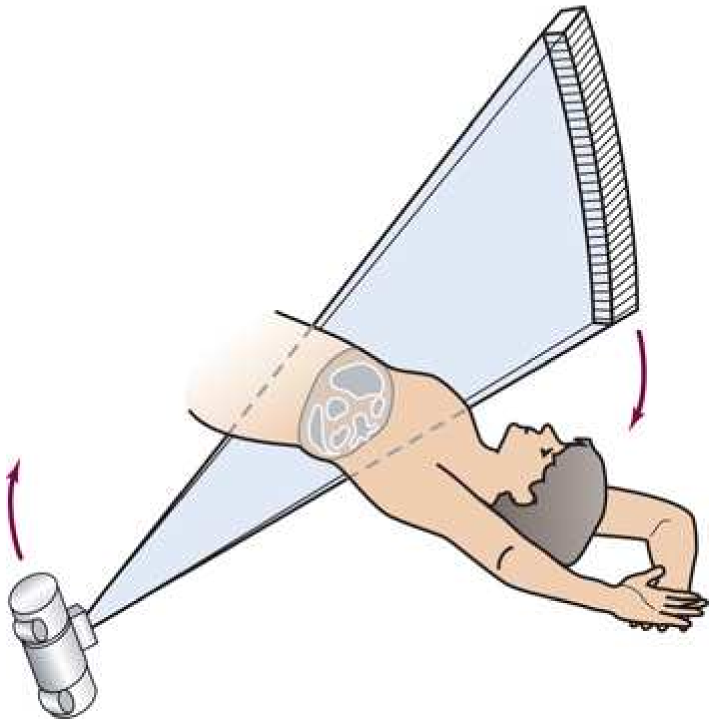


FIG. 25.1 CT scanner provides cross-sectional images by rotating around the patient.

Computed Tomography and Conventional Radiography

When a conventional x-ray exposure is made, the radiation passes through the patient and produces an image of the body part. Frequently, body structures are superimposed (Fig. 25.2). Visualizing specific structures requires the use of contrast media, varied positions, and usually more than one exposure. For example, the localization of masses or foreign bodies on an x-ray image often requires at least two exposures and a ruler calibrated for magnification.

During the CT examination, a tightly collimated x-ray beam is directed through the patient from many different angles, resulting in an image that represents a cross section of the area scanned. This imaging technique essentially eliminates the superimposition of body structures. The CT technologist controls the method of acquisition, the slice thickness, the reconstruction algorithm, and other factors related to image quality.

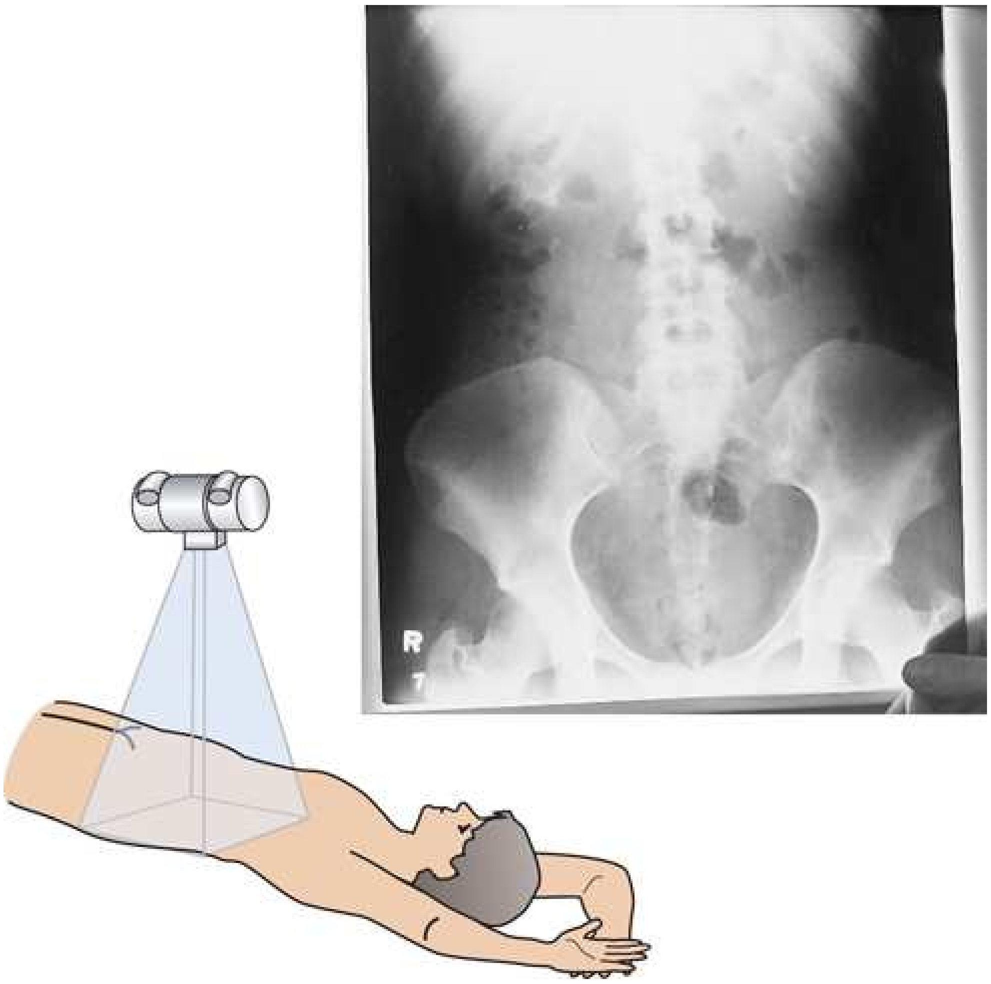


FIG. 25.2 Conventional radiograph superimposes anatomy and yields one diagnostic image with fixed density and contrast.

A patient is in supine position with his arms raised over his head. The radiation from the x-ray tube placed perpendicular to the body falls on the abdomen and pelvis. An x-ray view of the abdomen and the pelvis is next to it.

The digital radiograph of the abdomen illustrated in Fig. 25.3 shows high-density bone and low-density gas, but many soft tissue structures, such as the kidneys and intestines, are not clearly identified. A contrast medium is needed to visualize these structures. A CT examination of the abdomen demonstrates all of the structures that lie within the slice. In Fig. 25.4A, the liver, stomach, kidneys, spleen, and aorta can be identified. In addition to eliminating superimposition, CT is capable of differentiating tissues with similar densities. This differentiation of densities is referred to as *contrast resolution*. CT provides improved contrast resolution as compared with conventional radiography. This is due to a reduction in the amount of scattered radiation.

Fig. 25.4B is an axial image of the brain that differentiates the gray matter from the white matter and shows bony structures and cerebrospinal fluid within the ventricles. CT can show subtle differences in various tissues as in Fig. 25.4B. This allows radiologists to diagnose pathologic conditions more accurately than if they were to rely on radiographs alone. The CT image is digitized by the computer with numerous image manipulation techniques that can be used to enhance and optimize the diagnostic information available to the physician (Fig. 25.5).

FIG. 25.3 Digital kidney, ureter, and bladder (KUB).

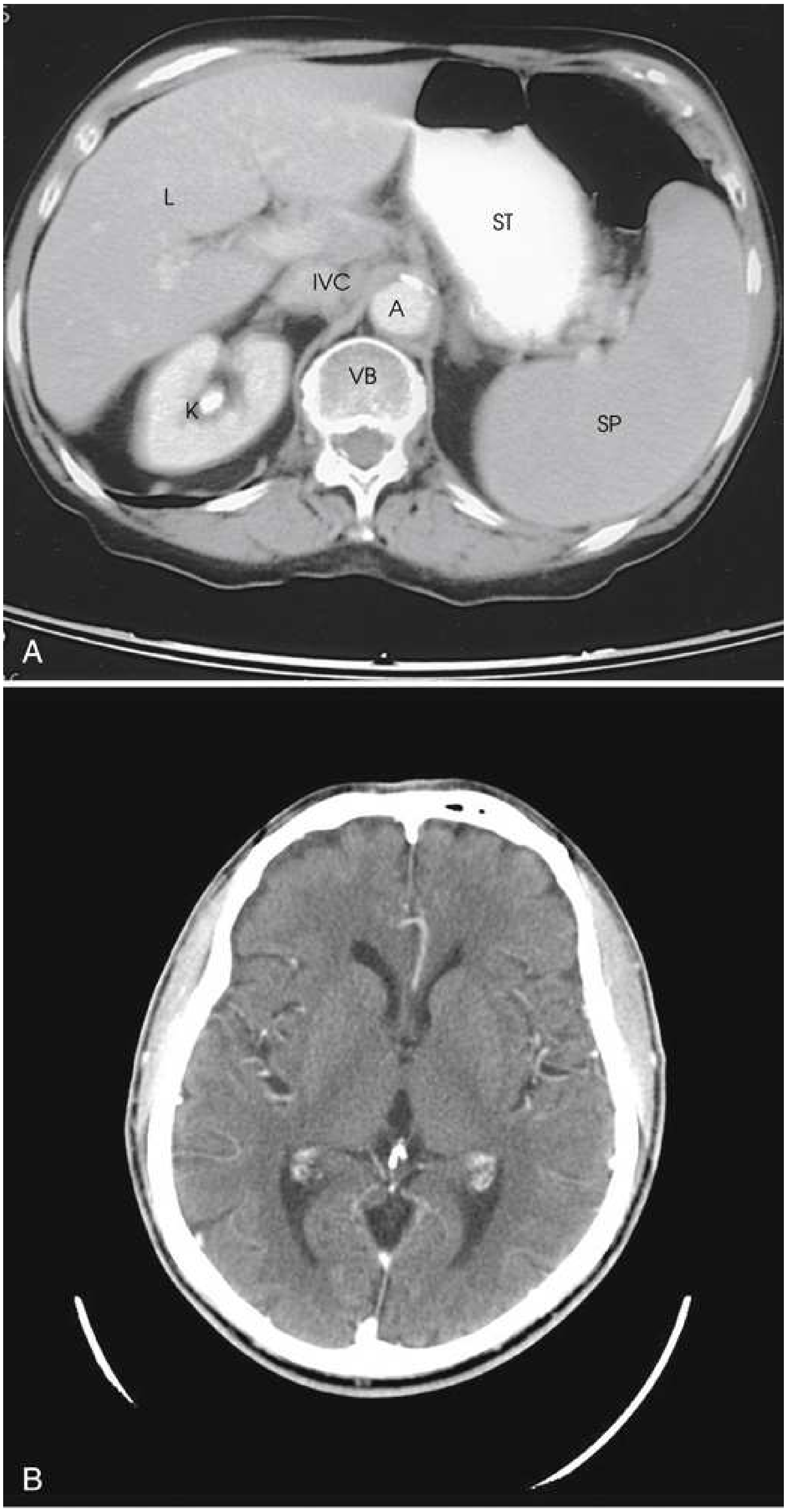


FIG. 25.4 (A) Axial image of abdomen showing liver *(L)*, stomach *(ST)*, spleen *(SP)*, aorta *(A)*, inferior vena cava *(IVC)*, vertebral body of thoracic spine *(VB)*, and kidney *(K)*. (B) Axial CT scan of lateral ventricles–anterior horns (RightALV), posterior horns (LeftPLV), and third ventricle (3V). B, From Kelley LL, Peterson CM: *Sectional anatomy for imaging professionals*, ed 2, St Louis, 2007, Mosby.

(A) An axial image of the abdomen shows the liver, stomach, kidneys, spleen, and aorta. The parts labeled are I V C, V B, S P, A, and S T. S T appears radiopaque. (B) An axial C T scan of brain shows differentiates the gray matter from the white matter and shows bony structures and cerebrospinal fluid within the ventricles. The outer layer appears radiopaque.

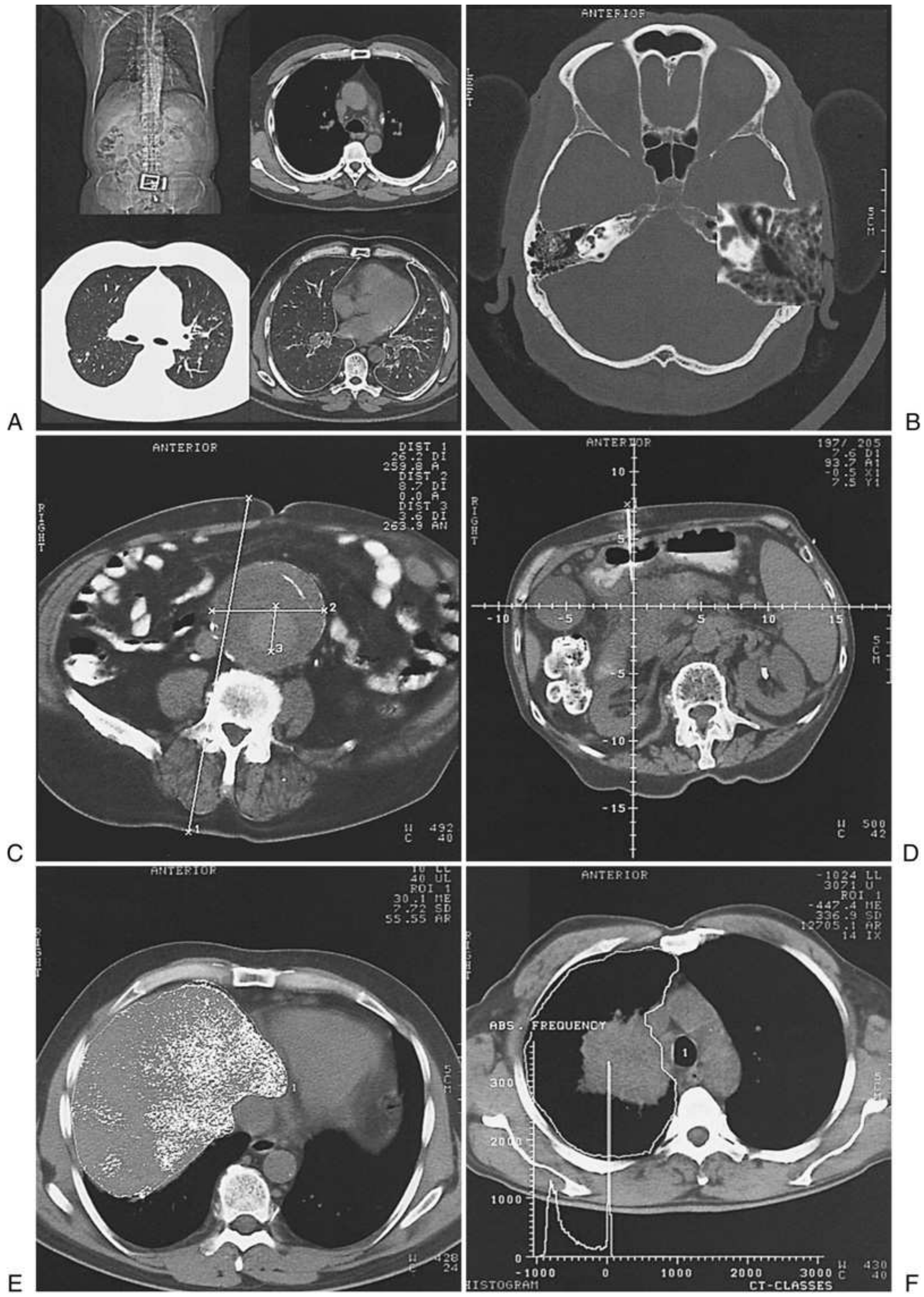


FIG. 25.5 Image manipulation techniques used to enhance diagnostic information in CT image. (A) Multiple imaging windows. (B) Image magnification. (C) Measurement of distances. (D) Superimposition of coordinates on the image. (E) Highlighting. (F) Histogram. Courtesy Siemens Medical Systems, Iselin, NJ.

(A) A C T image shows four imaging windows. (B) A C T image shows a magnified image of the brain. (C) A C T image shows a slanting vertical line passing through the image. (D) A C T shows a horizontal and a vertical line dividing the image into four quadrants. (E) A C T image shows a grainy white area on the left and a grey area on the right. (F) A C T image shows a histogram with a horizontal and a vertical axis at the bottom of the image.

Historical Development

CT was first performed successfully in 1970 in England at the Central Research Laboratory of EMI, Ltd. Hounsfield, an engineer for EMI, and Cormack, a nuclear physicist from Johannesburg, South Africa, are generally given credit for the development of CT. They were awarded the Nobel Prize in Physiology or Medicine in 1979 for their research. After CT was shown to be a useful clinical imaging modality, the first full-scale commercial unit, referred to as a *brain tissue scanner*, was installed in Atkinson Morley Hospital in 1971. An early dedicated head CT scanner is shown in Fig. 25.6. Physicians recognized its value for providing diagnostic neurologic information, and its use was accepted rapidly. The first CT scanners in the United States were installed in June 1973 at the Mayo Clinic, Rochester, Minnesota, and later that year at Massachusetts General

Hospital, Boston. These early units were also dedicated head CT scanners. In 1974, Ledley at Georgetown University Medical Center, Washington, DC, developed the first whole-body scanner, which greatly expanded the diagnostic capabilities of CT.

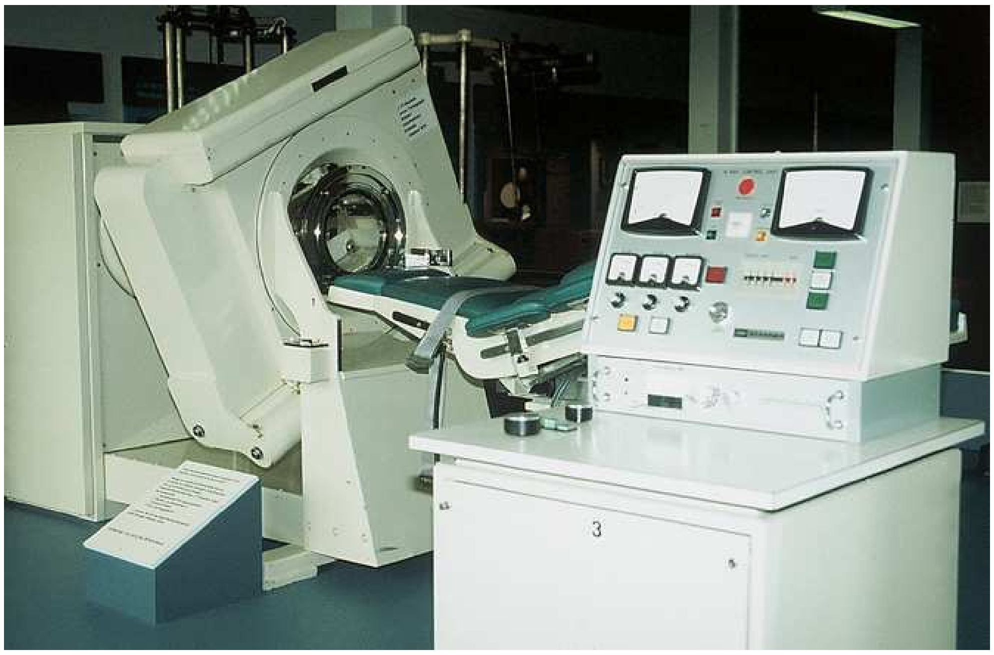


FIG. 25.6 First-generation EMI CT unit: dedicated head scanner. Photograph taken at Reöntgen Museum, Lennep, Germany.

After physicians accepted CT as a diagnostic modality, numerous companies, in addition to EMI, began manufacturing scanners. Although the units differed in design, the basic principles of operation were the same.

Computed Tomography Scanner Generation Classifications

CT scanners have historically been categorized by *generation*, which is a reference to the level of technologic advancement of the tube and detector assembly. The original “generation” classification of scanners was a clear distinction of tube movement versus detector rotational path. As scanner technology has progressed, the tube movement and detector rotation relationship have remained relatively constant, but the tube power source and the detector configurations have changed. Some authors have used slip ring or detector advancements to assign a generation number. These varied opinions and discussions have led to some confusion concerning scanner generation classifications. The following discussion of scanner generations follows the original standards of tube movement versus detector rotation.

The early units, referred to as *first-generation scanners*, worked by a process known as *translate/rotate*. The tube produced a finely collimated beam, or pencil beam. Depending on the manufacturer, one to three *detectors* were placed opposite the tube for radiation detection. The linear tube movement (translation) was followed by a rotation of 1 degree. Scan time was usually 3 to 5 minutes per scan, which required the patient to hold still for extended periods. Because of the slow scanning and reconstruction time, the use of CT was limited almost exclusively to neurologic examinations because of the aperture size and the water bag construction. A CT image from a first-generation scanner is shown in Fig. 25.7.

The *second-generation scanners* were considered a significant improvement over first-generation scanners. The x-ray tube emitted a fan-shaped beam that was measured by approximately 30 detectors placed closely together in a detector array. Tube and detector movement were still *translate/rotate*; however, the gantry rotated 10 degrees between each translation. These changes improved overall image quality and decreased scan time to about 20 seconds for a single slice. The time required to complete one CT examination remained relatively long.

The *third-generation scanners* introduced a *rotate/rotate movement*, in which the x-ray tube and detector array rotate simultaneously around the patient. An increase in the number of detectors (>750) and their arrangement in a “curved” detector array considerably improved image quality (Fig. 25.8). Scan times were decreased to 0.35 to 1 second per slice, which made the CT examination much easier for patients and helped decrease motion artifact. Advancements in computer technology also decreased image reconstruction time, substantially reducing examination time. Most current scanners are third-generation configurations with one of the following technical variations:

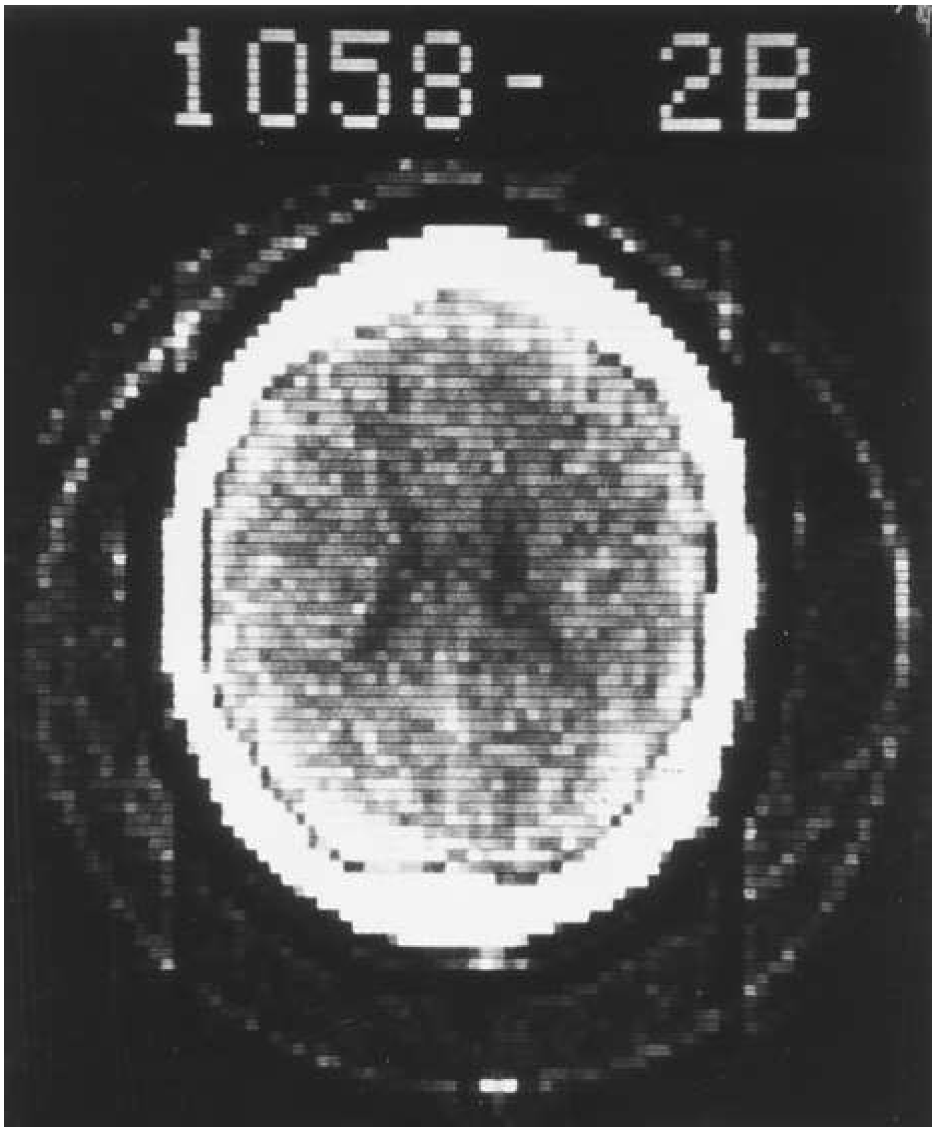


FIG. 25.7 Axial brain image from the first CT scanner in operation in the United States: Mayo Clinic, Rochester, Minnesota. The 80 × 80 matrix produced a noisy image. The examination was performed in July 1973.

- *Helical CT, single-slice helical CT (SSHCT).* Slip-ring technology allows 360-degree continuous rotation of tube and detector. Reduces scan times to sub-second per slice.
- *Multislice detectors (MSHCT or MDCT).* The increase in number of detector rows allows multiple slices to be produced in one rotation. As detector rows increase, the fan beam geometry of the x-ray beam has been adapted, the beginning of cone-beam configuration. Began with two-slice scanners and quickly moved to four slices and more.
- *Volume CT (VCT).* Multislice scanners with 64 detector rows or more. The x-ray beam geometry must be a cone-beam configuration to accommodate the increased length of the scanning field.

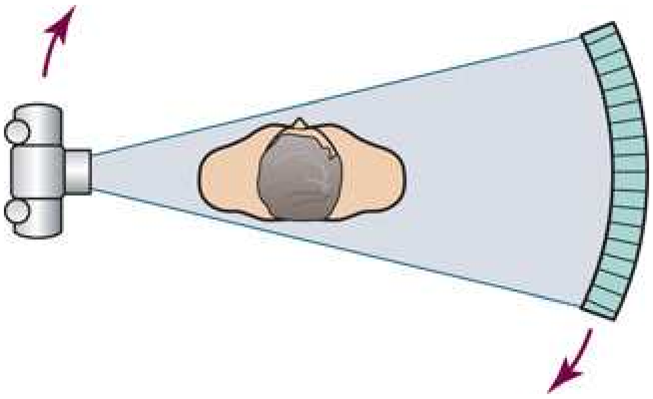


FIG. 25.8 Rotate/rotate movement: tube and detector movement of a third-generation scanner.

- *Flat-panel CT (FP-CT or FD-CT).* A detector plate similar to plates used in digital radiography (DR) replaces the typical detector configuration. In dedicated breast units, the tube and detector travel a full 360 degrees. In other applications, interventional and intraoperative, the unit functions more like a C-arm fluoroscopy unit, in which the tube and detector do not travel in a full 360 degrees. These scanners provide excellent spatial resolution but slightly lower contrast resolution.

The *fourth-generation scanners* introduced the *rotate-only movement* in which the tube rotates around the patient, but the detectors were in fixed positions, forming a complete circle within the gantry (Fig. 25.9). The use of stationary detectors required greater numbers of detectors to be installed in a scanner. Fourth-generation scanners tended to yield a higher patient dose per scan than previous generations of CT scanners because the CT tube is closer to the patient.

The *fifth-generation scanners* are classified as high-speed CT scanners because of millisecond acquisition times. These scanners are electron-beam scanners (EBCT), in which x-rays are produced from an electron beam in a fan beam configuration that strikes stationary tungsten target rings (Fig. 25.10). The detector rings are in a ±210-degree arc. These scanners were primarily used for cardiac studies because of the improved temporal resolution.

The *sixth-generation scanners* are dual-energy source (two x-ray tubes; DSCT, DE-CT) that have two sets of detectors that are offset by 90 degrees. These DSCT scanners provide improved temporal resolution needed for imaging moving structures such as the heart (Fig. 25.11). The latest dual source/dual detector (DSDD) CT scanners offer dual-energy capabilities, typically 80 and 120 kVp, between the two CT tubes. Using Flash Spiral scanning offered by Siemens, the dual source spiral scanning allows for gapless volume coverage using a pitch of 3.4, which increases the temporal resolution to one quarter of the rotation time. This technology allows a marked decrease in patient radiation dose, as no overlapping scanning occurs.

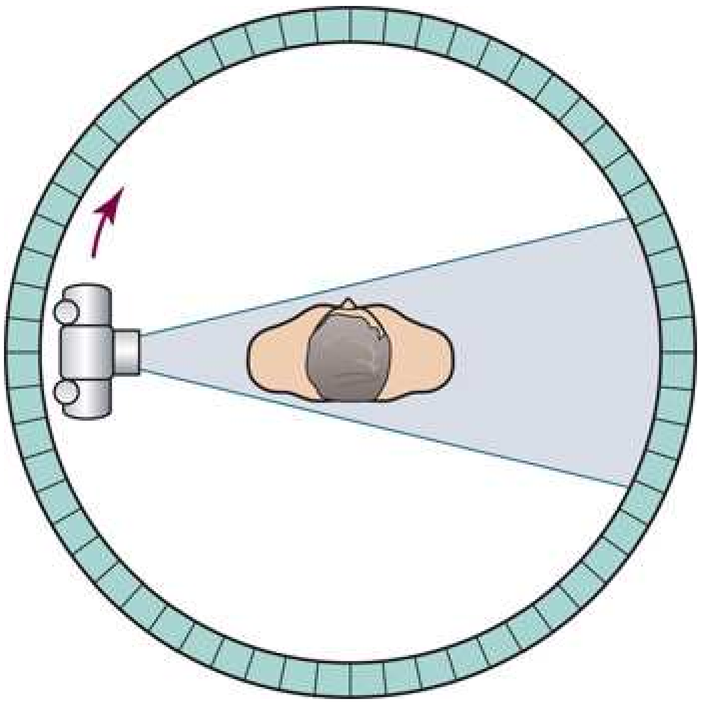


FIG. 25.9 Rotate-only movement: tube movement with stationary detectors of a fourth-generation scanner.

A patient is standing with his lateral position facing the x-ray tube. A x-ray tube on the side is rotating around the body. It is indicated by an arrow. The detector rings are in a plus or minus 210-degree arc around the patient.

Most scanners in use today are third-generation variations that have 4 to 320 rows of detectors in a single array. This increase in numbers of detector rows has increased the length of the scanning field, which requires the x-ray beam to be cone-shaped to encompass the full detector array. This is a change from the original third-generation fan beam. The flat panel detector also requires cone-beam geometry. The increased detector size and the cone-beam geometry pose various challenges in maintaining image quality, but this discussion is too involved for the purpose of this chapter.

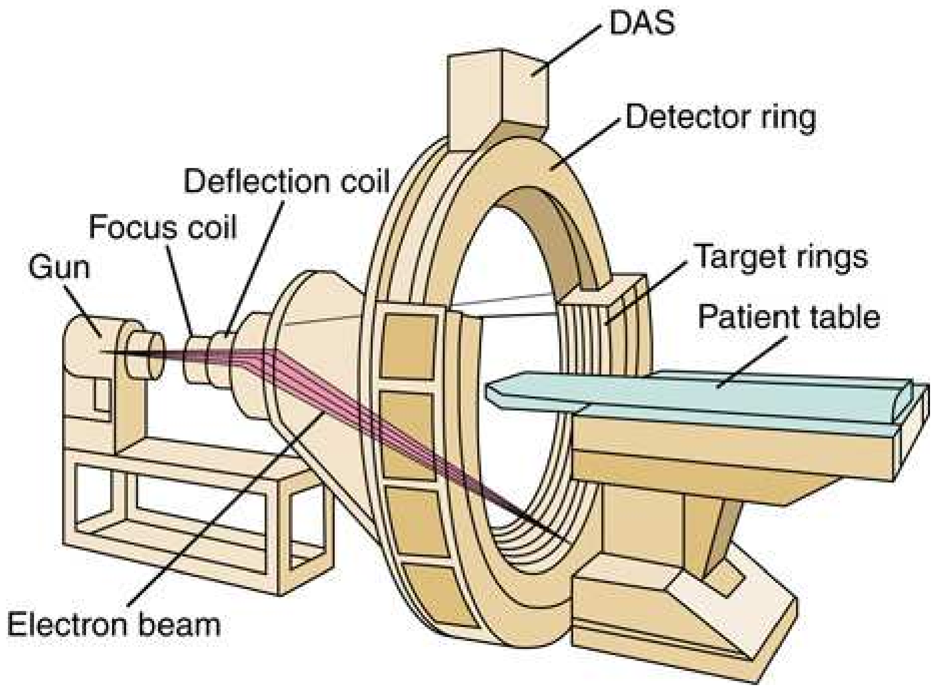


FIG. 25.10 Electron beam CT scanner configuration. X-rays, produced from electron beam, strike four target rings.

The x-rays are produced from an electron beam in a fan beam configuration that strikes stationary tungsten target rings. The parts labeled in the machine are as follows: D A S, detector ring, target rings, patient table, deflection coil, focus coil, gun, and electron beam.

Technical Aspects

The axial images acquired by CT scanning provide information about the positional relationships and tissue characteristics of structures within the section of interest. The computer performs a series of steps to generate one axial image. With the patient and gantry perpendicular to each other, the tube rotates around the patient, irradiating the area of interest. For every position of the x-ray tube, the detectors measure the transmitted x-ray values, convert them into an electrical signal, and relay the signal to the computer. The measured x-ray transmission values are called *projections (scan profiles)*, or *raw data*. When collected, the electrical signals are digitized, a process that assigns a whole number to each signal. The value of each number is directly proportional to the strength of the signal.

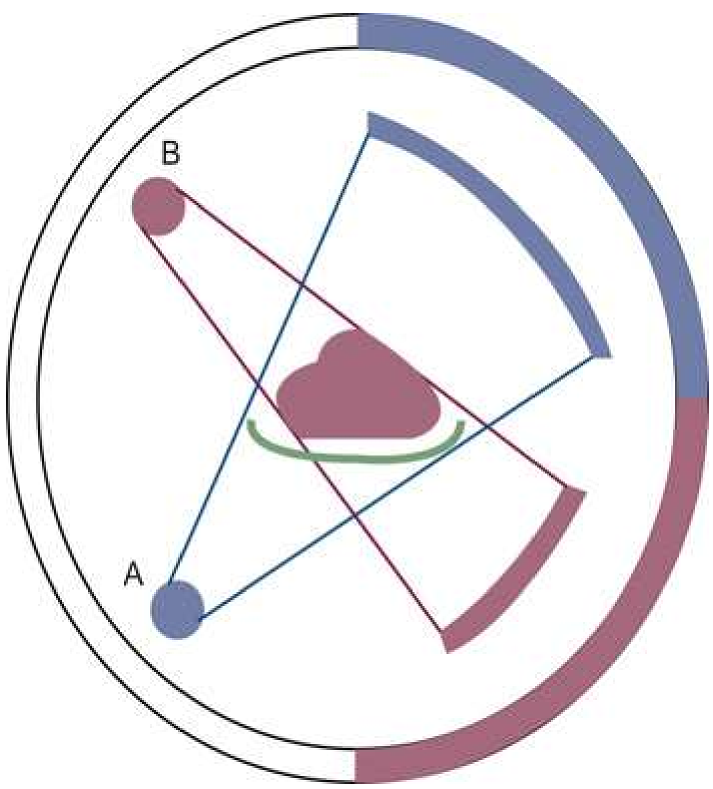


FIG. 25.11 Dual-source CT scanner (DSCT) configuration with tubes A and B rotating at a 90-degree relationship simultaneously. This is considered a sixth-generation scanner.

The digital image is an array of numbers arranged in a grid of rows and columns called a *matrix*. A single square, or picture element, within the matrix is called a *pixel*. The slice thickness gives the pixel an added dimension called the *volume element*, or *voxel*. Each pixel in the image corresponds to the volume of tissue in the body section being imaged. The voxel volume is a product of the pixel area and slice thickness (Fig. 25.12). The *field of view* (FOV) determines the amount of data to be displayed on the monitor.

Each pixel within the matrix is assigned a number that is related to the linear attenuation coefficient of the tissue within each voxel. These numbers are called *CT numbers* or *Hounsfield units*. CT numbers are defined as a relative comparison of x-ray attenuation of a voxel of tissue with an equal volume of water. Water is used as reference material because it is abundant in the body and has a uniform density; water is assigned an arbitrary value of 0. Tissues that are denser than water are given positive CT numbers, and tissues with lower density than water are assigned negative CT numbers. The scale of CT numbers ranges from −1000 (air/gas) to +1000 (dense bone). Average CT numbers for various tissues are listed in Table 25.1.

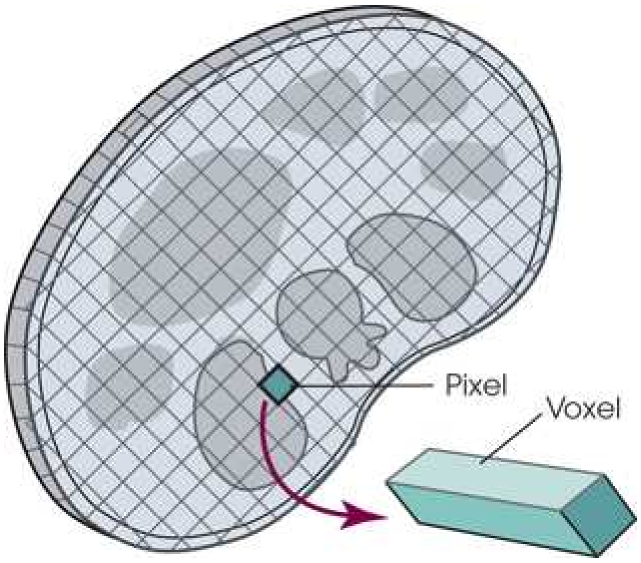


FIG. 25.12 CT image is composed of a matrix of pixels, with each pixel representing a volume of tissue (voxel).

A bean shaped object has a matrix of pixels on it. A few grey colored images are visible on the matrix. A pixel is highlighted in green. An arrow is pointing from the pixel to a green cuboid labeled voxel.

To display the digital image, each pixel within the image is assigned a level of gray. The gray level assigned to each pixel corresponds to the CT number for that pixel. The bit depth determines the number of shades of gray that can be assigned to a pixel. A bit depth of 8 would have 256 shades of gray available, whereas a bit depth of 12 would have 4096 shades.

TABLE 25.1

Average Hounsfield units (HU) for selected substances

Substance	HU
Air	−1000
Lungs	−250 to −850
Fat	−100
Orbit	−25
Water	0
Cyst	−5 to +10
Fluid	0 to +25
Tumor	+25 to +100
Blood (fluid)	+20 to +50
Blood (clotted)	+50 to +75
Blood (old)	+10 to +15
Brain	+20 to +40
Muscle	+35 to +50
Gallbladder	+5 to +30
Liver	+40 to +70
Aorta	+35 to +50
Bone	+150 to +1000
Metal	+2000 to +4000

System Components

The three major components of the CT scanner are shown in Fig. 25.13. Because each component has several subsystems, the following sections provide only a brief description of their main functions.

Computer

The computer provides the link between the CT technologist and the other components of the imaging system. The computer system used in CT has four basic functions: control of data acquisition, image reconstruction, storage of image data, and image display.

Data acquisition is the method by which the patient is scanned. The technologist must select numerous parameters, such as scanning in the conventional or helical mode, before the initiation of each scan. The *data acquisition system (DAS)* is involved in sequencing the generation of x-rays, turning the detectors on and off at appropriate intervals, transferring data, and monitoring the system operation.

The *reconstruction* of a CT image depends on the millions of mathematic operations required to digitize and reconstruct the raw data. This image reconstruction is accomplished using an array processor that acts as a specialized computer to perform mathematic calculations rapidly and efficiently, freeing the host computer for other activities. Currently CT units can acquire scans in less than 1 second and require only a few seconds more for image reconstruction.

FIG. 25.13 Components of a CT scanner: *1,* Computer and operator's console; *2,* gantry; *3,* patient table. Courtesy GE Medical Systems, Waukesha, WI.

An man is sitting in front of two computer screens on a console. A woman is standing looking at him with her arms crossed. A patient is sitting on the table next to the gantry. A woman is talking to the patient.

The *host computer* in CT has limited storage capacity, so image data can be stored only temporarily. Other storage mechanisms are necessary to allow for long-term *data storage* and *retrieval*. After reconstruction, the CT image data can be transferred to another storage medium, such as an optical disk. CT studies can be removed from the limited memory of the host computer and stored independently, a process termed *archiving*.

The reconstructed images are displayed on a monitor. At this point, the technologist or physician can communicate with the host computer to view specific images, post images on a scout, or implement image manipulation techniques such as zoom, control contrast and brightness, and image analysis techniques.

Gantry and Table

The *gantry* is a circular device that houses the x-ray tube, DAS, and detector array. Helical CT units also contain the continuous *slip ring* and high-voltage generator in the gantry. The components housed in the gantry collect the necessary attenuation measurements to be sent to the computer for image reconstruction.

The x-ray tube used in CT is similar in design to the tubes used in conventional radiography; however, it is specially designed to handle and dissipate excessive heat created during a CT examination. The newest CT x-ray tubes consist of a rotating anode to increase heat dissipation, a large metal anode, and a metal housing. Many CT x-ray tubes can handle around 8 million heat units (MHU), whereas advanced CT units can tolerate 20 MHU.

The detectors in CT function as image receptors. A detector measures the amount of radiation transmitted through the body and converts the measurement into an electrical signal proportional to the radiation intensity. Some current detectors are made of gadolinium oxysulfide (GOS) ceramic scintillation (solid-state) detectors.

The gantry can be tilted forward or backward up to 30 degrees to compensate for body part angulation. The opening within the center of the gantry is termed the *aperture*. Most apertures are about 28 inches (71.1 cm) wide to accommodate a variety of patient sizes as the patient table advances through it. To accommodate larger patients and for interventional applications, a 34-inch (85-cm) aperture is available.

For certain head studies, such as studies of facial bones, sinuses, or the sella turcica, a combination of patient positioning and gantry angulation results in a *direct coronal* image of the body part being scanned. Fig. 25.14 shows a typical direct coronal image of the paranasal sinuses.

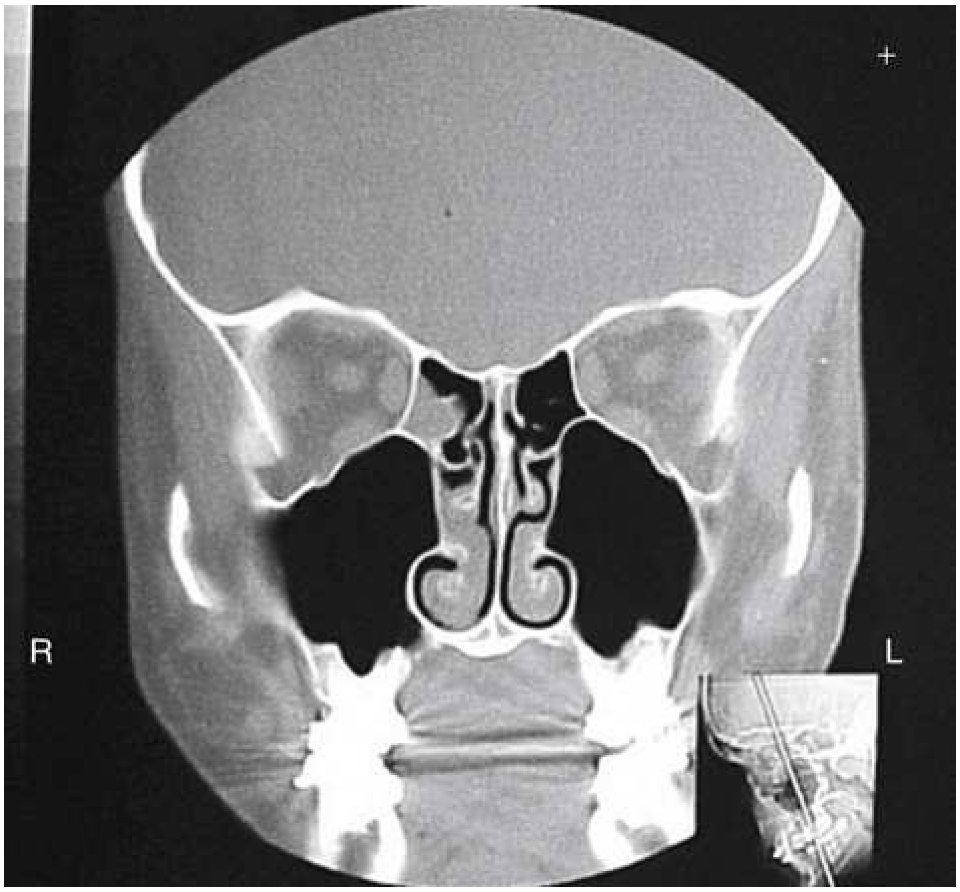


FIG. 25.14 Direct coronal of paranasal sinuses.

A direct coronal image of the paranasal sinuses shows two dark regions on either side in the middle. The surrounding area appears radiopaque. Another image at the bottom right shows a slanting vertical line passing across the image.

The *table* is an automated device linked to the computer and gantry. It is designed to move in increments *(index)* according to the scan program. The table is an extremely important part of a CT scanner. Indexing must be accurate and reliable, especially when thin slices (1 or 2 mm) are taken through the area of interest. Most CT tables can be programmed to move in or out of the gantry, depending on the examination protocol and the patient.

CT tables are made of a low-density carbon fiber composite, both of which support the patient without causing image artifacts. The table must be very strong and rigid to handle patient weight and at the same time maintain consistent indexing. All CT tables have a maximum patient weight limit; this limit varies by manufacturer from 450 to 650 lb. (204 to 295 kg). Exceeding the weight limit can cause inaccurate indexing, damage to the table motor, and even breakage of the tabletop, which could cause serious injury to the patient.

Accessory devices can be attached to the table for various uses. A special device called a *cradle* is used for head CT examinations. The head cradle helps hold the head still; because the device extends beyond the tabletop, it minimizes artifacts or attenuation from the table while the brain is being scanned. It can also be used in positioning the patient for direct coronal images.

Operator’s Console

The *operator’s console* (Fig. 25.15) is the area in which the technologist controls the scanner. A typical console is equipped with a keyboard for entering patient data and a graphic monitor for viewing the images. Other input devices, such as a touch display screen and a computer mouse, may also be used. The operator’s console allows the technologist to control and monitor numerous scan parameters. Imaging technique factors, slice thickness, table index, and reconstruction algorithm are some of the scan parameters that are selected at the operator’s console.

Before starting an examination, the technologist must enter the patient information. Usually, the first scan program selected is the scout program, from which the radiographer plans the sequence of axial scans. An example of a typical scout image is shown in Fig. 25.3. The operator’s console is also the location of the monitor, where image manipulation takes place. Most scanners display the image on the monitor in a 1024 matrix interpolated by the computer from the 512 reconstructed images.

One of the most important functions of the operator’s console is to initiate the process to store or archive the images for future viewing. Most modern imaging departments now have picture archiving and communications systems (PACS) that are used to store and retrieve soft copy (digital) images.

Other Components

Display monitor

For the CT image to be displayed on a monitor in a recognizable form, the digital CT data must be converted into a *grayscale image*. This process is achieved by the conversion of each digital CT number in the matrix to an analog voltage. The brightness values of the grayscale image correspond to the pixels and CT numbers of the digital data they represent.

FIG. 25.15 CT operator's console, workstation for three-dimensional image manipulation, and power injector control panel.

A workstation console is equipped with a keyboard and a graphic monitor. Other input devices, such as a touch display screen and a computer mouse are next to it. The gantry is on the other side of a glass wall.

Because of the digital nature of the CT image data, image manipulation can be performed to enhance the appearance of the image. One of the most common image processing techniques is called *windowing*, or *gray-level mapping*. This technique allows the technologist to alter the contrast of the displayed image by adjusting the window width (WW) and window level (WL). The *window width* is the range of CT numbers that are used to map signals into shades of gray. Basically, the window width determines the number of gray levels to be displayed in the image, controlling contrast resolution. A narrow window width means that there are fewer shades of gray, resulting in higher contrast. Likewise, a wide window width results in more shades of gray in the image, or a longer gray scale. The *window level* determines the midpoint of the range of gray levels to be displayed on the monitor. It is used to set the center CT number within the range of gray levels being used to display the image and controls image brightness. The window level should be set to the CT number of the tissue of interest, and the window width should be set with a range of values that would optimize the contrast between the tissues in the image. Fig. 25.16 shows an axial image seen in two different windows: a standard abdomen window and a bone window adjusted for the spine.

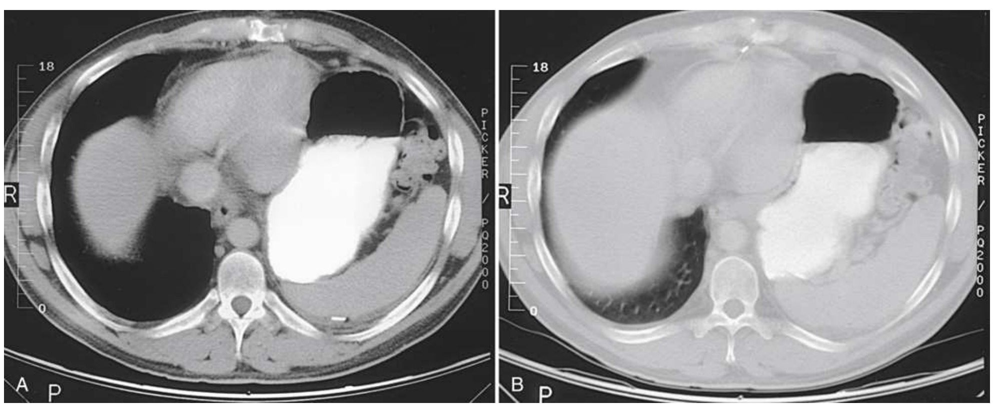


FIG. 25.16 (A) Abdominal image, soft tissue window. (B) Abdominal image, bone window.

The gray level of any image can be adjusted on the monitor to compensate for differences in patient size and tissue densities, or to display the image as desired for the examination protocol. Examples of typical window width and level settings are listed in Table 25.2. These settings are averages and usually vary by vendor and radiologist's preference. The level, although an average, is approximately the same as the CT numbers expected for the tissue densities.

TABLE 25.2

Typical window settings

CT examination	Width	Center (level)
Brain	190	50
Skull	3500	500
Orbits	1200	50
Abdomen	400	35
Liver	175	45
Mediastinum	325	50
Lung	2000	−500
Spinal cord	400	50
Spine	2200	400

Workstation for image manipulation and multiplanar reconstruction

Another advantage of the digital nature of the CT image is the ability to reformat the image data into coronal, sagittal, or oblique body planes without additional radiation to the patient. Image reformation in various planes is accomplished by stacking multiple contiguous axial images, creating a volume of data. Because the CT numbers of the image data within the volume are already known, a sectional image can be generated in any desired plane by selecting a particular plane of data. This postprocessing technique is termed *multiplanar reconstruction* (MPR). A coronal reformation from image data is shown in Figs. 25.17 and 25.18. Fig. 25.17 shows a coronal image of the abdomen (note the liver lesion), and Fig. 25.18 shows coronal images of the lungs displayed with a lung window width and window level. MPRs may also be performed in what is referred to as *curved planar reformations* to visualize structures better. Fig. 25.19 shows an axial image and oblique reformation of the mandible from the axial images. Other postprocessing techniques used today are three-dimensional imaging, surface rendering, and volume rendering (VR).

FIG. 25.17 Coronal reformatted image produced from axial images of abdomen and pelvis. Courtesy Philips Medical Systems.

FIG. 25.18 Coronal reformatted images produced from axial low-dose lung nodule study of the chest. Scans produced with Philips Brilliance iCT. Courtesy Philips Medical Systems.

A coronal reformatted image on the left shows a radiopaque region in the middle and the medial side of the lungs. A coronal reformatted image on the right shows radiolucent lungs surrounded by radiopaque area.

Diagnostic Applications

The original CT studies were used primarily for diagnosing neurologic disorders. As scanner technology advanced, the range of applications was extended to other areas of the body. The most commonly requested procedures involve the head, chest, abdomen, and pelvis. CT is the examination of choice for head trauma; it clearly shows skull fractures and associated subdural hematomas. CT examinations of the head are one of the first exams performed on patients being evaluated for stroke or cerebrovascular accidents where evidence of hemorrhage must be ruled out. CT imaging of the central nervous system can show infarctions, hemorrhage, disk herniations, craniofacial and spinal fractures, tumors, and cancers. CT imaging of the body excels at differentiating or distinguishing soft tissue structures within the chest, abdomen, and pelvis. Included in the numerous abnormalities shown in this region, are metastatic lesions, aneurysms (Fig. 25.20), abscesses, and fluid collections from blunt trauma.

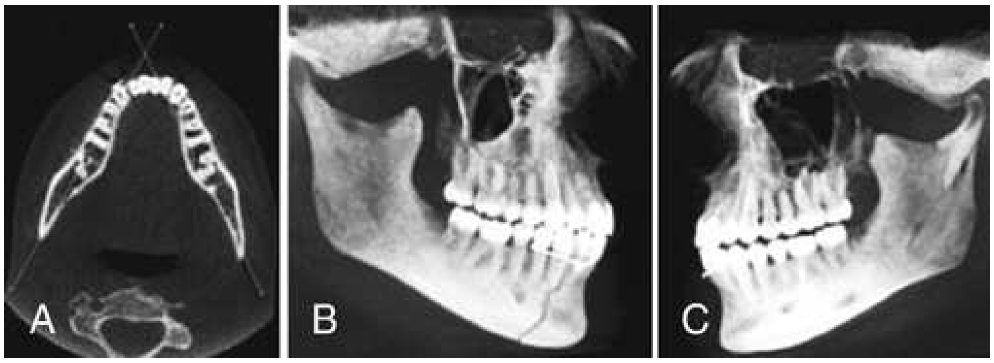


FIG. 25.19 (A) Axial mandible showing reformatted planes. (B) Oblique MPR of left mandible (note fracture). (C) Oblique MPR of right mandible. Courtesy Philips Medical Systems.

(A) A C T image shows the mandible. The outlines of the teeth appear radiopaque. (B) A C T image shows the oblique left mandible. The skull appears grey and the teeth appear radiopaque. (C) A C T image shows the oblique right mandible. The skull appears grey and the teeth appear radiopaque.

FIG. 25.20 Three-dimensional abdominal aortic aneurysm (AAA).

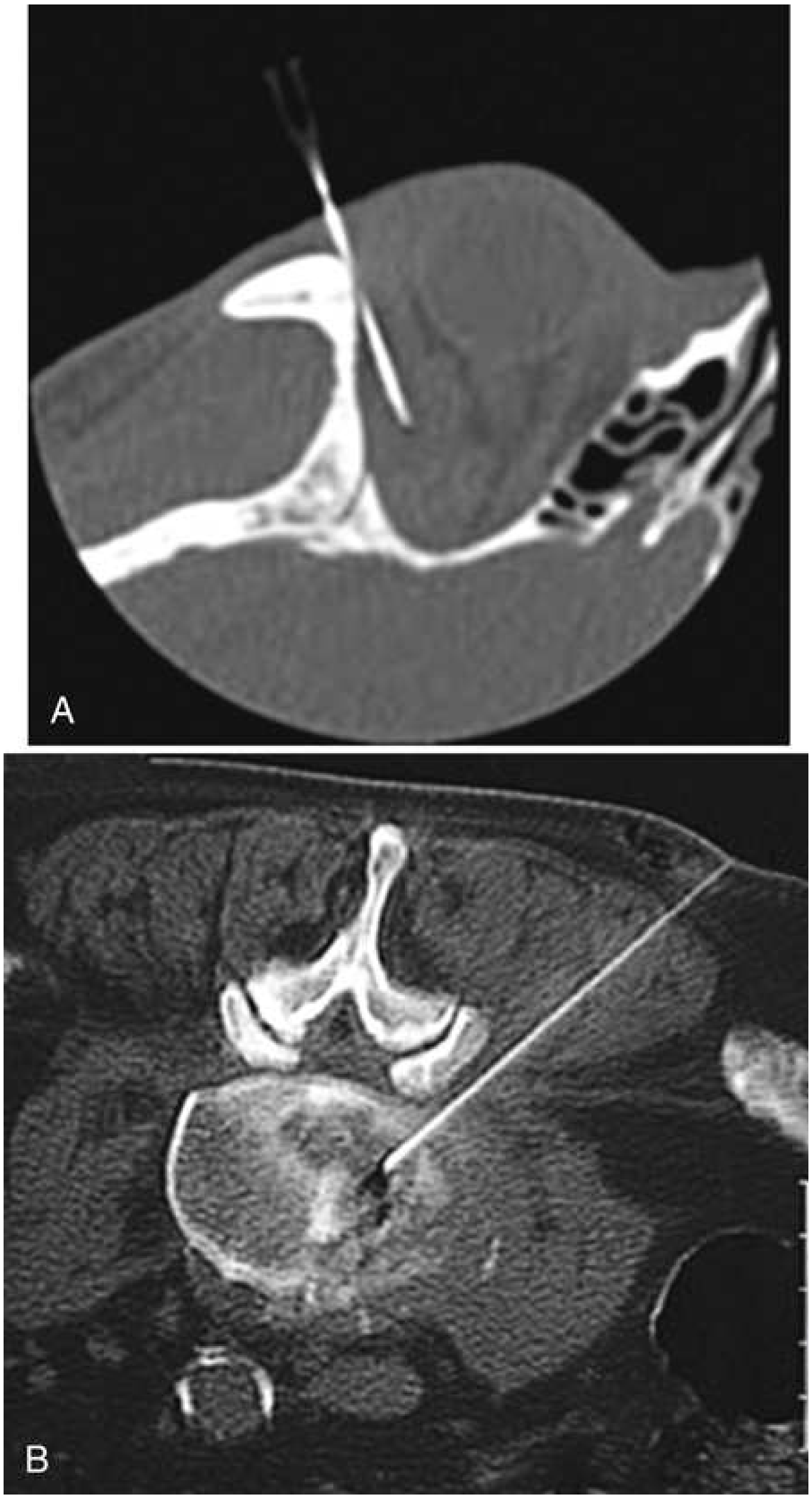


FIG. 25.21 (A) Needle biopsy of orbital mass. (B) Needle biopsy of infectious spondylitis of lumbar vertebral body.

CT is also used for numerous interventional procedures, such as abscess drainage, tissue biopsy (Fig. 25.21), and cyst aspiration. In addition, CT is used during radiofrequency ablations and cryoablations of tumors. Fig. 25.22 shows numerous structures and pathologic conditions identified by CT. Fig. 25.23 shows a liver lesion before radiofrequency ablation, during the procedure, and after ablation.

For any procedure, a protocol is required to maximize the amount of diagnostic information available. Specific examination protocols vary according to the needs of different medical facilities and physicians.

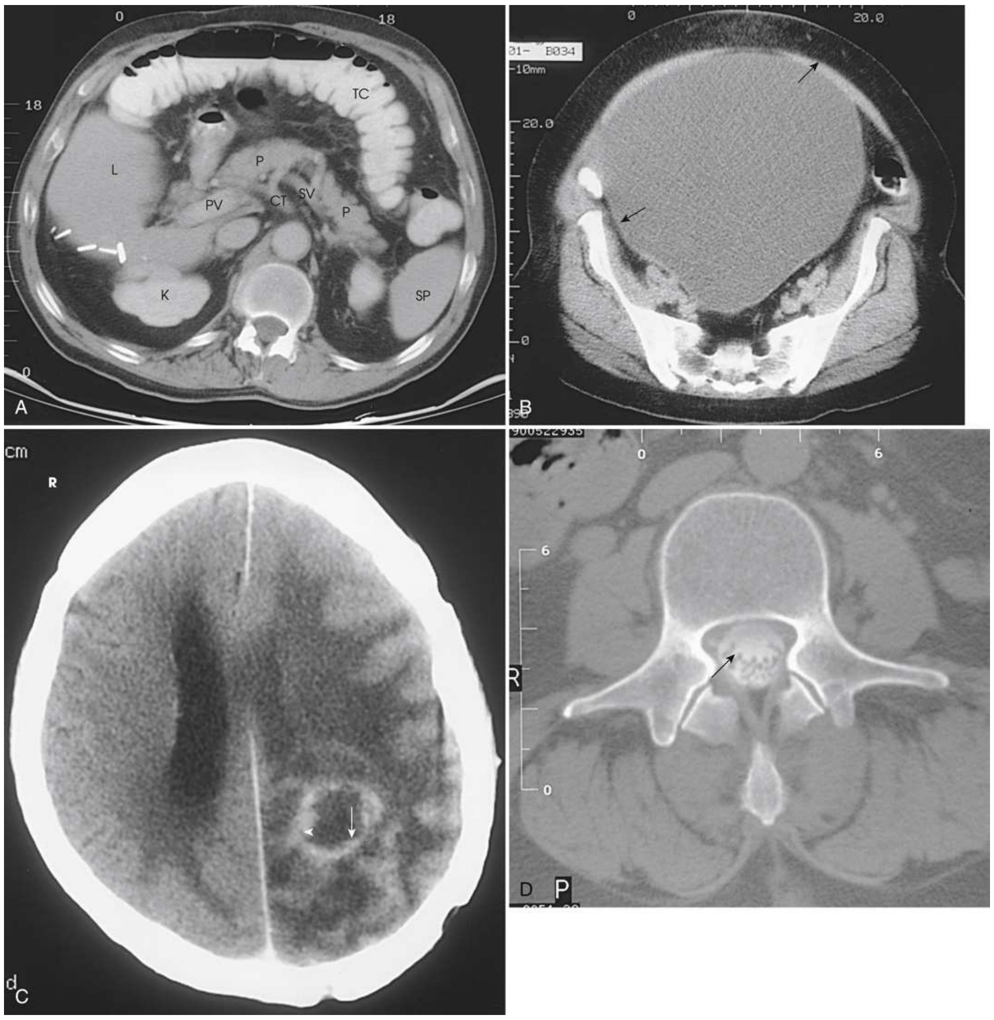


FIG. 25.22 (A) Abdominal image showing transverse colon *(TC)* with air-fluid levels; liver *(L)*, pancreas *(P)*, spleen *(SP)*, kidney *(K)*, portal vein *(PV)*, celiac trunk *(CT)*, and splenic veins *(SV)* are shown with contrast medium. Surgical clips are seen in posterior liver. (B) Abdominal image showing extremely large ovarian cyst *(arrows)*. (C) Brain image showing parietooccipital mass *(arrow)* with characteristic IV contrast ring enhancement *(arrowhead)*. (D) Image of L3 after myelography showing contrast material in thecal sac *(arrow)*.

(A) A C T image of the abdomen shows the colon. The parts labeled as liver, pancreas, spleen, kidney, portal vein, celiac trunk, and splenic veins. A few radiopaque clips are on the liver. (B) A C T image of the abdomen shows a vast grey area in the middle. It is indicated by two arrows. The region around appears radiolucent. (C) A C T image of the brain shows a dark region on the left side. It is indicated by a white arrow. (D) A C T image shows a contrast material along the borders of the thecal sac. It is indicated by a black arrow.

Contrast Media

A contrast medium is used in CT examinations to help distinguish normal anatomy from pathology and to make various disease processes more visible. A contrast agent can be administered intravenously, orally, or rectally. In general, intravenous (IV) contrast media are the same as media used for excretory urograms. Most facilities use non-ionic contrast material versus ionic contrast material for these studies because of the low incidence of reaction and known safety factors associated with non-ionic contrast material. IV contrast media is useful for demonstrating tumors within the head; Fig. 25.24 shows a brain scan with and without contrast media. The anterior lesion is evident in the unenhanced scan. In the enhanced scan, the tumor shows characteristic ring enhancement typical of specific tumors seen in CT scans. IV contrast media is also used to visualize vascular structures in the body.

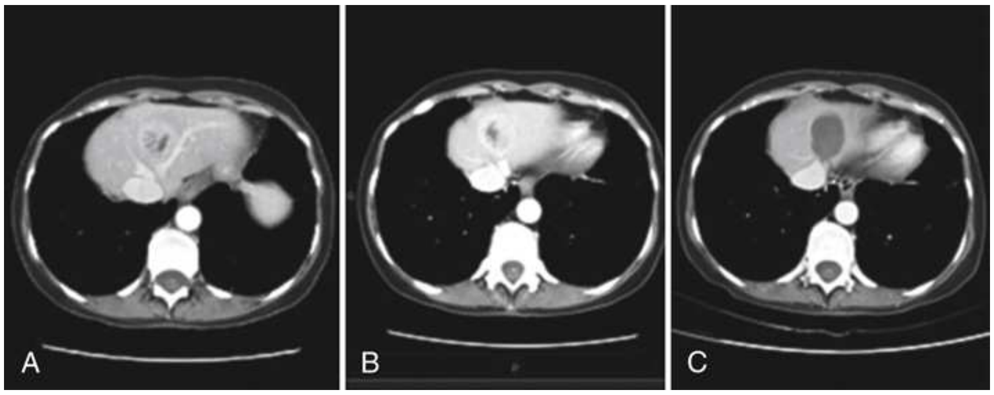


FIG. 25.23 Low-dose axial CT images from radiofrequency ablation study. Scans are before study (A), during study (B), and after study (C). Courtesy Philips Medical Systems.

(A) A C T image shows a liver lesion before radiofrequency ablation. A bulb like structure is projected from the liver. (B) A C T image shows a liver lesion during the procedure. The bulb like region is smaller. (C) A C T image shows a liver lesion after ablation. A grey region is on the liver.

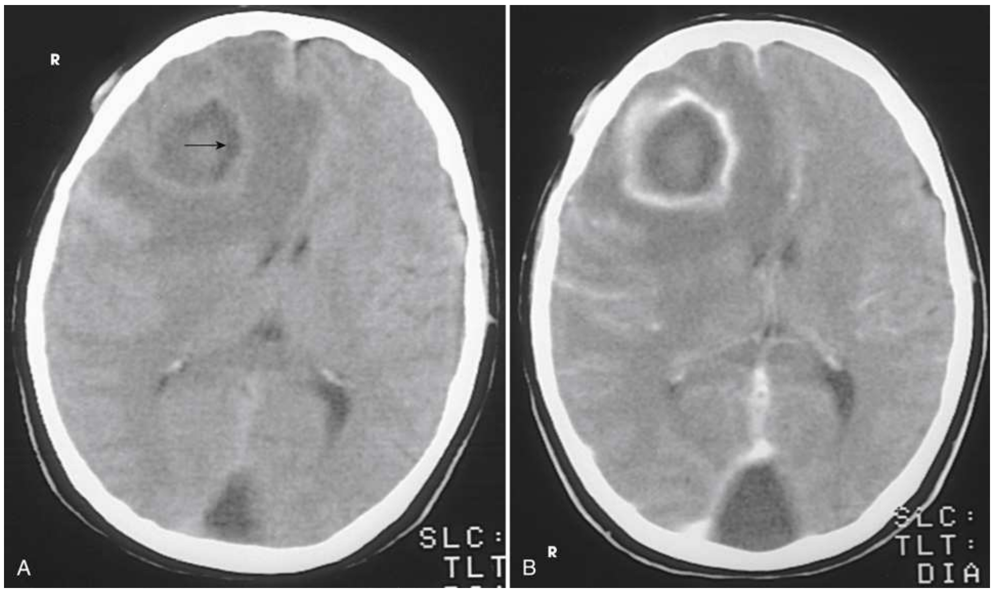


FIG. 25.24 (A) Brain image without IV contrast agent showing a low-density lesion *(arrow)*. (B) Brain image with IV contrast agent demonstrating ring enhancement.

(A) A C T image of the brain shows a light grey color region on the left. It is indicated by a black arrow. (B) A C T image of the brain shows a dark grey colored region on the left surrounded by a white region.

IV contrast media should be used only with the radiologist's approval and after careful consideration of the patient's medical and allergy history. The patient's renal function must be evaluated before iodinated contrast material is given. Creatinine (Cr) level and glomerular filtration rate (GFR) are the most common laboratory values used to determine renal function. Many CT examinations can be performed without IV contrast material if necessary, but the amount of diagnostic information available may be limited.

Oral contrast media can be used for imaging the abdomen. When given orally, the contrast material in the gastrointestinal tract helps differentiate between loops of bowel and other structures within the abdomen. An oral contrast medium is generally a 2% barium mixture. The low concentration prevents contrast artifacts but allows good visualization of the stomach and intestinal tract. An iodinated contrast material such as oral Hypaque diatrizoate meglumine or iohexol can be used, but it must be mixed at low concentrations to prevent contrast artifacts. A rectal contrast medium can be requested as part of an abdominal or a pelvic protocol when considering specific pathology. Usually mixed in the same concentration as the oral contrast medium, the rectal contrast material is useful for showing the distal colon relative to the bladder and other structures of the pelvic cavity. Water may also be given orally as a contrast medium, depending on the area of interest and pathologic indications.

Power Injector Use for Administering Intravenous Contrast Media

Power injector use in CT examinations became mandatory when the first helical CT scanners were introduced. Faster delivery of IV contrast media became necessary with the reduced scan times used in helical CT. The advantage of power injector use is that a bolus injection of contrast medium can be delivered quickly, which provides for better contrast enhancement of structures and better opacification of the blood vessels. The use of power injectors also provides a means to reproduce examination parameters and allows different vascular phases to be captured.

Equipment

Power injector equipment includes an injector assembly that is either ceiling mounted next to the scanner or on a movable stand. The injector head typically has two syringes, but some models may have only a single-syringe delivery system. If the injector head is a double-syringe system, each of the syringe controls is color-coded. The same color-coding system is shown on the injector control module that is next to the CT scan console. The injector must be programmed at the control module, but operational buttons are located on the injector head as well.

The control module for the system is typically placed on or near the operator console of the scanner. Each injector system has controls for flow rate of the injection, pounds per square inch (psi) of pressure used for the injection, amount of contrast medium to be delivered, and time delays. Dual-head systems have dual sets of controls for each syringe. Dual-head systems are used when the radiologist requests a saline flush to follow the contrast injection.

Special pressure syringes and pressure tubing must be used when injecting. The pressure injections must be closely monitored, and care must be taken that no air is in the syringe or tubing. The pressure syringes have oval etchings on the side of the syringe as a safety feature. If the syringe is full of contrast material, the oval etchings appear round when viewed through the syringe, owing to light refraction. If no fluid is present, the etchings remain oval in shape (Fig. 25.25).

Correct IV catheter size and placement are vital to the success of the CT examination. Catheters are typically placed in the arm veins in the antecubital fossa, but veins lower in the forearm can also be used. Small veins should be avoided because of the pressures used when injecting. Catheter size depends on the type of CT examination being performed. A routine, non-CTA examination typically uses a 22-gauge IV catheter with an injection rate of 2 mL/s. A CTA study requires a larger bore 18-gauge to 20-gauge IV catheter with an injection rate of 4 to 7 mL/s.

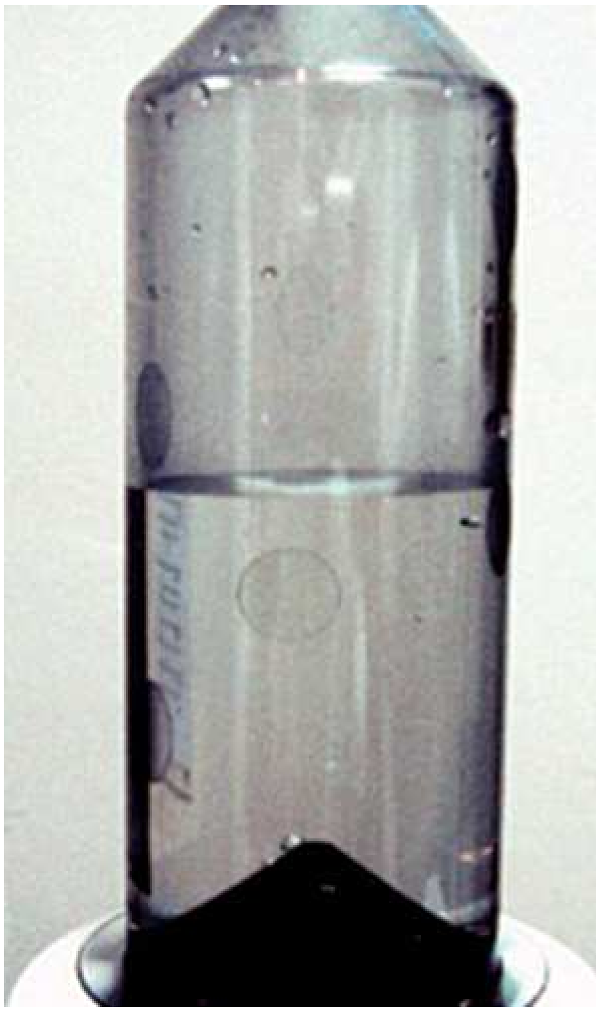


FIG. 25.25 CT pressure syringe partially filled with contrast material. Note oval etching above fluid level and round etching below fluid level.

Patient Care and Injection Safety

Patient positioning should be considered when placing the IV line. For many CT examinations, the patients must keep their arms resting above the head on a pillow or sponge during the examination. Care should be taken to make the patients as comfortable as possible while keeping their arms as straight as possible. The IV catheter should not be placed in a site that would be bent when the patient elevates the arms above the head.

Proper placement of the IV catheter should always be confirmed with a hand test injection of saline that mimics the injection rate of the examination. The ease of injection and the injection site should be observed and palpated during the test injection to confirm patency of the vein. Patients should be instructed to notify the CT technologist immediately if they experience any pain or discomfort at the injection site during the procedure.

All connections between the IV catheter injector tubing and syringe should be checked and tightened to prevent air from entering the IV line. The pressure syringe should be checked for air bubbles, and the etchings on the side of the syringe should be confirmed as round. The injected head and syringe should be pointed down to ensure that any potential air bubbles rise back into the syringe base and away from the IV line.

The patient should be instructed about the timing of the scan, the injection, and sensations of warmth and an odd taste caused by the dilation of the blood vessels. These sensations should be discussed with the patient, and the patient should be reassured that these are normal and fade quickly. The intensity of warmth and taste intensifies as the injection amount and rate increase, so these are more intense for a patient having a CTA study.

If the patient complains of discomfort at or near the injection site, the injection should be terminated, and the patient should be checked for a contrast extravasation (contrast material leaking out of the vein). If there are any changes in the appearance of the patient's arm (swelling, discoloration), the radiologist should be notified immediately. The CT technologist should be familiar with the department policy for the treatment of extravasation, which typically includes cold or hot compresses and elevation of the arm.

Factors Affecting Image Quality

In CT, the technologist has access to numerous scan parameters that can have a dramatic effect on image quality. The five main factors contributing to image quality are spatial resolution, contrast resolution, temporal resolution, noise, and artifacts.

Spatial Resolution

Spatial resolution is determined by the degree of blur, or the ability to see the difference between two objects that are close together. The method most commonly used to evaluate spatial resolution is the number of line pairs per centimeter (lp/cm). The scan parameters that affect spatial resolution include scanning section thickness, display FOV, matrix, reconstruction slice thickness, and algorithm/kernel. The detector aperture width is the most significant geometric factor that contributes to spatial resolution.

Contrast Resolution

Contrast resolution is the ability to differentiate between small differences in density within the image. Currently tissues with density differences of less than 0.5% can be distinguished with CT. The scan parameters that affect contrast resolution are slice thickness, reconstruction algorithm, image display (window width), and x-ray beam energy. The size of the patient and the detector sensitivity also have a direct effect on contrast resolution.

Temporal Resolution

Temporal resolution is the ability of the CT system to freeze any motion of a scanned object. It is the shortest amount of time needed to acquire a complete data set. The use of CT in cardiac imaging requires high (shortest time) temporal resolution to decrease heart motion. Factors that improve temporal resolution include multidetector CT (i.e., 64-, 128-, 256-, 320-slice), tube/gantry rotation time, and the development of dual-source CT.

Noise

The most common cause of *noise* in CT is *quantum noise*. This type of noise arises from the random variation in photon detection. Noise in a CT image primarily affects contrast resolution. As noise increases in an image, contrast resolution decreases. Noise gives an image a grainy quality or a mottled appearance. The following scan parameters may influence noise: matrix size, slice thickness, x-ray beam energy, and reconstruction algorithm. Scattered radiation and patient size also contribute to the noise of an image. New technology is available to prevent scatter radiation from hitting the detector. Fig. 25.26 shows the ClearRay Anti-Scatter Collimator (Philips Medical Systems), which greatly reduces noise and increases contrast resolution.

Artifacts

Metallic objects, such as dental fillings, pacemakers, and artificial joints, can cause starburst or *streak artifacts*, which can obscure diagnostic information. Dense residual barium from fluoroscopy examinations can cause *artifacts* similar to those caused by metallic objects. Many CT departments do not perform a CT examination in a patient until several days after barium studies to allow the body to eliminate the residual barium from the area of interest. Large differences in tissue densities of adjoining structures can cause artifacts that detract from image quality. Bone-soft tissue interfaces, for example, occur with the skull and brain, and together often cause streak or shadow artifacts on CT images; these artifacts are referred to as *beam hardening* (Fig. 25.27).

New software developments have greatly improved image quality and reduced artifacts. For example, interactive reconstruction methods, dual energy, metal artifact reduction algorithms, and artificial intelligence deep learning have greatly improved image quality not only at a lower dose but also with improved image resolution. Fig. 25.28 is an example of a metal artifact reduction algorithm in a tool used on Philips Medical CT systems referred to as orthopedic metal artifact reduction (OMAR).

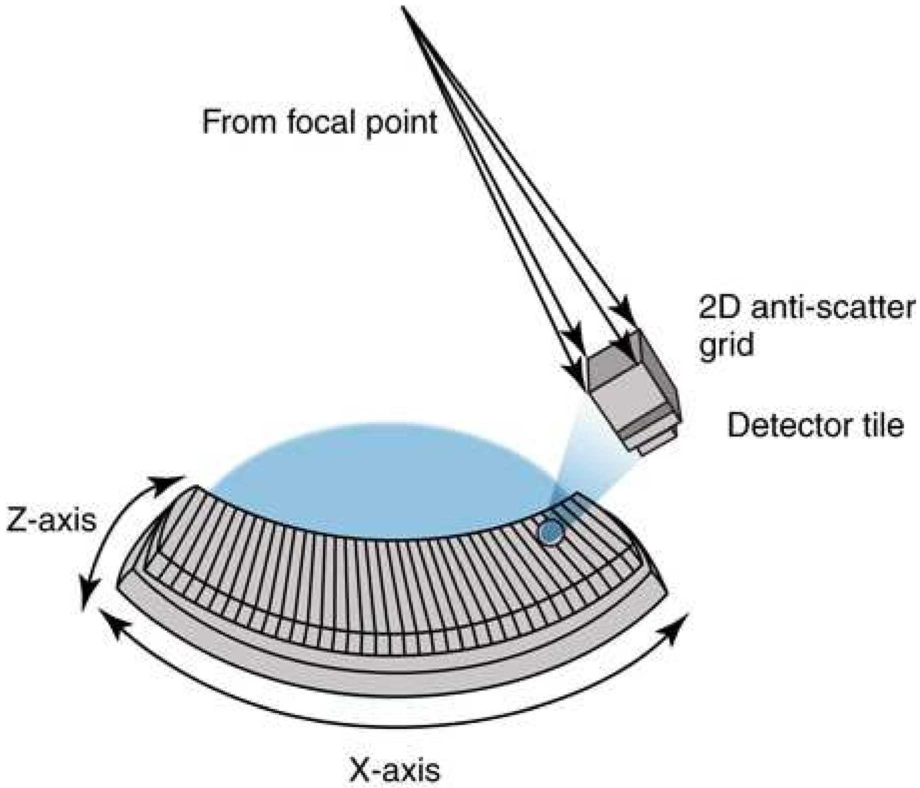


FIG. 25.26 Philips Medical Systems 2D Anti-Scatter Grid, which can be focused for true three-dimensional cone-beam geometry. Scatter reduction improves low contrast resolution. Courtesy Philips Medical Systems.

A Philips medical systems 2 D anti-scatter grid is projected on an arc with a x-axis and a z-axis. A blue colored circular region is on the arc. The parts labeled on the grid are from focal point, 2 D anti-scatter grid and detector line.

Other Factors

Patient factors

Patient factors also contribute to the quality of an image. If a patient cannot or will not hold still, the scan is likely to be nondiagnostic. Body size also can have an effect on image quality. Large patients attenuate more radiation than small patients; this can increase image noise, detracting from overall image quality. An increase in milliampere-seconds (mAs) is usually required to compensate for large body size. This increase results in a higher radiation dose to the patient. Image quality factors under technologist control include slice thickness, *scan time*, *scan diameter*, and patient instructions. Slice thickness is usually dictated by image *protocol.* As in tomography, the thinner the slice thickness, the better the image-recorded detail. Thin-section CT scans, often referred to as *high-resolution scans*, are used to show structures better (Fig. 25.29). However, thinner slices require more mA, increasing the dose to the patient.

FIG. 25.27 Streaking through the posterior fossa represents beam-hardening artifact. Normal appearance of the brain. *1,* Sphenoid sinus; *2,* trigeminal ganglion; *3,* fourth ventricle; *4,* temporal lobe; *5,* pons; *6,* middle cerebellar peduncle; *7,* cerebellar hemisphere.

As in conventional radiography, patient instructions are a crucial part of a diagnostic examination. Describing the procedure in layman's terms helps the patient understand what to expect during the exam and increases the level of compliance.

Scan times

Scan times are usually preselected by the computer as part of the scan protocol, but they can be altered by the technologist. When selecting a scan time, the technologist must take into account possible patient motion, such as inadvertent body movements, breathing, or peristalsis. A good guideline is to choose a scan time that would minimize patient motion while providing a quality diagnostic image. When it is necessary to scan an uncooperative patient quickly, using the shortest scan time possible may allow the technologist to complete the examination, although the quality of the images obtained is likely to be compromised.

FIG. 25.28 Philips Medical Systems iDos4 and OMAR techniques to reduce noise and artifacts on patient with a hip pinning. Courtesy Philips Medical Systems.

Scan diameter

The amount of the detector utilized for imaging is referred to as the scan FOV (SFOV). When imaging a pediatric patient, the entire detector does not have to be active for such a small patient. The image that appears on the monitor depends on the *display FOV (DFOV)*. The technologist can adjust the DFOV to include the entire cross section of the body part being scanned or to include only a specified region within the part. For most head, chest, and abdomen examinations, the selected scan diameter includes all anatomy of the body part to just outside the skin borders. Certain examinations may require the DFOV to be reduced to include specific anatomy, such as the sella turcica, sinuses, one lung, mediastinal vessels, suprarenal glands, one kidney, or the prostate.

Special Features

Dynamic Scanning

One advantage of CT is that data can be obtained for image reconstruction by the computer at a later time. The scanner can be programmed to scan through an area rapidly. In this situation, raw data are saved, but image reconstruction after each scan is bypassed to shorten scan time.

Dynamic scanning is based on the principle that after contrast agent administration, different structures enhance at different rates. Dynamic scanning can consist of rapid sequential scanning at the same level to observe contrast material filling within a structure, such as is performed when evaluating enhancement within a tumor. Another form is incremental dynamic scanning, which consists of rapid serial scanning at consecutive levels during the bolus injection of a contrast medium, such as is performed when evaluating the patient for aortic aneurysm or perfusion imaging on stroke patients.

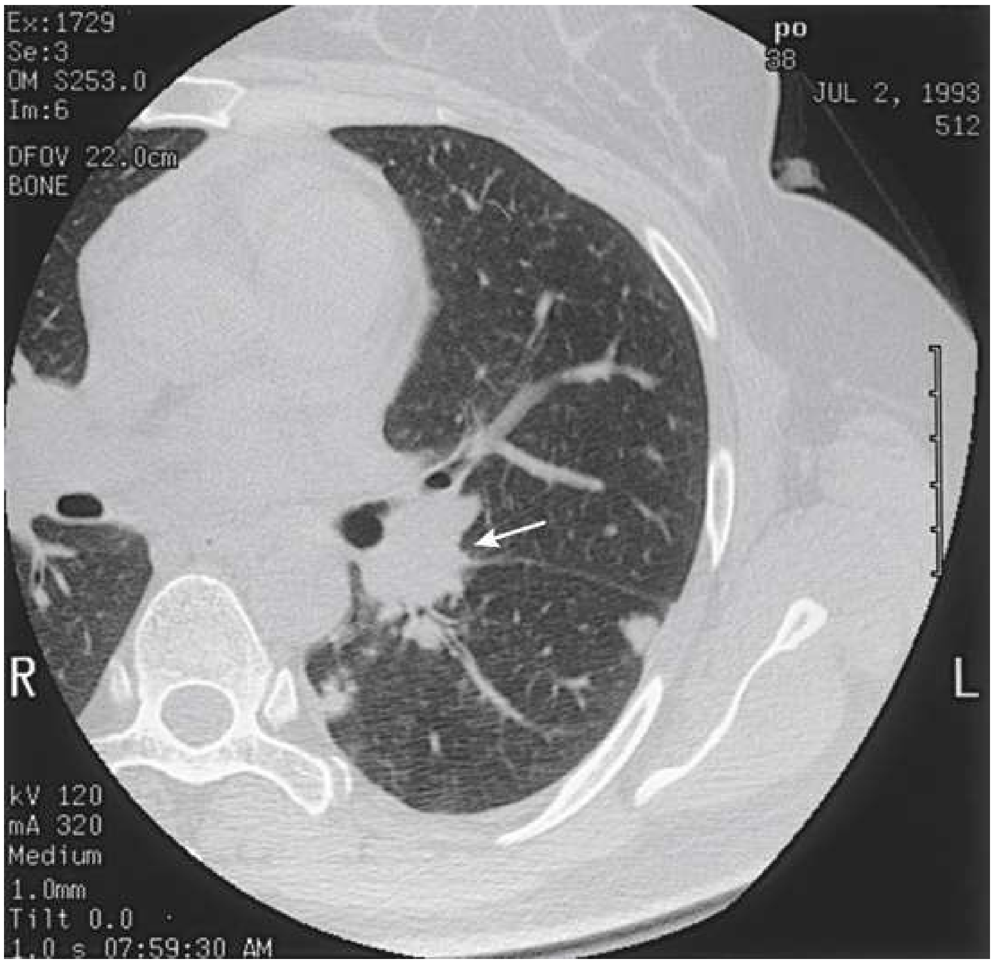


FIG. 25.29 High-resolution 1-mm slice using edge enhancement algorithm, showing nodule in left lung *(arrow)*.

Single Slice Spiral or Helical Computed Tomography

Single slice *spiral CT* (SSCT) and *helical CT* are terms used to describe a method of data acquisition in CT. During spiral CT, the gantry is rotating continuously while the table moves through the gantry aperture. The continuous gantry rotation combined with the continuous table movement forms the spiral path from which raw data are obtained one slice per revolution (Fig. 25.30). Slip-ring technology has made continuous rotation of the x-ray tube possible by eliminating the large high-voltage cables between the x-ray tube and the generators.

One of the unique features of spiral CT is that it scans a volume of tissue rather than a group of individual slices. This method makes it extremely useful for the detection of small lesions because an arbitrary slice can be reconstructed along any position within the volume of raw data. In addition, because a volume of tissue is scanned in a single breath, respiratory motion can be minimized. For a volume scan of the chest, such as shown in Fig. 25.31, the patient is instructed to hold the breath, and a tissue volume of 24 mm is obtained in a 5-second spiral scan. Two of the resultant images show a small lung nodule without breathing interference of *image misregistration;* a three-dimensional reconstruction of the lung clearly shows the pathologic condition. Spiral CT is especially useful when scanning uncooperative or combative patients, patients who cannot tolerate lying down for long periods, and patients who cannot hold still, such as pediatric patients or trauma patients. The use of spiral CT may decrease the amount of contrast medium necessary to visualize structures, making the examination safer and more cost-effective.

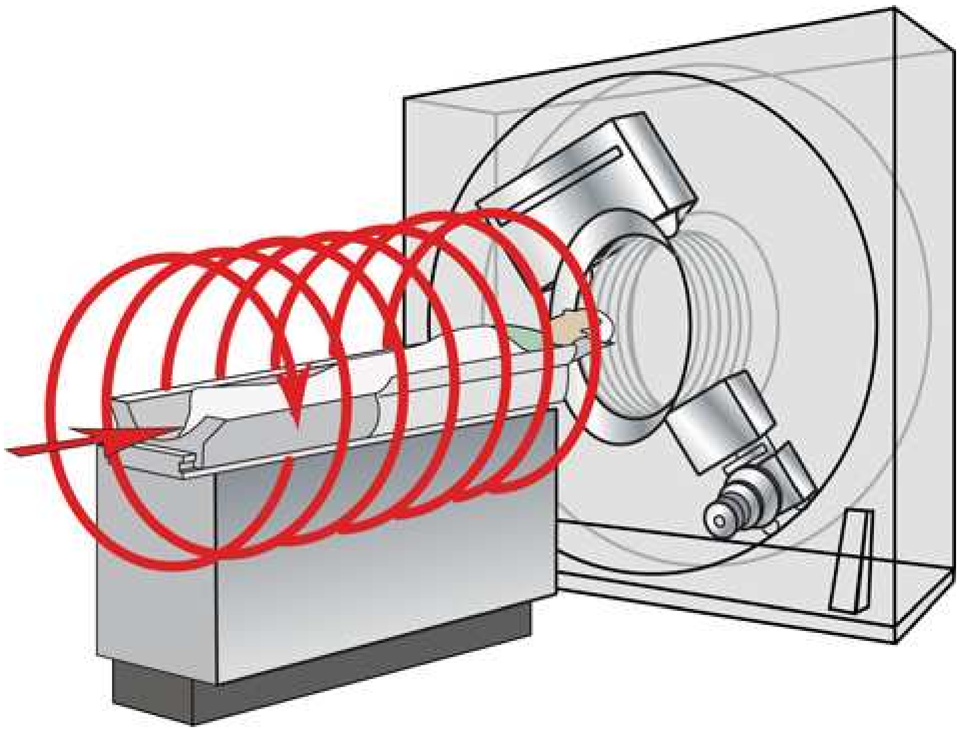


FIG. 25.30 Continuous gantry rotation combined with continuous table rotation, forming a spiral path of data.

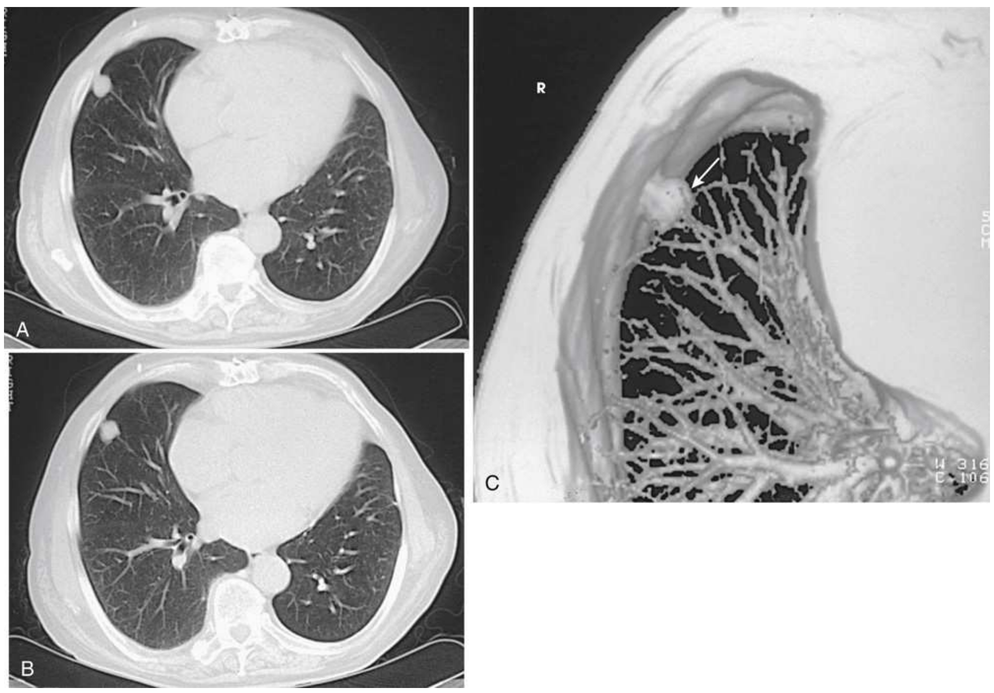


FIG. 25.31 (A and B) Spiral images of lung showing lung nodule and associated vasculature. (C) Three-dimensional reconstruction of lung nodule *(arrow)* after spiral scan. Courtesy Siemens Medical Systems, Iselin, NJ.

(A) and (B) A C T scan of the chest shows a pale white nodule between the lungs. (C) A three-dimensional image shows a white nodular region along the border of the grey region. There are many grey colored branches.

Multislice Spiral or Helical Computed Tomography

Multislice helical CT (MSHCT) or *multidetector CT (MDCT)* systems incorporate a detector array that contains multiple rows of detector (channels) along the *z* axis compared with the single row of detectors in conventional spiral CT (SSCT). Each channel comprises numerous elements. In a "four-row" scanner, the detector array is connected to four DASs that generate four channels of data (Fig. 25.32). This type of detector array would allow a scan four times faster than the conventional single row spiral/helical scanner. Current technology detector arrays have 4, 8, 16, 32, 64, 128, 256, and 320 rows or channels. The increased width of the detector now requires the x-ray beam to be a cone-beam configuration compared with the fan beam used for SSCT. The 64-, 128-, 256-, and 320-row scanners are referred to as VCT systems because of the amount of body section coverage in a single tube rotation. Figs. 25.33 and 25.34 were acquired on the Toshiba 320 row scanner in a single revolution. Fig. 25.33 is a three-dimensional VR pediatric chest image acquired in 0.035 seconds. Fig. 25.34 shows a 16-cm volume coverage that allows for whole-brain perfusion imaging for evaluation of stroke. Cardiac imaging using VCT is a rapidly growing component of CT imaging. The advantages of MSHCT/MDCT include isotropic imaging and postprocessing, greater anatomic coverage, multiphase studies, faster examination times, and improved spatial resolution. The advancement of VCT, with increasing larger detector arrays, has provided unique clinical opportunities in diagnostic medicine. Fig. 25.35 compares the *z*-axis coverage of 64-, 128-, and 320-row detectors.

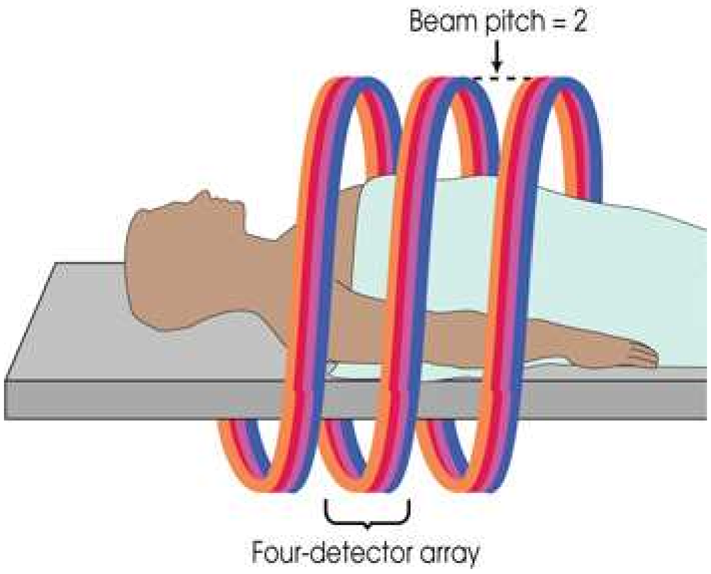


FIG. 25.32 Four-detector array with a beam pitch of 2 covers eight times the tissue volume of a single-slice spiral CT scan.

Diagram shows a patient is on supine position on the table. A helical coil with four detector arrays is drawn around the patient in the bed and the distance between the two coils is labeled as beam pitch equals 2. The

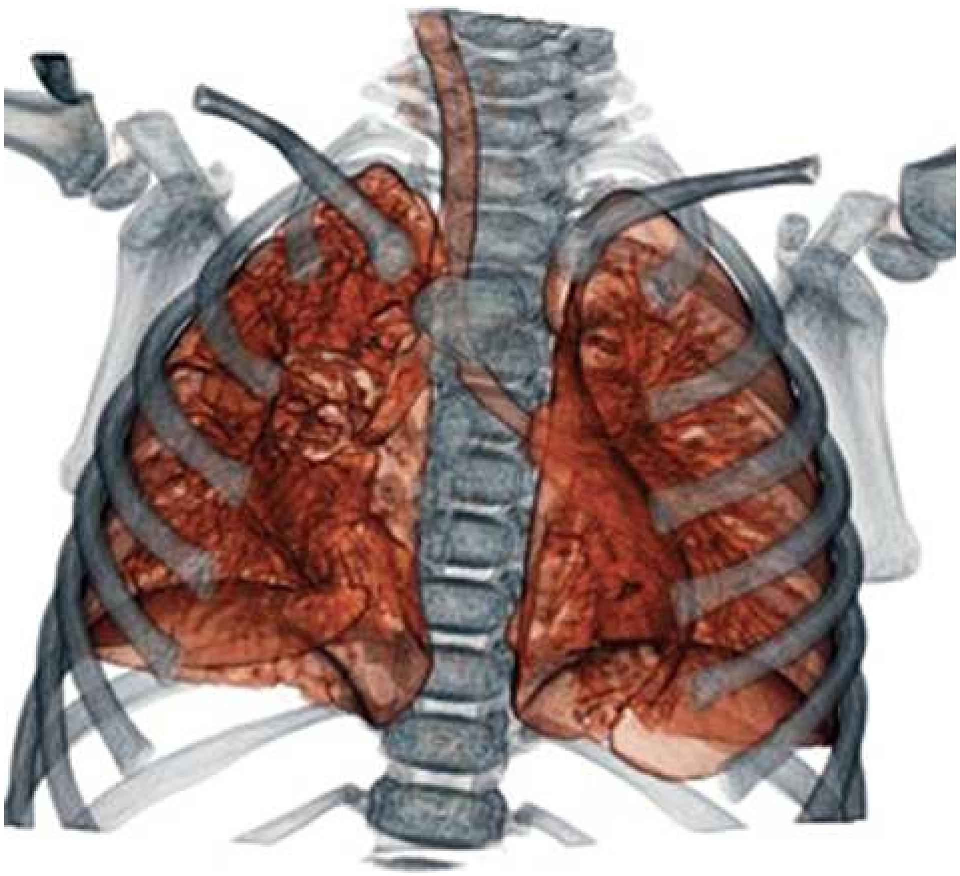


FIG. 25.33 Technology employing 320 detector rows makes it possible to scan an infant's chest with fine detail, low radiation dose, and fast acquisition times. This image is a three-dimensional VR acquired in a single rotation completed in 0.035 second. Courtesy Toshiba America Medical Systems.

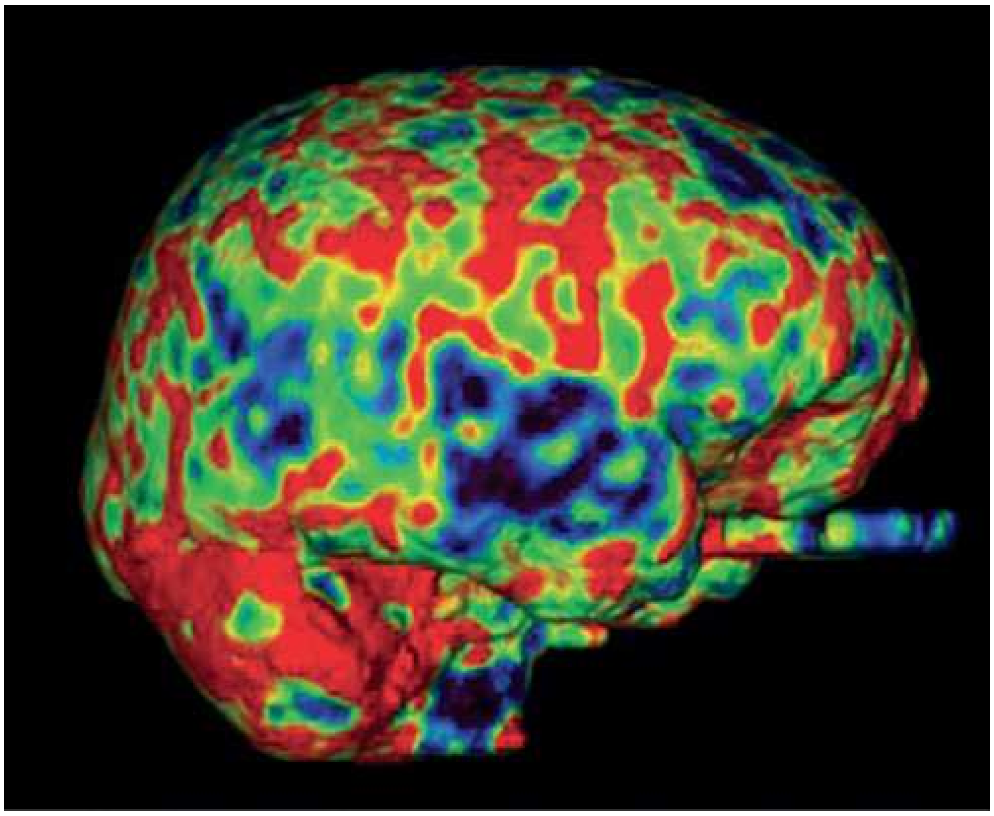


FIG. 25.34 Whole-brain imaging is possible with 16 cm of volume coverage. This three-dimensional VR whole-brain perfusion study shows evidence of acute stroke. Courtesy Toshiba America Medical Systems.

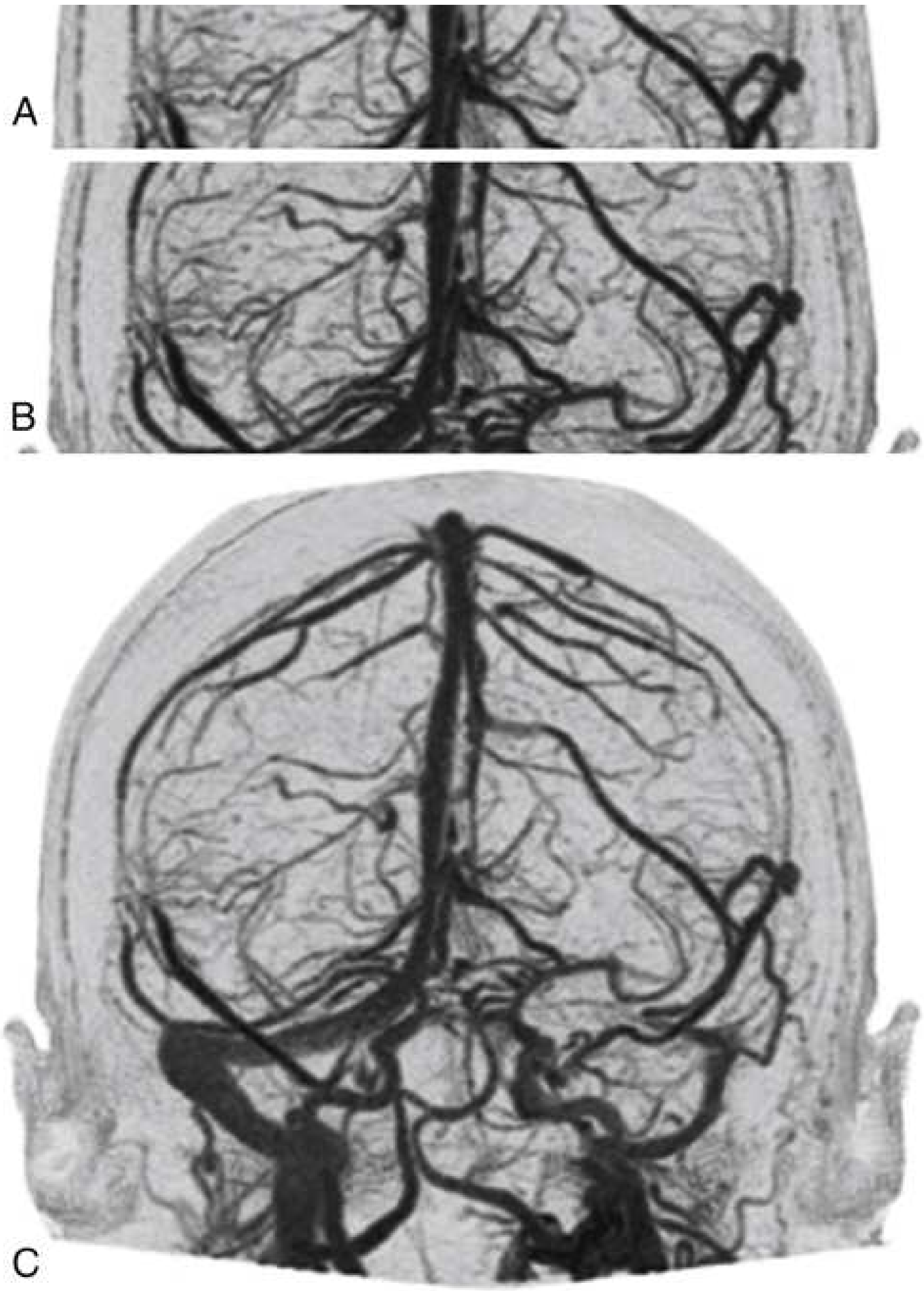


FIG. 25.35 Images show scan range for various row scanners. (A) 64-row scanner. (B) 128-row scanner. (C) 320-row scanner. The 320-row scanner allows complete imaging of the cranial vessels with one table location. Courtesy Toshiba America Medical Systems.

(A) A radiographic image shows a part of the cranial vessels. A dark tubular structure in the middle has several branches. (B) A radiographic image shows a bigger part of the cranial vessels. A dark tubular structure in the middle has several branches. (C) A radiographic image shows an enlarged image of the cranial vessels. A dark tubular structure in the middle has several branches.

Computed Tomography Angiography

CTA is an application of spiral CT that uses three-dimensional imaging techniques. With CTA, the vascular system can be viewed in three dimensions. The three basic steps required to generate CTA images are as follows:

1. Choice of parameters for IV administration of the *bolus* of contrast medium (i.e., injection rate, injection duration, and delay between bolus initiation and the start of the scan sequence)
2. Choice of spiral parameters to maximize the contrast medium in the target vessel (i.e., *scan duration*, collimation, and *table speed*)
3. Reconstruction of two-dimensional image data into three-dimensional image data

CTA has several advantages over conventional angiography. CTA uses spiral technology; an arbitrary image within the volume of data can be retrospectively reconstructed without exposing the patient to additional IV contrast medium or radiation. During postprocessing of the image data, overlying structures can be eliminated so that only the vascular anatomy is reconstructed. Finally, because CTA is an IV procedure that does not require arterial puncture, only minimal post-procedure observation is necessary.

Currently, CTA is replacing angiography as a diagnostic tool for some studies. This is especially true in departments using multi-row detectors that allow significantly faster scanning. Fig. 25.36 shows the vessels of the brain, whereas Fig. 25.37 shows the renal vessels in a three-dimensional format. The heart and coronary vessels are shown in Fig. 25.38, and a graft is shown in Fig. 25.39. Fig. 25.40 shows multiple reformations from a cardiac gated dose reduction method performed on a Philips Medical 256-row scanner. Fig. 25.41 is a brain perfusion study showing significant vascular changes on a patient with an acute stroke.

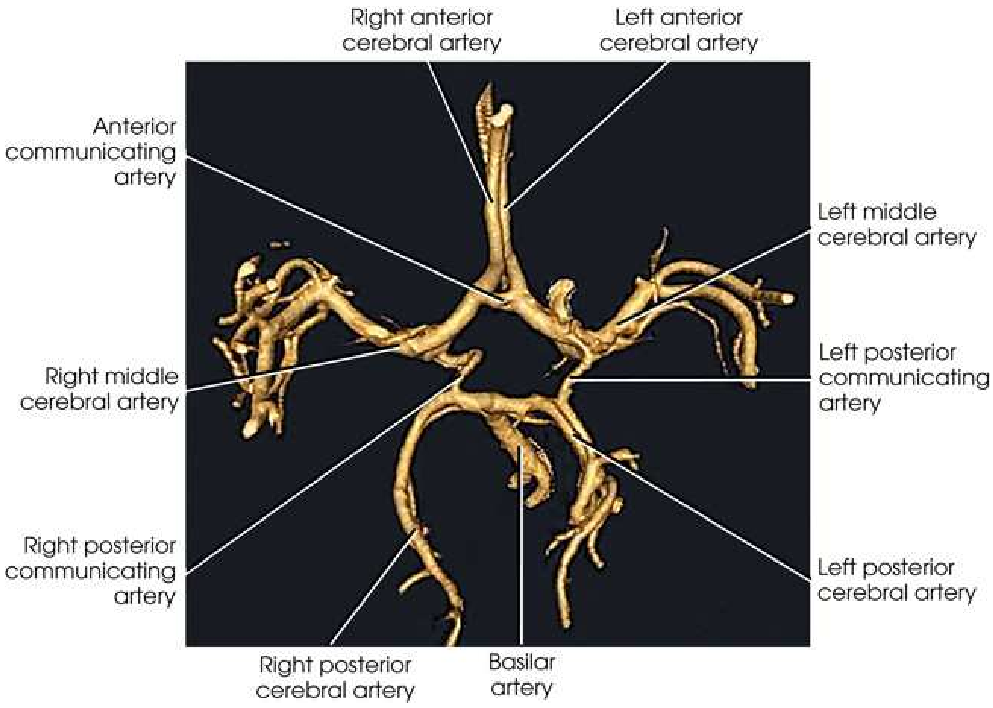


FIG. 25.36 Color CT angiography of circle of Willis.

The C T angiography shows the circle of Willis. It appears yellows. The parts labeled are marked clockwise as follows: basilar artery, right posterior cerebral artery, right posterior communicating artery, right middle cerebral artery, anterior communicating artery, right anterior cerebral artery, left anterior cerebral artery, left middle cerebral artery, left posterior communicating artery, and left posterior cerebral artery.

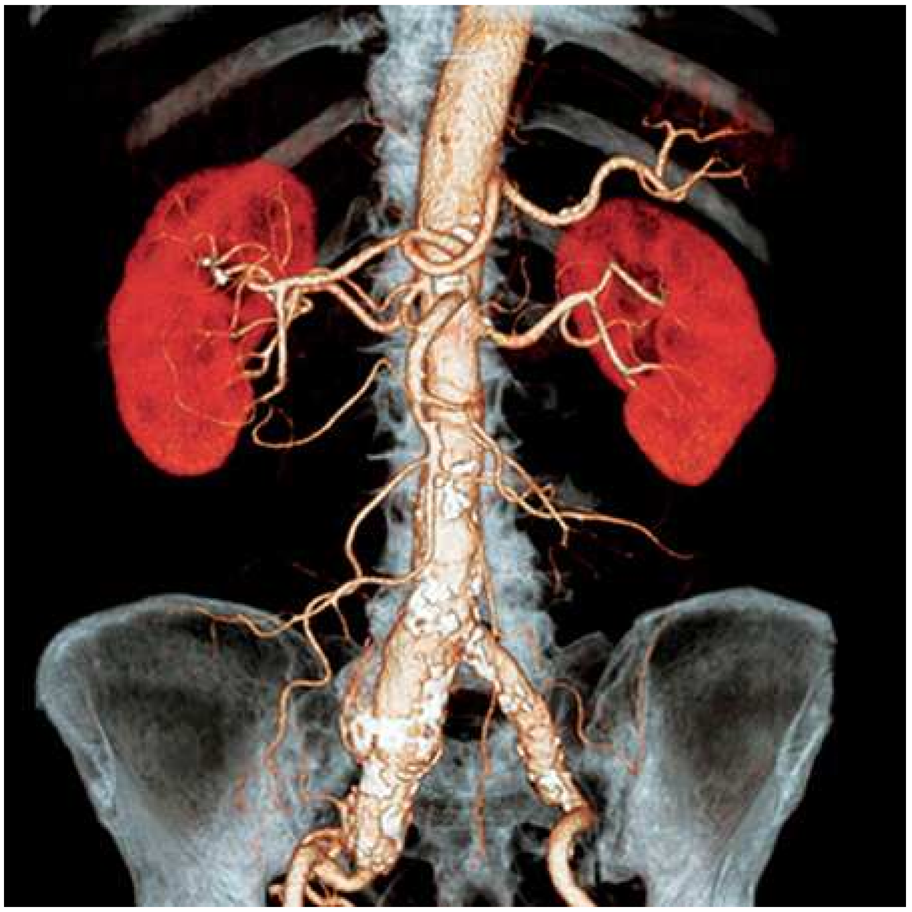


FIG. 25.37 Color CT angiography in three-dimensional format. Courtesy Toshiba America Medical Systems.

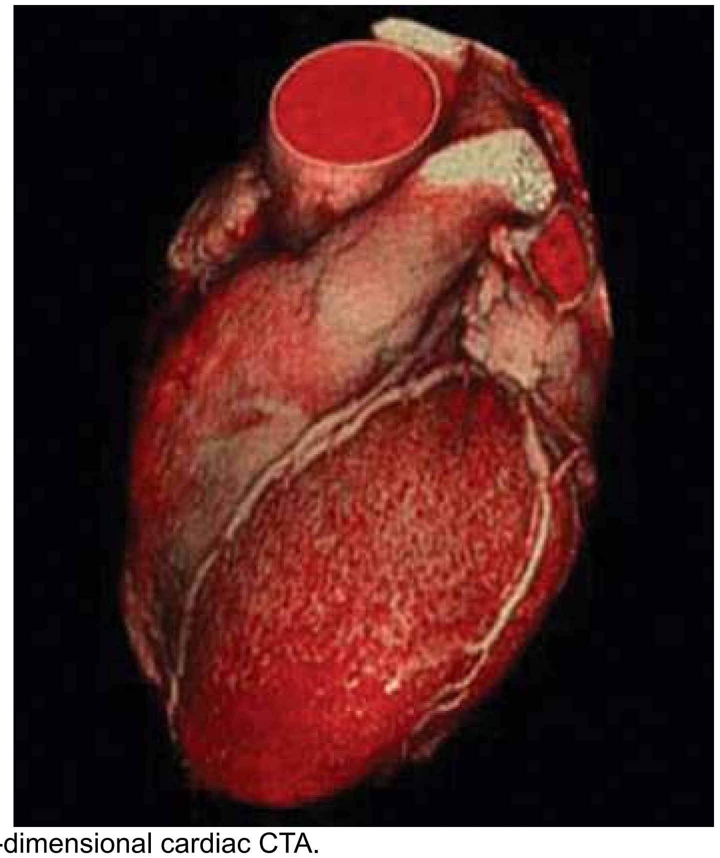


FIG. 25.38 Color three-dimensional cardiac CTA.

Three-Dimensional Imaging

A rapidly expanding area of CT is three-dimensional imaging. This is a *postprocessing* technique that is applied to raw data to create realistic images of the surface anatomy to be visualized. The introduction of advanced computers and faster software programs has dramatically increased the applications of three-dimensional imaging. The common techniques used in creating three-dimensional images include *maximum intensity projection* (MIP), *shaded surface display* (SSD), and *VR*. All techniques use three initial steps to create the three-dimensional images from the original CT data:

1. *Construction* of a volume of three-dimensional data from the original two-dimensional CT image data. This same process is used in MPR.
2. *Segmentation* to crop or edit the target objects from the reconstructed data. This step eliminates unwanted information from the CT data.
3. *Rendering* or *shading* to provide depth perception to the final image.

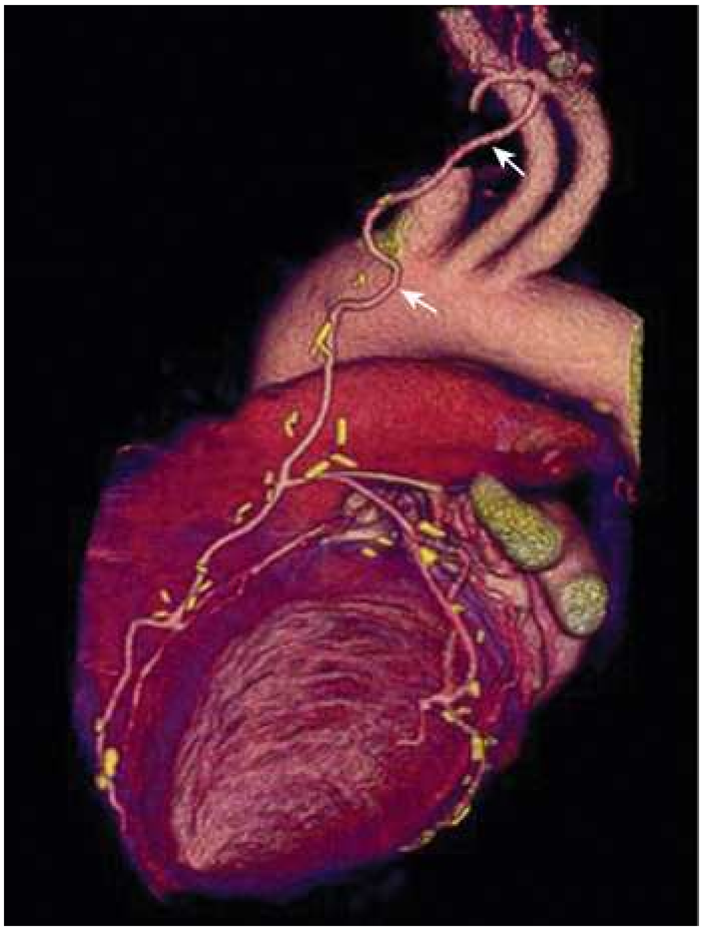


FIG. 25.39 Color three-dimensional cardiac CTA with graft *(arrows)*.

Maximum intensity projection

MIP consists of reconstructing the brightest pixels from a stack of two-dimensional or three-dimensional image data into a three-dimensional image. The data are rotated on an arbitrary axis, and an imaginary ray is passed through the data in specific increments. The brightest pixel found along each ray is *mapped* into a grayscale image. MIP is commonly used for CTA.

Shaded surface display

SSD provides a three-dimensional image of the surface of a particular structure. After the original two-dimensional data are reconstructed into three-dimensional data, the different tissue types within the image need to be separated. This process, called *segmentation*, can be performed by drawing a line around the tissue of interest or, more commonly, by setting *threshold values*. A threshold value can be set for a particular CT number. Any pixel that has an equal or greater CT number than the threshold value would be selected for the three-dimensional image. When the threshold value is set, and the data are reconstructed into a three-dimensional image, a shading technique is applied. The shading or rendering technique provides depth perception in the reconstructed image.

Volume rendering

VR techniques incorporate the entire volume of data into a three-dimensional image by summing the contributions of each voxel along a line from the viewer's eye through the data set. This results in a three-dimensional image in which the dynamic range throughout the image is preserved. Rather than being limited to surface data, a VR image can display a wide range of tissues that accurately depict the anatomic relationships between vasculature and viscera. Because VR incorporates and processes the entire data set, much more powerful computers are required to reconstruct three-dimensional VR images at a reasonable speed.

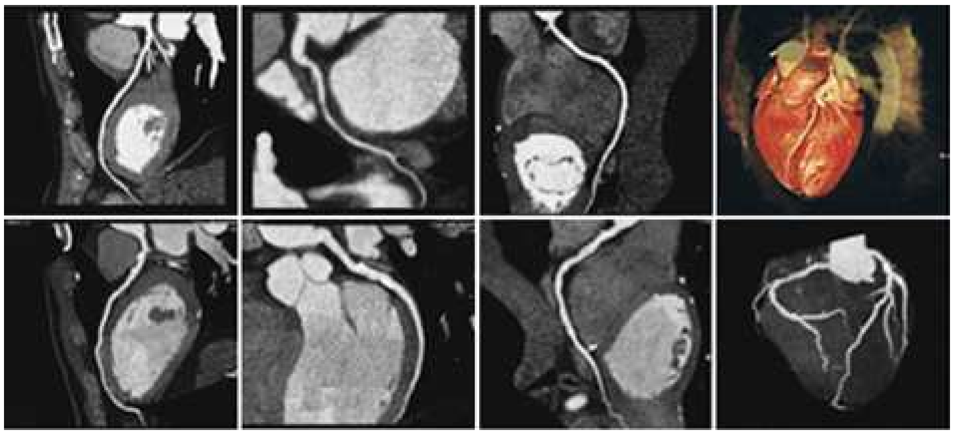


FIG. 25.40 Prospectively gated CT angiograms. Low-dose studies performed with Philips Step and Shoot Cardiac software, which has arrhythmia detection that stops scans until ECG stabilizes. Courtesy Philips Medical Systems.

Few C T angiograms show multiple reformations from a cardiac gated dose reduction method. One of the image shows the heart and coronary vessels. The heart appears red and the coronary vessels appear yellow.

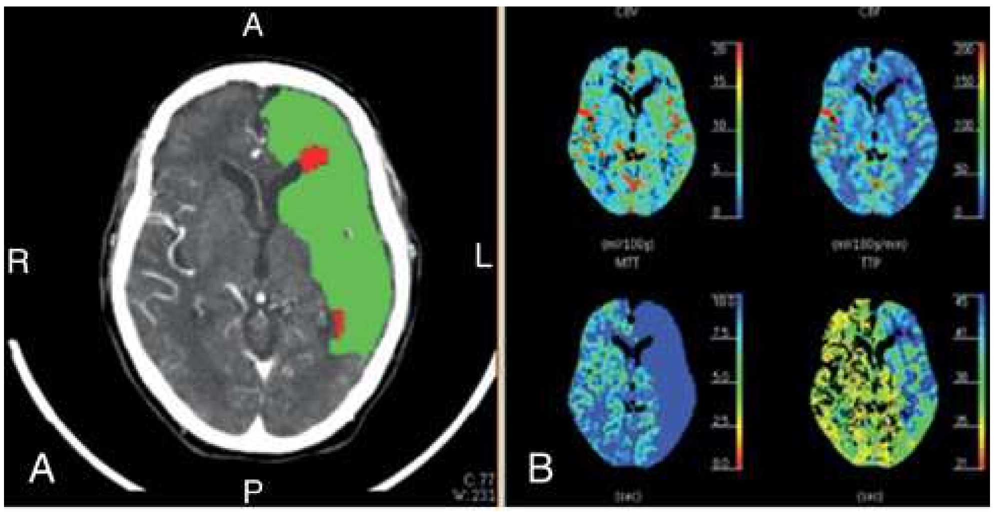


FIG. 25.41 CT brain perfusion study with brain perfusion parameter maps (B) and summary map overlays (A) showing areas of ischemic penumbra *(green)* and infarct *(red)*. Images were acquired using a lower dose protocol on a Philips Brilliance CT scanner. Courtesy Philips Medical Systems.

Referring physicians and surgeons use three-dimensional images to correlate CT images clinically to the actual anatomic contours of their patients (Fig. 25.42). These reconstructions are especially useful in surgical procedures. Three-dimensional reconstructions are often requested as part of patient evaluation after trauma and for presurgical planning. Fig. 25.43 shows examples of the three common three-dimensional rendering techniques.

Radiation Treatment Planning

Radiation therapy has been used for nearly as long as radiology has been in existence. The introduction of CT has had a major impact on radiation treatment planning. The use of spiral CT in conjunction with MPR provides a three-dimensional approach to radiation treatment planning. This method helps the dosimetrist plan treatment so that the radiation dose to the target is maximized, and the dose to normal tissue is minimized. The three-dimensional simulation software offers the following: volumetric, high-precision localization; calculation of the geometric center of the defined target; patient marking systems; and virtual simulators capable of producing digitally reconstructed radiographs in *real-time*. With the new, specially designed software, a single CT simulation procedure can replace a total of three procedures (one conventional CT scan and two conventional simulations) for radiation treatment planning (Fig. 25.44).

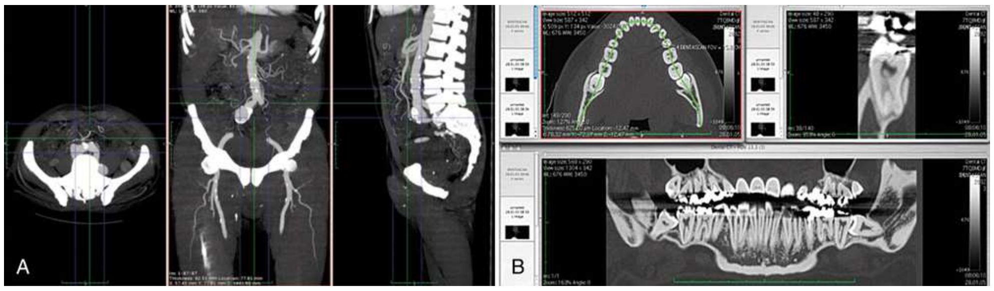


FIG. 25.42 (A) MPR of abdominal aorta. (B) Curved MPR of mandible.

(A) A M P R image shows the abdominal aorta, anterior view of the abdomen and pelvis, and lateral view of the vertebrae. (B) A M P R image shows the curved mandible, a tooth, and the front teeth. They appear radiopaque.

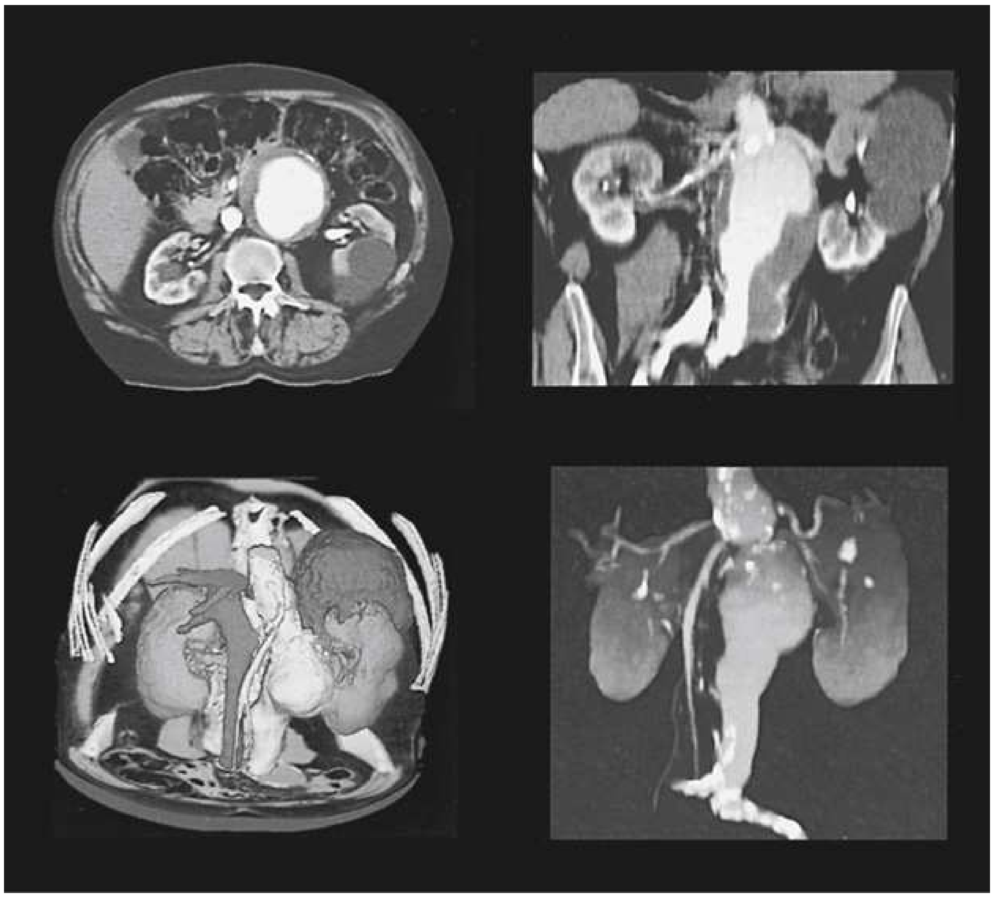


FIG. 25.43 Common three-dimensional rendering techniques used in CT. Courtesy Elicit, Hackensack, NJ.

If the CT system is being used for radiation treatment planning, the standard curved couch cannot be used. Instead, a flat, firm board should be placed on the couch. Most radiation therapy departments have their own CT units today. A flat patient couch is substituted on the dedicated therapy units. In this way, the actual therapy delivery can be simulated more accurately. Fig. 25.45 shows the external skin markers and structures that would be in the beam's path.

PET/CT Scanners

When a CT scanner is coupled with a positron emission tomography (PET) scanner, it is referred to as a PET/CT scanner. The PET/CT scanner comprises two scanners in close proximity to each other, with a single patient couch that travels between the two scanners. In some scanner configurations, there is a small gap between the scanner housings; in other configurations, the scanner appears to be a single unit. Current PET/CT scanners are typically third-generation scanners and incorporate the latest in detector technology. Most modern PET/CT scanners incorporate 8-, 16-, and 64-row detectors. PET/CT scanners are typically housed in the nuclear medicine department instead of the CT department. Refer to the nuclear medicine chapter for more details. The CT scanner is used for attenuation correction and anatomic correlation for the functional PET scans. In addition, many patients require a more detailed diagnostic CT examination. This requirement has enforced nuclear medicine technologists to obtain additional education and certification in CT to perform the diagnostic CT exams. Fig. 25.46 shows sagittal reconstructed CT spine images and the corresponding PET images with a PET/CT fusion image.

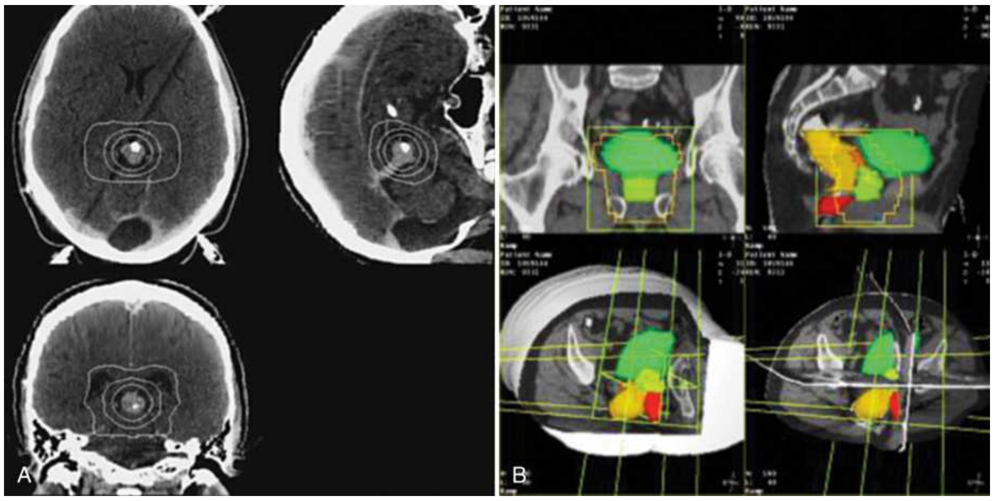


FIG. 25.44 (A) Brain localization in three planes. (B) Three-dimensional prostate therapy localization.

(A) shows one conventional C T scan and two conventional simulations. It has a circle in the middle surrounded by multiple circles. (B) shows three-dimensional images of the prostate. It appears greens, yellow, and red.

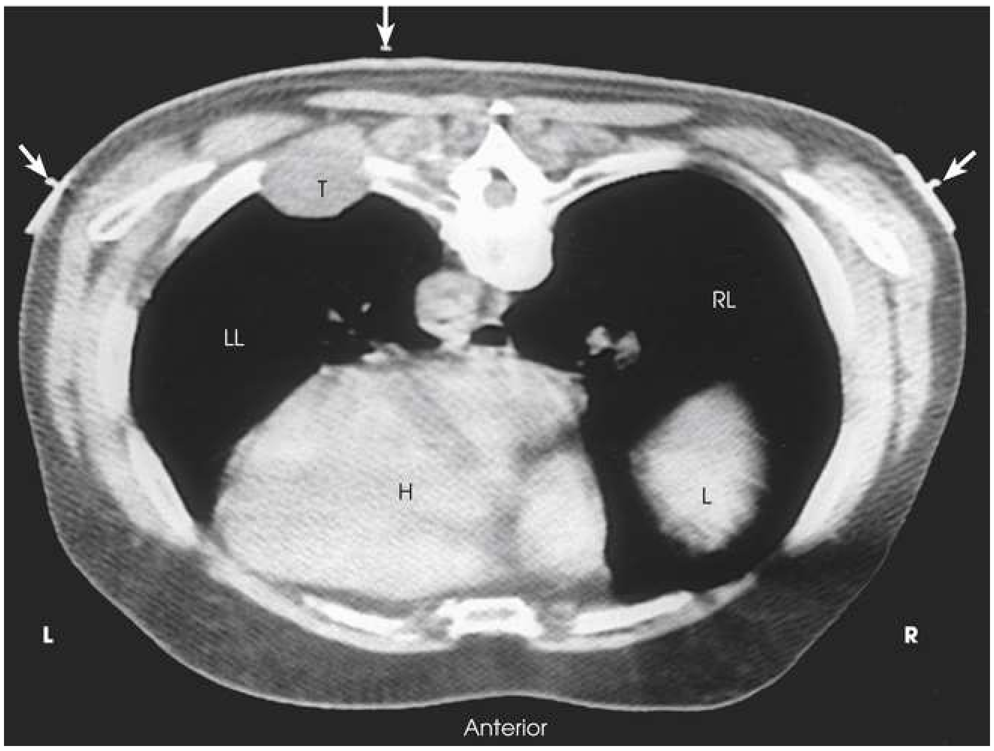


FIG. 25.45 Patient in prone position for radiation treatment planning. Radiopaque markers *(arrows)* show location of treatment field skin marks: tumor *(T)*, heart *(H)*, liver *(L)*, right lung *(RL)*, and left lung *(LL)*.

Quality Control

The goal of any quality assurance program in CT is to ensure that the system is producing the best possible image quality with the minimum radiation dose to the patient. A CT system is a complex combination of sensitive and expensive equipment that requires systematic monitoring for performance and image quality. Most CT systems require daily, weekly, or biweekly quality assurance testing to ensure proper operation. In addition to quality assurance testing, CT systems require preventative maintenance, which can be performed quarterly or more often by a manufacturer service engineer or private company.

Increasingly, the technologist is assigned the responsibility of performing and documenting routine quality assurance tests. Many technologists routinely perform daily test scans on a water phantom to measure the consistency of the CT numbers and to record the standard deviation. As data are recorded over time, the CT scanner's current operating condition and its performance over longer time periods can be evaluated. Many units are also capable of *air calibrations*, which do not require the water phantom and can be performed between patients for unit self-calibration.

A CT phantom is typically multi-sectioned and is constructed from plastic cylinders, with each section filled with test objects designed to measure the performance of specific parameters. Some phantoms are designed to allow numerous parameters to be evaluated with a single scan. The recommended quality assurance tests for evaluating routine performance includes contrast scale and the mean CT number of water, high-contrast resolution, low-contrast resolution, laser light accuracy, noise, uniformity, slice thickness, and patient dose.

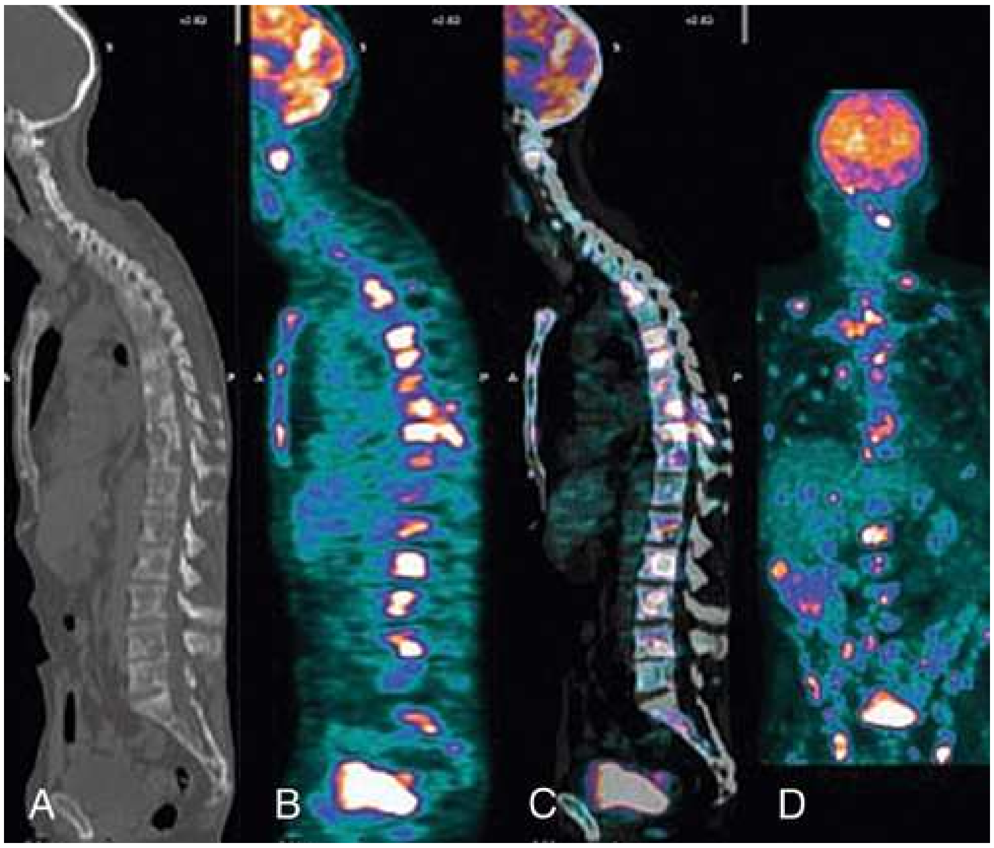


FIG. 25.46 Sagittal reformatted CT scan (A), sagittal PET (B), PET/CT fusion image (C), and coronal PET (D).

(A), (B), (C), and (D) shows sagittal reconstructed CT spine images and the corresponding P E T images with a P E T or C T fusion image. (A), (B), and (C) shows the lateral view of the body and (D) shows the anterior view. The brain appears orange and the spine appears white.

Computed Tomography and Radiation Dose

Calculating the radiation dose received during CT examinations presents a unique set of circumstances. Typically, radiation received during radiologic examinations comes from a fixed source with delivery to the patient in one or two planes (e.g., anteroposterior [AP] and lateral projections). These exposure parameters typically produce a much higher entrance skin dose than the exit skin dose, which creates a large dose gradient across the patient. In contrast, CT exposures (helical/spiral) originate from a continuous source that rotates 360 degrees around the patient. This results in a radially symmetric radiation dose gradient within the patient.

Equipment manufacturers are developing new hardware to reduce patient dose, including off-focal radiation suppression devices, beam shaping filters, *z*-axis efficiency with increased collimation, and improved data acquisition systems. Fig. 25.47 demonstrates the SmartShape wedge from Philips Medical Systems, which is an example of a beam-shaping filter. Note the dose reduction shown on the center image when the appropriate filter is applied. *z*-axis efficiency reduces dose effects related to "over scanning," which occurs in helical or spiral scanning systems. CT data acquisition systems utilize higher efficiency detector material to minimize electronic noise. Also, software development has allowed optimization of image quality based on iterative reconstruction. Using iterative reconstruction allows for a reduction in dose to the patient while maintaining image quality and reducing noise, which improves spatial resolution and low contrast detectability. For the pediatric population, dedicated protocols have been developed and included in the CT purchase.

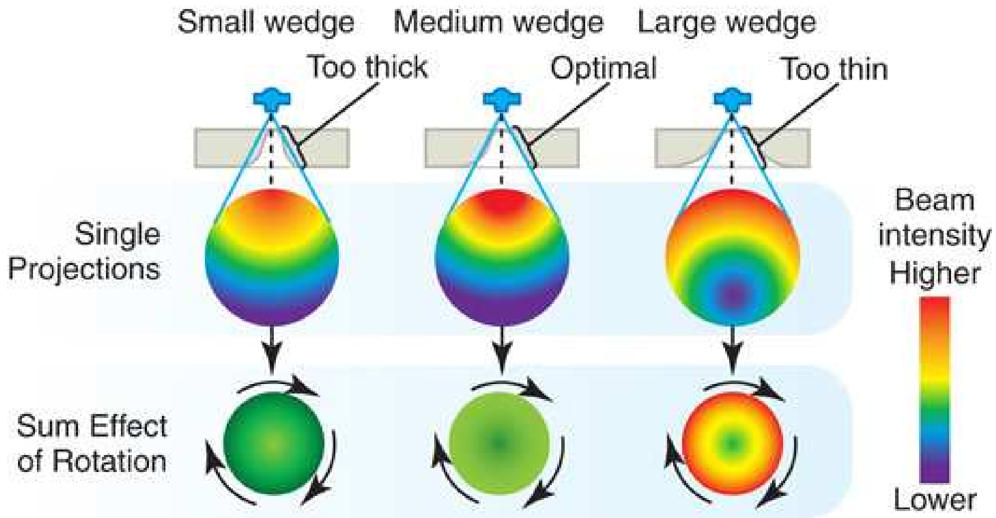


FIG. 25.47 Diagram represents selectable bowtie filters that reduce patient dose and improve image quality. These are referred to as SmartShape wedges on the Philips Brilliance iCT scanner. Note how correct wedge selection affects patient dose. Wedges are typically small (infants 0 to 18 months), medium (cardiac), and large (adult head and body). Wedge selection is built into scan protocols. Courtesy Philips Medical Systems.

A small wedge is too thick in single projections. The sum of rotation appears dark green. A medium wedge is optimal in single projection. The sum of rotation appears light green. A large wedge is too thin in a single projection. The sum of rotation appears red, yellow, and green.

Measurements of CT dose are typically performed using a circular CT dosimetry phantom that is made of polymethyl methacrylate (PMMA) with implanted thermoluminescent dosimeters (TLDs). The TLDs are positioned 1 cm below the surface around the periphery of the phantom and at the center (isocenter). The typical phantom sizes are 32 cm for body calculations and 16 cm for head calculations. For a single axial scan location (one full rotation of the tube, no table movement), the typical dose for the body phantom is 20 mGy at the periphery and 10 mGy at the isocenter. The typical dose for the head phantom is higher, at 40 mGy at the periphery and 40 mGy at the isocenter. See Fig. 25.48 for the body and Fig. 25.49 for the head. Dose is size dependent (e.g., dose differs depending on head scan or body scan and whether the patient is a child or an adult).

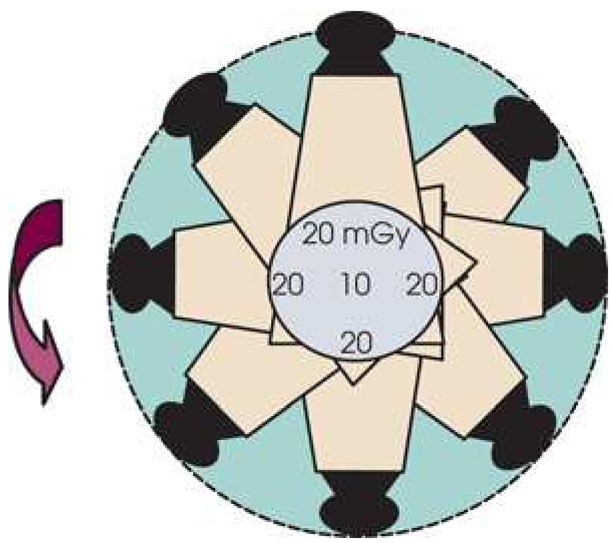


FIG. 25.48 CT dose profile for body. Data from McNitt-Gray MF: AAPM/RSNA physics tutorial for residents: topics in CT. Radiation dose in CT. *RadioGraphics* 22:1541, 2002.

Diagram shows for a single axial scan location (one full rotation of the tube, no table movement), the typical dose for the body phantom is 20 milligram at the periphery and 10 milligram at the isocenter.

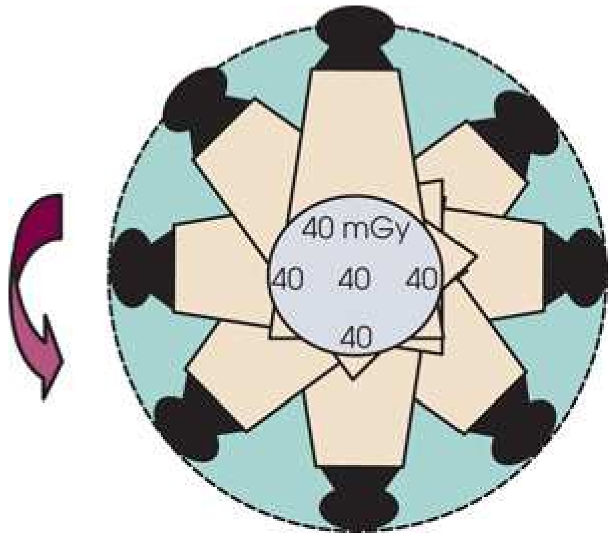


FIG. 25.49 CT dose profile for head. Data from McNitt-Gray MF: AAPM/RSNA physics tutorial for residents: topics in CT. Radiation dose in CT. *RadioGraphics* 22:1541, 2002.

Diagram shows for a single axial scan location (one full rotation of the tube, no table movement), the typical dose for the head phantom is higher, at 40 milligram at the periphery and 40 milligram at the isocenter.

Another component of dose to the patient is distribution of absorbed dose along the length of the patient from one single scan (full rotation at one table location). The radiation dose profile (Fig. 25.50) is not limited just to the slice location; the "tails" of the dose profile contribute to the absorbed dose outside of the primary beam. The size of the contribution to dose from the adjacent sections is directly related to the spacing of the slices, the width and shape of the radiation profile. The first method used to describe dose as a result of multiple scan locations was the *multiple scan average dose* (MSAD). MSAD described average dose resulting from scans over an interval length on the patient. Next was the *computed tomography dose index* (CTDI), which was calculated using a normalized beam width and a standard of 14 contiguous axial slices. This method required a dose profile measured with TLDs or film, neither of which was convenient. To overcome the measurement limitations, another dose index, the *CTDI100*, was developed. This dose index allowed profile calculations along the full length (100 mm) of a pencil ionization chamber and did not require nominal section widths. To provide a weighted average of the center and peripheral contributions, *CTDIw* was created. The final descriptor is *CTDIvol*, which accounts for the helical pitch or axial scan spacing that is used for a specific protocol. The most common reporting method of dose reporting on the present scanners is the *dose-length product* (DLP). This is the $CTDI_{vol}$ multiplied by the length of the scan (cm), and reported in mGy/cm.

Patient dose must be a part of the permanent record for each examination. Manufacturers display dose parameters in various ways. Fig. 25.51 is an example of how Philips Medical Systems displays dose information (note parameters within blue box just above the "go" button). To assist in preventing excessive exposure to patients, the American Association of Physicists in Medicine (AAPM) published a "Notifications Levels Statement" with preestablished *notification values* for individual scans using $CTDI_{vol}$ (mGy). Notification values (NV) are predetermined and set up within the exam protocol; the technologist is notified when any scan series within the complete exam protocol exceeds the preset value. The alert value (AV) notifies the technologist when the cumulative dose index value exceeds the preset value. The dose checking systems will track and report all instances when established diagnostic reference levels (DRLs) have been exceeded.

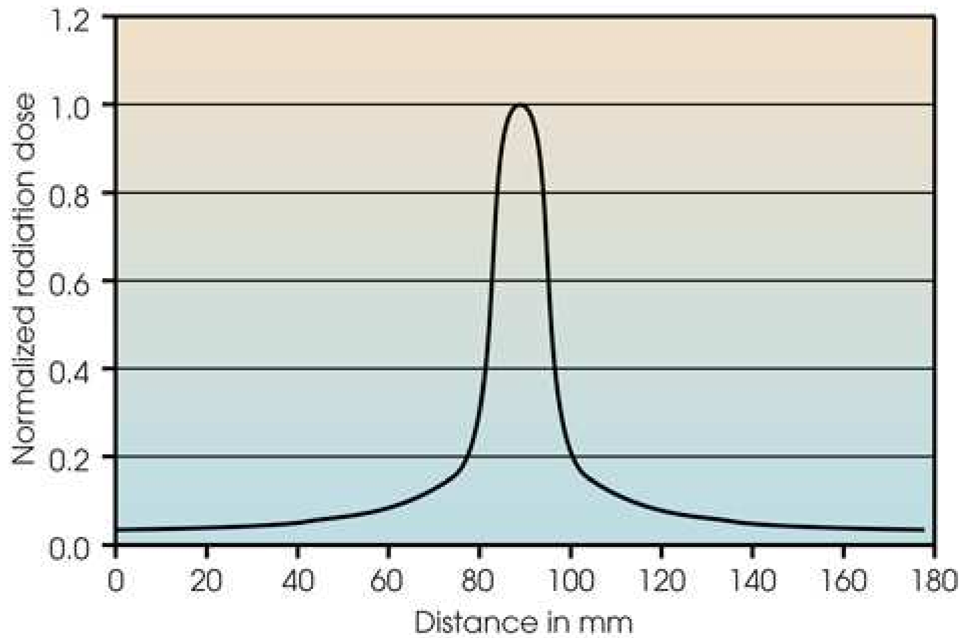


FIG. 25.50 Single-slice CT dose profile.

A graph has distance in millimeter scaled on the horizontal axis and normalized radiation dose scaled on the vertical axis. The values in the horizontal axis range from 0 to 180 with an interval of 20. The values in the vertical axis range from 0.0 to 1.2 with an interval of 0.2. A bell-shaped curve rises from (0, 0.05) and gradually increases. It then steadily increases and reaches a peak at (90, 1.0) and steadily drops and then gradually decreases (175, 0.05). Note: All data is approximate.

Estimating Effective Dose

Effective dose takes into account where the radiation dose is being absorbed (e.g., which tissue or organ has absorbed the radiation). The International Commission on Radiological Protection (ICRP) sets the weighting factors for each radiosensitive organ (available at www.ICRP.org). Effective dose is measured in sieverts (Sv) or rems (100 rem = 1 Sv). The effective dose is determined by multiplying the DLP by a region-specific conversion factor. The conversion factors are 0.017 mSv/mGy per cm for chest imaging, 0.019 mSv/mGy per cm for pelvis imaging, and 0.0023 mSv/mGy per cm for head imaging. The conversion factor for head scans is considerably less because fewer radiosensitive organs are irradiated. (The DLP for a given chest examination is 375 mGy; the resulting estimated effective dose is 375 multiplied by 0.017, which equals 6.4 mSv.)

Factors That Affect Dose

The factors that directly influence the radiation dose to the patient are beam energy (kVp), tube current (mA), rotation or exposure time (seconds), section or slice thickness (beam collimation), object thickness and attenuation (size of the patient, pediatric vs. adult), pitch or section spacing (table distance traveled in one 360-degree rotation), dose reduction techniques (mA modulation), patient centering, and distance from the tube to isocenter. Improper patient centering can result in an increase in surface dose. A 3-cm centering mistake can increase the surface dose (breasts) by 18%. A 6-cm mistake can increase surface dose by up to 41%. Patient shielding in the scan area is now possible with bismuth-filled shields, which yield little image artifact but provide 50% to 60% dose reduction to anterior radiosensitive organs. Adult breast shields, various sized pediatric breast shields, thyroid shields, and eye shields are presently available.

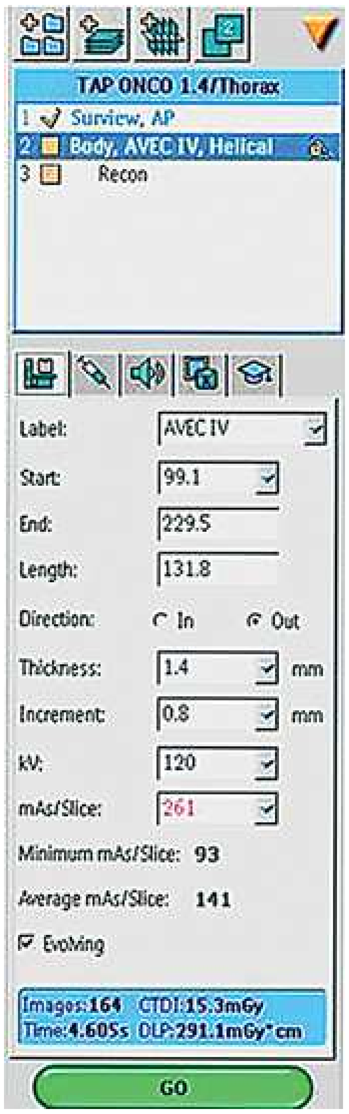
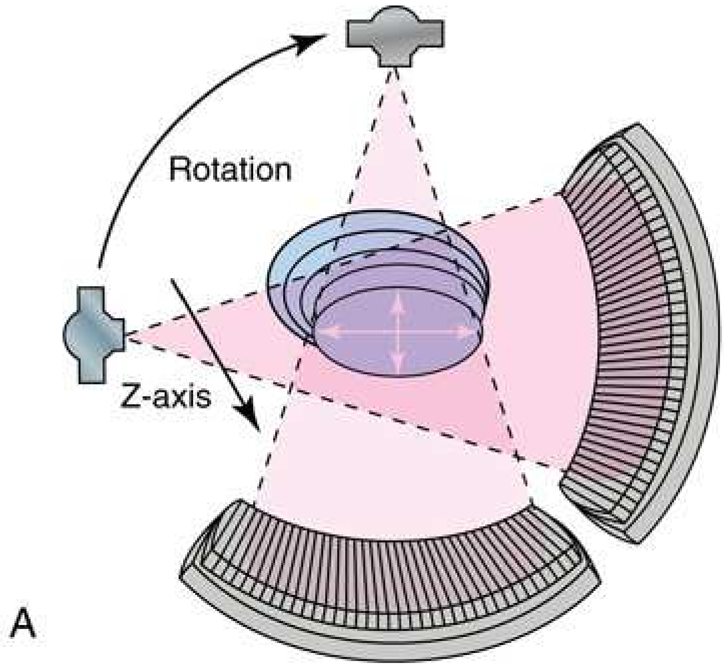


FIG. 25.51 Dose amounts must be reported for every series and protocol performed. Each manufacturer displays information differently. Note CTDI and DLP displayed inside the *blue box*. Courtesy Philips Medical Systems.

A screenshot of a page shows a blue box on top. The box is titled TAP ONCO 1.4 over thorax. The contents are as follows: 1 pick mark surview, A P. 2 checkbox body, A V E C I V, helical. 3 checkbox recon. The second line is highlighted. The parameters within blue box is just above the "go" button.

Each vendor has optimized the ability to use automatic exposure control in CT, developing a product for automatic tube current modulation (ATCM), and calculating or using patient attenuation measurements in one or more planes. Fig. 25.52 shows a technique of mA modulation that uses an AP and lateral scout image to calculate patient thickness, which results in automatic mA adjustments during the scan (see *red line*). New "selectable" filters (Fig. 25.53) allow different filter applications based on body section or patient age or size. These filters can reduce dose by nearly 30% when using 120 kVp and 45% when using 80 kVp. Equipment manufactures include an automated dose-optimized selection of the tube voltage, as in some instances a lower kVp may provide better images with a lower dose.



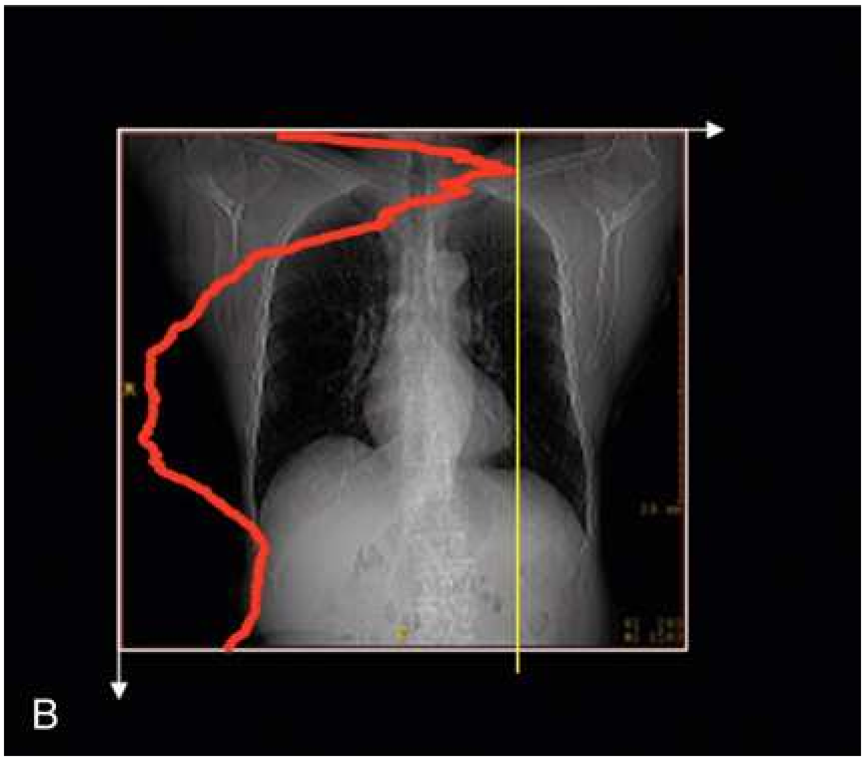


FIG. 25.52 (A) AP and lateral scout images performed for mA modulation calculations. Note thickness difference A/P versus R/L. (B) Philips DoseRight automated tube current selection (ACS). *Red line* shows *z*-axis dose modulation. Note technique increase in shoulder and abdomen region and technique decrease in lung region. Courtesy Philips Medical Systems.

(A) shows a tube device rotating is projected on two arcs with. A blue colored circular region is between the tube and the arcs. An arrow indicates z-axis. (B) A radiographic image has a red line and a vertical yellow line.

Beam collimation (slice thickness) varies in single-detector scanners and multidetector scanners. Beam collimation for single-detector systems has minimal effect on dose; however, this is not the case for multidetector scanners. These scanners have multiple ways to scan and reconstruct images. A multidetector scanner can perform axial scans of 4 × 1.25 mm (5-mm beam width, 1.25-mm slice reconstruction), 4 × 2.5 mm (10-mm beam width, 2.25-mm slice reconstruction), and 4 × 5 mm (20-mm beam width, 5-mm slice reconstruction). When all other parameters are kept constant, there are significant differences in dose. Beam collimation, not reconstruction thickness, results in a difference in some cases of 55% in the head phantom and 65% in the body phantom when comparing single-detector to multidetector scanners. See Table 25.3 for single-detector imaging dose chart, Table 25.4 for multidetector imaging dose chart, and Table 25.5 for multidetector imaging with new dose reduction techniques.

Patient size must be considered carefully when setting up scan parameters. A small adult or pediatric patient absorbs less of the entrance radiation than a larger patient. This results in an exit radiation dose of higher intensity. The American Association of Physicists in Medicine (AAPM) has introduced a parameter known as the size-specific dose estimate (SSDE) that estimates patient dose based on $CTDI_{vol}$ and patient size. See the AAPM Report 204 for further details.

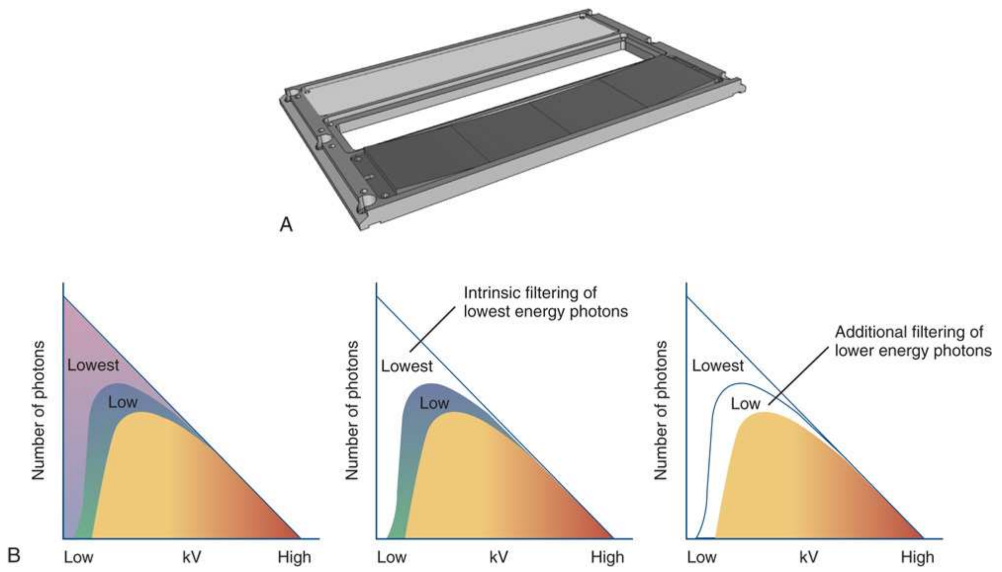


FIG. 25.53 (A) IntelliBeam adjustable filter that controls beam hardness (quality). Filters are used in conjunction with wedges to reduce patient dose. (B) Graph showing decrease in dose owing to elimination of low-energy photons *(far right diagram)*. Courtesy Philips Medical Systems.

(A) shows a grey colored rectangular board with light grey and white rectangles on it. (B) three graphs has the values low, kilovolt, high labeled on the horizontal axis and number of photons labeled on the vertical axis. The markings inside the graph are lowest, low.

TABLE 25.3

Single-detector doses

Collimation (mm)	$CTDI_W$ head phantom (mGy)	$CTDI_W$ body phantom (mGy)
1	46	20
3	42	19
5	40	18
7	40	18
10	40	18

Computed Tomography Dose Reduction and Safety

The following are best practice guidelines to follow to ensure lowest dose and patient safety within CT departments:

- Develop a comprehensive dose reduction strategy (Joint Commission Gap Analysis).
- Establish an exam request review process to eliminate unnecessary radiation—special consideration to multiphase exams.
- Utilize specific exam protocols with consideration given to reason for study, patient history, and as low as reasonably achievable (ALARA) principles.
- Institute specific exam protocol guidelines to ensure consistency across all sites.
- Appoint someone to audit and update exam protocols as needed.

Comparison of Computed Tomography and Magnetic Resonance Imaging

As CT was developing and advancing into a significant diagnostic modality, magnetic resonance imaging (MRI) was also progressing. Similar to CT, MRI was first used to image the brain, and whole-body scans were developed shortly afterward. As MRI advanced and the quality of the images improved, it became apparent that MRI images exhibited better low-contrast resolution than CT images. Brain soft tissue detail is not shown as well with CT as with MRI performed at approximately the same level (Fig. 25.54).

TABLE 25.4

Collimation (mm)	Total beam width (mm)	$CTDI_W$ head phantom (mGy)	$CTDI_W$ body phantom (mGy)
4×1.25	5	63	34
2×2.5	5	63	34
1×5	5	63	34
4×2.5	10	47	25
2×5	10	47	25
4×5	10	47	21

TABLE 25.5

Examination type	Scan mode	kVp	mAs	CTDIvol (mGy)
Adult abdomen and pelvis	Helical	120	160	11.4
Adult chest	Helical	140	20	2
Pediatric head	Helical	120	200	16.3

The initial introduction of MRI raised concerns that CT scanners would become obsolete. Each modality has been found to have unique capabilities. Both CT and MRI are useful for different clinical applications. As previously mentioned, CT does not show soft tissue as well as MRI, but CT shows bony structures better than MRI.

Patients often have ferrous metal within their bodies. MRI cannot always be used to scan such patients. CT is one option for these patients. The CT scanner does not affect metal in a patient, but metal can cause artifacts on CT images when the metal lies within the scan plane.

Many patients (especially pediatric and trauma patients) are extremely claustrophobic, combative, or uncooperative. CT is useful for scanning these patients quickly and easily because of the short gantry length, relatively large aperture, and short scan times.

Because equipment costs are less and a greater number of procedures can be accomplished per day, CT often is a less costly examination than MRI. Physicians have found that CT and MRI can be complementary examinations. In many situations, both examinations are ordered to provide as much diagnostic information as possible.

Future Considerations

For several decades, the diagnostic capabilities of CT have increased significantly, and the dose used is lower than that previously required. The development of iterative reconstruction methods and rapidly developing deep-learning algorithms using artificial intelligence are central to the advancement of CT as a discipline. With these advancements in technology, the CT technologist has an increased responsibility to understand contrast dynamics and the spiral scan parameters of pitch, collimation, scan timing, and table speed.

Advancements in dose reduction, improvement in spatial resolution, and temporal resolution will continue. Manufacturers are working hard to improve ALARA practices and to meet or exceed the standards published by Image Gently, The Alliance for Radiation Safety in Pediatric Imaging (www.imagegently.org), and Image Wisely: Radiation Safety in Adult Medical Imaging (www.imagewisely.org).

Progress in computing power and design have provided workstations that can generate three-dimensional models, rotate the models along any axis, and display the models with varying parameters (Figs. 25.55 and 25.56). Digital subtraction CT, multimodality image superimposition, and translucent shading of soft tissue structures are some advanced applications. Virtual colonoscopy (Fig. 25.57), virtual bronchoscopy, virtual cholangiopancreatography, and virtual labyrinthoscopy (inner ear) continue to evolve. As higher-quality images increase the accuracy of diagnosis and treatment, patient care will improve. Because of the superb diagnostic information and cost-effectiveness that CT provides, this imaging modality will continue to be a highly respected diagnostic tool.

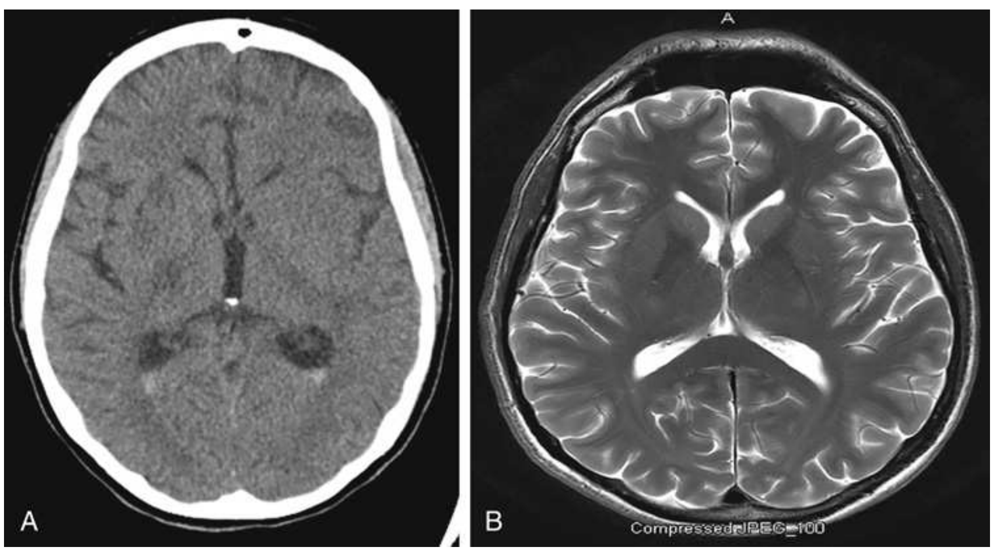


FIG. 25.54 Axial computed tomography (A) and magnetic resonance imaging (B) scans demonstrating the lateral ventricles: anterior horns and posterior horns, third ventricle, corpus callosum: genu (anterior), splenium (posterior), and head of the caudate nucleus. Courtesy MR Voxel Resources.

(A) An axial C T scan of the brain shows an irregular outer radiopaque covering. The brain appears grey and grainy. (B) An axial C T scan of the brain shows an irregular outer radiolucent region. The lateral ventricles and the head of the caudate nucleus appear radiopaque.

FIG. 25.55 Full-body three-dimensional reconstruction from 64-row CT scanner.

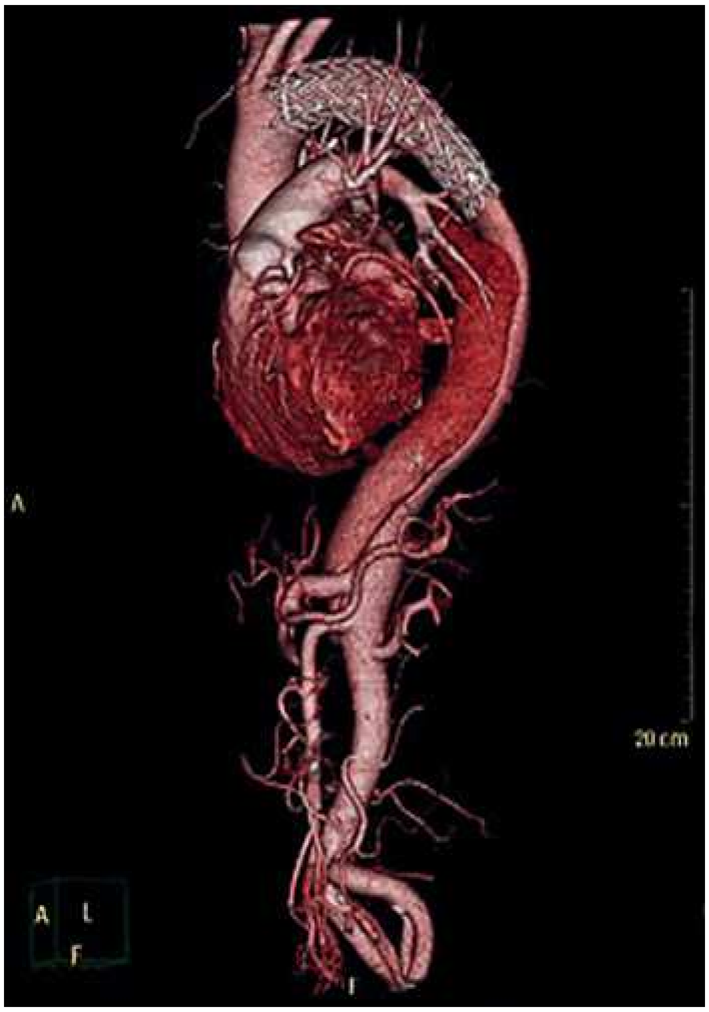


FIG. 25.56 Aortic arch stent shown on 500-mm three-dimensional reconstruction. Courtesy Philips Medical Systems.

FIG. 25.57 CT colonography. Courtesy Philips Medical Systems.

A three-dimensional reconstruction of the large intestine is on the left and an enlarged view of the colon is on the top-right. A C T image of the colon and a nodule like structure on the colon is on the bottom right.

Basic Computed Tomography Examination Protocols

It is impossible to list exact examination protocols due to the numerous scanner types, parameters, tube rotation speeds, and detector types that are used in CT imaging. Technical factors are directly related to the detector configuration that is used: number of detector rows and fixed array versus adaptive array. Many scans are performed using auto tube current modulation as opposed to fixed mA. This chapter is an overview of basic

CT scan protocols using an adaptive array, 16-row scanner. The values listed are close approximations of what can be used for the various examinations.

BASIC HEAD

Anatomical scan range	Scan type	Localizer scans	kVp	mAs	FOV	Scan slice thickness	Recon slice thickness	Gantry tilt	Recon kernel	IV contrast	Oral contrast
Skull base through vertex of head	Axial sequential	AP, LAT	120	250 auto	22cm	5mm	2.5mm	Match skull base	Medium average	No	No

Place patient in supine position with head in head holder. Ensure that patient is not rotated or tilted. Elevate table to bring coronal alignment light to the center of the skull. Landmark per equipment requirements (table movement for scout images). Perform scout images. Prescribe scan locations from skull base to vertex of head. Angle gantry to match skull base (occipital bone) (foramen magnum) and frontal bone (roof of orbit).

CORONAL SINUSES

Anatomical scan range	Scan type	Localizer scans	kVp	mAs	FOV	Scan slice thickness	Recon slice thickness	Gantry tilt	Recon kernel	IV contrast	Oral contrast
Entire sphenoid sinus through entire frontal sinus	Axial sequential	AP, LAT	120	200 auto	16cm	5mm 3mm	2.5mm 1.5mm	90° to max. sinus	Sharp bone	No	No

OPTION 1: Direct coronals—Place patient in prone position with extended chin resting in head holder (see diagram).
OPTION 2: Place patient in supine position with head in head holder (basic head positioning). Ensure that patient is not rotated or tilted. Elevate table to bring coronal alignment light to the center of the skull. Landmark per equipment requirements (table movement for scout images). Perform scout images. Prescribe scan locations to include entire sphenoid sinus through entire frontal sinus Angle gantry to 90° orientation to floor of maxillary sinus. Volume scans can be performed with either positioning option with MPRs in opposite planes. Direct coronal positioning provides better information about maxillary meatus.

SOFT TISSUE NECK

Anatomical scan range	Scan type	Localizer scans	kVp	mAs	FOV	Scan slice thickness	Recon slice thickness	Gantry tilt	Recon kernel	IV contrast	Oral contrast
Above floor of frontal fossa to mid aortic arch	Helical	AP, LAT	120	150 auto	20cm	5mm	2.5mm	Usually none	Medium average	Yes 15s delay	No

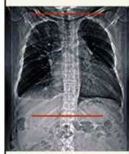
Place patient supine on table with head resting on radiolucent sponge. Ensure that patient's head and neck are within table scan range. Ensure that patient's head and shoulders are not rotated or tilted. Elevate table to bring coronal alignment light to the center of the neck. Landmark per equipment requirements (table movement for scout images). Tip chin up to bring plane of teeth perpendicular to tabletop. Perform scout images. Prescribe scan locations from above floor of frontal fossa to mid aortic arch. Usually no gantry tilt needed—however, scans should be perpendicular to midcoronal plane. Scans typically performed with IV contrast and a scan delay of 15 seconds.

CERVICAL SPINE

Anatomical scan range	Scan type	Localizer scans	kVp	mAs	FOV	Scan slice thickness	Recon slice thickness	Gantry tilt	Recon kernel	IV contrast	Oral contrast
Occipital condyles to below T2	Helical	AP, LAT	120	250 auto	16cm	3mm	1.5mm	Usually none	Sharp bone	No	No

Place patient supine on table with head resting on radiolucent sponge. Ensure that patient's head and neck are within table scan range. Ensure that patient's head and shoulders are not rotated or tilted. Elevate table to bring coronal alignment light to the center of the neck. Landmark per equipment requirements (table movement for scout images). Perform scout images. Prescribe scan locations from skull base/occipital condyles to below T1. Usually no gantry angle when scanning the entire C-Spine. If individual vertebral bodies are of interest—gantry can be angled to match vertebral bodies/disc spaces. Volume scans performed with MPRs in sagittal and coronal planes.

ROUTINE CHEST

	Anatomical scan range	Scan type	Localizer scans	kVp	mAs	FOV	Scan slice thickness	Recon slice thickness	Gantry tilt	Recon kernel	IV contrast	Oral contrast
	Above lung apices to below adrenal glands	Helical	AP, LAT	120	100 auto	Thorax margin	5mm	2.5mm	None	Medium average	Yes 25s delay	No

Place 22g needle in antecubital space—ensure patency. Place patient in supine position with head on pillow, cushion under patient's knees for comfort. Ensure that patient is not rotated or tilted. Elevate table to bring coronal alignment light to the center of the chest. Landmark per equipment requirements (table movement for scout images). Bring patient's arms above their head and support with sponges/pillows for comfort and to protect IV site. Perform scout images. Prescribe scan locations from above lung apices to below adrenal glands. Define FOV to include lateral margins of chest and use lateral scout to center FOV to include anterior and posterior margins of the chest. Scans typically performed with IV contrast and a scan delay of 25 seconds.

ROUTINE ABDOMEN

	Anatomical scan range	Scan type	Localizer scans	kVp	mAs	FOV	Scan slice thickness	Recon slice thickness	Gantry tilt	Recon kernel	IV contrast	Oral contrast
	Above hemidiaphragms to iliac crest	Helical	AP, LAT	120	200 auto	Body margin	5mm	2.5mm	None	Medium average	Yes 60s delay	Yes 24 hr/ 1 hr

Exams typically performed with oral contrast—give contrast 24 hours and 1 hour before exam or timing as requested by radiologist. Place 22g needle in antecubital space—ensure patency. Place patient in supine position with head on pillow, cushion under patient's knees for comfort. Ensure that patient is not rotated or tilted. Elevate table to bring coronal alignment light to the center of the abdomen. Landmark per equipment requirements (table movement for scout images). Bring patient's arms above their head and support with sponges/pillows for comfort and to protect IV site. Perform scout images. Prescribe scan locations from above hemidiaphragms to iliac crest (scan area must include all of liver). Define FOV to include lateral margins of abdomen and use lateral scout to center FOV to include anterior and posterior margins of the abdomen. Scans typically performed with IV contrast and a scan delay of 60 seconds.

ROUTINE PELVIS

	Anatomical scan range	Scan type	Localizer scans	kVp	mAs	FOV	Scan slice thickness	Recon slice thickness	Gantry tilt	Recon kernel	IV contrast	Oral contrast
	Above Iliac crest to mid symphysis pubis	Helical	AP, LAT	120	200 auto	Body margin	5mm	2.5mm	Usually none	Medium average	Yes 120s delay	Yes 24 hr/ 1 hr

Exams typically performed with oral contrast—give contrast 24 hours and 1 hour before exam or timing as requested by radiologist. Place 22g needle in antecubital space—ensure patency. Place patient in supine position with head on pillow, cushion under patient's knees for comfort. Ensure that patient is not rotated or tilted. Elevate table to bring coronal alignment light to the center of the pelvis. Landmark per equipment requirements (table movement for scout images). Bring patient's arms above their head and support with sponges/pillows for comfort and to protect IV site. Perform scout images. Prescribe scan locations from above iliac crest to mid symphysis or below symphysis. Define FOV to include lateral margins of pelvis and use lateral scout to center FOV to include anterior and posterior margins of the pelvis. Scans typically performed with IV contrast and a scan delay of 120–180 seconds.

EXTREMITY - KNEE

	Anatomical scan range	Scan type	Localizer scans	kVp	mAs	FOV	Scan slice thickness	Recon slice thickness	Gantry tilt	Recon kernel	IV contrast	Oral contrast
	Approx 2"–3" above to 2"–3" below joint or area of trauma	Helical	AP, LAT	120	140 200 auto	Knee margin	3mm	1.5mm	Usually none	Sharp bone	Depends on pathology	No

Place patient in supine position with head on pillow. Shift patient so extremity of interest is in midline of table if possible. Extend leg of interest if possible. Ensure that patient is not rotated or tilted. Elevate table to bring coronal alignment light to the center of the knee. Landmark per equipment requirements (table movement for scout images). Flex the unaffected knee to bring leg and foot away from scan plane through affected knee if possible. Perform scout images. Prescribe scan locations from approximately 2"–3" above joint to 2"–3" below joint or area of interest. Define FOV to include lateral margins of soft tissues and use lateral scout to center FOV to include anterior and posterior margins of the knee. Volume scans performed followed by MPRs.

PEDIATRIC IMAGING

The following five points should be considered for pediatric imaging: (1) "Child size" the radiation dose, (2) scan only when necessary, (3) scan only indicated areas, (4) multiphase scanning usually not indicated, (5) utilize shielding whenever possible. Most protocols are adjusted based on patient weight as opposed to patient age, with 55kg being the top of the scale for pediatric adjustments. Note: kVp and mAs values listed are typical low/high ranges for imaging based on patient weight.

PEDIATRIC PROTOCOLS

Anatomical region	Pediatric considerations	Scan type	Localizer scans	kVp	mAs	FOV	Scan slice thickness	Recon slice thickness	Gantry tilt	Recon kernel	IV contrast	Oral contrast
Head	Avoid eyes with scan plane	Helical	AP, LAT	80 120	100 200 auto	16-20 cm	5mm 3mm	2.5mm 1.5mm	Match skull base	Medium average	No	No
Soft tissue neck	Typically same coverage as adults	Helical	AP, LAT	80 120	20 80 auto	10-14 cm	5mm 3mm	2.5mm 1.5mm	Usually none	Medium average	Typically yes	No
C-spine	Typically entire C-spine, avoid eyes	Helical	AP, LAT	80 120	40 100 auto	10-14 cm	3mm	1.5mm	Usually none	Sharp bone	No	No
Chest	Restrict to area of interest, typically single phase for peds	Helical	AP, LAT	80 120	20 70 auto	Edge of anatomy	5mm 3mm	2.5mm 1.5mm	Usually none	Medium average	Yes	No
Abdomen	Restrict to area of interest, typically single phase for peds	Helical	AP, LAT	80 120	40 100 auto	Edge of anatomy	5mm 3mm	2.5mm 1.5mm	Usually none	Sharp bone	Yes	Yes
Pelvis	Restrict to area of interest, typically single phase for peds	Helical	AP, LAT	80 120	40 100 auto	Edge of anatomy	5mm 3mm	2.5mm 1.5mm	Usually none	Sharp bone	Yes	Yes
Extremities	Typically same coverage as adults	Helical	AP, LAT	80 120	50 150 auto	Edge of anatomy	3mm	1.5mm	Usually none	Sharp bone	Depends on pathology	No

Computed tomography technologists have a dual responsibility to not only understand the principles of CT but also the specific capabilities of their machines and universal standards of workflow. The connections the CT technologist makes while selecting scan protocols and parameters are directly related to the image quality, safety, and radiation dose delivered to the patient. CT technologists are on the front lines of imaging with robust, highly specialized technical systems that support the patient's needs, ranging from trauma to non-invasive lifesaving CT guided procedures, to low dose, highly sensitive, pediatric patient imaging, in just seconds of time. This section is a compilation of some useful advice from experienced CT technologists regarding best practices and universal guidelines for the practicing CT technologist.

1. ***Workflow:*** The CT technologist must know and understand the capabilities of their CT scanner system inside and out. With careful preparation and practice, the CT technologist must be ready to stop or pause the scanner and the injector at any moment. All of the preparation in the world will never account for each individual patient's experience while having a CT with IV contrast. If the CT technologist understands the ins and out of their scanner and knows the general principles of CT, departmental CT protocols, as well as basics of blood flow, the technologist will be able to think quickly and achieve the requested phase of contrast and blood flow even in unprecedented situations.
2. ***Pathology:*** The CT technologist is the final reviewer of the CT exam order. This includes understanding medical terminology that describes not only the patient's signs and symptoms, but also the pathology on which the provider is focusing for the patient's illness. It is imperative that the technologist, as the administrator of oral and IV contrast, understands and follows the radiologist protocol, including recognizing high thresholds for renal function labs values such as GFR (glomerular filtration rate) and creatinine. In addition, the technologist needs to be sure the patient does not have any allergies or counterindications to IV or oral contrast administration. This knowledge and final review allow for high image quality, as the technologist will select the CT scanner protocol and IV contrast protocol based on the patient's pathology, weight, and phase of blood flow to be achieved.
3. ***Positioning:*** There is a perception that positioning in CT does not matter, as the reconstruction options and tools to create them are endless. Accurate positioning, minimization of motion, and clear breathing instructions affect image quality. Equally important is reducing the patient's overall cumulative radiation dose. As mentioned in the text, as little as a 3-cm centering mistake can cost the patient as much as an 18% increase in surface dose. Extremity positioning is equally vital, especially when performing CT imaging for pre-operative planning protocols and vascular imaging on a traumatic extremity.
4. ***CT department scanner protocols and scope of practice:*** The CT technologist has a responsibility to know and understand departmental CT scanner protocols. The technologist is responsible for submitting the right CT exam, on the right patient at the prescribed contrast timing, with prescribed speed, rotation time, and pitch. The scope of practice for a CT technologist can vary from state to state and from institution to institution. It is imperative that the technologist follows the ASRT Professional Practice Standards for Medical Imaging and Radiation Therapy and its advisory opinions.
5. ***Pediatrics:*** CT technologists must select the appropriate CT Pediatric designed protocol for the pediatric patient's imaging. In general, the CT Pediatric protocols should be designed with markedly lower radiation dose thresholds than adult CT protocols. The same would correlate to any CT IV contrast injection and oral contrast protocols.
6. ***Anticipation and attention to detail:*** Anticipating the needs of the patient and recognizing the needs for delayed imaging based on the real-time pathology is a benefit to the patient and the radiologist. Many times, the radiologist is in a separate workspace away from the CT scanner. Therefore, it is in the best interest of both the patient and the radiologist if the technologist notices pathology that would benefit from additional imaging. The technologist can reach out swiftly to the radiologist in real time for a rapid prescription of additional images. Another example is the recognition of pathology, such as an abscess, head bleed, or appendicitis, needing urgent care. In these circumstances, the technologist can immediately contact the radiologist for prompt intervention. This practice can result in expedited care.
7. ***Professionalism and adherence to practice standards:*** It is inherent to a CT technologist's training and application to follow best practices in using the ARRT's Code of Ethics. The ARRT has provided a foundation for assessment, knowledge, and skills that are expressed through a technologist's choices in the decision-making process. The focus for the CT technologist should always be to use the best practices to create high-quality CT imaging studies and to care for the patient as safely as possible at the lowest dose.

Definition of Terms

air calibration: Scan of air in gantry; based on a known value of −1000 for air, the scanner calibrates itself according to this density value relative to actual density value measured.

algorithm: Mathematic formula designed for computers to carry out complex calculations required for image reconstruction; designed for enhancement of soft tissue, bone, and edge resolution. Also referred to as *kernel*.

anisotropic spatial resolution: Spatial resolution of a voxel in which all three axes of the volume element are not equal. Slice thickness is not equal to pixel size.

aperture: Opening of the gantry through which the patient passes during the scan.

archiving: Storage of CT images on a long-term storage device such as cassette tape, magnetic tape, CD/DVR, optical disk, or USB.

artifact: Distortion or an error in image that is unrelated to subject being studied.

attenuation: Coefficient CT number assigned to measured remnant radiation intensity after attenuation by tissue density.

axial: Describes plane of an image as presented by CT scan; same as *transverse*.

bolus: Preset amount of radiopaque contrast medium injected rapidly per IV administration to visualize high-flow vascular structures, usually in conjunction with dynamic scan; most often injected using a pressure injector.

channel: In multidetector CT, multiple rows of detectors (channels) are arranged along the longitudinal (*z*) axis of the patient. Each detector row (channel) consists of numerous elements.

computed tomography (CT): X-ray tube and detector assembly rotating 360 degrees around a specified area of the body; also called CAT (computed axial tomography) scan.

computed tomography dose index (CTDI): Radiation dose descriptor calculated with normalized beam widths for 14 contiguous sections or slices.

computed tomography dose index100 (CTDI100): Radiation dose descriptor calculated with the full length of a 100-mm pencil ionization chamber. Measures larger scan distances than CTDI, but only one location is calculated.
computed tomography dose indexvol (CTDIvol): Radiation dose descriptor that takes into account the parameters that are related to a specific imaging protocol. Considers helical pitch or axial scan spacing in its calculation. More accurate measure of dose per protocol.
computed tomography dose index (CTDIw): Radiation dose descriptor that provides a weighted average of the center and peripheral contributions to dose within the scan plane. More accurate than $CTDI_{100}$, owing to calculations from more than one location.
CT angiography: Use of volumetric CT scanning with spiral technique to acquire image data that is reconstructed into three-dimensional CT angiograms.
CT number: Arbitrary number assigned by computer to indicate relative density of a given tissue; CT number varies proportionately with tissue density; high CT numbers indicate dense tissue, and low CT numbers indicate less dense tissue. All CT numbers are based on the density of water, which is assigned a CT number of 0. Also referred to as a *Hounsfield unit.*
contrast resolution: Ability to differentiate between small variations in density within the image.
curved planar reformations: Postprocessing technique applied to stacks of axial image data that can be reconstructed into irregular or oblique planes.
data acquisition system (DAS): Part of detector assembly that converts analog signals to digital signals that can be used by the CT computer.
detector: Electronic component used for radiation detection; made of either high-density photo reactive crystals or pressurized stable gases.
detector assembly: Electronic component of CT scanner that measures remnant radiation exiting the patient, converting the radiation to an analog signal proportionate to the radiation intensity measured.
direct coronal: Describes position used to obtain images in coronal plane; used for head scans to provide images at right angles to axial images; patient is positioned prone for direct coronal images and supine for reverse coronal images.
dose length product (DLP): Commonly reported dose descriptor on CT scanners. Calculated by multiplying the $CTDI_{vol}$ by the length of the scan (cm). $DLP = CTDI_{vol} \times$ scan length.
dynamic scanning: Process by which raw data are obtained by continuous scanning; images are not reconstructed but are saved for later reconstruction; most often used for visualization of high-flow vascular structures; can be used to scan an uncooperative patient rapidly.
field of view (FOV): Area of anatomy displayed on the monitor; can be adjusted to include entire body section or a specific part of the patient anatomy being scanned.
gantry: Part of CT scanner that houses x-ray tube, cooling system, detector assembly, and DAS; often referred to as the "doughnut" by patients.
generation: Description of significant levels of technologic development of CT scanners; specifically related to tube/detector movement.
grayscale image: Analog image whereby each pixel in the image corresponds to a particular shade of gray.
helical CT: Data acquisition method that combines continuous gantry rotation with continuous table movement to form a helical path of scan data; also called *spiral CT.*
high-resolution scans: Use of scanning parameters that enhance contrast resolution of an image, such as thin slices, high matrices, high-spatial frequency algorithms, and small-display FOV.
host computer: Primary link between system operator and other components of imaging system.
Hounsfield unit (HU): Number used to describe average density of tissue; term is used interchangeably with *CT number*; named in honor of Hounsfield, who is generally given credit for development of the first clinically viable CT scanner.
image misregistration: Image distortion caused by combination of table indexing and respiration; table moves in specified increments, but patient movement during respiration may cause anatomy to be scanned more than once or not at all.
index: Table movement; also referred to as *table increments.*
isotropic spatial resolution: Spatial resolution of a voxel in which all three axes of the volume element are equal. Slice thickness is equal to pixel size.
mapping: Assignment of appropriate gray level to each pixel in an image.
matrix: Mathematical formula for calculation made up of individual cells for number assignment; CT matrix stores a CT number relative to the tissue density at that location; each cell or "address" stores one CT number for image reconstruction.
maximum intensity projection (MIP): Reconstruction of brightest pixels from stack of image data into a three-dimensional image.
multiplanar reconstruction (MPR): Postprocessing technique applied to stacks of axial image data that can be reconstructed into other orientations or imaging planes.
multiple scan average dose (MSAD): Dose descriptor that calculates average dose resulting from a series of scans over an interval length of scans.
noise: Random variation of CT numbers around some mean value within a uniform object; noise produces a grainy appearance in the image.
partial volume averaging: Calculated linear attenuation coefficient for a pixel that is a weighted average of all densities in the pixel; the assigned CT number and ultimately the pixel appearance are affected by the average of the different densities measured within that pixel.
pixel (picture element): One individual cell surface within an image matrix used for image display.
postprocessing techniques: Specialized reconstruction techniques that are applied to CT images to display the anatomic structures from different perspectives.
primary data: CT number assigned to the matrix by the computer; the information required to reconstruct an image.
protocol: Instructions for CT examination specifying slice thickness, table increments, contrast administration, scan diameter, and any other requirements specified by the radiologist.
quantum noise: Any noise in the image that is a result of random variation in the number of x-ray photons detected.
real time: Ability to process or reconstruct incoming data in milliseconds.
reconstruction: Process of creating a digital image from raw data.
region of interest (ROI): Measurement of CT numbers within a specified area for evaluation of average tissue density.

rendering: Process of changing the shading of a three-dimensional image; commonly used to increase depth perception of an image.
retrieval: Reconstruction of images stored on long-term device; can be done for extra film copies or when films are lost.
scan: Actual rotation of x-ray tube around the patient; used as a generic reference to one slice or an entire examination.
scan diameter: Also referred to as the zoom or focal plane of a CT scan; predetermined by the radiographer to include the anatomic area of interest; determines FOV.
scan duration: Amount of time used to scan an entire volume during a single spiral scan.
scan time: X-ray exposure time in seconds.
segmentation: Method of cropping or editing target objects from image data.
shaded surface display (SSD): Process used to generate three-dimensional images that show the surface of a three-dimensional object.
shading: Postprocessing technique used in three-dimensional reconstructions to separate tissues of interest by applying a threshold value to isolate the structure of interest.
slice: One scan through a selected body part; also referred to as a *cut*; slice thickness can vary from 0.35 mm to 1 cm, depending on the examination.
slip ring: Low-voltage electrical contacts within the gantry designed to allow continuous rotation of an x-ray tube without the use of cables connecting internal and external components.
spatial resolution: Ability to identify visibly anatomic structures and small objects of high contrast.
spiral CT: Scanning method that combines a continuous gantry rotation with a continuous table movement to form a spiral path of scan data; also called *helical CT.*
streak artifact: Artifact created by high-density objects that result in an arc of straight lines projecting across the FOV from a common point.
system noise: Inherent property of a CT scanner; the difference between the measured CT number of a given tissue and the known value for that tissue; most often evaluated through the use of water phantom scans.
table increments: Specific amount of table travel between scans; can be varied to move at any specified increment; most protocols specify from 1 mm to 20 cm, depending on type of examination; also referred to as *indexing.*
table speed: Longitudinal distance traveled by the table during one revolution of the x-ray tube.
temporal resolution: Ability of CT system to freeze motions of the scanned object; the shortest amount of time needed to acquire a complete data set.
threshold value: CT number used in defining the corresponding anatomy that comprises a three-dimensional object; any pixels within a three-dimensional volume having the threshold value (CT number) or higher would be selected for the three-dimensional model.
useful patient dose: Radiation dose received by the patient that is actually and converted into an image.
voxel (volume element): Individual pixel with the associated volume of tissue based on the slice thickness.
window: Arbitrary numbers used for image display based on various shades of gray; *window width* controls the overall gray level and affects image contrast; *window level* (center) controls subtle gray images within a certain width range and ultimately affects the brightness and overall density of an image.

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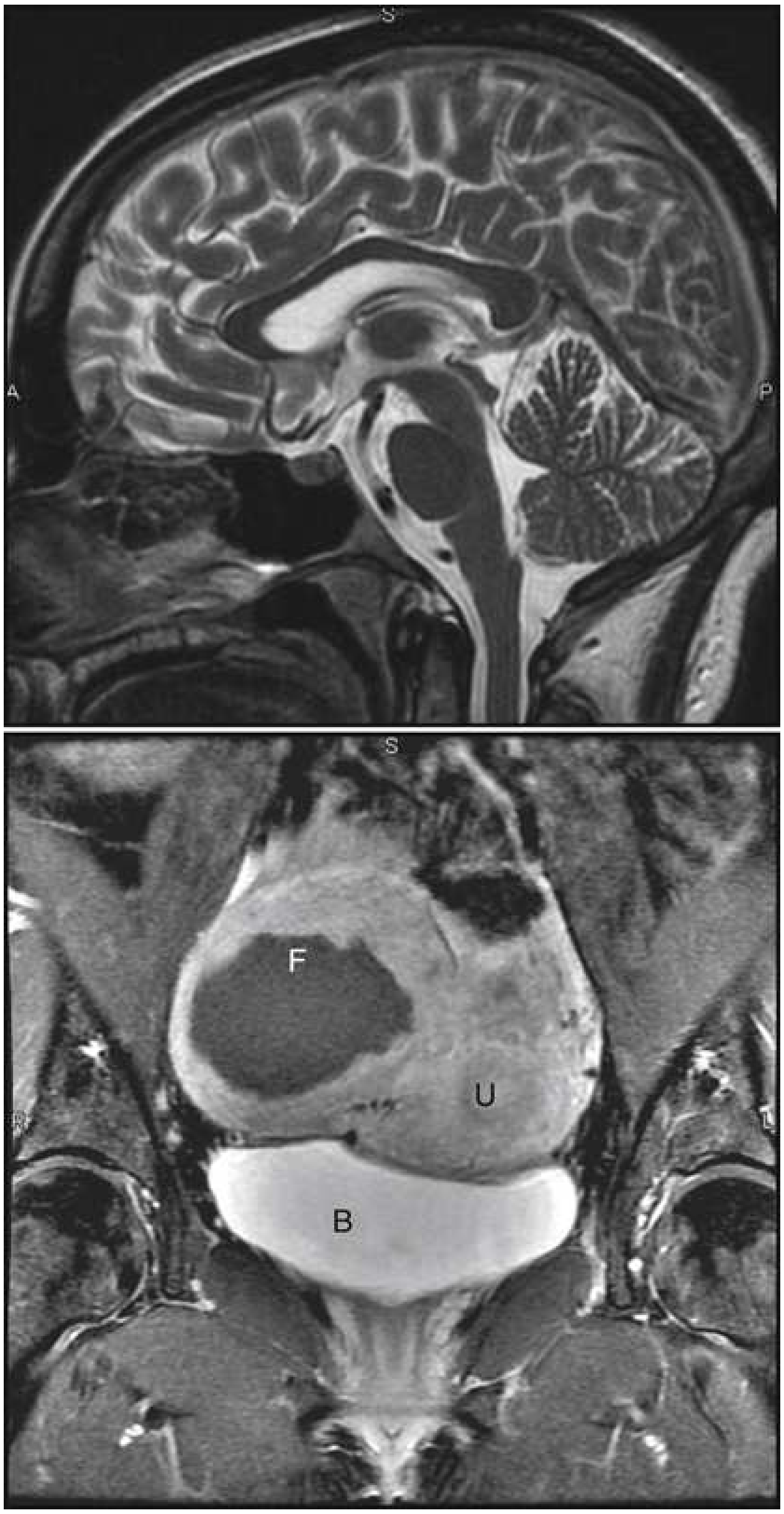
26: Magnetic Resonance Imaging



Bartram J. Pierce, and Elizabeth Nelson

OUTLINE

Principles of Magnetic Resonance Imaging

Magnetic resonance [a] imaging (MRI) is a noninvasive technique that produces computer-generated cross-sectional images similar to those of computed tomography (CT) (see Chapter 25), which contains anatomic and physiologic information. Using no ionizing radiation, MRI creates images through the interaction of magnetic fields and radio frequency energy on biologic tissues.

An interesting historical note: MRI was originally called *nuclear magnetic resonance* (NMR) imaging, with the word *nuclear* indicating that the nonradioactive atomic nucleus played an important role in the technique. This term was dropped because of public apprehension about nuclear energy and nuclear weapons—neither of which is associated with MRI in any way.

Comparison of Magnetic Resonance Imaging and Conventional Radiography

Despite being the mainstay of medical imaging for more than a century, conventional radiography has two significant weaknesses.

On a radiograph, all body structures exposed to the x-ray beam are superimposed into one flat or two-dimensional image. This makes it extremely difficult to separate individual organs or anatomic structures from one another. In many instances, multiple projections must be acquired to visualize these important structures. Cross-sectional imaging techniques, such as MRI, can create three-dimensional images with little or no superimposition of structures.

Contrast, or the ability to discriminate between two slightly different tissue densities, is necessary for imaging soft tissue structures. Because conventional radiography depends on differences in x-ray *attenuation* within the object and the sensitivity of the recording medium, it is difficult for radiographs to detect small differences in contrast. Typically, conventional radiographs can distinguish only tissues with large differences in attenuation of the x-ray beam (air, fat, bone, and metal). Soft tissue structures such as the liver and kidneys cannot be separated by differences in x-ray attenuation alone. For these structures, differences are magnified using contrast agents. MRI can distinguish very small differences in contrast among tissues by manipulating biologic tissue with magnetic fields and radio waves.

Best Practices

The production of high-quality diagnostic MR images requires the technologist to master a myriad of imaging parameters and options while at the same time paying strict attention to patient and staff safety. The following best practices will serve as a guide for the MRI technologist.

Safety

The MRI environment is a dangerous and potentially lethal environment. The primary responsibility of the MRI technologist is the safety of all individuals within this magnetic environment. The technologist must have sufficient knowledge and understanding to perform the following responsibilities:

- Serve as a gatekeeper to the magnet room (Zone 4) to ensure the safety of patients, visitors, and staff.
- Screen all equipment, staff, patients, and visitors to prevent any unsafe objects/devices from entering the magnet room (Zone 4).
- Pre-screen patients for the presence of implanted devices that require further investigation and/or coordination with device representatives.
- Use ferromagnetic detection systems (FMDS) to supplement the written and verbal screening process.
- Change patients into MRI-appropriate attire for exams (i.e., no street clothes).
- Use appropriate padding between the patient and the bore wall, between areas of skin-to-skin contact, and between cables/wires and the patient to prevent burns.
- Provide patients, visitors, and staff who remain within the magnet room during scanning with appropriate hearing protection.
- Clean equipment after each patient to prevent the transmission of pathogens.
- Incorporate a time-out, during which the imaging team verifies the following: right patient, proper screening, right exam, correct laterality, correct protocol, and appropriate contrast dose.

Appropriate Exam/Protocol

Choosing the appropriate exam and protocol requires exceptional sensitivity and specificity. The technologist must be an integral part of this equation by modeling the following behaviors:

- Thinking outside the box for patient positioning/coil usage. Patients are not always able to withstand the standard positioning or coil used for a procedure.
- Collaborating with radiologists on what sequences are most important for various exams.
- Incorporating the use of exam time reduction techniques, such as compressed sensing.
- Making use of motion reduction/freezing techniques to improve the quality of images.
- Incorporating the use of pulse sequences that acquire multiple image weights at once to reduce the time in which patients must remain on the table.
- Incorporating the use of artificial intelligence to reduce variability among technologists and increase consistency across follow-up exams.
- Understanding the need and use of contrast media.

Patient Management

MRI's unique environment presents the technologist with challenges that require the technologist to have above-average patient care/communication skills and understand the unique MRI environment. The technologist may demonstrate this expertise by carrying out the following tasks:

- Explaining the procedure to the patient on their level (e.g., adult vs. child).
- Paying attention to nonverbal cues that signify claustrophobia/pain/discomfort. The technologist can then make modifications to the patient position or imaging technique to ensure a successful exam.
- Communicating with the patient throughout the exam. This reduces anxiety, gives the patient a sense of how much time remains, and lets the patient know that they are not alone.
- Using distraction techniques such as lighting, music, prism glasses, airflow, and aromatherapy to combat claustrophobia. Medication and an accompanying friend or family member may also be helpful.

Historical Development

In the mid-1940s, Felix Bloch, working at Stanford University, and Edward Purcell, working at Harvard University, discovered the principles of NMR. Their work led to the use of nuclear magnetic spectroscopy for the analysis of complex molecular structures and dynamic chemical processes. This technology is still in use today for the nondestructive testing of chemical compounds. In 1952, Bloch and Purcell were jointly awarded the Nobel Prize in Physics for their development of new methods in making precise nuclear magnetic measurements.

In 1969, Raymond Damadian proposed the first MRI body scanner. He discovered that the relaxation times (discussed later in this chapter) of tumors differed from the relaxation times of normal tissue. This finding suggested that if images of the body could be obtained by producing maps of relaxation rates, it would be possible to differentiate normal from abnormal tissues. In 1973, Paul Lauterbur published the first cross-sectional images of objects obtained with MRI techniques. These first images were crude, and only large objects could be distinguished. Sir Peter Mansfield demonstrated how the signals could be rapidly analyzed mathematically, which made it possible to develop useful imaging techniques. Since those discoveries, MRI technology has advanced rapidly. Very small structures are commonly imaged quickly and with increased resolution and contrast. In 2003, the Nobel Prize in Physiology or Medicine was jointly awarded to Lauterbur and Mansfield for their discoveries in MRI.

Physical Principles

Signal Production

The structure of an atom is often compared with the structure of the solar system, with the sun representing the central atomic *nucleus* and the planets representing the orbiting electrons. MRI uses the properties of the nucleus to generate the signal containing the information that is used to construct the image. Clinical MRI scanners "image" hydrogen because it is the most abundant element in the body and is the strongest nuclear magnet on a per-nucleus basis.

Elements with odd atomic numbers, such as hydrogen, are called *MR-active nuclei* and have magnetic properties causing them to act like tiny bar magnets (Fig. 26.1). Ordinarily, in the absence of a strong magnetic field, these protons point in random directions, as shown in Fig. 26.2, creating no net magnetization. At this point they are not useful for imaging. However, if the body is placed within a strong uniform magnetic field, the protons will attempt to align themselves in one of two orientations: with the main magnetic field (parallel) or against the main magnetic field (antiparallel). At equilibrium, a slight majority of hydrogen protons will align with (parallel to) the main magnetic field (also called the *longitudinal plane*), resulting in a slight net magnetization of the imaging volume.

The protons do not line up precisely with the external magnetic field, but at an angle, causing them to rotate around the magnetic field in a manner similar to the wobbling of a spinning top. This wobbling motion, depicted in Fig. 26.3, is called *precession* and occurs at a specific *frequency* (rate) for a given atom's nucleus in a magnetic field of a specific strength. These precessing protons can absorb energy only if that energy matches the frequency at which they are wobbling. In MRI, the energy to excite the protons comes from *radio frequency* (RF) energy, typically found in the FM band of the electromagnetic spectrum. The absorption of energy by the precessing protons is referred to as *resonance.* This resonant or precessional frequency, called the Larmor frequency, varies depending on the field strength of the MRI scanner. For example, in a 1-tesla (T) scanner, the Larmor frequency is 42.58 MHz, but in a 3-T scanner, the precessional frequency is 127.74 MHz.

When an RF pulse is applied at the Larmor frequency, the protons absorb the energy and begin to resonate, resulting in a reorientation of the net tissue magnetization into a plane perpendicular to the main magnetic field. This is known as the *transverse plane.* The protons in the transverse plane are also precessing at the same resonant frequency. Faraday's law of induction states that a moving magnetic field induces an electrical current in a wire; therefore, the precessing protons (a moving magnet) in the tissues create an electrical current, the MRI signal, in the receiving coil or *antenna.*

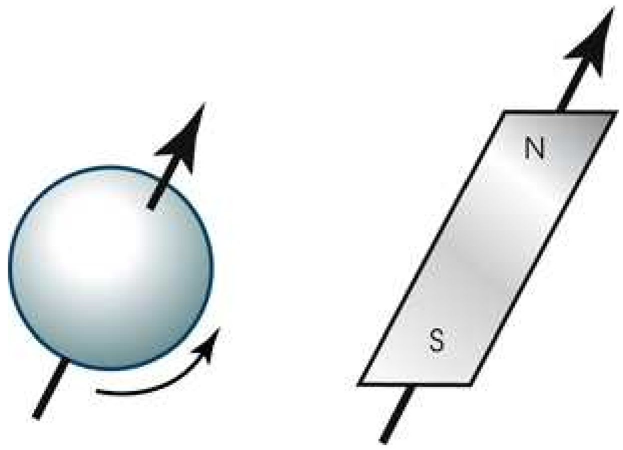


FIG. 26.1 A proton with magnetic properties can be compared to a tiny bar magnet. Curved arrow indicates that a proton spins on its own axis; this motion is different from that of precession.

The MRI signal is picked up by this sensitive antenna or coil, amplified, and processed by a computer to produce a sectional image of the body, which is viewed on a computer monitor. Since the information is in a digital format, it can be post-processed for additional diagnostic information.

Many other odd-numbered nuclei in the body can be used in MRI. Nuclei from elements such as phosphorus and sodium provide useful and different diagnostic information, particularly in efforts to understand the metabolism of normal and abnormal tissues. Metabolic changes may prove to be more sensitive and specific in detecting abnormalities than the more physical and structural changes recognized by hydrogen MRI. Nonhydrogen nuclei may also be used for combined imaging and spectroscopy, in which small volumes of tissue may be analyzed for chemical content.

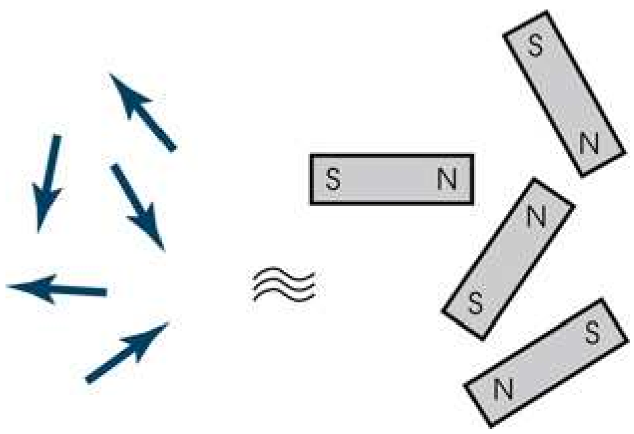


FIG. 26.2 In the absence of a strong magnetic field, the protons *(arrows)* point in random directions and cannot be used for imaging.

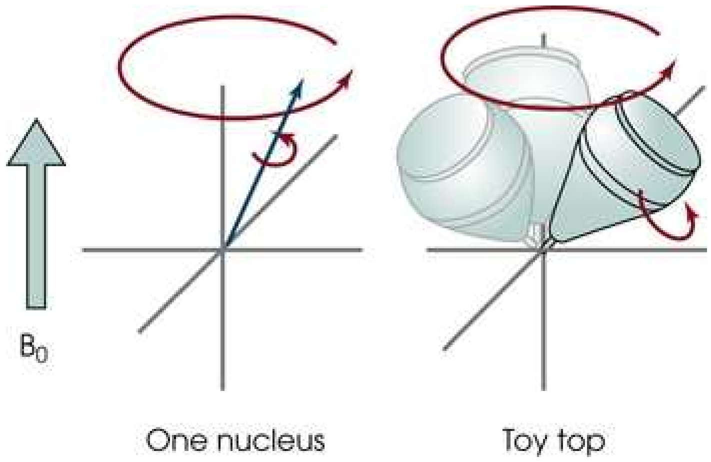


FIG. 26.3 Precession. The protons *(arrow)* and the toy top spin on their own axes. Both also rotate *(curved arrows)* around the direction of an external force in a wobbling motion called *precession*. Precessing protons can absorb energy through resonance. *B0* represents the external magnetic field acting on the nucleus. The toy top precesses under the influence of gravity.

The protons (arrow) and the toy top spin on their own axes. Both also rotate (curved arrows) around the direction of an external force in a wobbling motion called precession. Processing protons can absorb energy through resonance. B subscript 0 represents the external magnetic field acting on the nucleus. The toy top processes under the influence of gravity.

Significance of the Signal

As mentioned earlier, conventional radiographic techniques, including CT, produce images based on a single property of tissue: x-ray attenuation or density. MR images are more complex because they contain information about a variety of properties of tissue—proton density, relaxation rates, and flow phenomena. These properties contribute to the overall strength of the MRI signal. Computer processing converts signal strength to shades of gray on the image. Strong signals are represented by white in the image, and weak signals are represented by black.

One determinant of signal strength is the number of precessing protons in a given volume of tissue. Signal strength that depends on the concentration of protons is termed *proton density*. Most soft tissues, including fat, have a similar number of protons per unit of volume; therefore, the use of proton density characteristics alone separates these tissues poorly. Other tissues have few hydrogen nuclei per unit of volume; examples include the cortex of bone and air in the lungs. These tissues have a weak signal as a result of low proton density and can be easily distinguished from other tissues.

MRI signal intensity also depends on the relaxation times of the nuclei. *Relaxation* is the release of energy by the excited protons. Excited nuclei relax through two processes. The process of nuclei releasing their excess energy to the general environment or lattice (the arrangement of atoms in a substance) is called *spin-lattice relaxation.* The rate of this relaxation process is measured in milliseconds and is labeled as T1. *Spin-spin relaxation* is the release of energy by excited nuclei through interaction among themselves. The rate of this process is also measured in milliseconds, but is labeled as T2.

Relaxation (T1 and T2) occurs at different rates in different tissues. The environment of a hydrogen nucleus in the spleen differs from that of one in the liver; therefore, their relaxation rates differ, and the MRI signals created by these nuclei differ. The different relaxation rates in the liver and spleen result in different signal intensities and appearances on the image, enabling the viewer to discriminate between the two organs. Similarly, many types of tissue, such as fat and muscle, can be distinguished based on the relaxation rates of their nuclei. The most important factor in tissue discrimination is the relaxation time.

The signals produced by MRI techniques contain a combination of proton density, T1, and T2 information. It is possible to obtain images "weighted" toward any one of these three parameters by manipulating nuclei with specific *pulse sequences.* In most imaging sequences, a short T1 (fast spin-lattice relaxation rate) produces a high MRI signal on T1-weighted images. Conversely, a long T2 (slow spin-spin relaxation rate) generates a high signal on T2-weighted images.

The final property that influences image appearance is flow. For complex physical reasons, moving substances usually have weak MRI signals. (With some specialized pulse sequences, the reverse may be true; see the discussion of magnetic resonance angiography [MRA] later in the chapter.) With standard pulse sequences, flowing blood in vessels produces a low signal and is easily discriminated from surrounding stationary tissues without the need for the contrast agents required by regular radiographic techniques. Stagnant blood, such as an acute blood clot, typically has a high MRI signal in most imaging schemes because of its short T1 and long T2. Specific pulse sequences may facilitate the assessment of vessel patency or the determination of the rate of blood flow through vessels (Fig. 26.4).

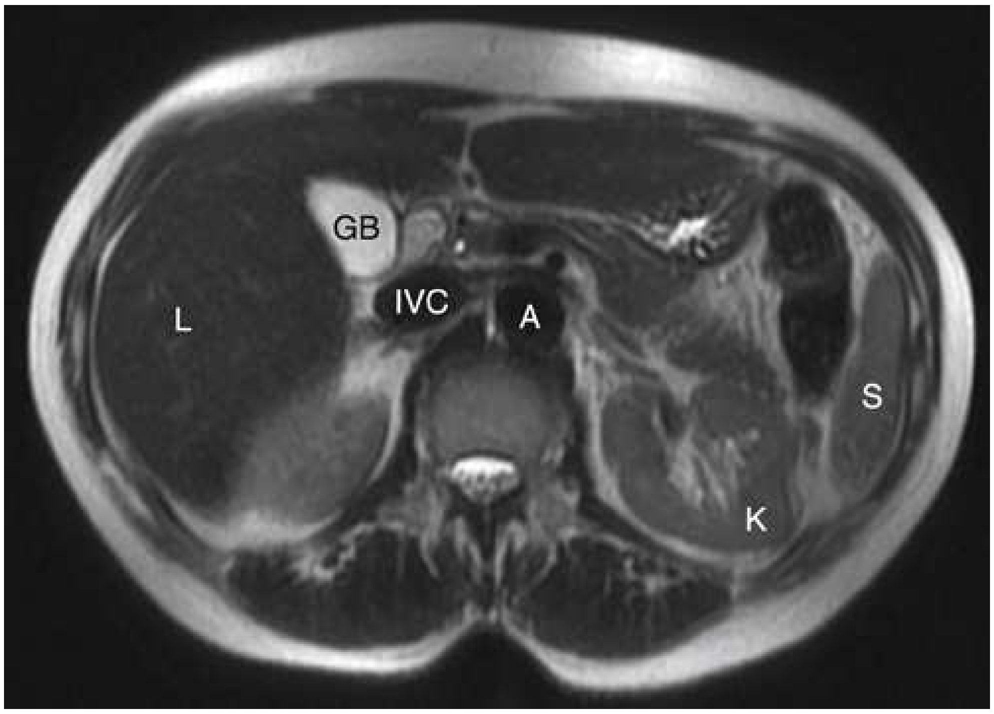


FIG. 26.4 T2-weighted image of an abdomen showing the flow void produced by flowing blood. *A,* Aorta; *GB,* gallbladder; *IVC,* inferior vena cava; *K,* kidney; *L,* liver; *S,* spleen.

Equipment

MRI requires a patient area (magnet room), an equipment room, and an operator's console. A separate diagnostic workstation is optional.

Console

The operator's console is used to control the imaging process (Fig. 26.5). At the console, the operator can interact with the system's computers and electronics to manipulate all necessary examination parameters and perform the appropriate examination. Images are viewed on a computer monitor to ensure that the examination is of appropriate diagnostic quality. Here, images can be manipulated, and hard copies of the exam can be produced if necessary. An independent workstation may be used to perform additional image manipulation or postprocessing when required.

Equipment Room

The equipment room houses all the electronics and computers necessary to complete the imaging process. The RF cabinet controls transmission of the radio wave pulse sequences. The gradient cabinet controls the additional time-varying magnetic fields necessary to localize the MRI signal. The array processors and computers receive and process the large amount of *raw data* received from the patient and construct the images the operator sees on the operator's console.

FIG. 26.5 Operator's console. This device controls the imaging process and allows visualization of images. Courtesy General Electric Healthcare.

Magnet Room

The magnet is the major component of the MRI system in the scanning room. It must be large enough to surround the patient and any antennas (coils) that are required for radio wave transmission and reception. Antennas are typically wound in the shape of a positioning device for a particular body part. These are commonly referred to as *coils*, or *RF antennas.* As the patient lies on the table, coils are placed either on, under, or around the part to be imaged. Once positioned, the patient is advanced into the center of the magnet (isocenter) (Fig. 26.6).

Various magnet types may be used to provide the strong uniform magnetic field required for imaging, as follows:

- *Resistive magnets* are simple but large electromagnets consisting of coils of wire. A magnetic field is produced by passing an electrical current through the wire coils. The greater the current, the higher the field strength. However, the electrical resistance of the wire coils produces heat, which limits the maximum strength of the magnetic field.
- *Superconductive (cryogenic) magnets* are also electromagnets. Their wire loops are cooled to very low temperatures with liquid helium to reduce electrical resistance. This permits higher magnetic field strengths than those produced by resistive magnets.
- *Permanent magnets* are a third source for the magnetic field. A permanent magnet has a constant field that does not require additional electricity or cooling. Early permanent magnets were extremely heavy, even compared with the massive superconductive and resistive units. Because of their weight, these magnets were difficult to place for clinical use. The magnetic fields of permanent magnets do not extend as far away from the magnet *(fringe field)* as do the magnetic fields of other types of magnets. Fringe fields are a problem because of their effect on nearby electronic equipment.

FIG. 26.6 Patient prepared for MRI. Courtesy General Electric Healthcare.

Various MRI systems operate at different magnetic field strengths. Magnetic field strength is measured in *tesla* (T) or *gauss* (G). Most MRI examinations are performed with field strengths ranging from 0.2 to 3 T. Resistive systems generally do not exceed 0.6 T, and permanent magnet systems do not exceed 0.3 T. Higher field strengths require superconductive technology, with popular field strengths of 1.5 T and 3 T. Clinical 7T MRI systems and research-oriented 11T MRI systems have been recently introduced. The advantage of these ultra-high field systems is greatly increased signal-to-noise ratio (SNR), which leads to increased resolution.

Prior to the development of actively shielded magnets, installing an MRI system in the hospital was a challenge owing to large magnetic fringe fields. Advances in magnet technology and the use of passive and actively shielded magnets have made the siting of MRI units more commonplace. The fringe fields of both resistive and superconducting magnets can now be “pulled in” or reduced to lessen the interference with nearby electronic and computer equipment. This shielding also reduces the effect of metal objects such as elevators or automobiles moving near the magnetic fringe field.

Stray radio waves present another challenge in the placement of MRI units. The radio waves used in MRI may be of the same frequency as the radio waves used for other nearby radio applications. Stray radio waves can be picked up by the MRI antenna coils and interfere with normal image production. MRI facilities require specially constructed rooms, called *Faraday cages,* to shield the receiving antennas from outside radio interference.

Specialty units have become available for limited applications. One example is an extremity MRI scanner (Fig. 26.7). This unit is designed so that the patient can sit comfortably in a chair while having an extremity or musculoskeletal joint imaged. These units are lightweight (approximately 1500 lb) and take up less space than conventional MRI scanners, and they produce good-quality images (Fig. 26.8).

FIG. 26.7 Extremity MRI scanner, 1 T. Courtesy ONI Medical Systems, Inc, Wilmington, MA.

FIG. 26.8 Coronal MRI of the knee obtained with extremity MRI scanner. Courtesy ONI Medical Systems, Inc, Wilmington, MA.

Infection Control

Because of the inherent dangers that exist within the MRI suite (e.g., projectiles, torque effects), developing and maintaining a strict infection-control protocol can be a challenge. Although it may be expected that all technologists will practice standard precautions, some may not realize that cleanliness of the magnet room is typically their responsibility. In many institutions, housekeeping is not allowed into the magnet room. It is important for technologists to be aware of the infection-control policies of their institution. Research has shown that various pathogens, including methicillin-resistant *Staphylococcus aureus* (MRSA), will grow within the bore of the magnet. For this reason, technologists must be diligent in their practice of infection control.

Safety of Magnetic Resonance Imaging

Because MRI does not use ionizing radiation, it is generally considered safe. However, there are many other potential safety issues from both direct and indirect effects that must be mentioned.

Opinions differ about the safety of the varying magnetic and RF fields to which the patient is directly exposed. Many studies in which experimental animal and cell culture systems were exposed to these fields over long periods have reported no adverse effects, whereas others have reported changes in cell cultures and embryos. RF energy is deposited in the patient during imaging and is dissipated in the body as heat. The resulting changes seem to be lower than the levels considered clinically significant, even in areas of the body with poor heat dissipation, such as the lens of the eye. The significance of direct short-term exposure (i.e., exposure of a patient) and long-term exposure (i.e., exposure of an employee who works with MRI) is unclear. No clear association of MRI with adverse effects in humans has been proven, but research is continuing.

Hazards related to the static magnetic field have been well documented. Objects containing ferromagnetic metals (e.g., iron, nickel, cobalt) may be attracted to the imaging magnet with sufficient force to injure patients or personnel who may be interposed between them. Scissors, oxygen tanks, and patient stretchers are among the many items that have been drawn into the magnetic fields at MRI sites. Metallic implants within patients or personnel may become displaced or dislodged and cause injury if they are in delicate locations. Examples include intracranial aneurysm clips, auditory implants, and metallic foreign bodies in the eye. Surgical clips, metal hardware, and artificial joints typically do not pose problems. Electromechanical implants such as non-MRI conditional pacemakers or internal cardiac defibrillators can malfunction when they are exposed to strong magnetic fields or RF energy. Patients who have such implants should not be allowed near the magnet. Fortunately, manufacturers continue to develop *MRI safe and conditional* implants, allowing these patients to be scanned safety under specific conditions. Anyone entering the magnet room (i.e., patients, visitors, and personnel) should be screened to ensure that they do not carry metallic objects into the magnet room or have objects in their bodies that could be adversely affected by exposure to strong magnetic fields.

Ferromagnetic detection systems (FMDS) have been developed to further enhance the screening process. FMDS detect ferrous objects that one may be carrying prior to entry into the exam room (Fig. 26.9). While FMDS can detect ferrous objects, the system should not replace a thorough written and verbal screening. There are also safety principles to follow once the patient is inside the exam room.

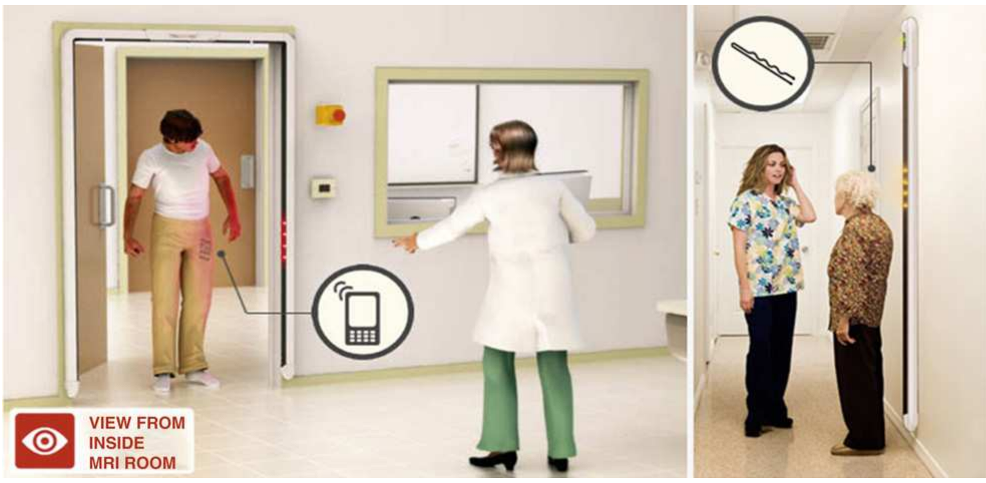


FIG. 26.9 Ferrous metal detectors serve as an additional safeguard preventing metal objects from entering the magnetic resonance scan room. *Left,* FerrAlert® ferromagnetic entryway detection system by Kopp Development Inc. *Right,* FerrAlert® ferromagnetic pre-screening detection system by Kopp Development Inc.(Courtesy Kopp Development, Inc.)

A pictorial representation on the left shows a man entering a room with a cell phone in his pocket. A woman wearing a coat is pointing at the cell phone in the pocket. An enlarged image of the cell phone emitting radiation is in the middle. A text below reads view from inside M R I room. A pictorial representation on the right shows a mom standing in the hallway with her hand on her hair and she is talking to an elderly woman standing in front of her. An enlarged image of a hairpin is on top.

Patients can receive local burns from wires, such as electrocardiogram (ECG) leads, and other monitoring devices that may touch their skin during MRI examinations. These injuries have included electrical burns caused by currents induced in the wires or thermal burns caused by heating of these wires. Such burns can be prevented by checking wires for frayed insulation, ensuring that no wire loops are within the magnetic field, and placing additional insulation between the patient and any wires exiting the MRI system. Additional insulation should also be placed between the patient and the bore of the magnet to prevent contact RF burns. Furthermore, padding should be placed between points of skin-to-skin contact to prevent burns (Fig. 26.10). Patients should remove all clothing and be gowned in hospital or facility apparel, as many clothing items are now manufactured with metallic threads that can cause contact burns to the patient.

The time-varying magnetic fields (gradients) in an MRI unit act on the machine itself, causing knocking or banging sounds. These noises can be loud enough to produce temporary or permanent hearing damage. Anyone in the magnet room during scanning must use earplugs or some other sound damping device to prevent auditory complications.

Claustrophobia can be a significant impediment to MRI in up to 20% of patients (Fig. 26.11). Patient education is perhaps most important in preventing this problem, but medication, appropriate lighting, music, aromatherapy, air movement, and mirrors or prisms that enable a patient to look out of the imager may be helpful. Claustrophobia can also be prevented by having a family member or friend accompany the patient and be present in the room during the scan.

In superconductive magnet systems, rapid venting (quench) of the supercooled liquid gas (helium) from the magnet or its storage containers into the surrounding room space is a rare but possible hazard. As the helium fills the magnet room, it replaces the oxygen, resulting in unsafe levels and posing a risk of unconsciousness or asphyxiation. Oxygen monitoring devices in the magnet or cryogen storage room can signal personnel when the oxygen concentration becomes too low. Personnel may then evacuate the area and activate ventilation systems to exchange the escaped gas for fresh air.

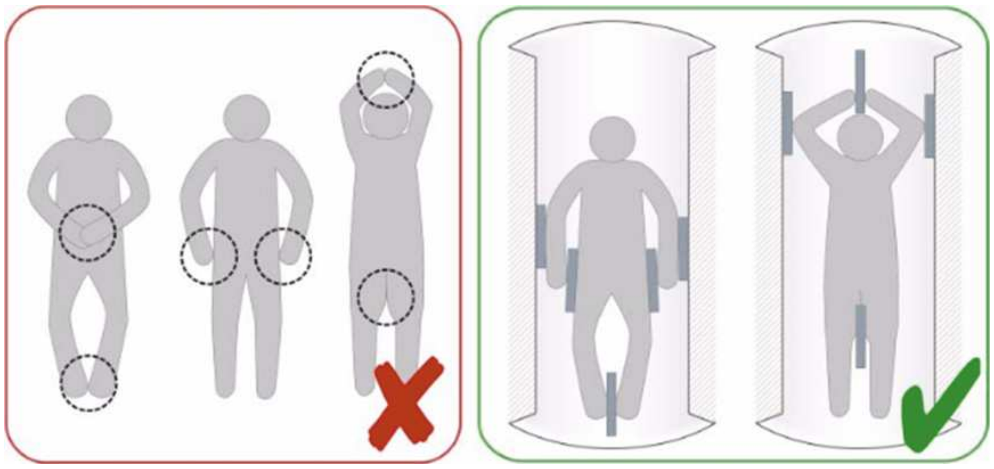


FIG. 26.10 To avoid radio frequency contact burns, padding should be placed between points of skin-to-skin contact to prevent burns. Courtesy Siemens Healthineers.

A red box on the left shows three people next to each other. In the red box: The person on the left is standing with his arms resting on the abdomen and the soles of his foot are touching each other. These two areas are circled. A person in the middle is standing with both the arms placed outside. Both his hands are circled. A person on the right is standing with both the arms stretched over his head. The pelvis and the arms are circled. In the green box: A person on the left is in a cylindrical room. A shield is placed between his foot, on the sides of the hip and the lateral surface of both the arms. A person on the right is in a cylindrical room with both the hands placed over the head. A shield is placed between the hands, on the sides of the elbow and between the thighs.

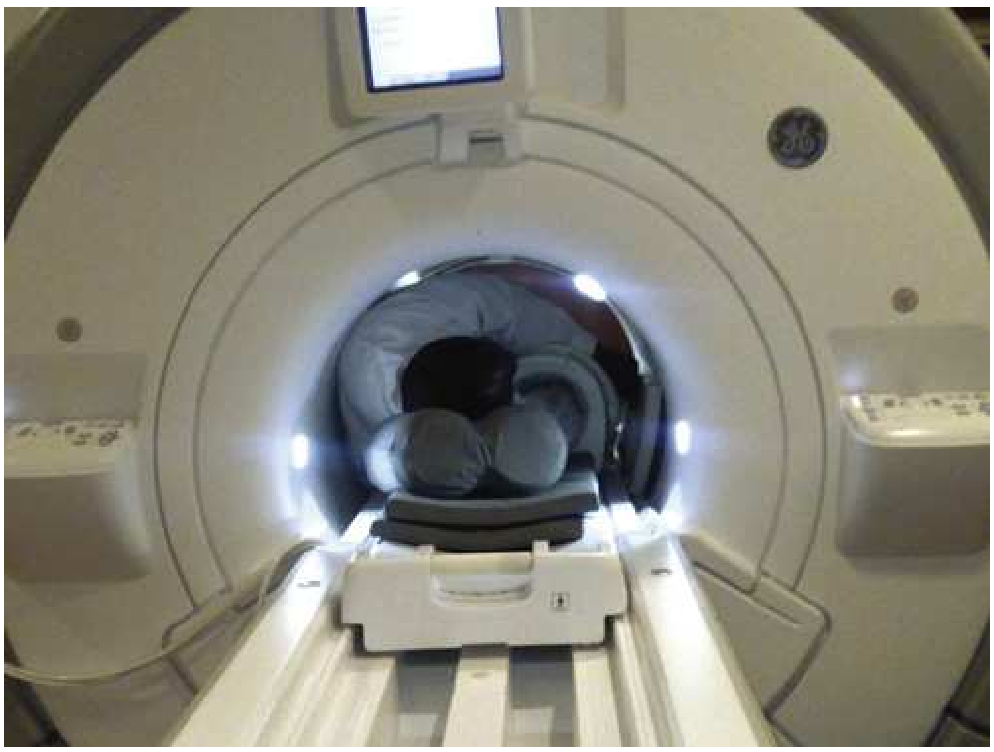


FIG. 26.11 Patient inside a superconducting 1.5-T magnet. Some patients cannot be scanned because of claustrophobia. Courtesy General Electric Healthcare.

Examination Protocols

Imaging Parameters

The availability of many adjustable parameters such as repetition time (TR), echo time (TE), acquisition plane, slice thickness, and imaging matrix makes MRI a complex imaging technique. Knowledge of the patient's clinical condition or disease is also important in choosing the proper technique or exam protocol.

The operator may choose to obtain MR images in any orthogonal (i.e., sagittal, coronal, transverse) or oblique plane. These are independently and directly acquired images with equal resolution in any plane (Fig. 26.12). Another MRI technique, especially when numerous thin slices or multiple imaging planes are desired, is three-dimensional imaging. In this technique, MRI data are collected simultaneously from a three-dimensional block of tissue rather than from a series of slices. Special data collection techniques and subsequent computer analysis allow the technologist greater flexibility for postprocessing (Fig. 26.13).

Slice thickness is an important parameter in the production of MR signal and the visualization of pathology. More MRI signal is available from a thicker slice than a thinner slice, so thicker slices may provide images that are less grainy (more signal to noise) but contain lower resolution, potentially hiding small pathologic lesions. Slice thickness is adjusted by the technologist based on the type of lesion under investigation.

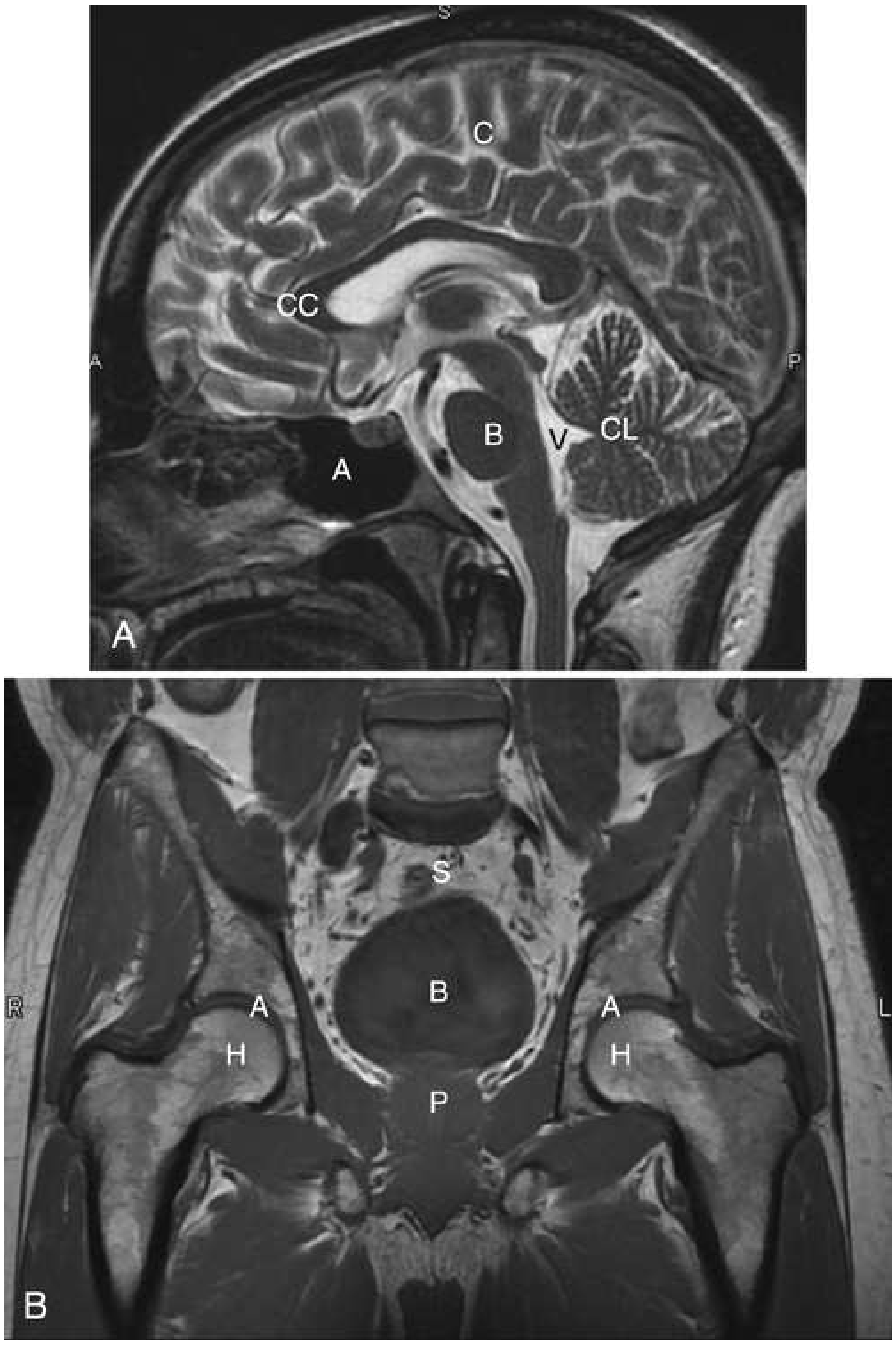


FIG. 26.12 Two images (different patients) from a 3-T superconductive MRI scanner, showing excellent resolution of images. (A) This image shows remarkable anatomic detail in a midsagittal image of the head. *A,* Air in sinuses; *B,* brain stem; *C,* cerebrum; *CC,* corpus callosum; *CL,* cerebellum; *V,* ventricle. (B) This coronal image of the pelvis shows anatomic relationships of the prostate *(P)*, which is enlarged and elevating the bladder *(B)*. Hips *(H)* and acetabula *(A)* are also shown. A loop of the sigmoid *(S)* colon is on top of the bladder. This degree of resolution in coronal or sagittal images would be difficult to obtain by reformatting a series of transverse CT slices.

(A) A M R I image shows the section of the head. The parts labeled are as follows: sinuses, brain stem, cerebrum, corpus callosum, cerebellum, and ventricle. (B) A M R I image shows the pelvis. The parts labeled are as follows: prostate, bladder, hips, acetabula.

Imaging matrix (the size of the pixel or voxel) affects not only MR signal but also image resolution and scan time. A finer matrix allows small lesions to be seen but contains less signal to noise and takes longer to acquire. A larger matrix contains more signal but can potentially hide small lesions. It is a balancing act for the technologist to adjust the matrix based on the part being imaged and the patient's condition.

The imaging parameters used in MRI are called *pulse sequences*. A pulse sequence is a combination of gradients and RF pulses chosen to favor a particular tissue (contrast) as quickly as possible (speed) while minimizing artifacts and maximizing the SNR. Depending on the choice of pulse sequence and imaging parameters, the resulting images may be more strongly weighted toward proton density, T1, or T2 information. Depending on the relative emphasis given to these factors, normal anatomy (Fig. 26.14) or a pathologic lesion (Fig. 26.15) may be more easily recognized. It is not unusual for a lesion to stand out dramatically when one pulse sequence is used yet be nearly isointense (same MRI signal as surrounding normal tissue) with a different pulse sequence.

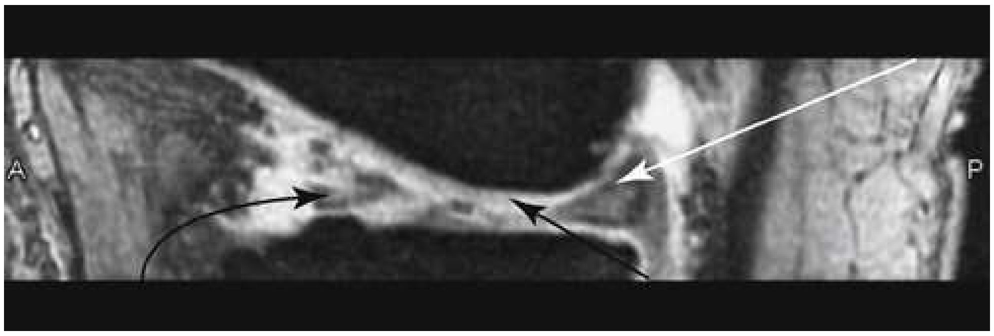


FIG. 26.13 Single slice from three-dimensional acquisition of the knee on a 3-T MRI unit. Data from an entire volume within the imaging coil are obtained concurrently. The data may be reconstructed into thin slices in any plane, such as the sagittal image shown here. This imaging sequence shows hyaline cartilage *(black arrow)* as a rim of fairly high signal intensity overlying the bone. Meniscal fibrocartilage *(white arrow)* has low signal intensity. High signal intensity from joint fluid in a tear *(curved arrow)* within the anterior horn of the meniscus is visualized.

A M R I shows a single slice from three-dimensional acquisition of the knee. The hyaline cartilage is indicated by a black arrow, the meniscal fibrocartilage is indicated by a white arrow and the joint fluid is indicated by a curved arrow.

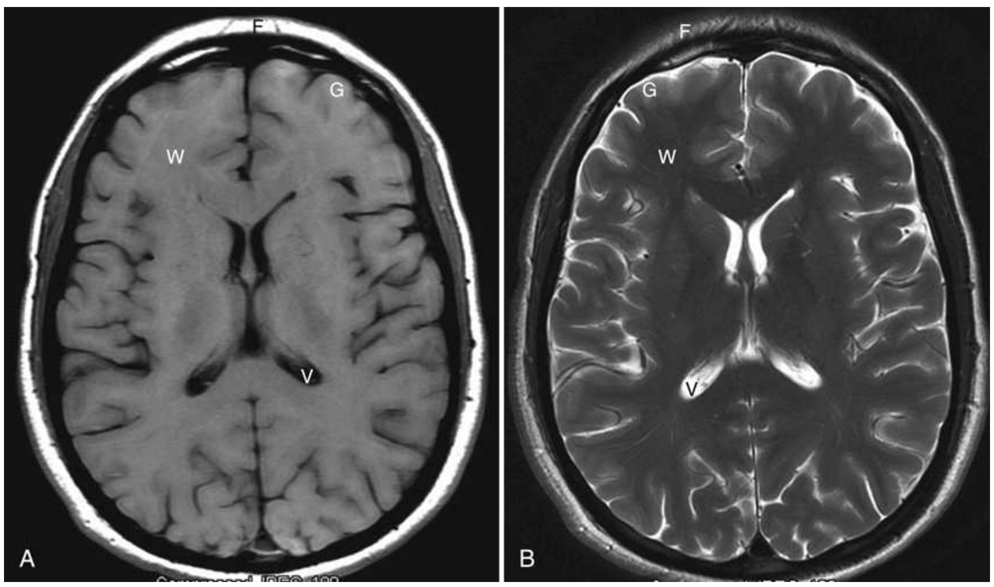


FIG. 26.14 Axial 3-T images through a normal brain. (A) T1-weighted image shows relatively low differentiation of gray matter *(G)* and white matter *(W)* within the brain. (B) Heavily T2-weighted image shows improved differentiation between gray and white matter. Cerebrospinal fluid within the ventricles *(V)* also changes in appearance with a change in pulse sequence (low signal on T1-weighted image); fat *(F)* normally shows high signal intensity, whereas on the T2-weighted image, the signal intensity of fat is less than that of cerebrospinal fluid.

(A) An axial C T image of the brain shows the grey matter, the white matter, the ventricles and fat. They are labeled as G, W, V, and F respectively. The outer covering of the brain appear radiopaque. (B) An axial C T image of the brain shows the grey matter, the white matter, the ventricles and fat. They are labeled as G, W, V, and F respectively. The outer covering of the brain appear radiolucent.

Pulse sequences are classed depending on the timing of the gradient and RF pulses. Although the discussion of pulse sequences is outside the scope of this chapter, they can be divided into two major categories. *Spin echo* sequences yield true T1-, T2-, or proton density–weighted images and are the standard pulse sequences used for all routine imaging. Classic spin echo sequences tend to have long scan times, so researchers have developed fast or turbo spin echo, which can dramatically shorten the scan time. Another type of spin echo pulse sequence is inversion recovery. *Inversion recovery* is a sequence that can minimize or null the signal intensity of a particular tissue. The most common are short tau inversion recovery (STIR), which nulls fat signal, and fluid-attenuated inversion recovery (FLAIR), which nulls signal from cerebrospinal fluid (CSF) in brain imaging. *Gradient echo* sequences are used where the scan time must be short, as in breath-hold abdominal scans. They generate T1- and T2*-weighted images. They are also used in imaging flowing blood (see the discussion of MRA later in this chapter) or pooling blood from hemorrhage or trauma (susceptibility weighting). Researchers continue to develop new pulse sequences for specific applications.

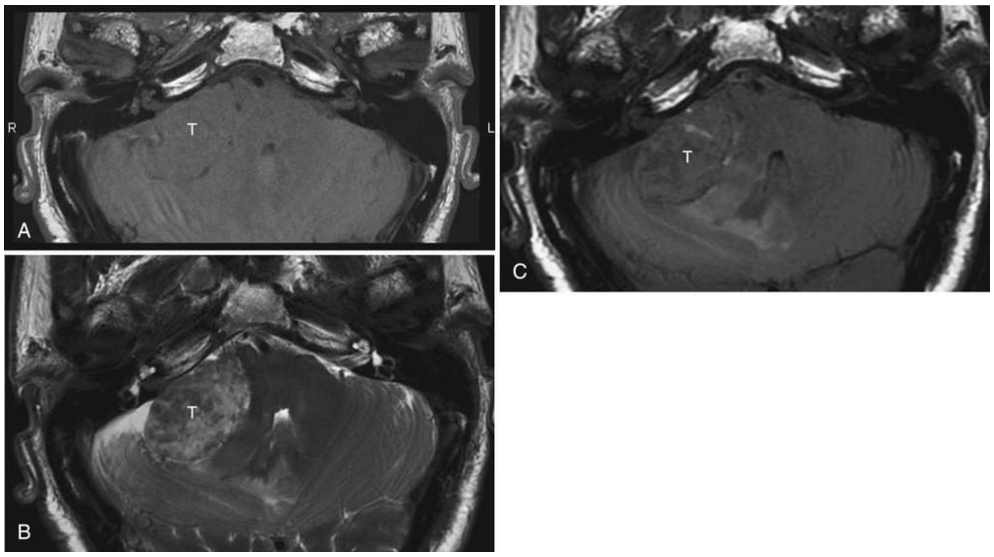


FIG. 26.15 Axial magnetic resonance imaging (MRI) showing the use of different pulse sequences and their effect on the visualization of the cerebellopontine angle tumor. (A) T1-weighted image shows that limited contrast exists between the tumor *(T)* and normal brain. (B) The lesion becomes dramatically more obvious using the pulse sequence of the T2-weighted image. (C) The lesion is still visible on a FLAIR pulse sequence, but not as well as in the T2-weighted image. Choice of pulse sequence is critical. These images also show how the lack of bone artifact makes MRI superior to CT for imaging of posterior fossa lesions.

(A) A M R I image of the cerebellopontine angle tumor shows limited contrast exists between the tumor. (B) A M R I image of the cerebellopontine angle tumor shows the pulse sequence. T is labeled on it. (C) A M R I image of the cerebellopontine angle tumor shows posterior fossa lesions.

Positioning

Patient positioning for MRI is usually straightforward. Generally, the patient lies supine on a table that is subsequently advanced into the magnetic field. As previously discussed, it is important to make sure that the patient has no contraindications to MRI, such as an unsafe cardiac pacemaker or intracranial aneurysm clips. Claustrophobia may be a problem for some patients, as previously noted, because the imaging area is tunnel-shaped in most MRI system configurations (see Fig. 26.11).

Coils

Receiving *coils* are used for transmitting the RF pulse and/or receiving the MRI signal (as described earlier in the section on signal production). Some coils can both transmit and receive (transmit/receive coils), whereas others may only receive the signal (receive-only coils).

The body part to be examined determines the placement and shape of the surface or receiving coil that is used for imaging (Fig. 26.16). Most coils are round or oval, and the body part to be examined is inserted into the coil's open center. Some coils, rather than encircling the body part, are placed directly on the patient over the area of interest. Another form of receiving coil is the endocavity coil, which is designed to fit within a body cavity such as the rectum. This enables a receiving coil to be placed closer to an internal organ that may be distant from surface coils applied to the exterior body, as when imaging the prostate or uterus. Endocavity coils may also be used to image the wall of the cavity itself (Fig. 26.17).

FIG. 26.16 Examples of coils used for magnetic resonance imaging. *Upper row, left to right,* Foot/ankle coil, breast coil, and knee coil. *Lower row, left to right,* Shoulder coil, functional head coil, and wrist coil. Courtesy Invivo Corporation.

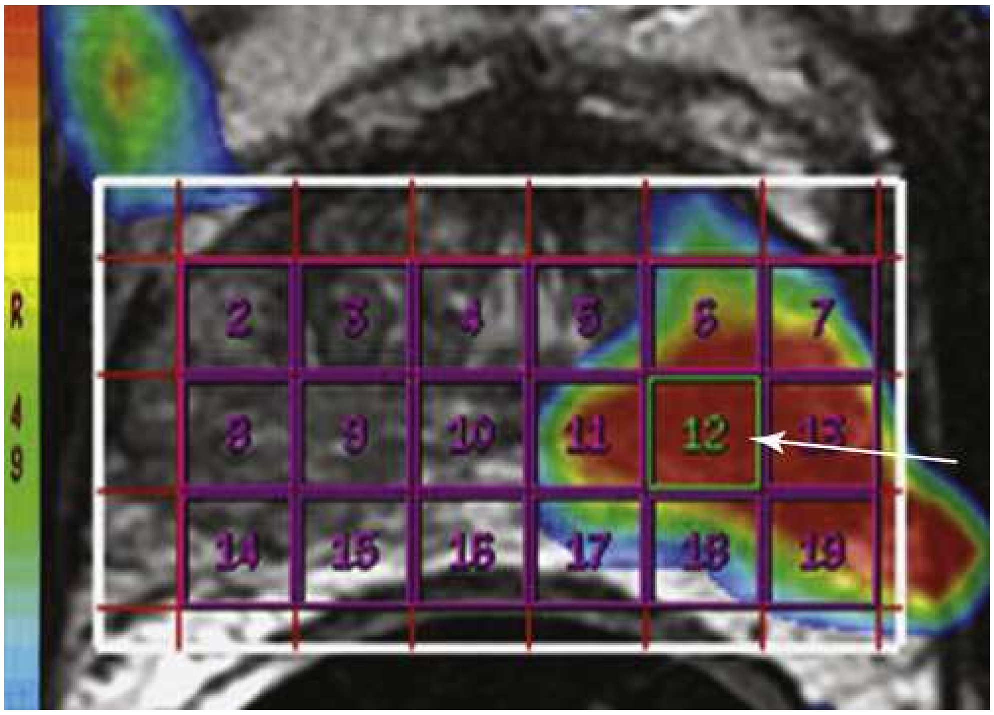


FIG. 26.17 Axial image of prostate obtained with an endorectal coil. The increased resolution allowed by the endorectal coil makes it possible to perform magnetic resonance spectroscopy *(PROSE)*. The spectroscopy map shows an elevated citrate level *(arrow)*, consistent with tumor. Courtesy GE Healthcare.

Patient Monitoring

Although most MRI sites are constructed so that the operator can see the patient during imaging, visibility is often limited, leaving the patient relatively isolated within the MRI room (see Fig. 26.11). At most sites, intercoms are used for verbal communication with the patient, and all units have “panic buttons” with which the patient may summon assistance. These devices may be insufficient, however, to monitor the health status of a sedated, anesthetized, or unresponsive patient. MRI-safe/conditional devices are available to monitor multiple physiologic parameters such as heart rate, respiratory rate, blood pressure, and oxygen concentration in the blood. The technologist should monitor the patient visually and verbally at all times.

Contrast Media

Contrast agents widen the signal differences (contrast to noise) in MR images between various normal and abnormal structures. MRI contrast agents most commonly used in the United States for routine clinical use in the whole body are gadolinium-containing compounds. Gadolinium is a metal with *paramagnetic* qualities. Pharmacologically, an IV-administered gadolinium compound acts similarly to a radiographic iodinated IV agent; it is distributed through the vascular system and its major route of excretion is the urine. A gadolinium compound respects the blood-brain barrier (e.g., it does not leak out from the blood vessels into the brain substance unless the barrier has been damaged by a pathologic process).

Gadolinium compounds can be used in the evaluation of any body part, including the central nervous system and the musculoskeletal system. The most important clinical action of gadolinium compounds is the shortening of the T1 relaxation time. In T1-weighted images, this provides a high-signal, high-contrast focus in areas where gadolinium has accumulated. As seen in Fig. 26.18, gadolinium-containing contrast has leaked through the broken blood-brain barrier into the brain substance. In gadolinium-enhanced T1-weighted images, brain tumors or metastases are better distinguished from their surrounding edema than in routine T2-weighted images. Gadolinium improves the visualization of small tumors or tumors with a signal intensity similar to that of a normal brain, such as meningiomas. Rapid IV injections of gadolinium are routinely used in dynamic imaging studies of body organs such as the liver and kidneys, similar to techniques using standard radiographic iodinated agents in CT. Contrast-enhanced MRA is routinely performed to image the blood vessels of the neck (carotid) and body.

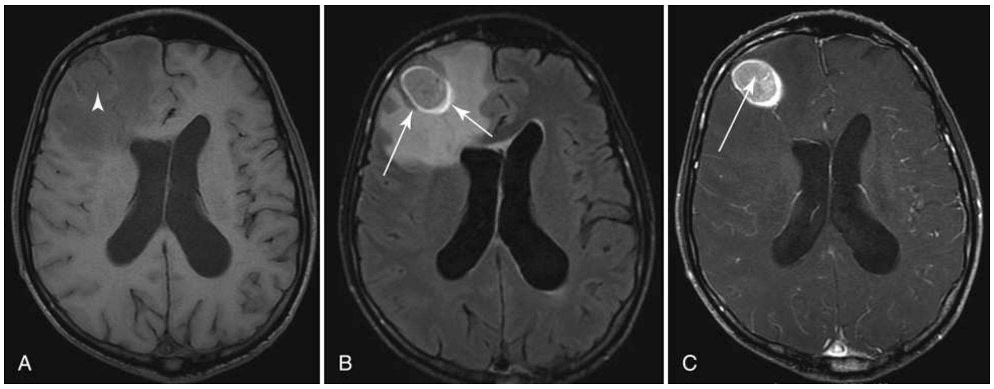


FIG. 26.18 Use of IV gadolinium contrast medium for lesion enhancement in axial images of the brain. (A) T1-weighted sequence. A single brain lesion *(arrowhead)* is seen as a focal area of low signal intensity in a large area of edema. The borders of the lesion are difficult to delineate. (B) FLAIR image. Areas of high signal *(arrows)* represent tumor and surrounding edema. (C) T1-weighted image obtained using similar parameters after IV administration of gadolinium. Lesion borders and size *(arrow)* are much more conspicuous.

(A) A C T image shows a single brain lesion. It is indicated by a white arrowhead. The borders of the lesion are not definite. (B) A C T image shows areas of high signal. It is indicated by two arrows. (C) A C T image shows areas of lesion border. It is indicated by a white arrow. The borders of the lesion are definite.

In general, gadolinium agents are nonspecific; however, organ-specific agents have been developed, primarily for imaging the liver. Research and development of novel contrast agents to improve the specificity of MRI imaging continues.

Despite the fact the gadolinium is a toxic substance, gadolinium-based contrast agents (GBCAs) are well tolerated, typically have fewer side effects than iodine-based contrast agents, and are not nephrotoxic. Nevertheless, patients with severe kidney disease and reduced renal function are susceptible to developing a life-threatening condition known as nephrogenic systemic fibrosis (NSF).

Gadolinium has also been discovered in the brain and body tissues of patients with normal renal function. Gadolinium-based contrast agents should be used only when clinically necessary.

Oral contrast agents can be used in conjunction with gadolinium-based contrast agents. Oral contrast agents are typically incorporated in the imaging of the small bowel. The oral contrast agent provides distention of the small bowel, which promotes the evaluation of inflammatory bowel disease (Fig. 26.19).

Gating

In areas of the body such as the chest or abdomen, where heart motion or breathing can degrade image quality, respiratory and/or cardiac gating or triggering can be employed. Even fast pulse sequences have difficulty freezing this type of motion. These techniques acquire image data only during specific parts of the cardiac or respiratory cycle. Cardiac and respiratory gating obtain image data throughout the entire cardiac or respiratory cycle but record the point in the cycle where the data was acquired and then reconstruct that data motion-free. Cardiac and respiratory triggering use a specific point in the cardiac or respiratory cycle to trigger the acquisition of data. Each method has its advantages and disadvantages, but the end result of both methods is motion-free images (Fig. 26.20).

FIG. 26.19 Magnetic resonance enterography. The oral contrast agent provides distention of the small bowel, which promotes the evaluation of inflammatory bowel disease.

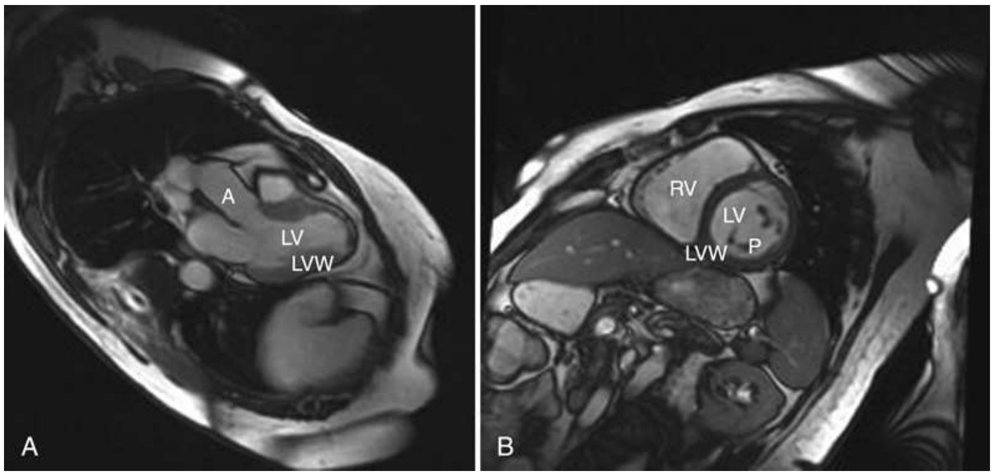


FIG. 26.20 Electrocardiogram-gated images of the heart. (A) Left ventricular outflow tract. (B) Short-axis images. *A*, Aorta; *LV*, left ventricle; *LVW*, left ventricular wall; *P*, papillary muscles; *RV*, right ventricle.

(A) An electrocardiogram-gated image of the heart shows the aorta, left ventricle, and left ventricular wall. (B) An electrocardiogram-gated image of the heart shows the right ventricle, left ventricle, papillary muscles, left ventricular wall.

Other Considerations

When MRI was first introduced, long imaging times were required to produce diagnostic images. With advances in computer technology and pulse sequence developments, images can now be acquired much more quickly, reducing the time the patient is in the scanner. New pulse sequences have been developed for specialized applications, such as the ability to perform dynamic scans and free-breathing abdominal imaging. These fast sequences can accentuate the bright signal of fluid, allowing for myelographic effects in spine imaging or arthrographic effects in joint imaging.

Quality assurance is important in a complex technology such as MRI. Calibration of the unit is generally performed by service personnel. Routine scanning of phantoms by the technologist can be useful for detecting any problems that may develop.

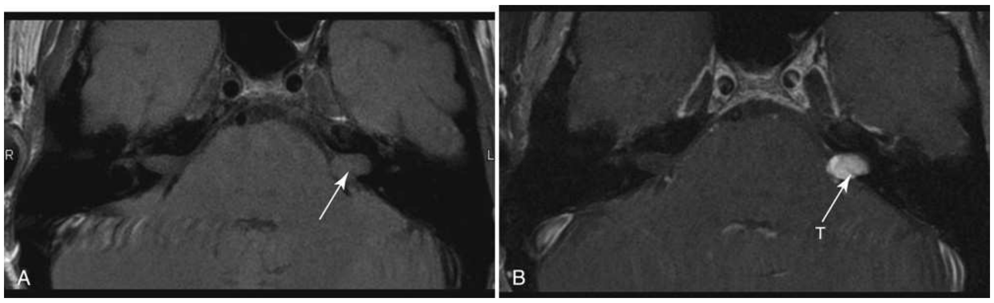


FIG. 26.21 Axial magnetic resonance imaging of the brain in a patient with an acoustic nerve tumor arising from the complex of the seventh and eighth cranial nerves. (A) Precontrast T1-weighted image shows an inhomogeneous area of abnormality *(white arrows)*, with mass effect expanding the area of the nerve complex. (B) Image obtained at the same level after gadolinium enhancement. Active tumor *(T)* shows high signal intensity.

(A) Precontrast T 1-weighted image shows an inhomogeneous area of abnormality. It is indicated by a white arrow. (B) Precontrast T 1-weighted image shows high signal intensity. It is indicated by a white arrow.

Clinical Applications

Central Nervous System

MRI is the modality of choice for imaging of the central nervous system. It is routinely used in almost all examinations of the brain, with the exception of acute trauma. MRI is superior in the brain because of its inherent ability to differentiate the natural contrast among tissues such as gray and white matter (see Fig. 26.14). This ability allows MRI to be more sensitive than CT in detecting changes in white matter disease, such as multiple sclerosis. The development of specialized pulse sequences such as FLAIR helps visualize lesions in the periventricular area that were previously difficult to detect. MRI is also superior at imaging the posterior fossa (cerebellum and brain stem) because cortical bone does not produce any signal in MRI. This area is often obscured on CT because of beam-hardening artifact. Almost all brain lesions—such as primary and metastatic tumors, pituitary tumors, acoustic neuromas (tumors of the eighth cranial nerve), and meningiomas—are better seen on MRI. The use of IV gadolinium-based contrast has allowed better differentiation and increased sensitivity in detecting these lesions (Fig. 26.21). Cerebral infarction is identified sooner using diffusion-weighted imaging compared with CT. Diffusion-weighted imaging also gives MRI the ability to determine the age of lesions or differentiate acute from chronic ischemic changes.

MRI is also routinely used to image the spinal canal and its contents. The ability of MRI to image directly in the sagittal plane allows for the screening of a large area in a single examination. T2-weighted pulse sequences permit the separation of CSF and the spinal cord, as in myelography, without the use of a contrast medium (Fig. 26.22). Because of its inherent ability to differentiate slight changes in soft tissue contrast, MRI is exquisitely sensitive to cystic changes associated with tumors within the spinal cord. The visualization of bone marrow is useful in the detection and diagnosis of metastatic disease, pathologic and nonpathologic vertebral fractures, and diskitis (infection). MRI is also commonly used in the imaging of disk disease. Direct visualization of the posterior longitudinal ligament in the sagittal plane and vertebral disks in the oblique plane shows the severity of herniation in disks (Fig. 26.23). The use of IV gadolinium contrast helps differentiate between recurrent disk herniation and postoperative scar tissue, a crucial clinical distinction.

Chest

Ultrafast pulse sequences and software algorithms have made it possible to obtain motion-free images of the chest and heart. Cardiac gating (imaging only during a certain part of the cardiac cycle), respiratory gating or triggering, breath-hold scans, and ultrafast imaging sequences have enabled MRI to excel at cardiac imaging. MRI can show anatomy and produce functional data (e.g., ejection fractions, chamber volume) similar to nuclear medicine and echocardiography. Studies of congenital heart disease, imaging of masses, and heart muscle viability are now routine (Fig. 26.24). MRI may also be used to image the chest wall, thoracic outlet, and brachial plexus region.

FIG. 26.22 Sagittal T2-weighted magnetic resonance imaging through the thoracic spine. High signal from cerebrospinal fluid *(CSF)* outlines the normal spinal cord *(S)*, giving a myelogram-like effect without the use of contrast agents.

Breast MRI, once used only sparingly, has become an essential part of breast imaging. It is routinely used to screen high-risk patients preoperatively to define the extent of disease and screen the contralateral breast for additional disease. Once in treatment, patients undergo breast MRI to monitor adjuvant therapy, such as chemotherapy or radiation (Fig. 26.25). In addition, breast MRI is the method of choice for imaging the rupture of breast implants.

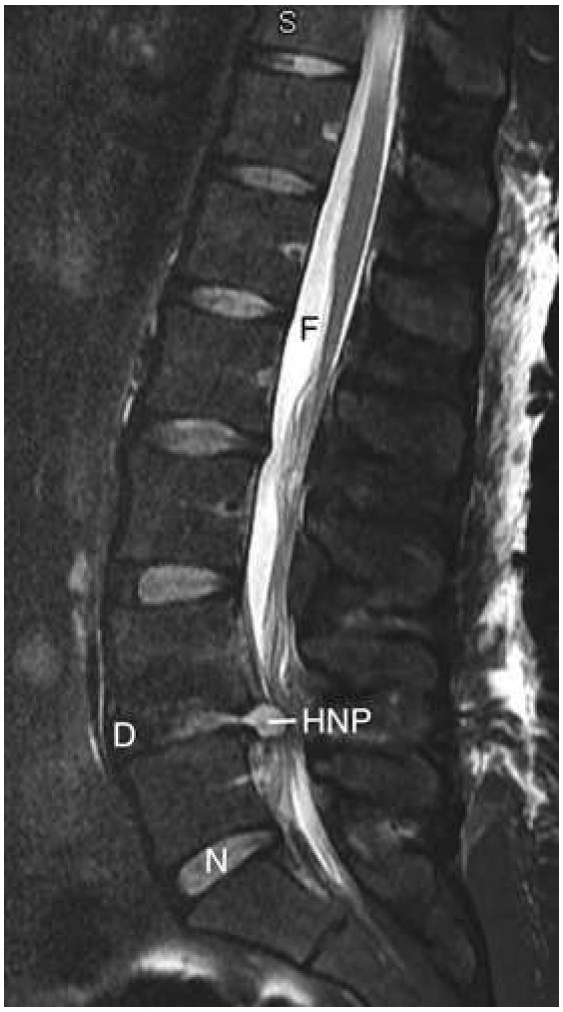


FIG. 26.23 Sagittal T2-weighted image of the lumbar spine. The spinal canal is filled with high-signal-intensity cerebrospinal fluid *(F)*, except for low-signal-intensity linear nerve roots running within the spinal canal. Normal vertebral disks have a high-signal-intensity nucleus pulposus *(N)*. Desiccated disks *(D)* show low signal intensity. At L4-5, note the herniated nucleus pulposus *(HNP)* protruding into the spinal canal and compressing the nerve roots.

A magnetic resonance imaging through the lumbar spine shows three curved lines. The grey region is labeled as herniated nucleus pulposus (H N P), the dark region is labeled as desiccated disks (D), and the a oval shaped region below is labeled as nucleus pulposus (N).

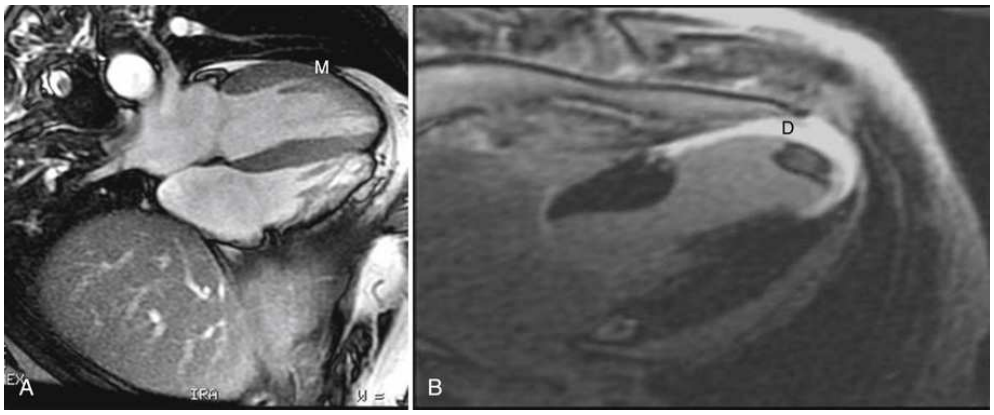


FIG. 26.24 Cardiac MRI: four-chamber view from two different patients. (A) T2-weighted image showing normal myocardium in the wall of the left ventricle *(M)* before the administration of contrast medium. (B) Delayed-enhancement image (inversion recovery) showing bright signal in the wall of the left ventricle, representing infarcted or dead myocardium *(D)*.

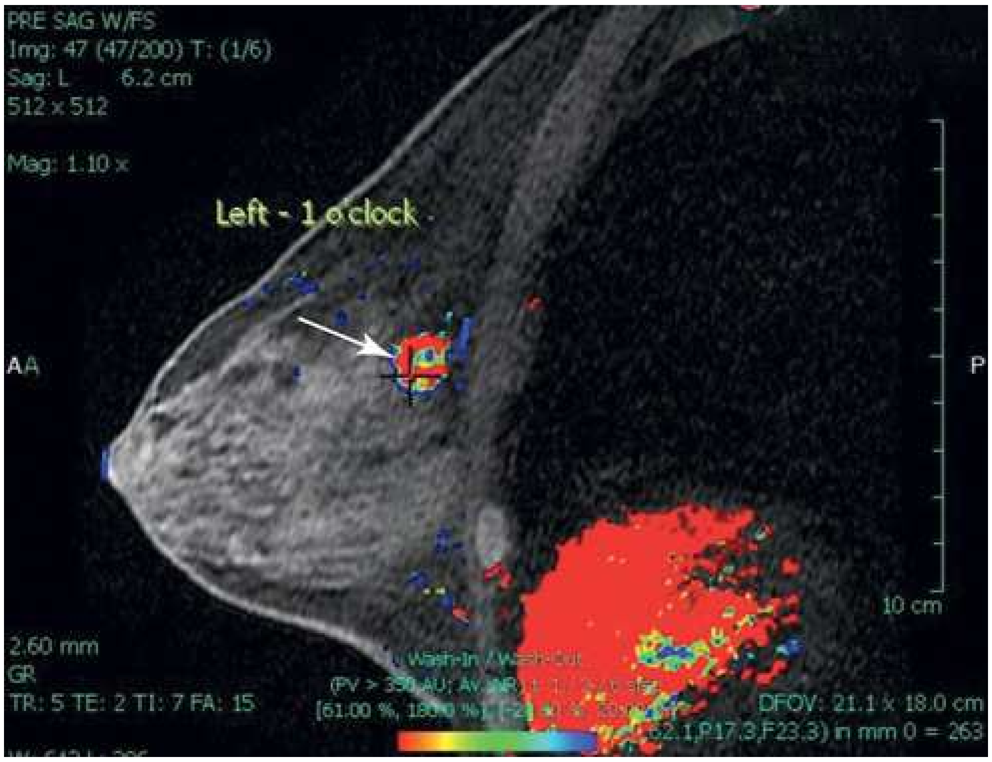


FIG. 26.25 MRI of the breast is postprocessed and showing contrast wash in and wash out. The patient is a 68-year-old woman with an enhancing mass in the left breast at the 1 o'clock position *(arrow)*.

Abdomen

Although abdominal imaging is also affected by respiratory motion, the use of ultrafast scanning techniques with the ability to acquire two- and three-dimensional volumes in a breath-hold scan has made MRI extremely useful as a problem-solving tool in cases involving the abdomen. Typically not used as a primary diagnostic tool, MRI can serve to follow up questionable results from other modalities such as CT and ultrasound. One exception is liver imaging, in which MRI may be more sensitive in detecting primary and metastatic tumors. The use of liver-specific IV contrast agents has improved sensitivity and specificity in imaging liver lesions. MRI has the ability to predict the histologic diagnosis of certain abnormalities such as hepatic hemangiomas, which have a distinctive appearance. Moreover, the use of in-phase and out-of-phase images can help distinguish between benign and malignant adrenal tumors (Figs. 26.26 and 26.27).

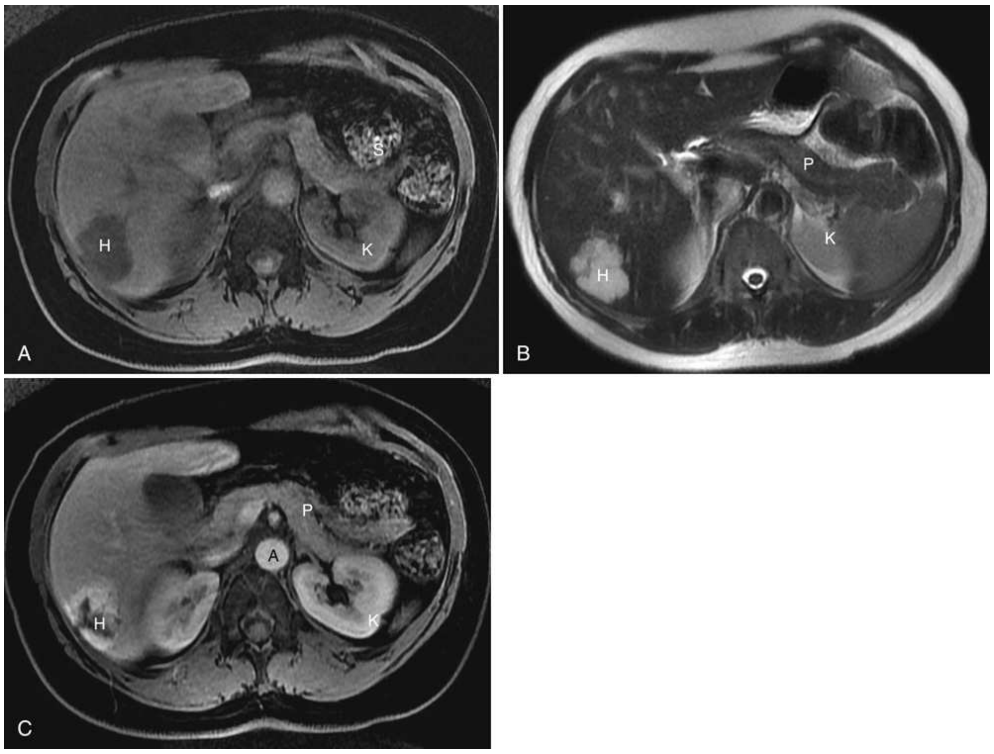


FIG. 26.26 Multiple images through the liver of a patient with hemangioma *(H)*. (A) Axial T1-weighted image. (B) Axial T2-weighted image. (C) Axial T1-weighted postcontrast image. This image shows the classic fill-in of contrast material from the periphery of the lesion toward the center. MRI also shows the other abdominal organs and their relationship quite well: kidneys *(K)*, pancreas *(P)*, stomach *(S)*, and aorta *(A)*.

(A) An M R I of the liver shows hemangioma on the left and the kidneys on the right. (B) An M R I of the liver shows pancreas on the top and kidneys below it. (C) An M R I of the liver shows pancreas on the top, hemangioma on the left, aorta in the middle, and kidneys on the right.

Pelvis

Respiratory motion has little effect on the structures of the pelvis. Therefore, these structures can be better visualized than structures in the upper abdomen. The ability of MRI to image in the coronal and sagittal planes is helpful in examining the curved surfaces in the pelvis. Bladder tumors are shown well, including tumors at the dome and base of the bladder, which can be difficult to evaluate in the transverse dimension. In the prostate (see Fig. 26.17), MRI is useful in detecting a neoplasm and its spread. In the female pelvis, MRI can be used to image benign and malignant conditions (Fig. 26.28).

Musculoskeletal System

The ability to image in multiple planes with excellent soft tissue contrast as well as the ability to image bone marrow have rapidly expanded the role of MRI in musculoskeletal imaging. The lack of bone artifact in MRI permits excellent visualization of the bone marrow (Fig. 26.29) and facilitates the more effective diagnosis of pathologic conditions such as stress fractures and avascular necrosis (Fig. 26.30). Local staging of soft tissue and bone tumors is best accomplished with MRI (Fig. 26.31).

MRI has become the imaging modality choice for small and large joints. It has replaced radiographic arthrography in all joints, although MR arthrography is now routinely performed. The ability to assess damage to ligaments, tendons, and menisci as well as quantify the loss of cartilage is very helpful in treating osteoarthritis of the knee and other joints (see Fig. 26.13).

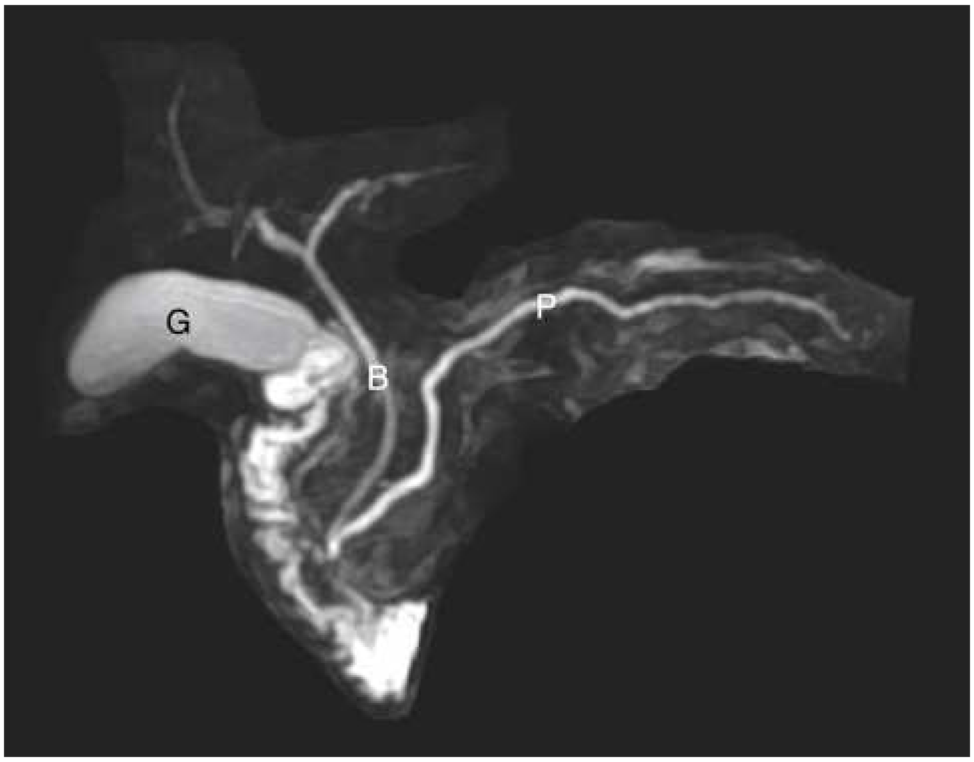


FIG. 26.27 Magnetic resonance cholangiopancreatography: heavily T2-weighted images specially designed to image the gallbladder *(G)* and biliary *(B)* and pancreatic ducts *(P)*.

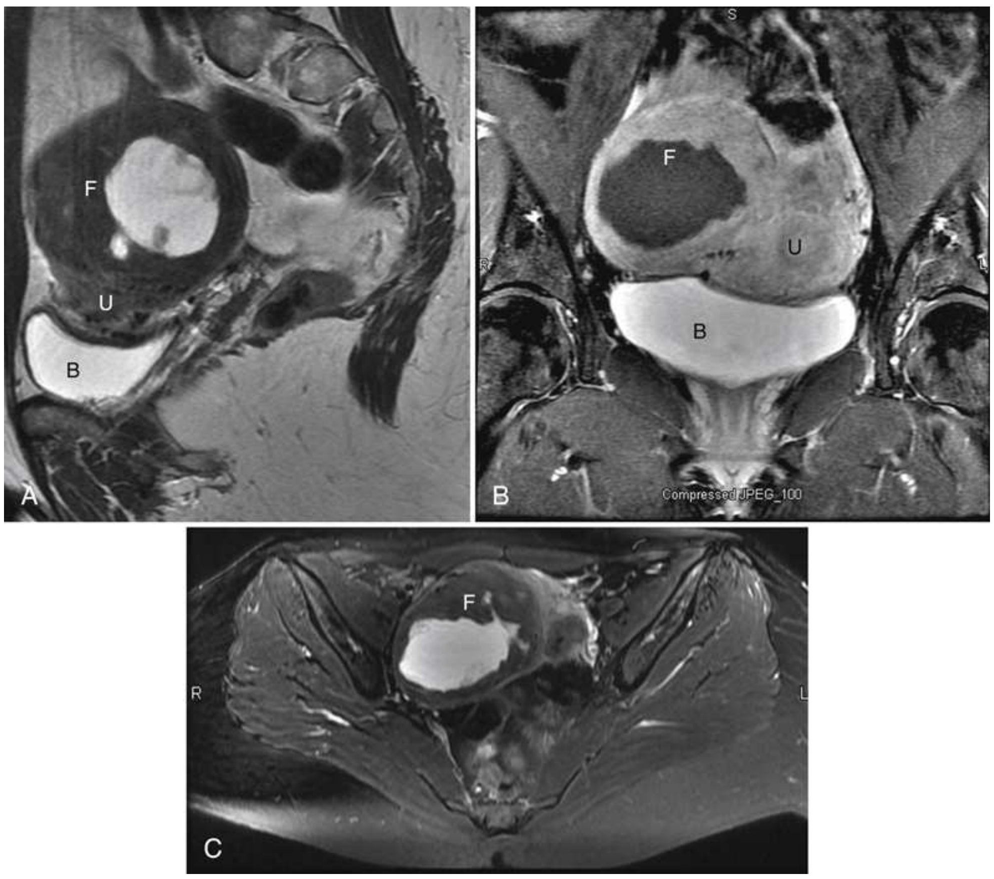


FIG. 26.28 Multiple images through a female pelvis. (A) Sagittal T2-weighted image. (B) Coronal T1-weighted image after administration of contrast agent. (C) Axial T1-weighted image after administration of contrast agent with fat saturation. All images show the different components of a uterine fibroid *(F)*. The relationship between the uterus *(U)* and bladder *(B)* is shown well using multiple imaging planes.

(A) A M R I image of the female pelvis shows a uterine fibroid (F), uterus (U), and bladder (B). The bladder appears radiopaque and the rest of the region appears radiolucent (B) A M R I image of the female pelvis shows a uterine fibroid (F), uterus (U), and bladder (B). The bladder appears radiopaque. The fibroid appears dark and the uterus appears grey. (C) A M R I image of the female pelvis shows a uterine fibroid (F).

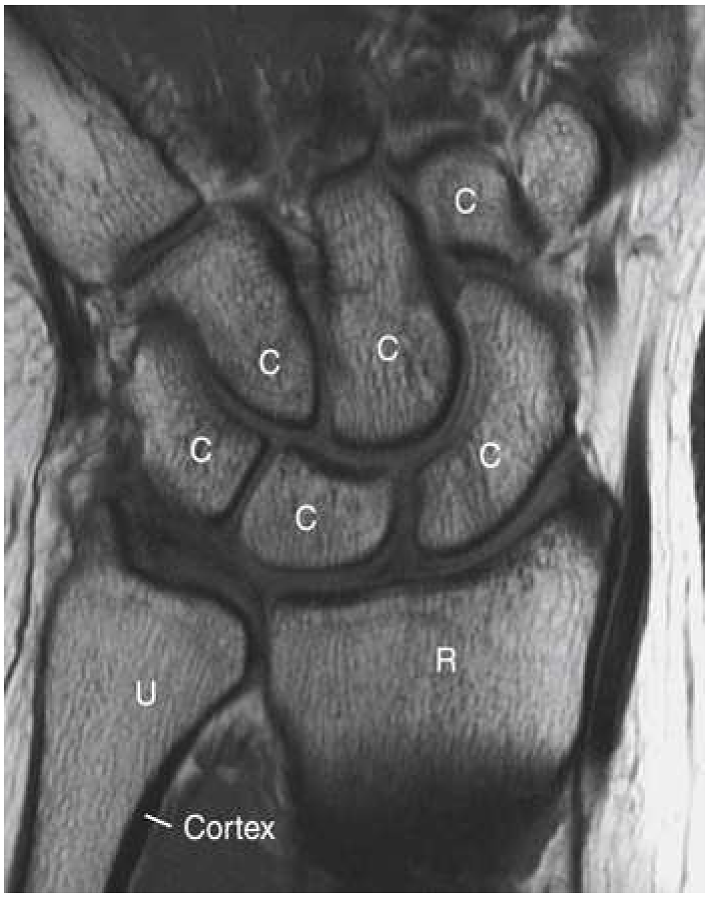


FIG. 26.29 T1-weighted coronal MRI of the wrist using a surface coil to improve visualization of superficial structures. Marrow within the carpal bones *(C)*, radius *(R)*, and ulna *(U)* has high signal as a result of its fat content. A thin black line of low-signal cortex surrounds the marrow cavity of each bone, and trabecular bone can be seen as low-signal detail interspersed within marrow.

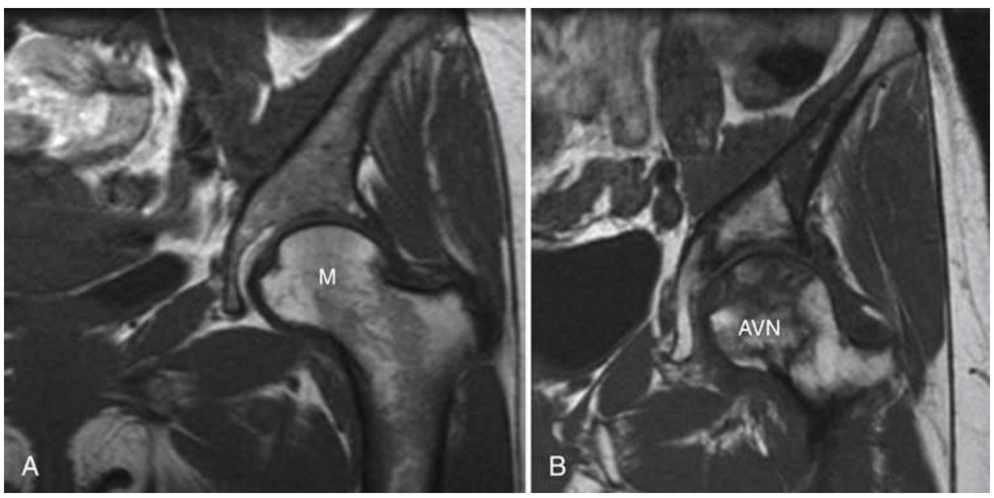


FIG. 26.30 Two T1-weighted images of the left hip from different patients. (A) Normal bone marrow signal *(M)*. (B) Abnormal bone marrow signal consistent with avascular necrosis *(AVN)*.

(A) A M R I of the hip shows a bone marrow signal (M) on the femur head. It has grey patches on it. (B) A M R I of the hip shows avascular necrosis (A V N) on the femur head. It has dark patches on it.

Vessels

MRA is the imaging of vascular structures by MR. Two techniques used to obtain images of flowing blood are time-of-flight (TOF) and phase-contrast (PC) imaging. With either of these techniques, MRAs can be obtained in two- or three-dimensional volumes. In TOF imaging, a special pulse sequence is used to suppress the MRI signal from the anatomic area surrounding the vessels of interest. Consequently, an MRI signal is given only by material that is outside the area of study when the signal-suppressing pulse occurs. Incoming blood vessels appear bright, whereas stationary tissue signal is suppressed (Fig. 26.32). PC imaging takes advantage of the shifts in phase, or orientation, experienced by magnetic nuclei moving through the MRI field. Special pulse sequences enhance these effects in flowing blood, producing a bright signal in vessels when the unchanging signal from stationary tissue is subtracted. PC imaging is used when data about the velocity and direction of blood are needed.

FIG. 26.31 Coronal T1-weighted image of the ankle. Bone marrow shows high signal intensity because of fat. Osteochondral defect seen in the dome of the talus *(T)* shows low signal intensity. *C,* Calcaneus; *F,* fibula; *S,* tibia.

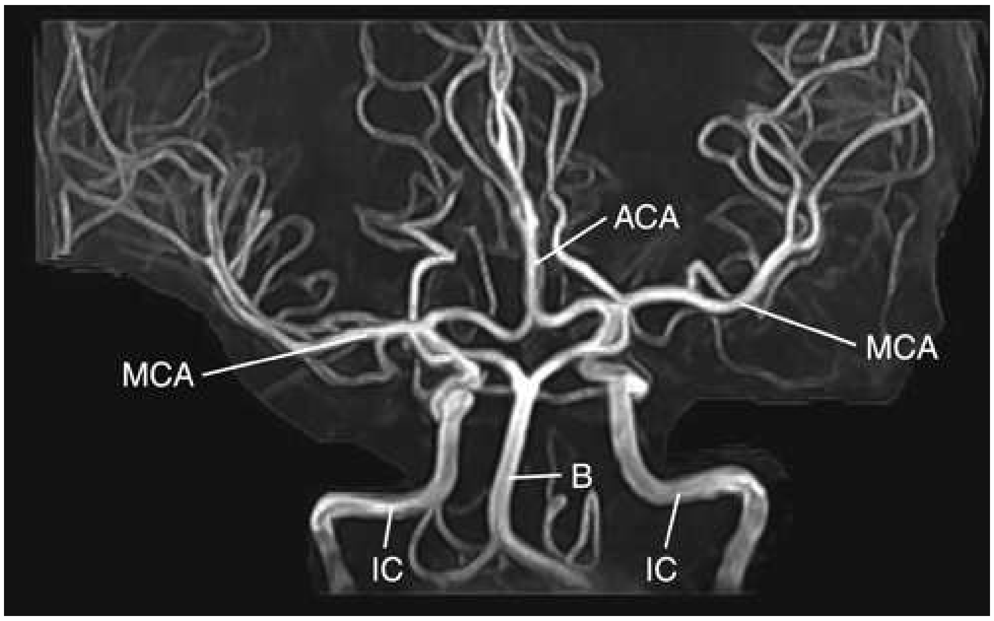


FIG. 26.32 MRA shows intracranial arterial vessels in the AP view. *ACA,* Anterior cerebral arteries; *B,* basilar artery; *IC,* internal carotids; *MCA,* middle cerebral artery. In the center is the circle of Willis.

A M R I shows the intracranial arterial vessels. The parts labeled are as follows: anterior cerebral arteries, basilar artery, internal carotids, middle cerebral artery. In the center is the circle of Willis.

FIG. 26.33 Contrast-enhanced MRA shows carotid arteries *(CA)* from the aortic arch *(AA)* to the circle of Willis *(COW)*.

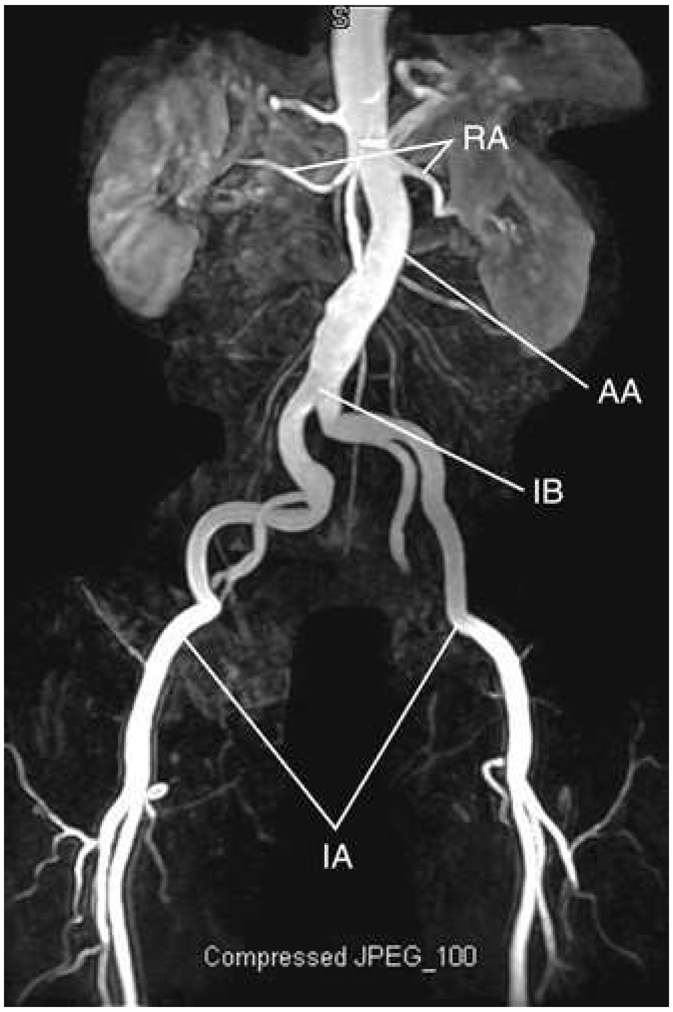


FIG. 26.34 Contrast-enhanced MRA of the abdominal aorta *(AA)* shows the renal arteries *(RA)*, iliac bifurcation *(IB)*, and iliac arteries *(IA)*.

TOF imaging can be used with the injection of IV gadolinium-containing contrast material. Gadolinium shortens the T1 relaxation time of blood, thus increasing its signal intensity and allowing a decrease in imaging time (breath-hold sequences) and three-dimensional volume imaging in the long axis of the vessel. Imaging of the carotid (Fig. 26.33), thoracic, abdominal, and pelvic arteries (Fig. 26.34) is possible in this way. With the use of a moving table, the aorta can be imaged from the heart to the feet. This is routinely performed to screen for lesions in the peripheral vasculature. Vascular imaging can be used to look for dissections, aneurysms, arteriovenous malformations, plaque, stenosis, and occlusions.

Diffusion and Perfusion

The sensitivity of MRI to motion can be a handicap or a potential source of information. Motion artifacts interfere with upper abdominal images that are affected by heart and diaphragmatic motion, yet flow-sensitive pulse sequences can image flowing blood in blood vessels.

Specialized techniques have been developed that can image the *diffusion* and *perfusion* of molecules within matter. Molecules of water undergo random motion within tissues, but the cellular membranes (or lack thereof) affect the rate of such diffusion. Tissues have structure, and these structures affect the rates and directions of diffusion and perfusion; in other words, diffusion and perfusion are not entirely random in a structured tissue. These microscopic motions can be detected by specialized MRI pulse sequences that can image their rate and direction. Diffusion and perfusion motion differ among tissue types. Diffusion patterns of gray matter in the brain differ from the diffusion patterns in more directionally oriented fiber tracts of white matter. This concept is currently used in diffusion tensor imaging.

Diffusion and perfusion imaging are most often used in the brain to visualize ischemic changes such as stroke. Recovery from acute stroke can be predicted by viewing the mismatch between the diffusion and perfusion images. Diffusion and perfusion imaging can produce clinically significant images that may help us understand white matter degenerative diseases (e.g., multiple sclerosis, ischemia, infarction) (Fig. 26.35), develop possible therapies to return blood flow to underperfused brain tissue, and characterize brain tumors. Similar applications for the rest of the body have been developed, allowing diffusion and perfusion imaging to be used in imaging of the abdominal and pelvic organs as well as the spine.

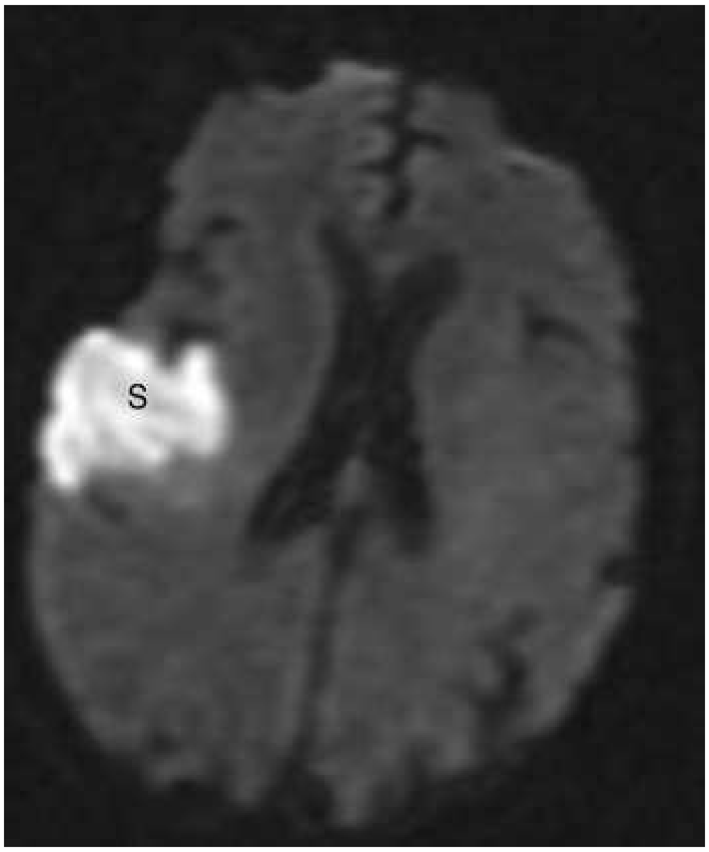


FIG. 26.35 Diffusion-weighted image shows acute ischemic infarct (stroke) *(S)* in the territory of the right middle cerebral artery. Lack of diffusion in this area turns it bright on this heavily T2-weighted image.

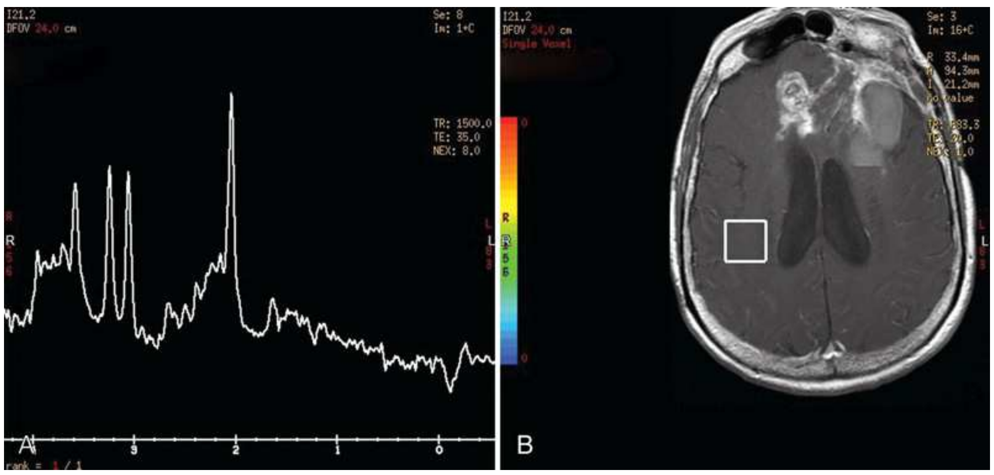


FIG. 26.36 Routine spectroscopy in a patient with a primary brain tumor. Voxel shows normal brain spectra in an area unaffected by the brain tumor.

Spectroscopy

In routine MRI, the purpose is to produce detailed pictures of the anatomy being imaged. This is accomplished by spatially localizing the MRI signal in a volume of tissue. In magnetic resonance spectroscopy (MRS), the result is a graph, or spectrum, of the chemical composition of the volume of tissue being "imaged." This graph denotes not only the chemical compounds present, but also the relationship between the quantity of each compound. In pathologic conditions in which the imaging characteristics are similar or difficult to interpret, MRS can add vital information leading to a more accurate interpretation.

MRS is most commonly used in the brain. It can be helpful in diagnosing metabolic conditions, tumor recurrence versus necrosis, and pathologic processes (Fig. 26.36). The use of MRS is becoming more widespread in breast and prostate imaging to differentiate between normal and abnormal tissue. It has also been used to study normal physiologic changes such as those seen in muscle contraction (Fig. 26.37).

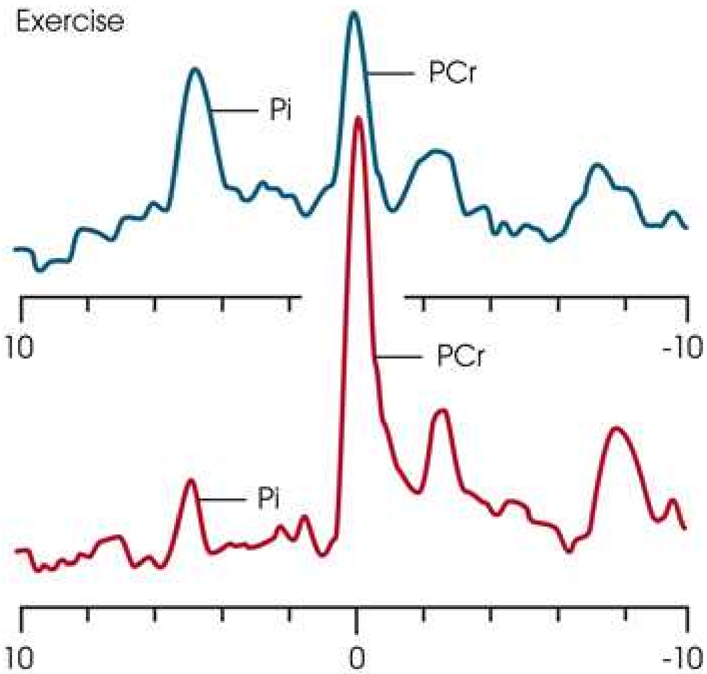


FIG. 26.37 Spectra from human muscle before *(red line)* and during *(blue line)* exercise. Thin horizontal lines represent separate baselines for each spectrum. Each peak represents a different chemical species, and the area under the peak down to the baseline indicates the amount of substance present. The inorganic phosphate *(Pi)* peak increases with exercise as energy-rich phosphocreatine *(PCr)* is used to provide energy for muscle contraction.

A graph shows Spectra from human muscle before exercise is indicated by a red line and during exercise is indicated by a blue line. Thin horizontal lines represent separate baselines for each spectrum. The inorganic phosphate (P i) peak increases with exercise as energy-rich phosphocreatine (P C r).

Functional Magnetic Resonance Imaging

Functional MRI (fMRI) records active areas of the brain during certain activities or after the introduction of stimuli, such as visual or auditory stimuli. Typically, fMRI uses the differences in the magnetic properties of oxygenated and deoxygenated blood to visualize active areas of the brain. The use of oxygenated and deoxygenated blood as contrast agents is known as blood oxygen level–dependent (BOLD) imaging. The human body is composed of approximately 50% oxygenated and 50% deoxygenated blood. Oxygenated blood displays diamagnetic properties: that is, it does not affect molecules in the surrounding area. Deoxygenated blood is a paramagnetic substance, which increases T2* decay and decreases the availability of signals in the area immediately surrounding it (magnetic susceptibility artifact). Because of this increase in magnetic susceptibility artifact, it is possible for MRI to measure the difference between oxygenated and deoxygenated blood. As blood flow increases to areas of activation, the MRI scanner distinguishes the subtle differences in signal and registers the area of brain activity.

Currently, fMRI is used in many areas of research to increase our understanding of human brain anatomy and function. Studies involving the visual cortex, memory, Alzheimer disease, schizophrenia, and many other topics have been performed through fMRI. fMRI may prove useful in areas of lie detection and mind reading. It holds promise for the future of MRI, not only as a diagnostic tool, but also as a predictor of future behaviors and disease processes.

Conclusion

Since its development in the 1970s, MRI has evolved into an advanced, widely used tool that is necessary for the diagnosis, staging, and treatment of disease. Today, MRI is the imaging modality of choice for studying the central nervous and musculoskeletal systems. The role of MRI in breast, cardiac, and body imaging continues to expand. New techniques in MR spectroscopy and fMRI will enhance its usefulness.

MRI's ability to utilize multiple biological parameters in its image acquisition, the development of new pulse sequences and more sensitive hardware, and the use of newly developed organ-specific contrast agents will keep MRI at the forefront of the imaging world.

Definition of Terms

antenna: Device for transmitting or receiving radio waves.
artifact: Spurious finding in or distortion of an image.
attenuation: Reduction in energy or amount of a beam of radiation when it passes through tissue or other substances.
coil: Single or multiple loops of wire (or another electrical conductor such as tubing) designed to produce a magnetic field from current flowing through the wire or to detect a changing magnetic field by voltage induced in the wire.
contrast: Degree of difference between two substances in some parameter, with the parameter varying depending on the technique used (e.g., attenuation in radiographic techniques or signal strength in MRI).
cryogenic: Relating to extremely low temperature (see *superconductive magnet*).
diffusion: Spontaneous random motion of molecules in a medium; a natural and continuous process.
echo planar imaging: Fast pulse sequence that can be used to create MR images within a few milliseconds.

fat-suppressed images: Images in which the fat tissue in the image is made to be of a lower, darker signal intensity than the surrounding structures.
ferromagnetic detection system: System that identifies ferrous objects that one is carrying on their person prior to entry into the magnet room.
frequency: Number of times that a process repeats itself in a given period (e.g., the frequency of a radio wave is the number of complete waves per second).
fringe field: Portion of the magnetic field that extends away from the confines of the magnet; it cannot be used for imaging, but can affect nearby equipment or personnel.
gating: Organizing data so that the information used to construct the image comes from the same point in the cycle of a repeating motion, such as a heartbeat. The moving object is "frozen" at that phase of its motion, thus reducing image blurring.
gauss (G): Unit of magnetic field strength (see *tesla*).
gradient echo: A pulse sequence that uses a gradient instead of a 180-degree RF refocusing pulse to generate T2-weighted images.
inversion recovery: Standard pulse sequence available on most MR imagers; the name indicates that the direction of longitudinal magnetization is reversed (inverted) before relaxation (recovery) occurs.
longitudinal plane: This plane corresponds to the direction of the main magnetic field in superconducting magnets and is the location of protons awaiting excitation.
magnetic resonance (MR): Process by which certain nuclei, when placed in a magnetic field, can absorb and release energy in the form of radio waves. This technique can be used for chemical analysis or for the production of cross-sectional images of body parts. Computer analysis of the radio wave data is required.
MRI conditional: An item that has been demonstrated to pose no known hazards in a specified MRI environment with specified conditions of use.
MRI safe: An item that poses no known hazards in any MRI environment.
noise: Random contributions to the total signal that arise from stray external radio waves, imperfect electronic apparatus, or other interference. Noise cannot be eliminated, but can be minimized; it tends to degrade the image by interfering with accurate measurement of the true MRI signal, similar to the difficulty in maintaining a clear conversation in a noisy room.
nuclear magnetic resonance (NMR): Another name for magnetic resonance; this term is not commonly used.
nucleus: The central portion of an atom, composed of protons and neutrons.
paramagnetic: Referring to materials that alter the magnetic field of nearby nuclei. Paramagnetic substances are not directly imaged by MRI, but instead change the signal intensity of the tissue where they localize, acting as MRI contrast agents. Paramagnetic agents shorten the T1 and T2 of the tissues they affect—actions that tend to have opposing effects on signal intensity.
perfusion: Flow of blood through the vessels of an organ or anatomic structure; usually refers to blood flow in the small vessels (e.g., capillary perfusion).
permanent magnet: An object that produces a magnetic field without requiring an external supply of electricity.
precession: Rotation of an object around the direction of a force acting on that object. This should not be confused with the axis of rotation of the object itself (e.g., a spinning top rotates on its own axis, but it may also precess [wobble] around the direction of the force of gravity that is acting on it).
proton density: Measure of proton (i.e., hydrogen, because its nucleus is a single proton) concentration (number of nuclei per given volume); one of the major determinants of MRI signal strength in hydrogen imaging.
pulse: *See radio frequency (RF) pulse.*
pulse sequence: A coordinated series of gradient activations and RF transmissions designed to excite nuclei in such a way that their energy release has varying contributions from proton density, T1, or T2 processes.
radio frequency (RF) pulse: A short burst of radio waves. If the radio waves are of the appropriate frequency, they can give energy to nuclei that are within a magnetic field by the process of resonance. Length of the pulse determines amount of energy given to the nuclei.
raw data: Information obtained by radio reception of the MRI signal as stored by a computer. Specific computer manipulation of these data is required to construct an image from them.
relaxation time: Measure of the rate at which nuclei, after stimulation, release their absorbed energy.
resistive magnet: Simple electromagnet in which electricity passing through coils of wire produces a magnetic field; can be turned on and off.
resonance: Process of energy absorption by an object that is tuned to absorb energy of a specific frequency only. All other frequencies do not affect the object (e.g., if one tuning fork is struck in a room full of tuning forks, only the forks tuned to that identical frequency would vibrate [resonate]).
signal: In MRI, induction of current into a receiver coil by precessing magnetization.
slice: Cross-sectional image; can also refer to the thin section of the body from which data are acquired to produce the image.
spectroscopy: Science of analyzing the components of an electromagnetic wave, usually after its interaction with some substance (to obtain information about that substance).
spin echo: Standard MRI pulse sequence that can provide T1-weighted, T2-weighted, or proton density–weighted images. The name indicates that a declining MRI signal is refocused to gain strength (similar to an echo) before it is recorded as raw data.
spin-lattice relaxation: Release of energy by excited nuclei to their general environment; one of the major determinants of MRI signal strength. T1 is a rate constant measuring spin-lattice relaxation. Also called T1 relaxation.
spin-spin relaxation: Release of energy by excited nuclei as a result of interaction among themselves; one of the major determinants of MRI signal strength. T2 is a rate constant measuring spin-spin relaxation. Also called T2 relaxation.
superconductive magnet: Electromagnet in which the coils of wire are cooled to an extremely low temperature so that resistance to the conduction of electricity is nearly eliminated (superconductive).
superparamagnetic: Material that has a greater effect with a magnetic field; it can dramatically decrease the T2 of tissues, causing a total loss of signal by the absorbing structures.
T1: Spin-lattice relaxation.
T2: Spin-spin relaxation.

tesla (T): Unit of magnetic field strength; 1 T equals 10,000 gauss or 10 kilogauss (other units of magnetic field strength). The earth's magnetic field approximates 0.5 gauss.

transverse plane: The plane perpendicular to the longitudinal plane where the MRI signal can be measured.

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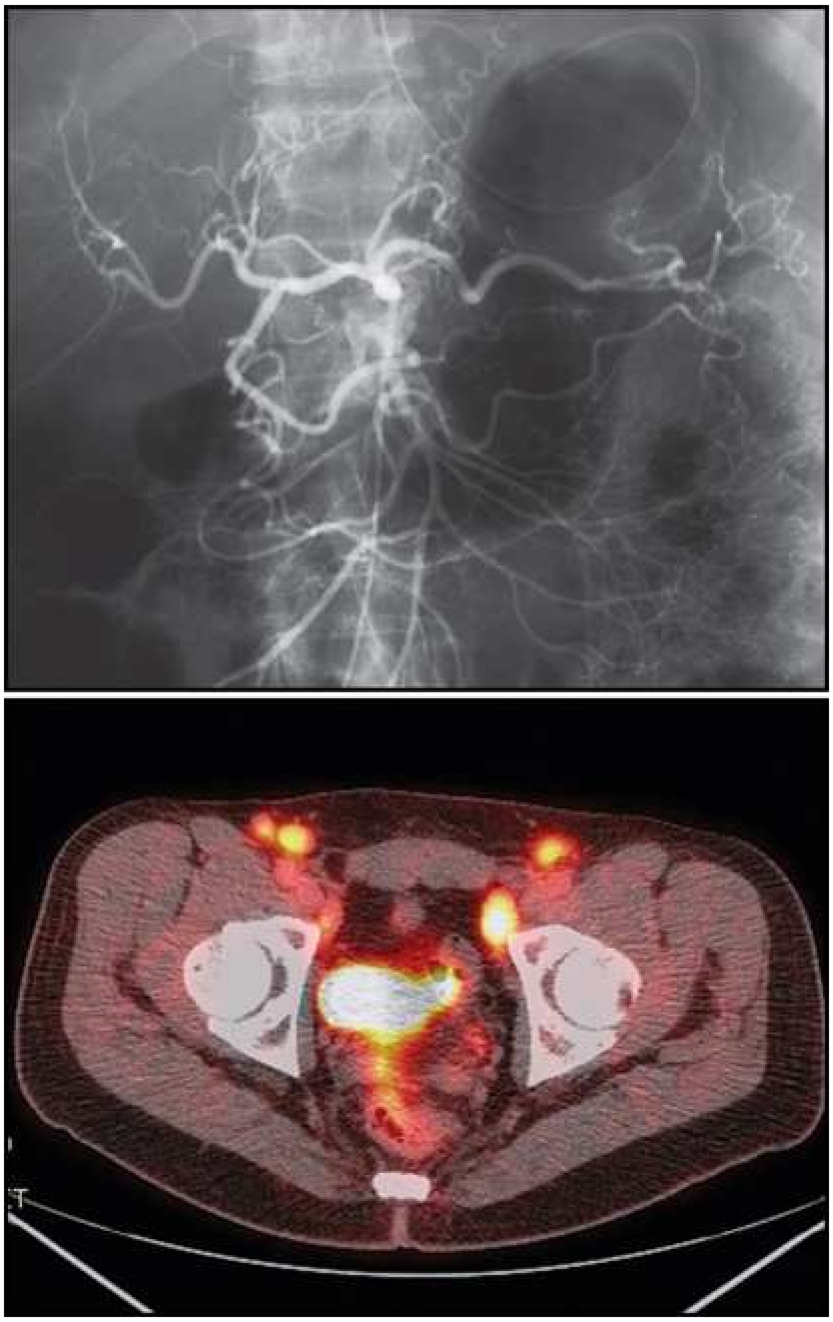
[a] Almost all italicized words on the succeeding pages are defined at the end of this chapter.

27: Vascular, Cardiac, And Interventional Radiography



Lynette Petrie

Historical Development

In January 1896, just 10 weeks after the announcement of Roentgen's discovery of x-rays, Haschek and Lindenthal announced that they had produced a radiograph showing the blood vessels of an amputated hand using a thick emulsion of chalk, known as Teichmann's mixture, as a contrast medium. This work heralded the beginning of angiography. The advancement of angiography was hindered, however, by the lack of suitable contrast media and low-risk techniques to deliver the media to the desired location. By the 1920s, researchers were using sodium iodide as a contrast medium to produce lower limb angiography studies. The contrast medium was either injected through a needle that punctured the vessel or through a ureteral catheter that passed into the body through a surgically exposed peripheral vessel.

The first human cardiac catheterization was reported in 1929 by Forssman, a 25-year-old surgical resident who passed a catheter, via an arm vein, into his own heart and then walked to the radiology department where a chest radiograph was produced to document his medical achievement. Catheterization of the heart soon became a valuable tool used primarily for diagnostic purposes. Through the 1940s, the basic catheterization study remained relatively uncomplicated and easy for physicians to perform; however, the risk to the patient was significant.

In 1952, shortly after the development of a flexible thin-walled catheter, Seldinger announced a *percutaneous* [a] method of catheter introduction. The Seldinger technique eliminated the surgical risk, which exposed the vessel and tissues. This technique is described in detail later in this chapter. Selective coronary *angiography* was first reported by Sones in 1959, when he inadvertently injected contrast media into the right coronary artery of a patient who was undergoing routine aortography. In 1962, Ricketts and Abrams described a percutaneous method for selective coronary angiography. This method was further perfected in the late 1960s with the introduction of preshaped catheters designed to engage the ostium of the right and left coronary arteries.

Innovations in guidewire and catheter technology continued alongside increased research into intraluminal treatments, or endovascular interventions. It has been said the "Fathers of Interventional Radiology and Cardiology" were Charles Dotter and Andreas Grüntzig, respectively. Dotter performed the first successful dilation of a superficial femoral artery in 1964 using coaxial catheters. In the November 1964 edition of *Circulation*, percutaneous transluminal angioplasty (PTA) was described by Dotter with co-author Dr. Melvin Judkins. In 1966, Dotter fabricated a reinforced balloon dilating catheter, but it was not used on patients. Dr. Werner Portsman (Berlin, Germany) introduced "*Korsett Balloon Kather*," an 8 Fr outer Teflon catheter with four longitudinal slits in 1973. A latex balloon catheter was inflated inside the longitudinal slits. In September 1977, Dr. Andreas Grüntzig successfully used a balloon PTA to treat a left anterior descending coronary artery stenosis. Grüntzig and Hopff introduced the double-lumen, balloon-tipped catheter. One lumen allows the passage of a guidewire and fluids through the catheter. The other lumen communicates with a balloon at the distal end of the catheter. When inflated, the balloon expands to a size much larger than the catheter. Double-lumen, angioplasty balloon catheters are available in sizes ranging from 3 to 9 Fr, with attached balloons varying in length and expanding to diameters of 2 to 20 mm or more. Transluminal angioplasty can be performed in virtually any vessel that can be reached percutaneously with a catheter. In 1978, Molnar and Stockum described the use of balloon angioplasty for dilation of strictures within the biliary system. Balloon angioplasty is also conducted in venous structures, ureters, and the gastrointestinal tract.

The 1980s saw the development of expandable metallic stents. Andrew Cragg, Charles Dotter, Cesare Gianturco, Dierk Maas, Julio Palmaz, and Hans Wallsten were the first stent pioneers. These stents were composed primarily of a stainless-steel alloy or thermal memory stents made of nitinol (alloy of nickel and titanium) and were self or balloon expandable. Three stents available for use in 1985 were the Gianturco Z, Palmaz, and Wallstent. Dotter continued advancement of cardiovascular procedures by first using Streptokinase for selective pharmacological *thrombolysis*. In the 1980s, Urokinase was used for this widely performed procedure. In the 1990s and early 2000s, developments in thrombolysis were due to the advancement of fibrinolytic agents *(recombinant tissue plasminogen activators)*.

Therapeutic vascular occlusion procedures began in 1931 with an open surgical *embolization* of a carotid cavernous fistula. Dr. Shoji Ishimore used Gelfoam pieces through a polyethylene tube into an exposed carotid artery. It was not until the 1980s and 1990s however, that *Transcatheter embolization* became popular with the advancement of embolization agents, such as gelatin sponges (Gelfoam), polyvinyl alcohol (Ivalon), liquid and rapidly solidifying polymers including cyanoacrylate glue, coils, and detachable balloons.

Early angiograms consisted of single radiographs or the visualization of vessels by fluoroscopy. Because the advantage of *serial imaging* within angiography was recognized, cassette changers, roll film changers, cut film changers, cine and serial spot-filming/digital devices were developed. Until the early 1990s, most angiograms recorded flowing contrast media in a series of images that required rapid film changers or *cinefluorography* devices; however, presently, digital subtraction angiography (DSA) systems are used almost exclusively.

The resolution possible with early digital equipment was a drawback to the use of digital imaging in angiography. Larger matrix size, the obvious solution to this problem, allowed for acceptable resolution but also created another problem: how to acquire and store large volumes of digital information. In the late 1970s and early 1980s, the high-speed parallel transfer disk was introduced to solve the acquisition and short-term storage problem. This new disk acquired and stored an entire coronary angiogram and made real-time digital playback during the procedure possible. Permanent storage of the digital images remained a problem, however. Floppy disk and computer tape storage were inadequate solutions because they required significant time and supplies. Long-term storage of large amounts of digital images has benefited from advances in computer technology, which provide high-speed, large-capacity methods of storage, capable of acquiring large amounts of data (terabytes) with very high resolution.

Current imaging equipment has increased image quality while reducing patient dose and can produce images up to a rate of 30 frames per second. DSA imaging and faster data processing provide the interventionalist with a variety of tools for image manipulation, analysis, and measurement that are almost immediately available, dramatically reducing patient procedure time and allowing for diagnostic and interventional procedures to occur simultaneously.

Over the last 50 years, there have been tremendous advances in radiologic and cardiovascular medicine and technology. Radiographic imaging and recording equipment, physiologic monitoring equipment, and cardiovascular pharmaceuticals and supplies became increasingly reliable. The use of computers in cardiovascular interventional laboratories has facilitated the development of this rapidly growing subspecialty of the cardiovascular medical and surgical sciences. These advances and trends have enabled angiography to evolve from a simple diagnostic investigation to its current state as a sophisticated diagnostic study and interventional procedure.

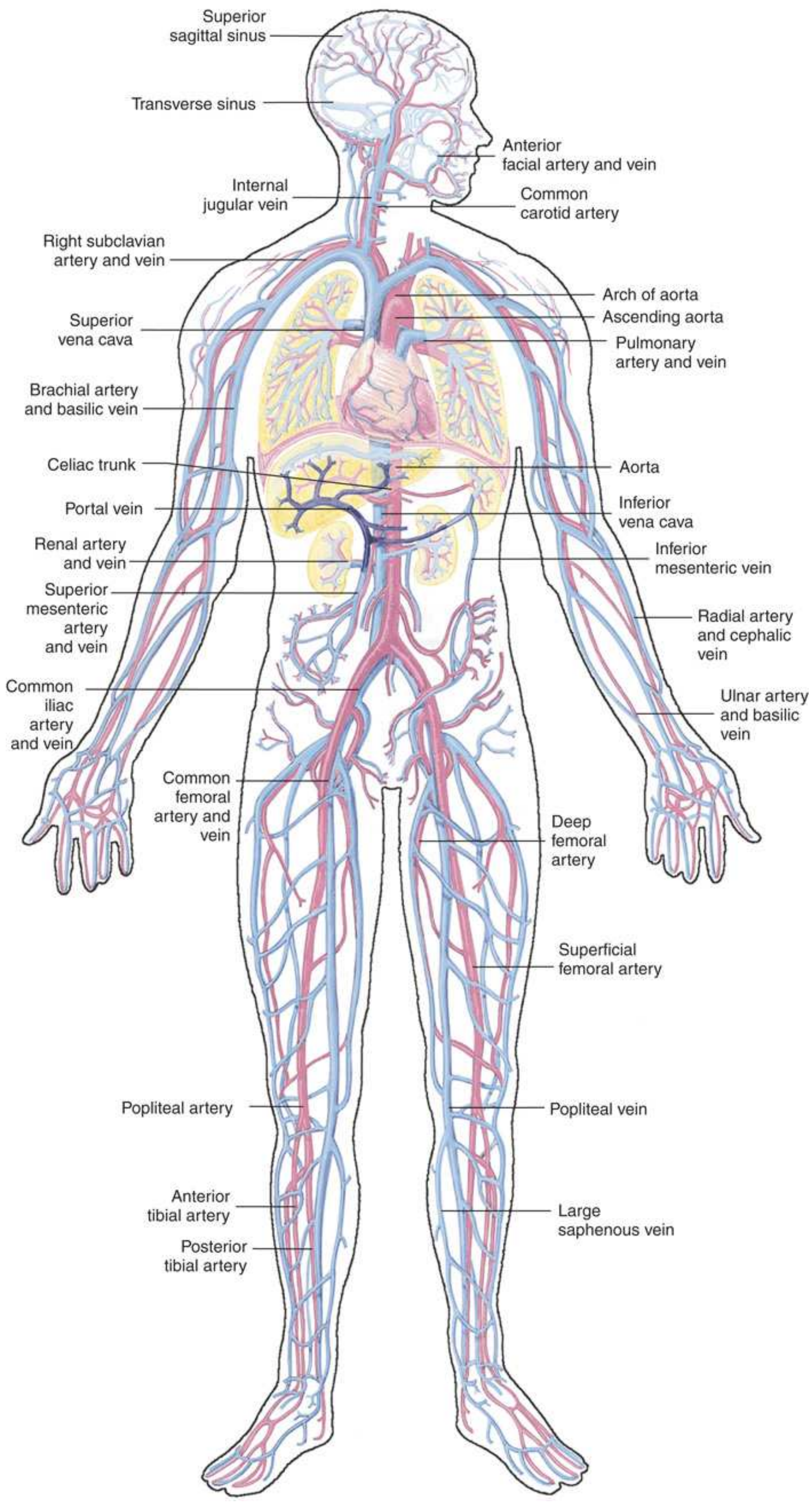


FIG. 27.1 Major arteries and veins: *red,* arterial; *blue,* venous; *purple,* portal.

Diagram shows the circulatory system of the human body consisting of the blood-vascular system and lymphatic system. The major arteries and veins are highlighted in red, arterials are highlighted in blue and the venous are highlighted in purple. The parts labeled on the left side are as follows: superior sagittal sinus, transverse sinus, internal jugular vein, right subclavian artery and vein, superior vena cava, brachial artery and basilic vein, celiac trunk, portal vein, renal artery and vein, superior mesenteric artery and vein, common iliac artery and vein, common femoral artery and vein, popliteal artery, anterior tibial artery, posterior tibial artery. The parts labeled on the right are as follows:

anterior facial artery and vein, common carotid artery, arch of aorta ascending aorta, pulmonary artery and vein, aorta, inferior vena cava, inferior mesenteric vein, radial artery and cephalic vein, ulnar artery and basilic vein, deep femoral artery, superficial femoral artery, popliteal vein, large saphenous vein.

Anatomy

Circulatory System

The *circulatory system* has two complex systems of intimately associated vessels. Through these vessels, fluid is transported throughout the body in a continuous, unidirectional flow. The major portion of the circulatory system transports blood and is called the *blood-vascular system* (Fig. 27.1). The minor portion, called the *lymphatic system*, collects fluid from the tissue spaces. This fluid is filtered throughout the lymphatic system, which conveys it back to the blood-vascular system. The fluid conveyed by the lymphatic system is called *lymph.* Together, the blood-vascular and lymphatic systems carry oxygen and nutritive material to the tissues. They also collect and transport carbon dioxide (CO_2) and other waste products of metabolism from the tissues to the organs of excretion: the skin, lungs, liver, and kidneys.

Blood-Vascular System

The blood-vascular system consists of the *heart*, *arteries*, *capillaries*, and *veins.* The *heart* serves as a pumping mechanism to keep the blood in constant circulation throughout the vast system of blood vessels. *Arteries* convey the blood *away* from the heart. *Veins* convey the blood *back* toward the heart.

Two circuits of blood vessels branch out of the heart (Fig. 27.2). The first circuit is the arterial circuit or the *systemic circulation*, which carries oxygenated blood to the organs and tissues. Every organ has its own vascular circuit that arises from the trunk artery and leads back to the trunk vein for return to the heart. The systemic arteries branch out, treelike, from the aorta to all parts of the body. The arteries are usually named according to their location. The systemic veins usually lie parallel to their respective arteries and are given the same names.

The second circuit is the *pulmonary circulation*, which takes blood to the lungs for CO_2 exchange and for the reoxygenation of the blood, which is carried back to the arterial systemic circulation. The pulmonary trunk arises from the right ventricle of the heart, passes superiorly and posteriorly for a distance of about 2 inches (5 cm), and then divides into two branches, the right and left pulmonary arteries. These vessels enter the root of the respective lung and, following the course of the bronchi, divide and subdivide to form a dense network of capillaries surrounding the alveoli of the lungs. Through the thin walls of the capillaries, the blood discharges CO_2 and absorbs oxygen from the air contained in the alveoli. The oxygenated blood passes onward through the pulmonary veins for return to the heart. In the pulmonary circulation, the deoxygenated blood is transported by the pulmonary arteries, and the oxygenated blood is transported by the pulmonary veins.

Two main trunk vessels arise from the heart. The first is the aorta for the systemic circulation: the arteries progressively diminish in size as they divide and subdivide along their course, finally ending in minute branches called *arterioles.* The arterioles divide to form the capillary vessels, and the branching process is then reversed: the *capillaries* unite to form *venules*, the beginning branches of the veins, which unite and reunite to form larger and larger vessels as they approach the heart. These venous structures empty into the right atrium, then into the right ventricle, and then into the second main trunk that arises from the heart—the pulmonary trunk, or the pulmonary circulation. The process of oxygen exchange is carried out in small venous structures and then in larger and larger pulmonary veins. The pulmonary veins join to form four large veins (two from each lung), which empty into the left atrium, then into the left ventricle, and then into the aorta, which starts the circulation again throughout the body.

The pathway of venous drainage from the abdominal viscera to the liver is called the *portal system.* In contrast to the systemic and pulmonary circuits, which begin and end at the heart, the portal system begins in the capillaries of the abdominal viscera and ends in the capillaries and sinusoids of the liver. The blood is filtered and then exits the liver via the hepatic venous system, which empties into the *inferior vena cava (IVC)* just proximal to the right atrium.

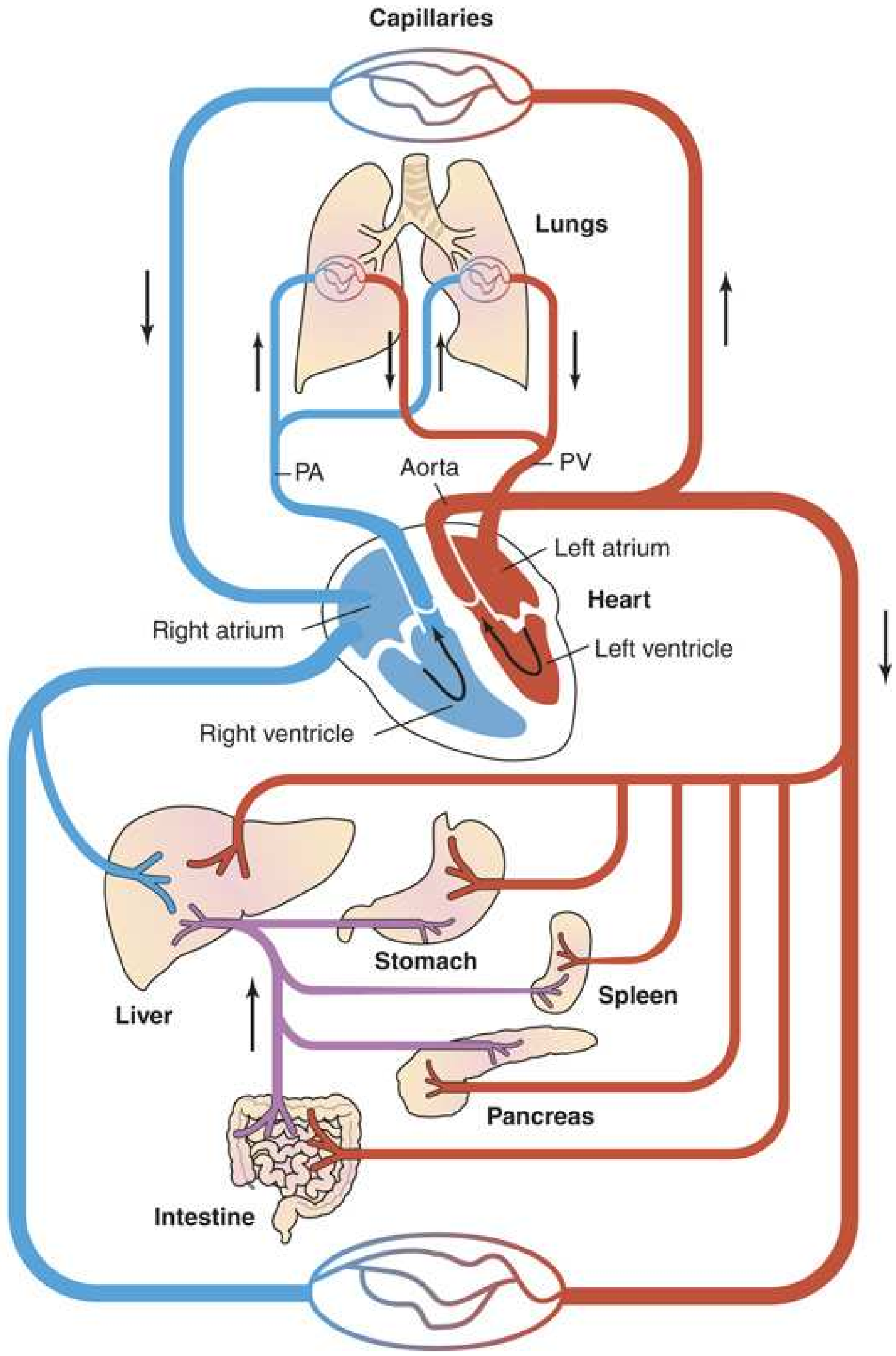


FIG. 27.2 Pulmonary, systemic, and portal circulation: oxygenated *(red)*, deoxygenated *(blue)*, and nutrient-rich *(purple)* blood.

Two circuits of blood vessels branch out of the heart. The first circuit is the arterial circuit or the systemic circulation, which carries oxygenated blood to the organs and tissues. The systemic arteries branch out, treelike, from the aorta to all parts of the body. The second circuit is the pulmonary circulation, which takes blood to the lungs for CO_2 exchange and for the reoxygenation of the blood, which is carried back to the arterial systemic circulation. The pulmonary trunk arises from the right ventricle of the heart, passes superiorly and posteriorly for a distance of about 2 inches, and then divides into two branches, the right and left pulmonary arteries. These vessels enter the root of the respective lung and, following the course of the bronchi, divide and subdivide to form a dense network of capillaries surrounding the alveoli of the lungs. Through the thin walls of the capillaries, the blood discharges CO_2 and absorbs oxygen from the air contained in the alveoli. The oxygenated blood passes onward through the pulmonary veins for return to the heart.

The systemic veins are arranged in a superficial set, and in a deep set with which the superficial veins communicate; both sets converge at a common trunk vein. The systemic veins end in two large vessels opening into the heart: the *superior vena cava (SVC)* leads from the portion of the body above the diaphragm, and the IVC leads from below the level of the diaphragm.

The capillaries connect the arterioles and venules to form networks that pervade most organs and all other tissues supplied with blood. The capillary vessels have exceedingly thin walls through which the essential functions of the blood-vascular system take place: the blood constituents are filtered out, and the waste products of cell activity are absorbed. The exchange takes place through the medium of tissue fluid, which is derived from the blood plasma and is drained off by the lymphatic system for return to the blood-vascular system. The tissue fluid undergoes modification in the lymphatic system. As soon as this tissue fluid enters the lymphatic capillaries, it is called *lymph.*

The *heart* is the central organ of the blood-vascular system and functions solely as a pump to keep the blood in circulation. It is shaped like a cone and measures approximately 4¾ inches (12 cm) in length, 3½ inches (9 cm) in width, and 2½ inches (6 cm) in depth. The heart is situated obliquely in the central mediastinum, primarily to the left of the midsagittal plane. The base of the heart is directed superiorly, posteriorly, and to the right. The apex of the heart rests on the diaphragm against the anterior chest wall and is directed anteriorly, inferiorly, and to the left.

The muscular wall of the heart is called the *myocardium.* Because of the force required to drive blood through the extensive systemic vessels, the myocardium is about three times as thick on the left side (the arterial side) as on the right (the venous side). The membrane that lines the interior of the heart is called the *endocardium.* The heart is enclosed in the double-walled *pericardial sac.* The exterior wall of this sac is fibrous. The thin, closely adherent membrane that covers the heart is referred to as the *epicardium* or, because it also serves as the serous inner wall of the pericardial sac, the *visceral pericardium.* The narrow, fluid-containing space between the two walls of the sac is called the *pericardial cavity.*

The heart is divided by septa into right and left halves, with each half subdivided by a constriction into two cavities, or chambers. The two upper chambers are called *atria*. Each *atrium* consists of a principal cavity and a lesser cavity called the *auricle.* The two lower chambers of the heart are called *ventricles.* The opening between the right atrium and right ventricle is controlled by the right atrioventricular (tricuspid) valve, and the opening between the left atrium and left ventricle is controlled by the left atrioventricular (mitral or bicuspid) valve.

The atria and ventricles separately contract (*systole*) in pumping blood and relax or dilate (*diastole*) in receiving blood. The atria precede the ventricles in contraction; while the atria are in systole, the ventricles are in diastole. One phase of contraction (referred to as the heartbeat) and one phase of dilation are called the *cardiac cycle.* In the average adult, one cardiac cycle lasts 0.8 seconds. The heart rate, or number of pulsations per minute, varies with size, age, and gender. Heart rate is faster in small persons, young individuals, and females. The heart rate is also increased with exercise, food, and emotional disturbances.

The atria function as receiving chambers. The superior and IVC empty into the right atrium (Fig. 27.3); the two right and left pulmonary veins empty into the left atrium. The ventricles function as distributing chambers. The right side of the heart handles the venous, or deoxygenated, blood, and the left side handles the arterial, or oxygenated, blood. The left ventricle pumps oxygenated blood through the aortic valve into the aorta and the systemic circulation. The three major portions of the aorta are the ascending aorta, the aortic arch, and the descending aorta. The right ventricle pumps deoxygenated blood through the pulmonary valve into the pulmonary trunk and the pulmonary circulation.

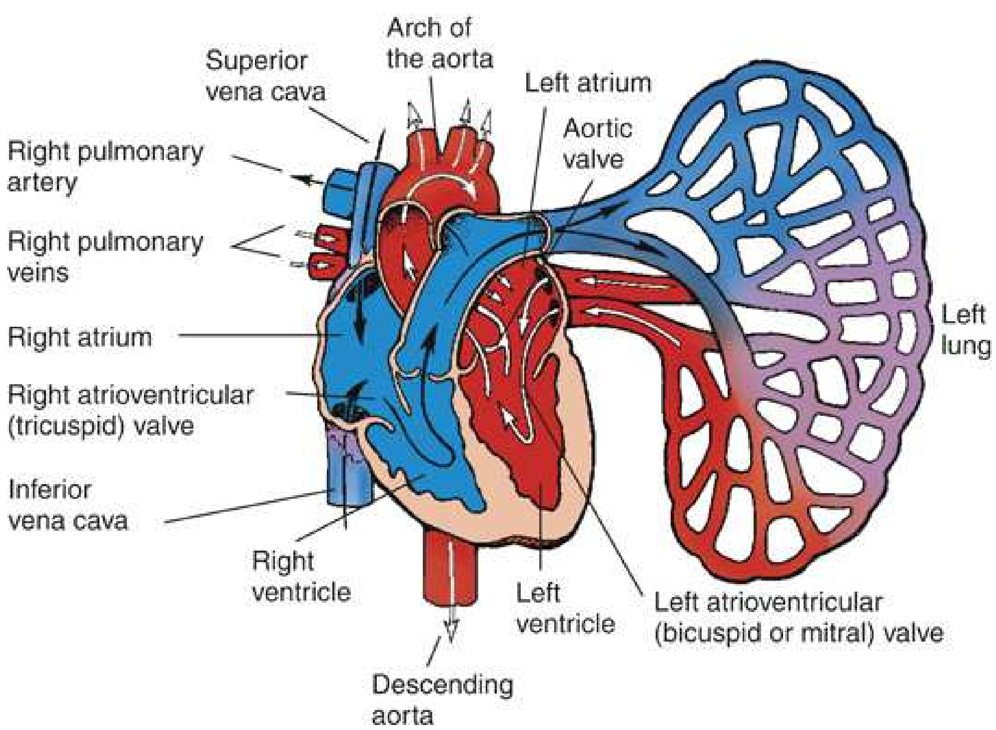


FIG. 27.3 Heart and great vessels: deoxygenated blood flow *(black arrows)*; oxygenated blood flow *(white arrows)*.

Diagram shows a heart and its great vessels pumping oxygenated and deoxygenated blood. Black arrows in the diagram shows the flow of deoxygenated blood and white arrows show the flow of oxygenated blood. The parts labeled are marked in clockwise direction as follows: descending aorta, right ventricle, inferior vena cava, right atrioventricular (tricuspid) valve, right atrium, right pulmonary veins, right pulmonary artery, superior vena cava, arch of the aorta, left atrium, aortic valve, left lung, left atrioventricular (bicuspid or mitral) valve, and left ventricle.

Blood is supplied to the myocardium by the right and left coronary arteries. These vessels arise in the aortic sinus immediately superior to the aortic valve (Fig. 27.4). Most of the cardiac veins drain into the coronary sinus on the posterior aspect of the heart, and this sinus drains into the right atrium (Fig. 27.5).

The ascending aorta arises from the superior portion of the left ventricle and passes superiorly and to the right for a short distance. It then arches posteriorly and to the left and descends along the left side of the vertebral column to the level of L4, where it divides into the right and left common iliac arteries. The common iliac arteries pass to the level of the lumbosacral junction, and divide into the internal iliac, or hypogastric, artery and the external iliac artery. The internal iliac artery passes into the pelvis. The external iliac artery passes to a point about midway between the anterior superior iliac spine and pubic symphysis and then enters the upper thigh to become the common femoral artery.

The velocity of blood circulation varies with the rate and intensity of the heartbeat. Velocity also varies in the different portions of the circulatory system based on distance from the heart. The speed of blood flow is highest in the large arteries arising at or near the heart because these vessels receive the full force of each wave of blood pumped out of the heart. The arterial walls expand with the pressure from each wave. The walls then rhythmically recoil, gradually diminishing the pressure of the advancing wave from point to point, until the flow of blood is normally reduced to a steady, non-pulsating stream through the capillaries and veins. The beat, or contraction and expansion of an artery, may be felt with the fingers at several points and is called the *pulse.*

Complete circulation of the blood through the systemic and pulmonary circuits, from a given point and back again, requires about 23 seconds and an average of 27 heartbeats. In certain contrast examinations of the cardiovascular system, tests are conducted to determine the circulation time from the point of contrast media injection to the site of interest.

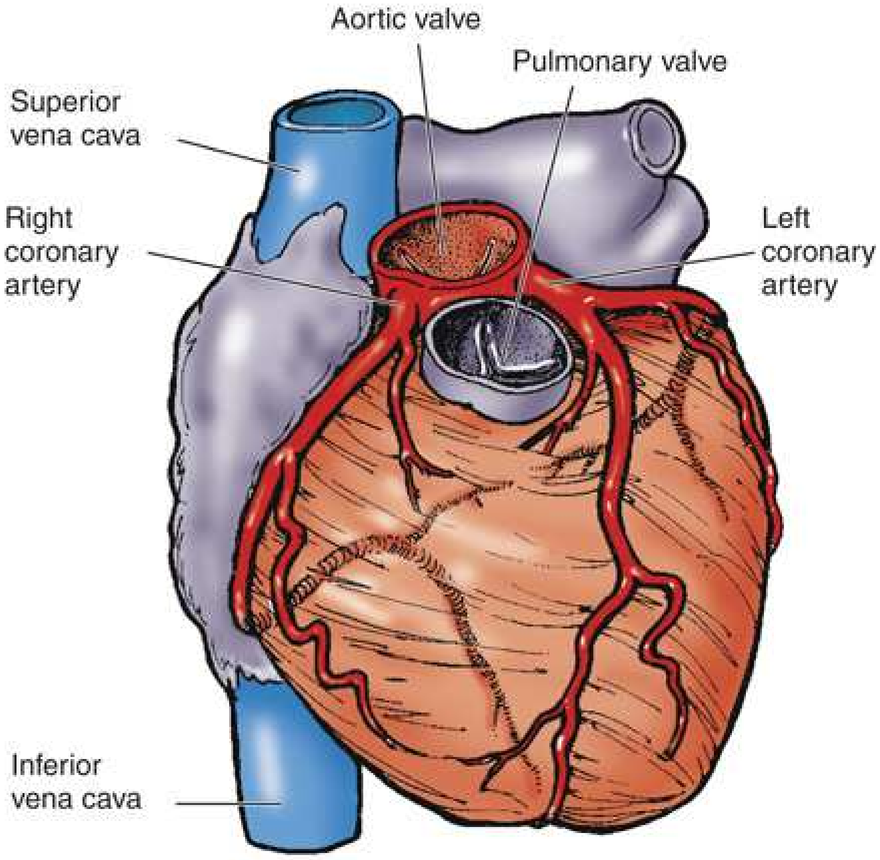


FIG. 27.4 Anterior view of coronary arteries.

Diagram shows the anterior view of coronary arteries in a heart. The parts labeled are marked in clockwise direction as follows: inferior vena cava, right coronary artery, superior vena cava, aortic valve, pulmonary valve, and left coronary artery.

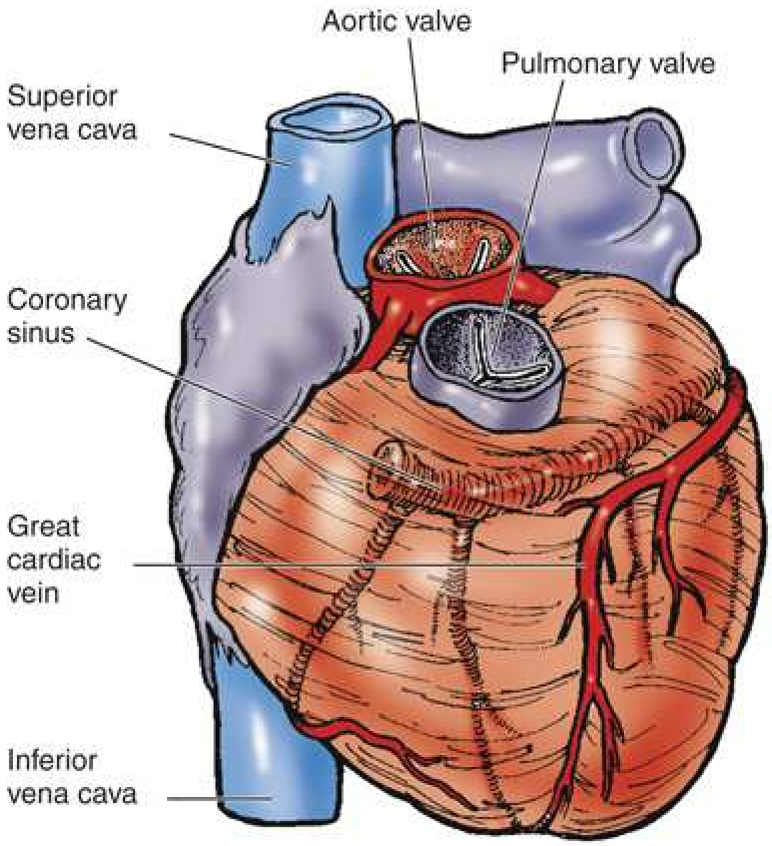


FIG. 27.5 Anterior view of coronary veins.

Diagram shows the anterior view of coronary veins in a heart. The parts labeled are marked in clockwise direction as follows: inferior vena cava, great cardiac vein, coronary sinus, superior vena cava, aortic valve, and pulmonary valve.

Lymphatic System

The lymphatic system consists of an elaborate arrangement of closed vessels that collect fluid from the tissue spaces and transport it to the blood-vascular system. Almost all lymphatic vessels are arranged in two sets: (1) a superficial set that lies immediately under the skin and accompanies the superficial veins and (2) a deep set that accompanies the deep blood vessels and with which the superficial lymphatics communicate (Fig. 27.6). The lymphatic system lacks a pumping mechanism, such as the heart of the blood-vascular system. The lymphatic vessels are richly supplied with valves to prevent backflow, and the movement of the lymph through the system is believed to be maintained primarily by extrinsic pressure from the surrounding organs and muscles.

The lymphatic system begins in complex networks of thin-walled, absorbent capillaries situated in the various organs and tissues. The capillaries unite to form larger vessels, which form networks and unite to become still larger vessels as they approach the terminal collecting trunks. The terminal trunks communicate with the blood-vascular system.

The lymphatic vessels are small in caliber and have delicate, transparent walls. Along their course the collecting vessels pass through one or more nodular structures called *lymph nodes.* The nodes occur singly but are usually arranged in chains or groups of 2 to 20. The nodes vary from the size of a pinhead to the size of an almond or larger. They may be spherical, oval, or kidney shaped. Large groupings of lymph nodes are typically found in the neck, armpits, and groin. Each node has a hilum through which arteries and veins enter, and *efferent lymph vessels* emerge. *Afferent lymph vessels* do not enter at the hilum, but rather enter the node opposite the hilum and break into wide capillaries that surround the lymph follicles and form a canal known as the *peripheral* or *marginal lymph sinus*. This network of capillaries continues into the medullary portion of the node, where absorption and interchange of tissue fluids and cells occur. The capillaries then converge into several efferent lymph vessels that leave the node at the hilum. In addition to the lymphatic capillaries, blood vessels, and supporting structures, each lymph node contains masses, or follicles, of lymphocytes that are arranged around its circumference.

Lymphocytes are added to the lymph inside the lymph nodes. It is thought that most of the lymph is absorbed by the venous system from these nodes, and only a small portion of the lymph is passed on through the conducting vessels to the terminal trunks.

The main terminal trunk of the lymphatic system is called the *thoracic duct*. The lower, dilated portion of the duct is known as the *cisterna chyli*. The thoracic duct receives lymphatic drainage from all parts of the body below the diaphragm and from the left half of the body above the diaphragm. The thoracic duct extends from the level of L2 to the base of the neck, where it ends by opening into the venous system at the junction of the left subclavian and internal jugular veins.

Three terminal collecting trunks—the right jugular, the subclavian, and the bronchomediastinal trunks—receive the lymphatic drainage from the right half of the body above the diaphragm. These vessels open into the right subclavian vein separately or occasionally after uniting to form a common trunk called the *right lymphatic duct*.

Lymphography is seldom performed in current practice because of the superior imaging capabilities of magnetic resonance imaging (MRI), computed tomography (CT), and positron emission tomography (PET) (Fig. 27.7). A more detailed description of lymphography is provided in previous editions of this text.

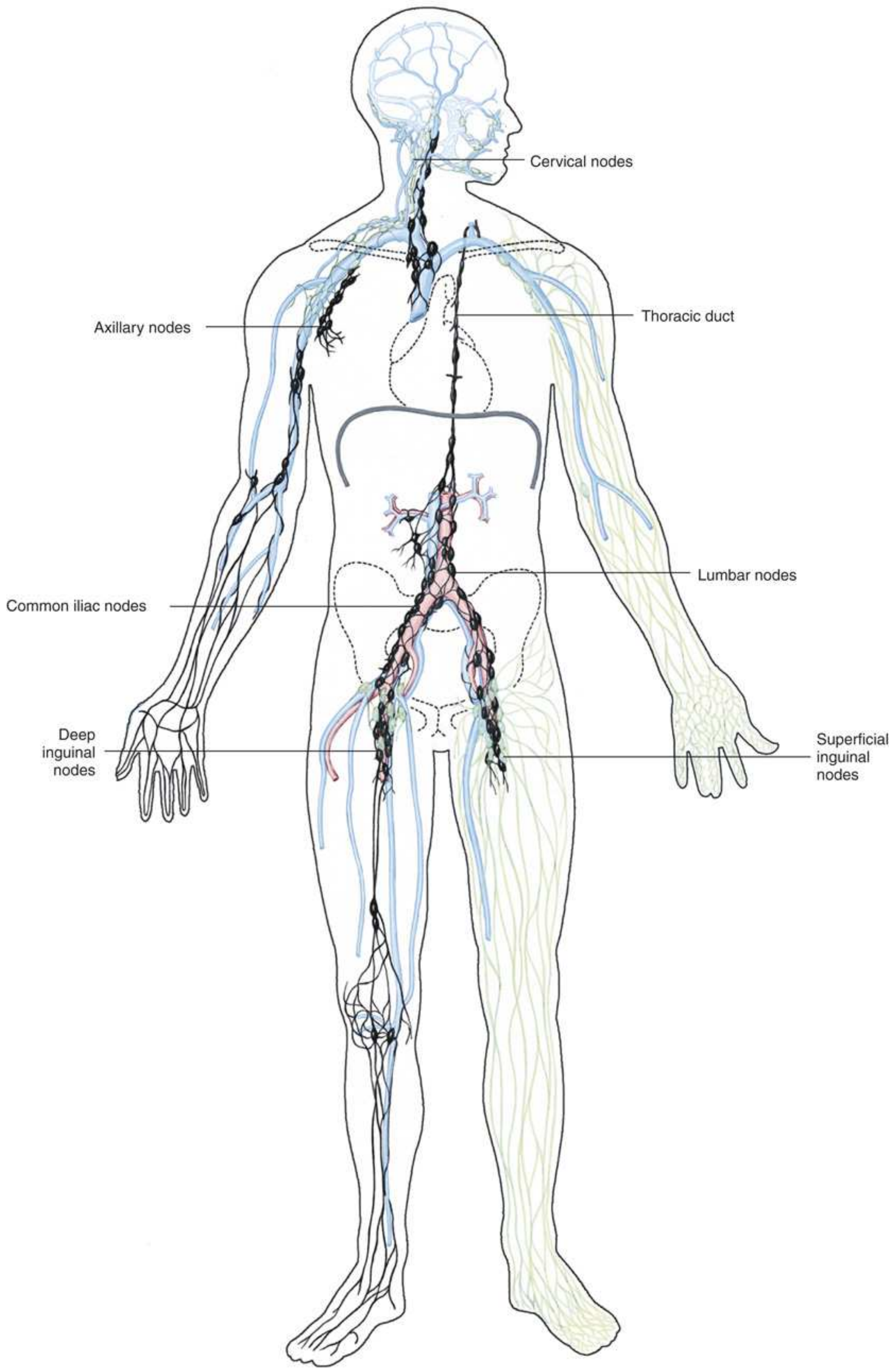


FIG. 27.6 Lymphatic system: *Green,* Superficial; *Black,* Deep.

Diagram shows the lymphatic system of a human body that consists of two sets of vessels. The superficial set is highlighted in green and the deep set is highlighted in black. The parts labeled are marked in clockwise direction as follows: deep inguinal nodes, common iliac nodes, axillary nodes, cervical nodes, thoracic duct, lumbar nodes, and superficial inguinal nodes.

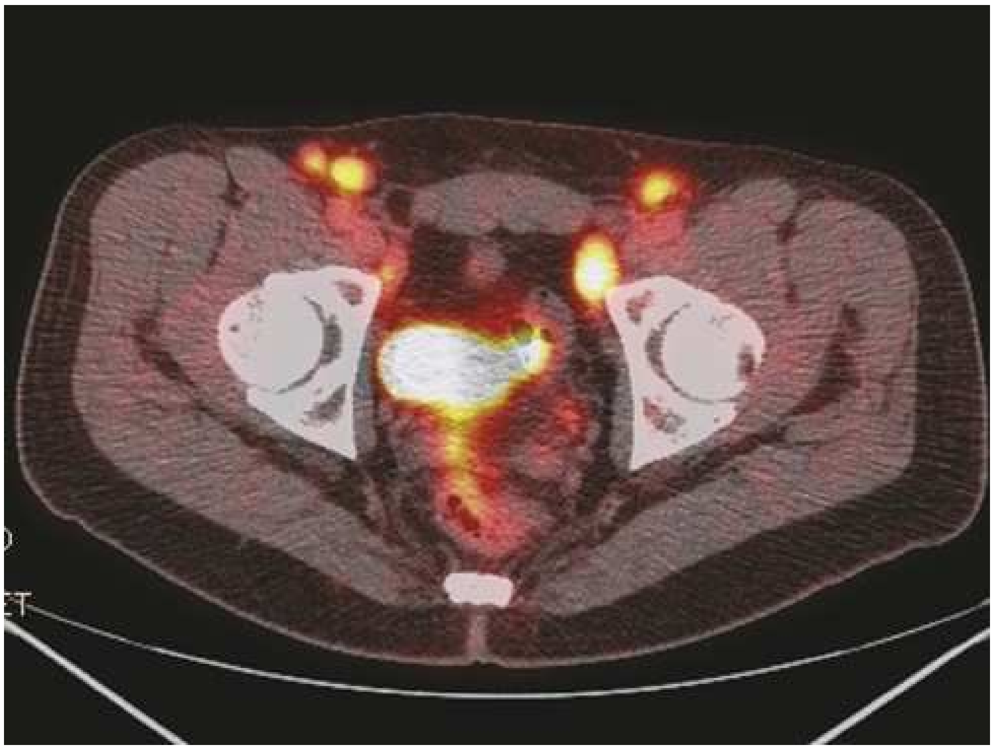


FIG. 27.7 Axial PET/CT of lymph nodes with lymphoma.

Angiography

Definitions and Indications

Angiography is a general term that describes the radiologic examination of vascular structures within the body after the introduction of a contrast media or gas. This procedure is primarily used to identify the anatomy or pathologic process of blood vessels. Angiography procedures include *arteriography* and *venography*. Examinations are more precisely named for the specific blood vessel opacified and the method of injection, e.g. renal arteriography.

Blood vessels are not normally visible on conventional radiography because no natural contrast exists between them and other soft tissues of the body. These vessels must be filled with a radiopaque contrast media to delineate them for radiography. Today computerized tomography angiography (CTA) and magnetic resonance angiography (MRA) are commonly performed *non-invasive* diagnostic angiographic studies. These imaging studies are discussed in subsequent chapters. This chapter will discuss catheter-directed angiography, in which radiographic images of vessels are taken as iodinated contrast is injected via catheters placed percutaneously into the vessels. The *percutaneous* introduction of catheters into vessels is considered *minimally invasive*. Most angiographic procedures are performed to investigate anatomic variances, such as vascular disease, tumor, or injury; however, some evaluate the motion or function of an organ, such as the heart. Catheter-directed angiographic procedures can be purely diagnostic or, as is most commonly the case, are a combination of both diagnostic and interventional (therapeutic) procedures. Many vascular pathologies are amendable to some type of percutaneous vascular intervention or treatment immediately after a diagnosis is confirmed with catheter-directed angiography.

Chronic cramping leg pain after physical exertion, a condition known as *claudication*, may prompt a physician to order an arteriogram of the lower limbs to determine whether atherosclerosis is diminishing the blood supply to the leg muscles. A *stenosis* or *occlusion* is commonly caused by *atherosclerosis* and is an indication for an interventional procedure such as percutaneous transluminal angioplasty. Cerebral angiography is performed to detect and verify the existence and exact position of an intracranial vascular lesion such as an *aneurysm*. An aneurysm can be treated with interventional procedures such as coil embolization.

Angiographic procedures of the heart are usually performed by interventional cardiologists rather than radiologists; however, there are many shared techniques and similarities between vascular interventional radiology and cardiac catheterization and interventional cardiology.

Angiography Team

The angiography team primarily consists of the physician (Interventional Radiologist, Interventional Cardiologist, or Interventional Neuroradiologist), one or more radiologic technologists, and one or more registered nurses. Other specialists, such as an anesthetist or respiratory technologist, may be necessary, depending on the patient's condition. Over the years, angiography rooms have developed from relatively simple diagnostic imaging rooms to large interventional suites, comparable to operating rooms (ORs) with multiple imaging capabilities. These suites can accommodate high-volume, high-risk, high-acuity patients, and require a large number of multi-modality personnel to perform effective procedures.

The radiologic technologist is a key member of the angiography team and must receive dedicated education in either vascular interventional or cardiac interventional radiography. The technologist prepares the angiographic room, assists the physician with angiographic imaging, ensures necessary supplies are readily available, and is often a scrub assistant to the physician. The technologist is also actively involved in patient education, patient positioning, preparing angiographic and medical equipment, maintaining a sterile field during procedures, and ensuring radiation protection and safety measures are followed. The primary role of the nurse is to manage the overall patient care, including sedating and monitoring the patient and documenting the procedure. In some cardiac catheterization facilities, technologists with additional training and certification may also administer procedural medications, monitor the patient, and record patient *hemodynamic data*. Clear communication regarding the roles and responsibilities of staff during a procedure is essential.

FIG. 27.8 Modern single-plane digital angiography suite. Courtesy GE Medical.

Preparation of Angiographic Procedure Room

The angiography suite and every item in it should be scrupulously clean. The room should be fully prepared, with every item needed or likely to be needed on hand before the patient is admitted. Cleanliness and advance preparation are important in procedures that must be carried out under aseptic conditions. The technologist should observe the following guidelines in preparing the room:

- Ensure patient information is entered correctly on acquisition equipment.
- Check the angiographic equipment and all working parts of the equipment and adjust the controls for the procedure being performed.
- Ensure all patient safety equipment is available, including emergency equipment.
- Ensure all appropriate sterile supplies for the procedure are available as needed.

A comprehensive angiography suite contains a considerable amount of equipment other than angiographic imaging equipment (Fig. 27.8). Patient monitoring systems are necessary to record patient electrocardiogram (ECG) data, blood pressure readings, and pulse oximetry pre, peri, and immediately post-procedure. Emergency equipment must be readily available, including resuscitation equipment (e.g., a defibrillator for the heart) and anesthesia apparatus. Other imaging equipment, such as ultrasound, may be required for certain procedures or situations. Interventional devices often require accessory equipment to function. It is important for the technologist to understand when and how each piece of equipment is used and operated in a safe manner.

Radiation Protection

Radiation protection during angiography is extremely important for patients and staff. Angiography procedures, especially interventional procedures, can include extended periods of fluoroscopy and multiple imaging sequences. The technologist is expected to know how to effectively use the imaging equipment to produce quality images while limiting the radiation dose.

There are many radiation safety features inherent in angiography equipment, such as shielding, collimators, low-dose parameters for imaging, low pulse rates for fluoroscopy, and last image hold on monitors designed to limit the radiation dose. Patient gonadal shielding should be available and used when it does not interfere with the procedure. Keeping the IR as close to the patient as possible reduces radiation scatter, and keeping the tube as far from the patient as possible reduces skin dose. All staff must wear lead protective clothing during fluoroscopy studies and maintain as much distance as they can from the tube during exposures. Leadequivalent shielding should be utilized as much as possible to reduce the radiation dose to staff; when possible, staff should leave the examination room when imaging sequences are performed. Angiography suites are designed to allow observation of the patient at all times and provide adequate protection to the physician and staff. These goals are usually accomplished with leaded glass observation windows between the examination room and control room.

Contrast Media

Opaque contrast media containing organic iodine solutions are most commonly used in angiographic studies. Iodine absorbs x-ray energy, resulting in radiopaque images of iodinated filled structures. The iodine in the contrast media is incorporated into water-soluble molecules formed as tri-iodinated benzene rings, meaning there are three iodine atoms on each particle in solution (a 3:1 ratio).

Although usually tolerated, the injection of iodinated contrast media may cause undesirable consequences. The contrast medium is subsequently filtered out of the bloodstream by the kidneys. It causes physiologic cardiovascular side effects, including peripheral vasodilation, hypotension, and renal toxicity. It may also produce nausea and an uncomfortable burning sensation. Most significantly, the injection of iodinated contrast media may invoke allergic reactions. These reactions may be minor (e.g., hives, slight difficulty in breathing) and require minimal treatment, or they may be severe and require immediate medical intervention. Severe reactions are characterized by a state of shock in which the patient exhibits shallow breathing and a high pulse rate and may lose consciousness. The administration of contrast media is one of the significant risks in angiography.

There are two major classes of tri-iodinated contrast: ionic and nonionic. Ionic contrast agents have high solubility, low viscosity, and high osmolar properties. Nonionic contrast agents have high viscosity and low osmolar properties. Nonionic contrast media cause fewer physiologic cardiovascular side effects, less intense sensations, and fewer allergic reactions.

Another type of contrast medium is a dimer, in which the two benzene rings are bonded together as the anion. Ionic contrast media with a dimer result in six iodine atoms for every two particles in solution, which yields the same 3:1 ratio as nonionic contrast media. The ionic dimer has advantages over the ionic monomeric molecule, primarily by reducing osmolality, but it lacks some of the properties of the nonionic molecule. Nonionic contrast media can also be found as a dimer, which yields a ratio of 6:1 because it does not dissociate into two particles, producing an osmolality similar to blood.

All forms of iodinated contrast media are available in various iodine concentrations. The agents of higher concentration are more opaque. Typically, 30% iodine concentrations (300 mg/mL) are used for cerebral and limb arteriography, whereas 35% concentrations (350 mg/mL) are used for visceral angiography. Peripheral venography may be performed with 30% or lower concentrations. Ionic agents of higher concentration and nonionic agents are more viscous and produce greater resistance in the catheter during injection.

Patients with a predisposition to allergic reaction may be pretreated with a regimen of antihistamines and steroids to help prevent anaphylactic reactions to contrast media. Patients who have a history of severe reaction to iodinated contrast media or with compromised renal function may undergo procedures in which CO_2 is used as a contrast agent. CO_2 is less radiopaque than blood and appears as a negative or void in angiographic imaging. CO_2 is approved for use only below the diaphragm because the possibility of emboli is too great near the brain. CO_2 imaging is possible only in the DSA environment because it requires a narrow contrast window and the ability to stack or combine multiple images to provide a single image free of bubbles or fragmented vascular opacification. Specific kVp values should be employed to display the CO_2 optimally in contrast to the rest of the body. Faster imaging rates are also required, usually 10 frames per second, because the CO_2 dissipates quickly within the blood.

Injection Techniques

Angiography primarily involves placing the catheter within a vessel and injecting a contrast media so that the vessel and its major branches are opacified. In a selective injection, the catheter tip is positioned into the orifice of a specific artery so that only that specific vessel is opacified. This technique has the advantage of more densely opacifying the vessel and limiting the superimposition of other vessels.

A contrast medium may be injected by hand with a syringe, but ideally, it should be injected with an automatic injector. The major advantage of automatic injectors is that a specific quantity of contrast media can be injected during a predetermined period. Another advantage to automatic injectors is the ability to operate these remotely from a shielded control room. This reduces radiation exposure to physician and staff while still allowing visualization of images and patient. Automatic injectors have controls to set the injection rate, injection volume, and maximum pressure. Another useful feature, the linear rate rise, sets a time interval during which the injector gradually achieves the set injection rate. This rate rise may prevent a catheter from being dislodged from its target vessel by reducing sudden catheter motion during contrast injection.

Because the opacifying contrast media are carried away from the area of interest by blood flow, the injection and demonstration of opacified vessels usually occur simultaneously. The injector is often electronically connected to the rapid serial radiographic imaging equipment to coordinate the timing between the injector and the onset of imaging.

Angiographic Imaging Techniques

Under fluoroscopic guidance, the intravascular catheter is positioned within the target vessel and a suitable imaging position and field of view are selected. At this point, an image that does not have a large dynamic range should be established; no part of the image should be significantly brighter than the rest of the image. This image can be accomplished by proper positioning, but it often requires the use of compensating filters. Most imaging systems have built-in compensating filters. If compensating filters are not properly placed, image quality is reduced significantly. Automatic controls in the system adjust the exposure factors so that the brightest part of the image is at that level. An unusually bright spot satisfies the automatic controls and causes the rest of the image to lie at significantly reduced levels, where the camera performance is worse. Proper positioning and technique are essential for high-quality imaging.

As the imaging sequence begins, an image that will be used as a subtraction mask (without contrast media) is acquired, digitized, and stored in the digital memory. Images are produced when the x-ray tube is energized, and x-ray exposures are taken in rapid sequence at 65 to 95 kVp and between 5 and 1000 mAs. The dose for each exposure may be the same as that used for a single conventional radiograph. As there is potential for high patient dose in angiography, it is important to utilize all methods available to decrease patient dose while maintaining optimal imaging quality. Images can be acquired at variable rates, from 1 image every 2 to 3 seconds up to 30 images per second.

The *acquisition rate* or imaging rate can also be varied during an imaging sequence or run. Most commonly images are acquired at a faster rate during the passage of contrast media through the arteries, or atrial phase, and then at a reduced rate in the venous phase, during which the blood flow is much slower. This procedure minimizes the radiation exposure to the patient but provides a sufficient number of images to show the clinical information. Each of these digitized images is electronically *subtracted* from the mask, and the subtraction image is amplified (contrast enhanced) and displayed in real time so that the subtraction images appear essentially instantaneously during the imaging procedure. The images are simultaneously stored on a *digital imaging system.*

Some DSA equipment allows the table or the image receptor, such as a flat panel detector system, to be moved during acquisition. The movement is permitted to "follow" the flow of contrast media as it passes through the arteries. Sometimes called the "bolus chase" or "DSA stepping" method, this technique is particularly useful for evaluating the arteries in the pelvis and lower limb. Previously, several separate imaging sequences would be performed with the image receptor positioned in a different location for each sequence, requiring an injection of contrast media for each sequence. The bolus chase method requires only one injection of contrast media, and the imaging sequence follows (or "chases") the contrast media as it flows down the limb. The imaging sequence may be preceded or followed by a duplicate sequence without contrast media injection to enable subtraction. Occasionally, this method may need to be repeated because the contrast media in one leg may flow faster than in the other.

Misregistration, a major problem in DSA, occurs when the mask and the images displaying the vessels filled with contrast media do not exactly coincide. Misregistration is sometimes caused by voluntary movements of the patient, but it is also caused by involuntary movements such as bowel peristalsis or heart contractions. Preparing the patient by describing the sensations associated with injection of contrast media and the importance of holding still can help eliminate voluntary movements. It is also important to have the patient suspend respiration during the imaging sequence.

During the imaging procedure, the subtraction images appear on the display monitor (Fig. 27.9). Often a preliminary diagnosis can be made at this point. Some *postprocessing* is performed after each exposure sequence to improve visualization of the anatomy of interest or to correct misregistration. The processed images are available on the computer monitor for review by the radiologist. As more advanced imaging software becomes available, more involved postprocessing, including quantitative analysis, can be performed before the end of the procedure, allowing for accurate peri-procedure diagnosis and treatment planning.

In most institutions, DSA images are stored in a *picture archive and communication system (PACS)*. These digital images can be transmitted via a computer network throughout the hospital or to remote locations for consultation with an expert or referring physician.

Angiographic Imaging Equipment

Rapid serial imaging used in angiography requires x-ray tubes to have high heat load ratings and multiple focal-spot sizes. Large focal-spot sizes of 0.8 to 1.2 mm are most capable of withstanding a high heat load and are used for abdominal and thoracic angiography. Small focal-spot sizes of 0.4 to 0.6 mm provide more detailed imaging and are used for cerebral and peripheral angiography. Magnification studies require focal spot sizes of 0.1 to 0.3 mm. X-ray tubes may have to be specialized to satisfy these extreme demands. Rapid serial imaging also necessitates radiographic generators with high-power output. Because short exposure times are needed to compensate for all patient motion, the generators must be capable of producing high-milliampere output. Imaging systems may be used either singly or in combination at right angles to obtain simultaneous frontal and lateral images of the vascular system under investigation with one injection of contrast media. This arrangement of units is called a *biplane imaging system* (Fig. 27.10). These biplane imaging systems are considered optimal for carotid, cerebral, and pediatric angiographic procedures.

FIG. 27.9 DSA image of common carotid artery showing stenosis *(arrow)* of internal carotid artery.

FIG. 27.10 Modern biplane digital angiography suite. Courtesy GE Medical.

Magnification

Magnification occurs intentionally and unintentionally in angiographic imaging sequences. Different magnification levels can be utilized by employing different focusing filters inside the image receptor. Varying the distance of the image receptor can increase this type of magnification. Intentional use of magnification can result in a significant increase in resolution of fine-vessel recorded detail. Fractional focal-spot tubes of 0.3 mm or less are necessary for direct radiographic magnification techniques. The selection of a fractional focal spot necessitates the use of low milliamperage. Short exposure time (1 to 200 ms) is necessary because of the size and load capacity of the smaller focal spot.

The formula for manual magnification is as follows:

$$M = \frac{SID}{SOD} \; or \; \frac{SID}{SID - OID}$$

The SID is the *source-to-image-receptor distance*, the SOD is the *source-to-object distance*, and the OID is the *object-to-image-receptor distance.* For a 2:1 magnification study using an SID of 40 inches (101 cm), the focal spot and the image receptor are positioned 20 inches (50 cm) from the area of interest. A 3:1 magnification study using a 40-inch (101-cm) SID is accomplished by placing the focal spot 13 inches (33 cm) from the area of interest and the image receptor 27 inches (68 cm) from the area of interest.

Unintentional magnification occurs when the area of interest cannot be placed in direct contact with the image receptor. The magnification that occurs as a result of these circumstances is frequently 20% to 25%. A 25% magnification occurs when a vessel within the body is 8 inches (20 cm) from the image receptor—OID of 8 inches (20 cm)—and the SID is 40 inches (101 cm).

Angiographic images do not represent vessels at their actual size, and this must be taken into account when direct measurements are made from angiographic images. Increasing SID while maintaining OID can reduce unintentional magnification. When any measurement is necessary, the DSA postprocessing quantitative analysis programs require the radiologist to calibrate the system by measuring an object in the imaging field of known value. Some systems calibrate by using the known position of the table, the image receptor, and x-ray tube and the tube angulation.

Three-Dimensional Intraarterial Angiography

To acquire a three-dimensional model of a vascular structure, a C-arm is rotated around the region of interest (ROI) at speeds up to 60 degrees per second. The C-arm makes a preliminary sweep while mask images are acquired. Images are acquired at 7.5 to 30 frames per second. The C-arm returns to its initial position, and a second sweep is initiated. Just before the second sweep, a contrast medium is injected to opacify the vascular anatomy. The second sweep matches mask images from the first sweep, producing a rotational subtracted DSA sequence. The DSA sequence is sent to a three-dimensional rendering computer where a three-dimensional model is constructed. This model provides an image that can be manipulated and analyzed. It has proved to be a valuable tool for interventional approaches and for evaluation before surgery. Various methods of vessel analysis are available with three-dimensional models. Aneurysm volume calculation, interior wall analysis, bone fusion, and device display all are possible (Figs. 27.11 and 27.12).

Angiographic Procedures

Angiographic imaging systems place the image receptor above the tabletop and the x-ray tube below. Generally, for angiographic procedures, patients lie supine, with the central ray located below entering the posterior of the patient first, then exiting the anterior of the patient on its course to the image receptor. The position of the central ray technically results in PA projections; however, commonly used projections and tube angulations in angiography are described as AP projections. For example, a 45-degree left anterior oblique (LAO) is obtained by rotating the image receptor 45 degrees toward the patient's left; a 30-degree cranial projection is obtained by rotating the image receptor 30 degrees toward the patient's head. Fluoroscopy is often used to determine the final position and angulation of the central ray required to achieve the desired image.

Patient Care

Before the angiographic procedure, it is necessary to explain the procedural process, risks, benefits, and alternative options to the patient and/or their family. Written informed consent is obtained to document that the patient gives their permission to proceed with the procedure. Informed consent is a legal document required for most angiographic procedures. Potential risks or complications of catheter directed angiography include vasovagal reaction; stroke; heart attack; death; infection; bleeding at the puncture site; nerve, blood vessel, or tissue damage; and allergic reaction to the contrast media. Bleeding at the puncture site is usually easily controlled with pressure on the site. Blood vessel and tissue damage may require a surgical procedure. A vasovagal reaction is characterized by sweating and nausea caused by a decrease in blood pressure. The patient's legs should be elevated, and intravenous (IV) fluids may be administered to help restore blood pressure. Minor allergic reactions to iodinated contrast media, such as hives and congestion, are usually controlled with medications and may not require treatment. Severe allergic reactions may result in shock, which is characterized by shallow breathing, high pulse rate, and possibly loss of consciousness. Angiography is performed only if the benefits of the examination outweigh the risks.

FIG. 27.11 Three-dimensional angiography provides for reconstruction of the skeletal vessels and the anatomy.

Patients are usually restricted to clear liquid intake and routine medications before undergoing angiography. Adequate hydration from liquid intake may minimize kidney damage caused by iodinated contrast media. Solid food intake is restricted to reduce the risk of aspiration related to vomiting.

Contraindications to angiography are determined by physicians and include previous severe allergic reaction to iodinated contrast media, severely impaired renal function, impaired blood clotting factors, and inability to undergo a surgical procedure or general anesthesia.

Risks of general anesthesia are greater than the risks associated with most angiographic procedures; therefore, conscious sedation is given, when applicable, to minimize patient discomfort and reduce anxiety.

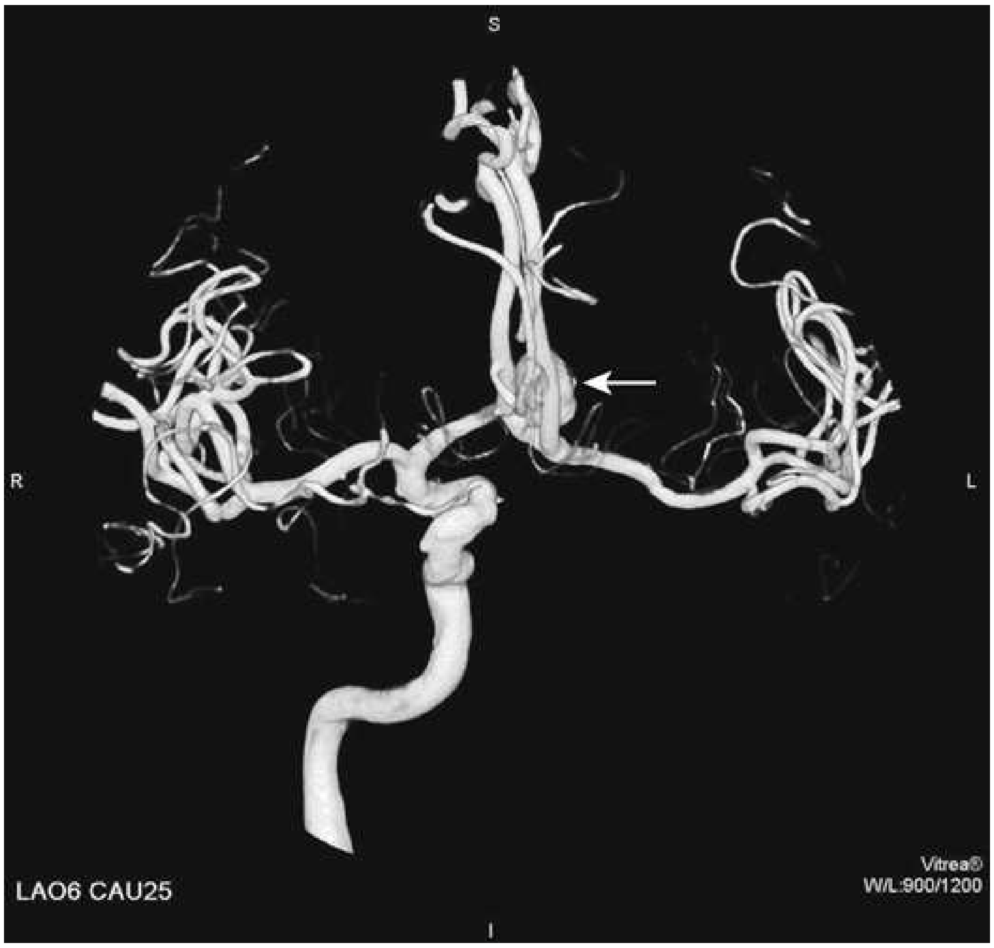


FIG. 27.12 Three-dimensional reconstruction of left internal carotid artery. Note the anterior communicating artery aneurysm *(arrow)*.

Pre-Procedure

A pre-procedure checklist is a useful tool to maximize patient safety during the procedure. A checklist may include the following:

- The planned procedure
- Indications for the procedure
- Patient history and physical examination (H&P) to include: medications, allergies, previous surgeries, sedation risks, possible pregnancy
- Laboratory blood work (within appropriate date parameters): CBC, renal profile, PT/INR
- Verification of informed consent
- The preferred vascular access site
- Expected discharge arrangements

Prior to the procedure, patient vital signs (i.e., ECG, blood pressure monitoring, *pulse oximetry*) are recorded. The pre-agreed site for vascular access is visually assessed and, for arteriography, arterial pulses distal to the arterial access site are assessed. The strength of distal pulses is documented prior to the procedure and will be assessed again post-procedure. Numerous sites can be used for vascular access and catheter introduction. The specific sites vary according to procedure, the age and body habitus of the patient, the preference of the physician, and vascular disease. The most frequent sites used for arteriography are the femoral and radial arteries. For venography and venous interventions, the brachial, axillary, subclavian, jugular, femoral, or popliteal veins may be chosen.

Peri-procedure

Infection complications from percutaneous vascular access are rare; however, best practices in sterile technique are essential. The chosen vascular access site is exposed, shaved when necessary, and cleaned with an antimicrobial solution. Chlorhexidine-based skin preparations are most commonly used. The scrub assistant, or physician, will drape and adhere sterile coverings around the exposed vascular access site, ensuring an adequate sterile field will be maintained throughout the procedure. The following considerations are taken when preparing the skin site and surrounding sterile field: providing adequate space to safely prepare, handle, and store opened sterile supplies during the procedure, such as access needles, guidewires, catheters, and sterile solutions; having the ability to move angiographic equipment into multiple angles around the patient without disrupting the sterile field; having the ability to incorporate additional imaging or interventional equipment into the sterile field; and knowing the location of patient monitoring devices, cables, and IV and fluid lines that are covered by sterile drapes.

Time out

Immediately before vascular access is obtained, a “time out” procedure is performed. This is a universal protocol in which all procedural team members stop what they are doing and collectively verify that the patient in the room is the correct patient for the correct procedure on the correct body part.

Vascular Access And Catheterization

Historically the common femoral artery was the most commonly used arterial access site for angiography because it was associated with the fewest risks. The radial artery is quickly becoming the preferred access site, especially during cardiac catheterization, as the radial artery is superficial and more accessible than the femoral artery the skeletal which allows for more control of bleeding. Accessing the radial artery also results in a more comfortable post-catherization recovery for the patient.

Catheterization for filling vessels with contrast media is preferred to needle injection of the media. The advantages of catheterization are as follows:

- The risk of *extravasation* is reduced.
- Most body parts can be reached for selective injection.
- The patient can be positioned as needed.
- The catheter can be safely left in the body while radiographs are being examined.

In 1952, shortly after the development of a flexible thin-walled catheter, Seldinger[1] announced a percutaneous method of catheter introduction. Seldinger described the method as puncture of both walls of the vessel (the anterior and posterior walls). The steps of the Seldinger technique are described in Fig. 27.13. The modified Seldinger technique allows for puncture of the anterior wall only and has become the preferred method. With this percutaneous technique, the arteriotomy or venotomy is no larger than the external diameter of the catheter, or vascular sheath used, minimizing bleeding. Patients can usually resume normal activity within 24 hours after the examination. Most outpatient angiographic studies can be performed in the morning, allowing the patient to be discharged later that same day. The risk of infection is less than in surgical procedures because the vessel and tissues are not exposed.

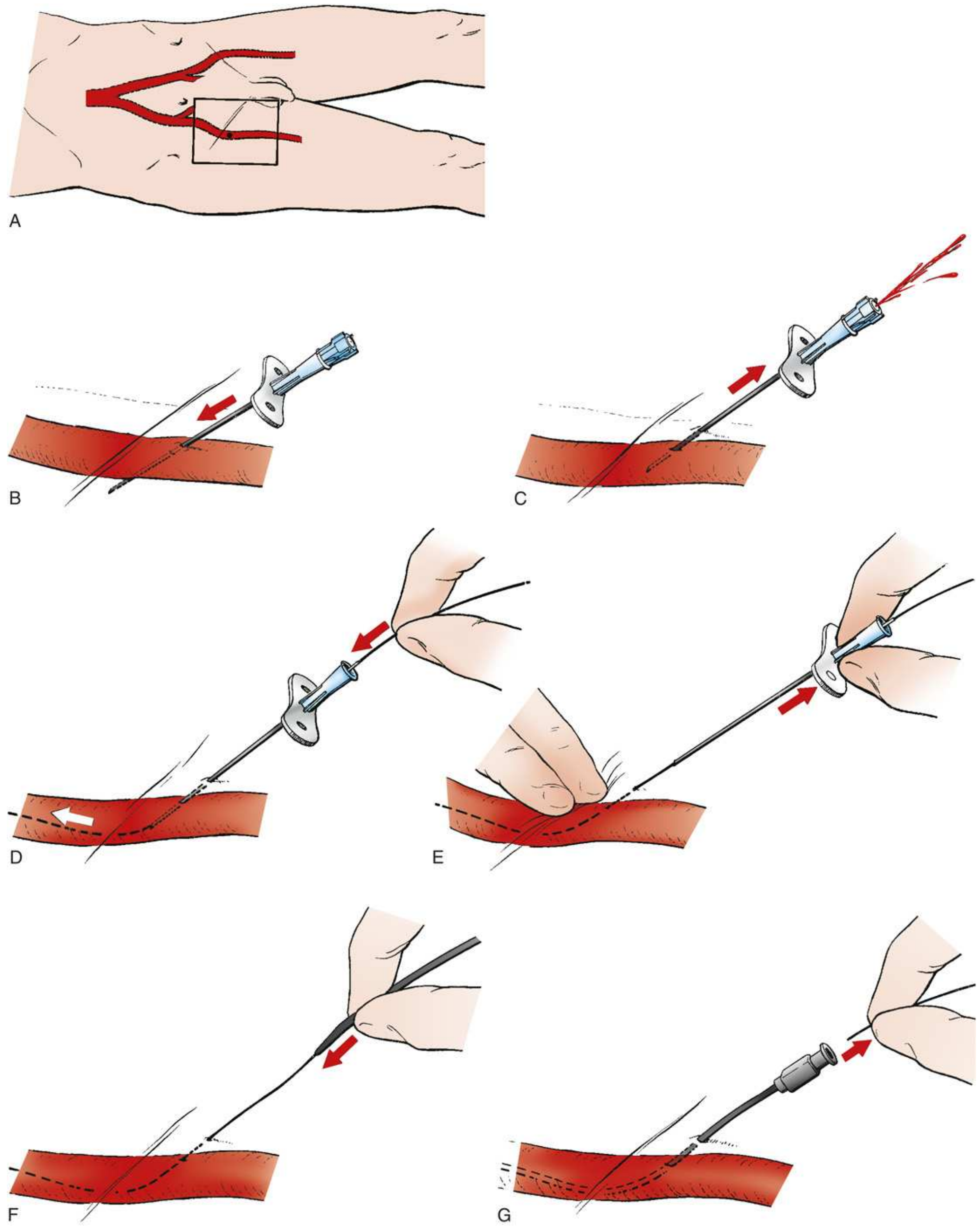


FIG. 27.13 Seldinger technique. (A) The ideal puncture occurs in the femoral artery just below the inguinal ligament. (B) Beveled compound needle containing an inner cannula pierces through the artery. (C) Needle is withdrawn slowly until there is blood flow. (Modified Seldinger would puncture only here, on the anterior wall.) (D) The needle's inner cannula is removed, and a flexible guidewire is inserted. (E) Needle is removed; pressure fixes the wire and reduces hemorrhage. (F) Catheter is slipped over the wire and into the artery. (G) Guidewire is removed, leaving the catheter in the artery.

(A) A patient is in supine position. The femoral artery is highlighted and it is punctured with a needle. (B) A beveled compound needle containing an inner cannula pierces through the artery. It is indicated by an arrow. (C) The needle is withdrawn slowly and blood splatters through the hole on top. It is indicated by an arrow. (D) The needle's inner cannula is removed, and a hand is inserting a flexible guidewire. (E) A hand is removing the needle and the pressure fixes the wire and reduces hemorrhage. It is indicated by an arrow. (F) A hand is slipping the catheter over the wire and into the artery. It is indicated by an arrow. (G) A hand is removing the guidewire, leaving the catheter in the artery. It is indicated by an arrow.

After the needle is introduced into the appropriate vessel, a guidewire is threaded through the needle and into the vascular system. The needle is removed over the guidewire and a catheter is then threaded onto and over the guidewire. Under fluoroscopic guidance, the guidewire and catheter are maneuvered to the desired location inside the patient by pushing, pulling, and turning the end of the catheter outside the patient. The guidewire helps to stabilize, manipulate, and guide the catheter while reducing any damage to the lumen of the vessel. When the wire is removed from the catheter, the catheter is aspirated to ensure blood return and then infused, or flushed, with sterile solution, most commonly heparinized saline, to help prevent clot formation. If multiple catheter exchanges are expected, a vascular sheath may be used. Assisting the physician in the catheterization process is often the responsibility of the technologist.

Vascular needles

Numerous vascular access needles are available for percutaneous procedures. Needle size is based on the external diameter of the needle and is assigned a gauge size. To allow for appropriate guidewire matching, the internal diameter of the needle must be known. Vascular access needles come in different types, sizes, and lengths. The most commonly used access needle for adult angiographic, or cardiovascular procedures is an 18-

gauge needle that is 2.75 inches (7 cm) long. This particular needle is compatible with a 0.035-inch guidewire, which is the most frequently used guidewire in cardiovascular procedures. Appropriate needle size is predicated on the type or size of guidewire needed, the size of the patient, and the vessel to be accessed. To decrease the chances of vascular complications, the smallest gauge needle that meets the above-mentioned criteria is used for vascular access. Access needles for pediatric patients come in smaller gauge sizes with shorter lengths (Fig. 27.14).

Guidewires

Guidewires are used in angiography and other special procedures as a platform over which the catheter is advanced. To decrease the possibilities of complications, the guidewire should be advanced into the vasculature ahead of the catheter. After the guidewire is positioned in the area of interest, the position of the guidewire is fixed, and the catheter is advanced until it meets the tip of the guidewire. Similar to needles, guidewires come in various sizes, shapes, and lengths, and care must be taken to match the proper guidewire to the selected access needle and catheter. The diameter of the guidewire is measured in inches. Common diameters are between 0.010 and 0.038 inches. Guidewire lengths typically range from 40 cm to 300 cm.

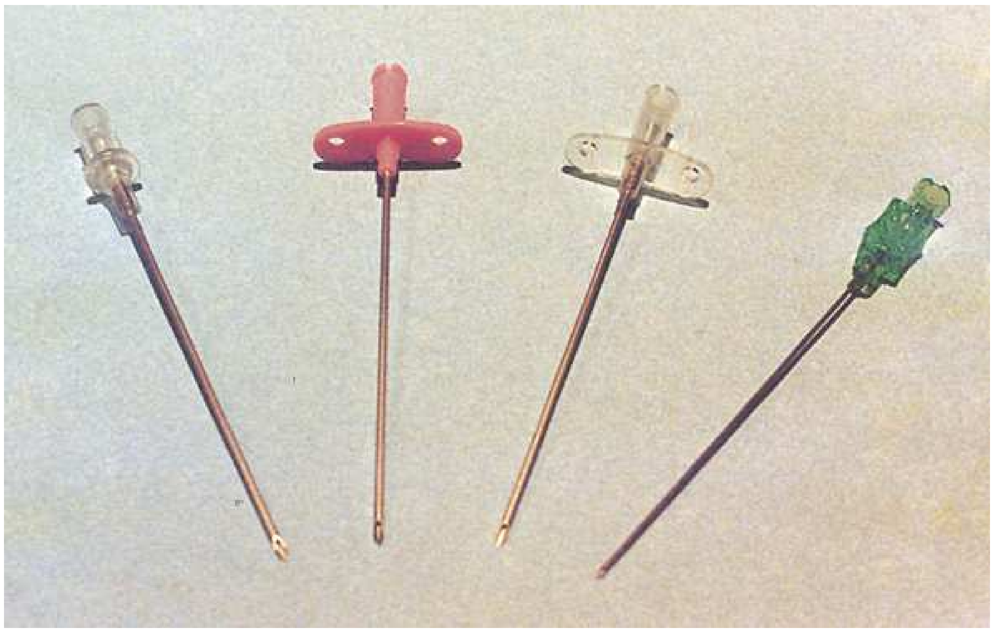


FIG. 27.14 Various needles used during catheterization.

Four needles with different caps are placed next to each other. The one on the left has a transparent cap. The one next to it has a pink cap. The other one also has a transparent cap and the last one has a green cap.

Most guidewires are constructed of stainless steel, with a core or mandrel encased circumferentially within a tightly wound spiral outer core of spring wire. The mandrel gives the guidewire its stiffness and body. The length of the mandrel within the wire determines the flexibility of the wire. The shorter the mandrel, the more flexible the wire, and the more likely it is to traverse tortuous anatomy. A safety ribbon is built into the tip of the guidewire to prevent wire dislodgment in case the wire fractures. Many stainless-steel guidewires are coated with polytef (Teflon) to provide lubricity and to decrease the friction between the catheter and wire. Similarly, the Teflon coating is thought to help decrease the thrombogenicity of the guidewire.

Plastic alloy guidewires consist of a hydrophilic plastic polymer coating. These wires provide a smooth outer coating, with a pliable tip, and exhibit a high degree of torque or maneuverability (Fig. 27.15).

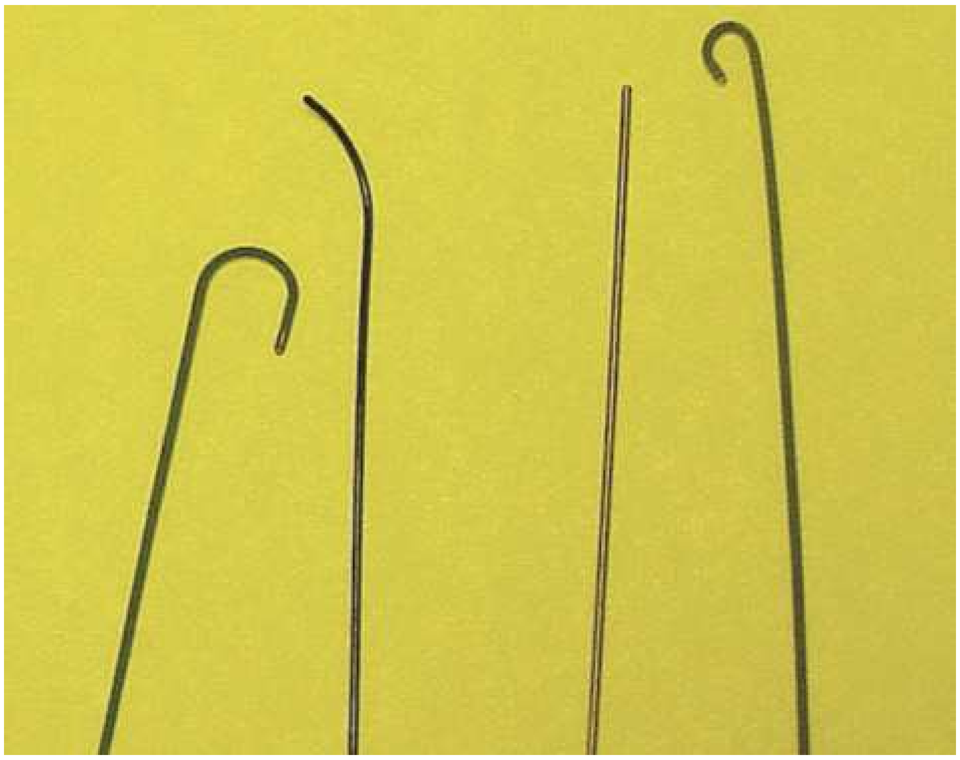


FIG. 27.15 A guidewire allows the user a high degree of torque and maneuverability. Various lengths and shaped tips are available.

Four guide wires of various lengths and shapes are placed next to each other. The guide wire on the ends has curved ends. One of the guide wire in the middle is slightly bent and the other one has a pointy tip.

Micropuncture access sets

Micropuncture access sets allow vascular access using a smaller gauge needle, typically 21-gauge that accepts a 0.018-inch guidewire. Once the 0.018 guidewire is in the vessel, a coaxial short access catheter with a removable inner dilator is advanced over the 0.018 guidewire. The wire and inner dilator are removed, leaving the access catheter in the vessel. The access catheter has a lumen that will accept a 0.038 guidewire (Fig. 27.16).

FIG. 27.16 Micro puncture access set.From left: 21-gauge needle; 0.018 guidewire; 5-Fr coaxial short access catheter with 3-Fr removable inner dilator; 5-Fr access catheter with 3-Fr inner dilator remove (accepts 0.038 guidewire; #-French inner dilator). From Kaufman JA: Fundamentals of angiography. In Kaufman JA, Lee MJ, editors: *Vascular and interventional radiology: the requisites*, ed 2, Philadelphia, 2014, Elsevier.

Four micro puncture access set guide wires and needles are next to each other. From left: 21-gauge needle, 0.018 guidewire, 5-F r coaxial short access catheter with 3-F r removable inner dilator, 5-F r access catheter with 3-F r inner dilator.

Angiographic catheters

Angiographic catheters are manufactured in various forms, each with a particular advantage in size, shape, maneuverability or torque, and maximum injection rate (Fig. 27.17). Sizes of catheter are categorized by diameter and length. Catheter diameter is measured in French (Fr) sizes, with 1 Fr being equivalent to 0.33 mm or 0.013 inches. Common angiographic catheters range in size from 3 Fr (0.039 inch) to 8 Fr (0.105 inch). For diagnostic catheters, French sizes refer to the outer diameter of the catheter. Not all catheters of the same French size have the same inner diameter, or lumen size. The lumen size is usually printed on the catheter packaging. It is important to know the lumen size of a catheter to ensure correct fit for guidewires, micro-catheters, and interventional devices. Commonly used catheters vary in length from 40 cm to 100 cm, although specialized micro-catheters can be as long as 150 cm.

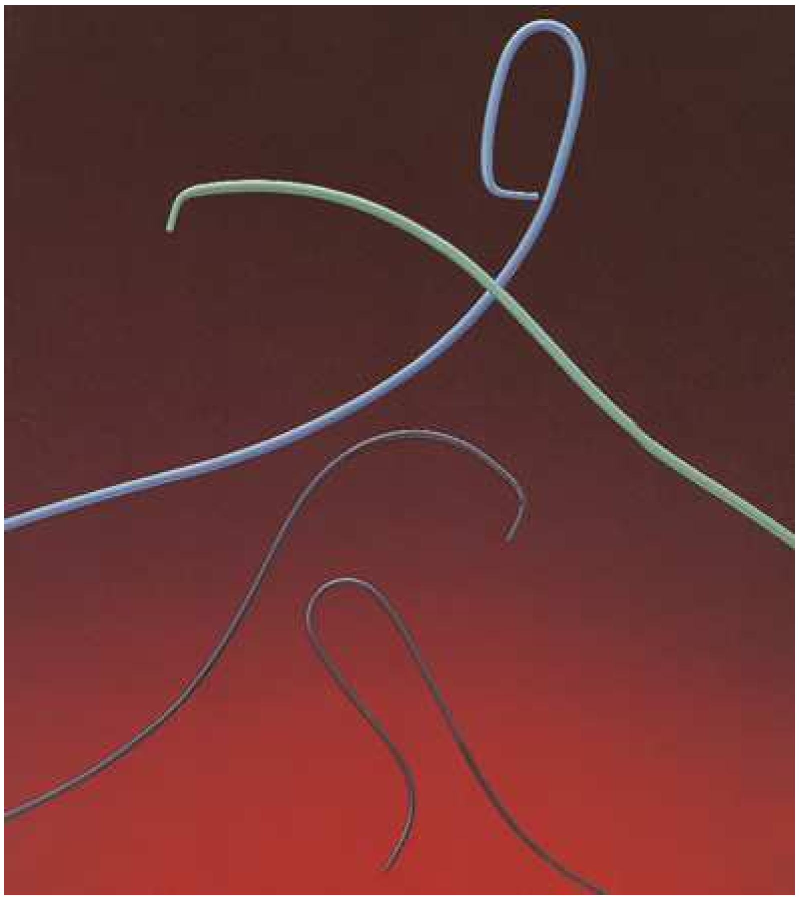


FIG. 27.17 Selected catheter shapes used for angiography. Courtesy Cook, Inc., Bloomington, IN.

Catheters are made of pliable plastic to straighten for insertion over the guidewire. The catheters normally resume their original shape after the guidewire is withdrawn. Some catheters have multiple side holes to facilitate high-volume and high-pressure injection rates of contrast media, which are optimal for angiographic imaging in large vascular structures, such as in the aorta. These are commonly known as "flush" catheters. An example of a flush catheter is a Pigtail catheter, which has a tightly curled catheter tip with multiple side holes allowing a large bolus of contrast media to be injected very quickly and safely. Maximum injection pressure rates and flow rates are listed on catheter packaging to prevent catheter damage and possible harm to the patient during automatic pressure injections. Selective catheters have only an end hole, allowing contrast media to be injected in one direction only. These "end-hole" catheters are available in many different predetermined designs, or shapes, that help physicians maneuver the catheter tip into the origin of a particular vessel for selective contrast media injections.

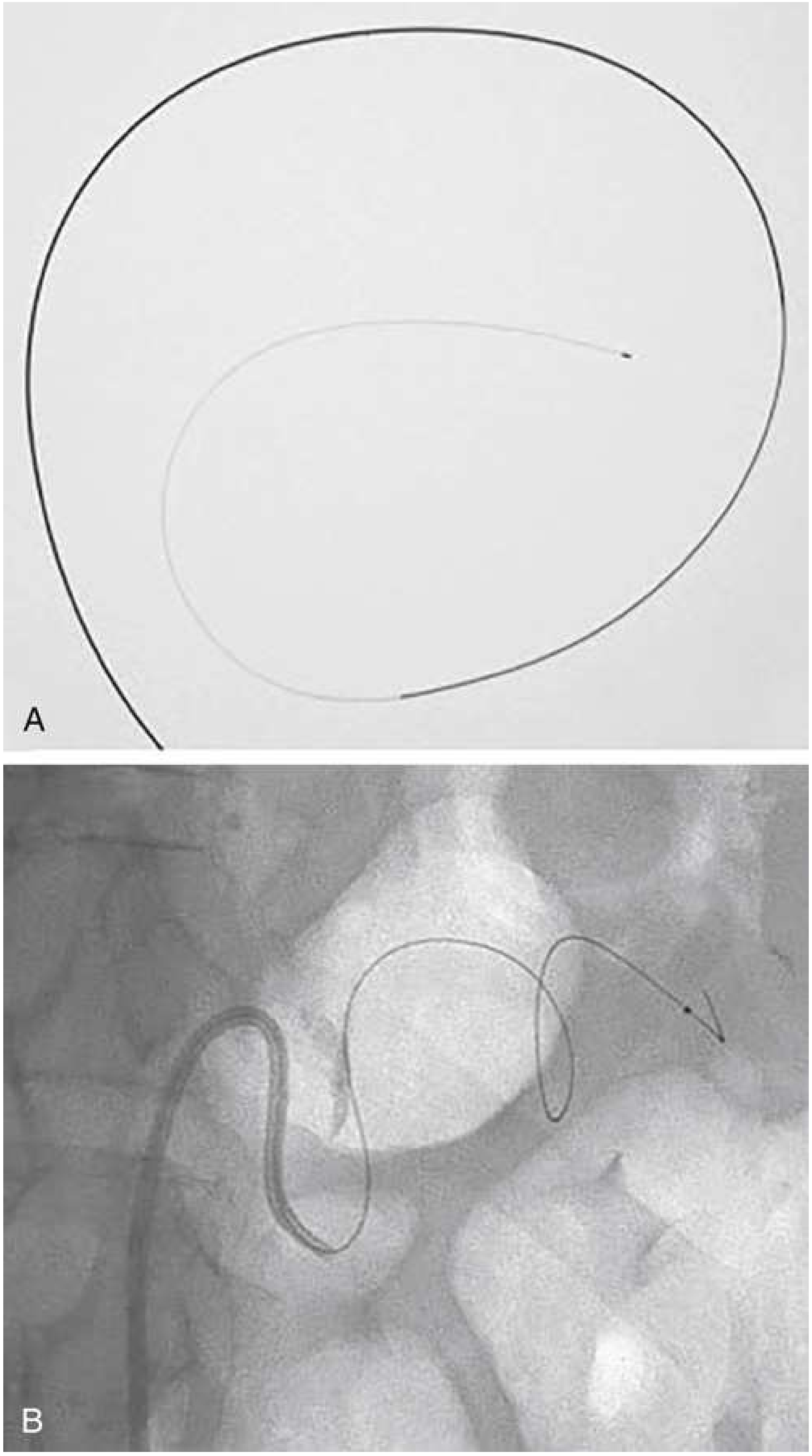


FIG. 27.18 (A) Typical microcatheter that tapers from 3-Fr to 2.3-Fr with radiopaque marker at tip. (B) Microcatheter is advanced over a 0.016-inch guidewire into distal splenic artery through a larger diagnostic selective catheter. From Kaufman JA: Fundamentals of angiography. In Kaufman JA, Lee MJ, editors: *Vascular and interventional radiology*: *the requisites*, ed 2, Philadelphia, 2014, Elsevier.

Micro-catheters and micro-guidewires are often used for distal, or super-selective, catheterization. These micro-catheter systems are usually threaded through a diagnostic catheter, or a specialized guiding catheter, coaxially, for additional support during super-selective procedures. (Fig. 27.18).

Introducer sheaths

Introducer sheaths are frequently used in angiographic procedures when multiple catheter exchanges are expected, or to assist with vascular closure at the end of the procedure. When the sheath has been placed, controlled access of the vasculature is ensured while reducing vessel trauma by limiting numerous catheter passages through the vessel wall.

Introducer sheaths are short catheters consisting of a slotted, rubberized back-bleed valve and a sidearm extension port. The back-bleed valve prevents the loss of blood volume during catheter exchanges or guidewire manipulations. The sidearm extension port may be used to infuse medications, monitor blood pressure, or inject contrast media to visualize the vessel or adjacent vessels.

Similar to angiographic catheters, introducer sheaths come in various French sizes and lengths. Unlike catheters, however, introducer sheaths are identified according to the French size catheter they can accommodate, e.g. a 5 Fr introducer sheath will accept a 5 Fr catheter. To accomplish this, the outer diameter of an introducer sheath is 1.5 to 2 Fr sizes larger than the catheter it can accept; hence a 5 Fr introducer has an outer diameter of nearly 7 Fr. Typically, introducer sheaths range in length from 10 to 90 cm (4 to 35 inches) (Fig. 27.19).

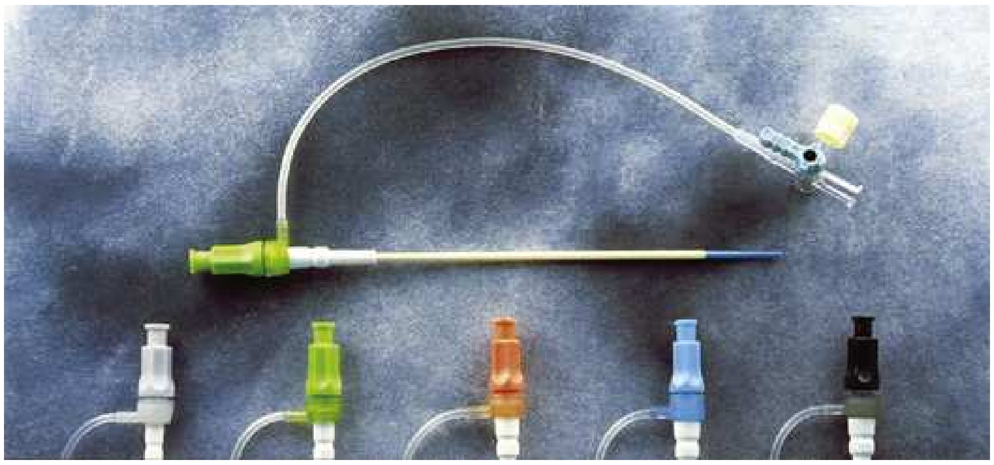


FIG. 27.19 Various types of introducer sheaths used during catheterization.

Post-Procedure

When the examination is complete, the catheter and sheath are removed. Pressure is applied to the site until complete hemostasis is achieved, while maintaining adequate blood flow through the vessel. Pressure can be applied manually by staff, by external pressure devices, or with percutaneous vascular closure devices. These percutaneous devices, considered internal closure devices, were designed for closing arteriotomies in the femoral artery after using sheath sizes between 4 and 8 Fr (Fig. 27.20). These devices work either by placing a collagen plug, a thrombin-collagen slurry, or a sealant gel between the artery and the skin, or by closing the arteriotomy with suture or a small surgical clip. Percutaneous vascular closure devices reduce time to achieve hemostasis and allow patients to ambulate sooner than with manual pressure and external pressure devices.

After procedures using common femoral arterial access, the patient remains supine and is placed on complete bed rest for 2 to 6 hours to decrease the chances for the development of bleeding or *hematoma* at the access site. Manual pressure and external pressure devices are used to obtain hemostasis for radial arteriotomies. Post-procedure recovery from radial arterial access is considered more comfortable for patients; only the affected arm is immobilized, allowing the patient to sit upright immediately postprocedure and often allowing them to ambulate sooner than with femoral arterial access. Obtaining hemostasis after venous access is achieved with manual pressure at the site.

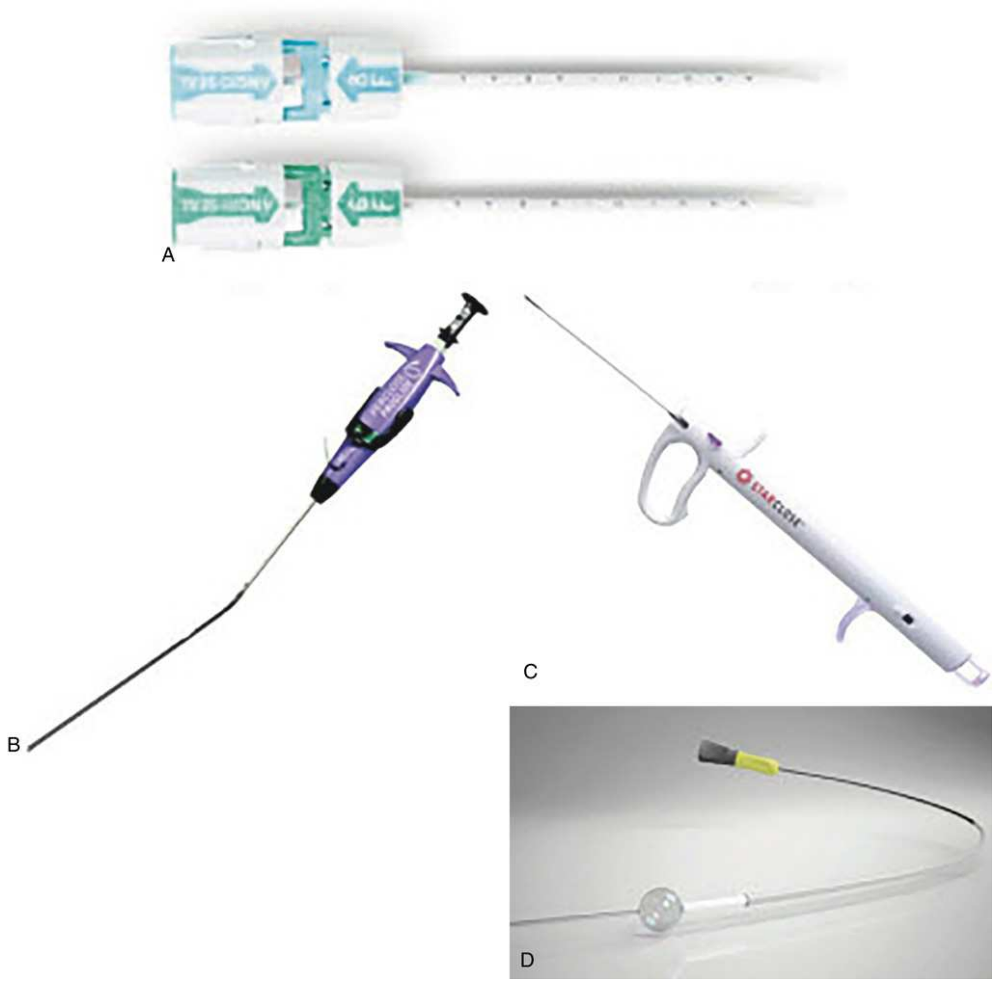


FIG. 27.20 Vascular closure devices. (A) Angio-Seal; (B) Perclose; (C) StarClose; (D) Mynx. A, Courtesy St. Jude Medical, Inc., St. Paul, MN; B and C, courtesy Abbott Vascular, Redwood City, CA; D, courtesy AccessClosure, Inc., Santa Clara, CA.

Angiography Procedures

Aortography

Visualization of the aorta is achieved by placing a multihole, or flush, catheter into the aorta at the desired level, using the modified Seldinger technique. *Aortography* is usually performed with the patient in the supine position for simultaneous frontal and lateral imaging, with the central ray perpendicular to the imaging system.

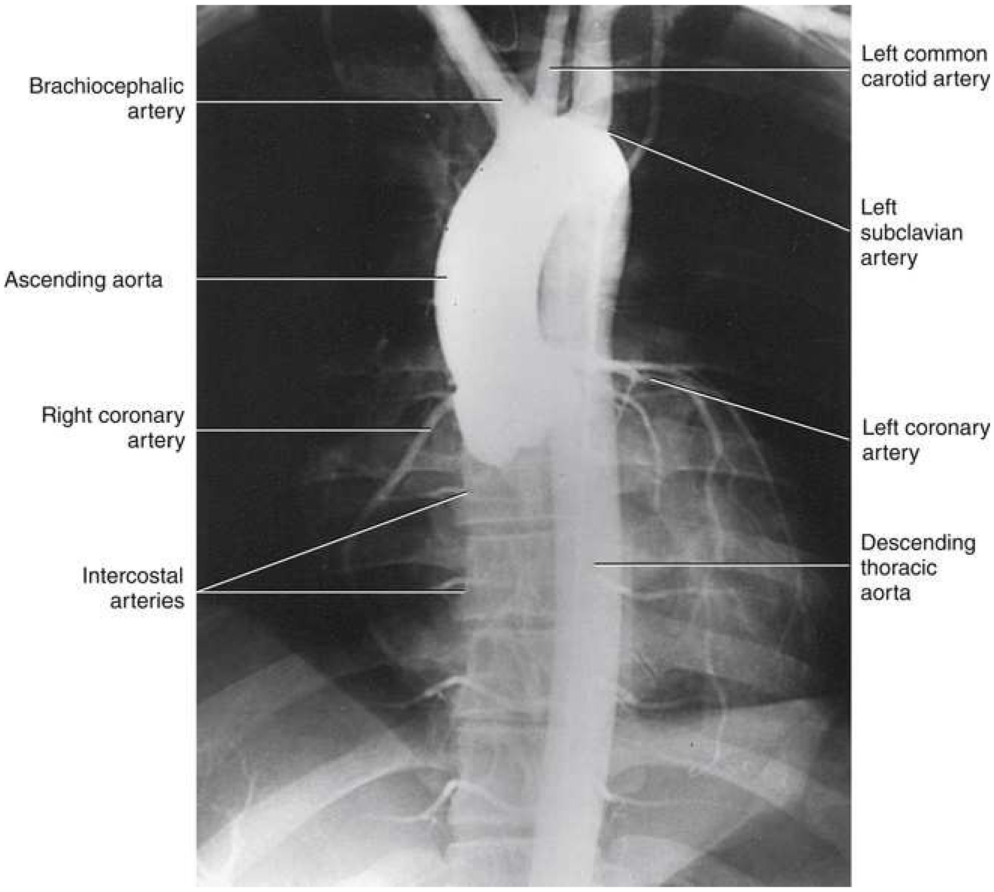


FIG. 27.21 AP thoracic aorta that also shows right and left coronary arteries.

A thoracic aortography shows the thoracic aorta, and left and right coronary arteries. The ascending aorta is radiopaque. The parts labeled are marked in clockwise direction as follows: intercostal arteries, right coronary artery, ascending aorta, brachiocephalic artery, left common carotid artery, left subclavian artery, left coronary artery, descending thoracic aorta.

Thoracic Aortography

Catheter-directed thoracic aortography is performed to evaluate congenital pathology, to accurately measure and assess aortic anatomy prior to endovascular intervention, and to assess post interventional or postsurgical conditions.

When performing this exam, the technologist does the following:

- For best results, increase lateral SID, so that magnification is reduced.
- A 45-degree LAO projection (45-degree right posterior oblique RPO) often produces an adequate study of the aorta.
- For lateral projections, move the patient's arms superiorly so that they do not appear in the field of view.
- For all projections, direct the perpendicular central ray to the center of the chest at the level of T7. The entire thoracic aorta should be visualized, including the proximal brachiocephalic, carotid, and subclavian vessels.
- Contrast media injection rates range from 15 to 25 mL/s for a total volume of 30 to 50 mL.
- Make the exposure at the end of suspended inspiration (Fig. 27.21).

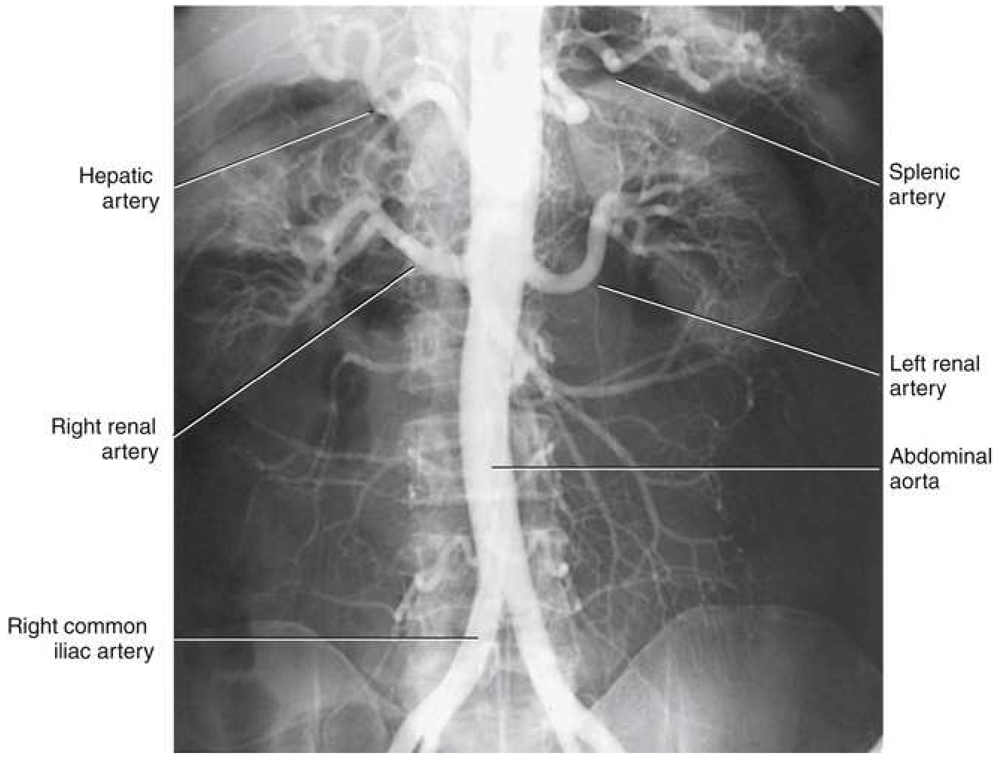


FIG. 27.22 AP abdominal aorta.

An abdominal aortography shows the abdominal aorta. The top of the aorta is radiopaque which splits into two at the bottom. The parts labeled are marked in clockwise direction as follows: right common iliac artery, right renal artery, hepatic artery, splenic artery, left renal artery, and abdominal aorta.

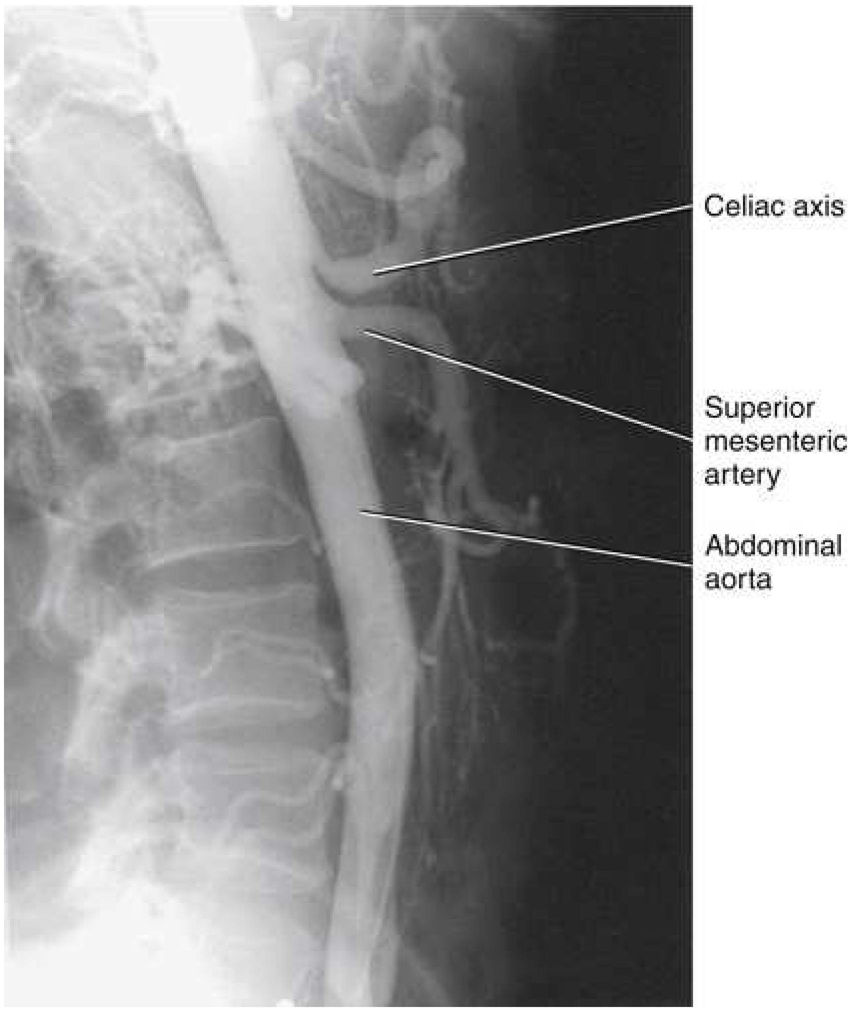


FIG. 27.23 Lateral abdominal aorta.

An abdominal aortography shows the lateral abdominal aorta. The top of the aorta is radiopaque. The parts labeled on the right side are as follows: celiac axis, superior mesenteric artery, abdominal aorta.

Abdominal Aortography

Abdominal aortography may be performed to accurately measure and assess aortic anatomy and pathology immediately prior to endovascular intervention. It may also be performed to assess post-interventional and post-surgical conditions.

- Direct the perpendicular central ray at the level of L2 so that the aorta is visualized from the diaphragm to the aortic bifurcation.
- The AP projection shows best the renal artery origins, the aortic bifurcation, and the course and general condition of all abdominal visceral branches.
- The lateral projection best shows the origins of the celiac and superior mesenteric arteries because these vessels arise from the anterior abdominal aorta.
- For the lateral projection, move the patient's arms superiorly so that arms are out of the image field.
- Usually, collimate the field in the anterior aspect of the lateral projection. Filters may be necessary to reduce the image contrast in FOV. Superficial bowel gas in the anterior aspect and the lumbar spine in the posterior aspect are both present in the FOV.
- Contrast media injection rates range from 15 to 20 mL/s for a total volume of 25 to 40 mL.
- Make the exposure at the end of suspended expiration (Figs. 27.22 and 27.23).

Visceral Arteriography

Abdominal visceral arteriographic studies (Fig. 27.24) are usually performed to visualize tumor vascularity; to accurately identify the extent of atherosclerotic disease, thrombosis, or occlusion; and to locate the site of bleeding. An appropriately shaped catheter is introduced and advanced into the orifice of the desired artery.

- Position the patient in the supine position.
- Direct the central ray perpendicular to the image receptor.
- If necessary, use oblique projections to improve visualization or avoid superimposition of vessels.
- For all abdominal visceral studies, obtain angiograms during suspended expiration.

Selective abdominal visceral arteriograms are described in the following sections.

Celiac arteriogram

The celiac artery normally arises from the aorta at the level of T12 and carries blood to the stomach and proximal duodenum, liver, spleen, and pancreas.

- For the angiographic examination, center the patient to the image receptor.
- Direct the central ray to L1 (Fig. 27.25).
- Contrast media injection rates range from 5 to 10 mL/s for a total volume of 20 to 35 mL.
- To visualize the portal venous system, it is necessary to extend the imaging sequence.

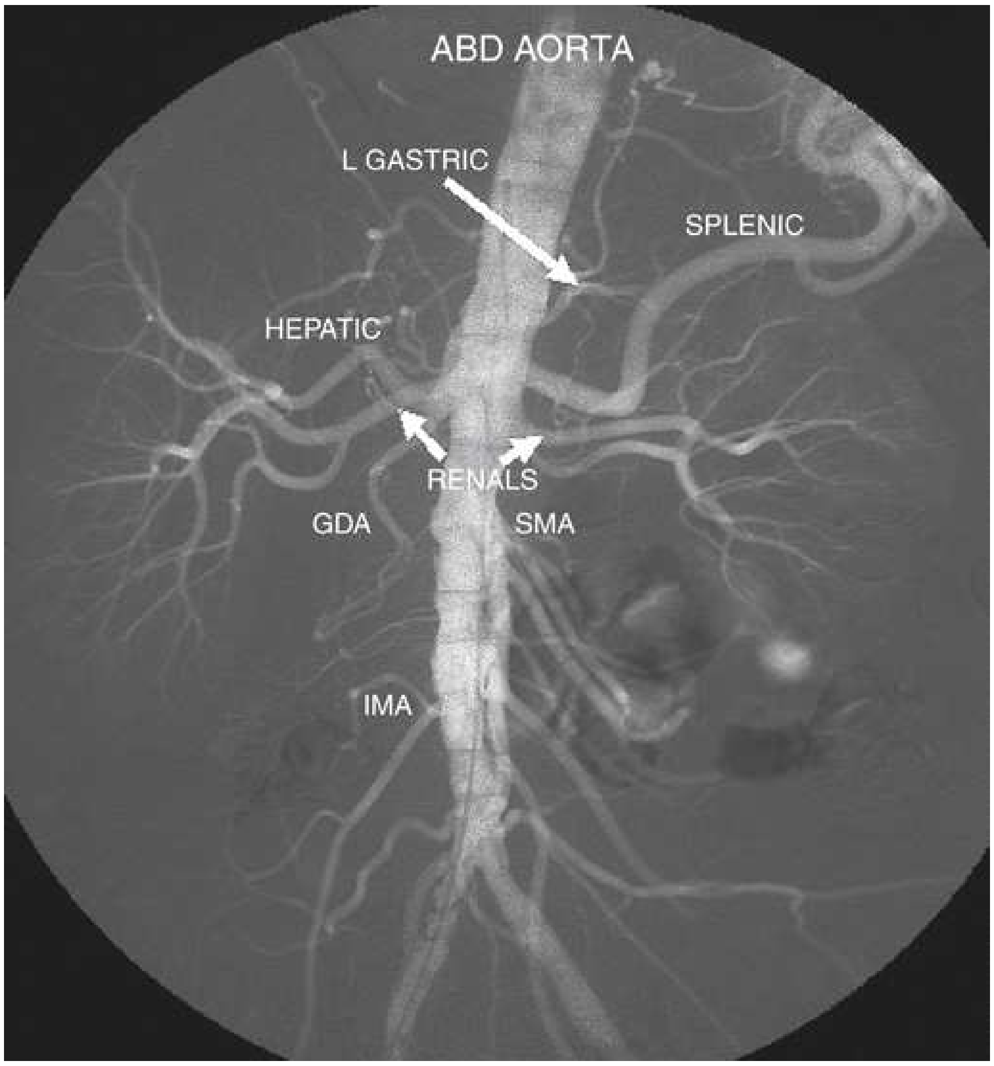


FIG. 27.24 Abdominal aortogram showing visceral arteries. *ABD AORTA,* Abdominal aorta; *GDA,* gastroduodenal artery; *IMA*, inferior mesenteric artery; *SMA*, superior mesenteric artery.

An abdominal aortogram shows the visceral arteries of the abdominal aorta. The parts labeled are marked in clockwise direction as follows: inferior mesenteric artery, G D A, hepatic, l gastric, splenic, renals, and superior mesenteric artery.

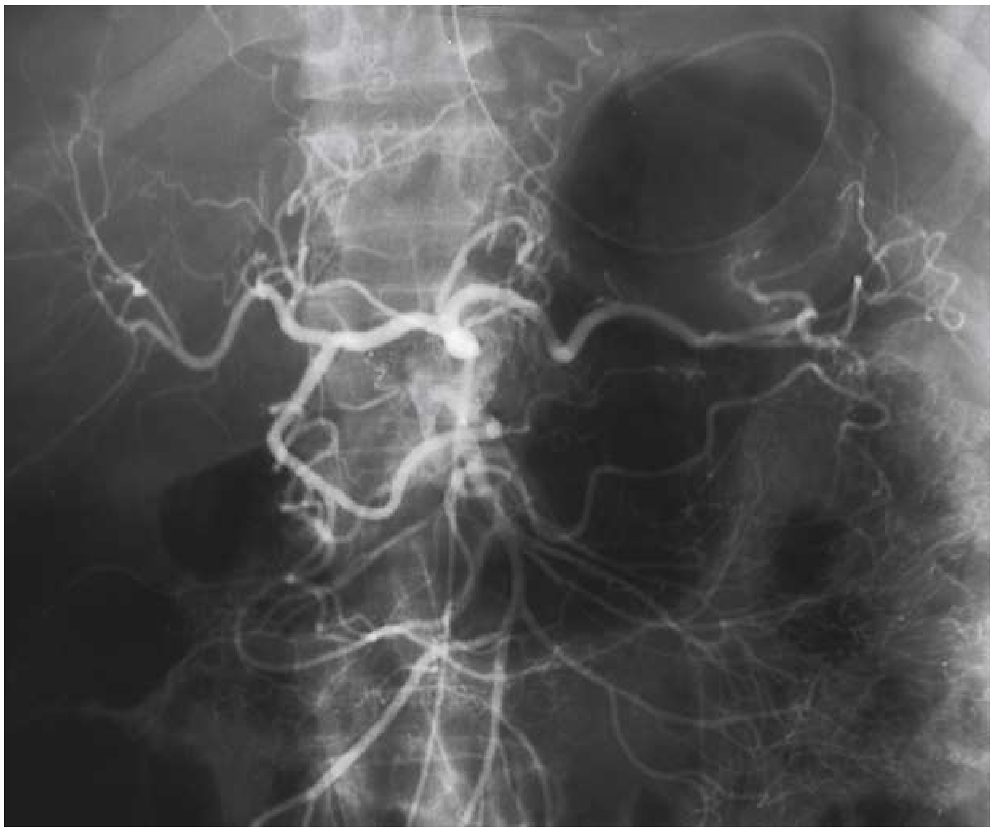


FIG. 27.25 Superselective celiac artery injection.

An celiac arteriogram shows a catheter passing through the vertebra in the middle. Long irregular branches rise from the vertebra to the surrounding areas. It appears radiopaque and the surrounding region appears radiolucent.

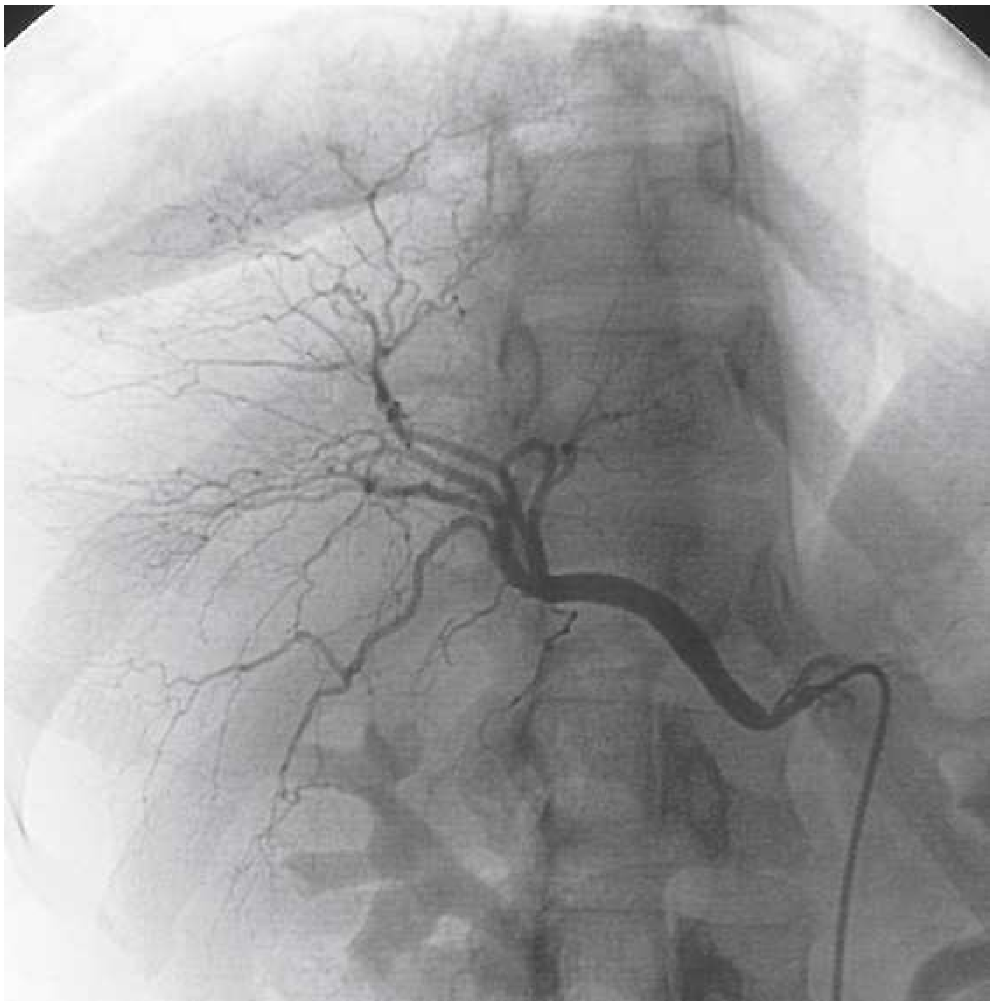


FIG. 27.26 Superselective hepatic artery injection.

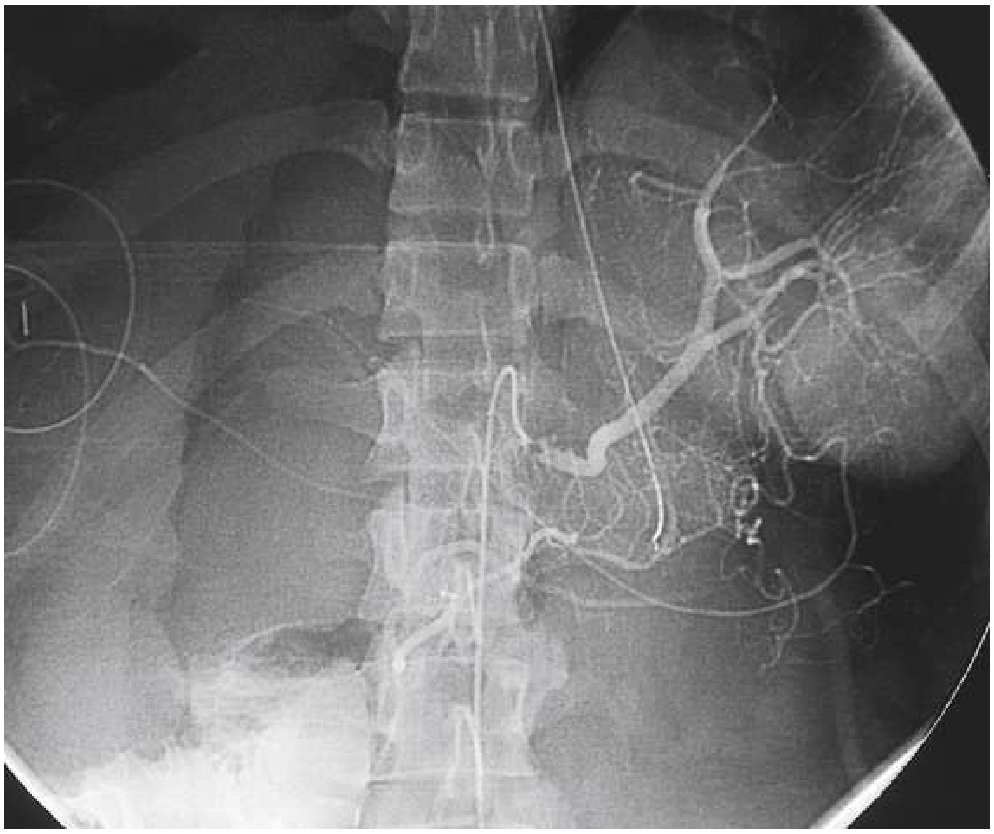


FIG. 27.27 Superselective splenic artery injection.

Hepatic arteriogram

The common hepatic artery branches from the right side of the celiac artery and supplies circulation to the liver, stomach and proximal duodenum, and pancreas.

- Position the patient so that the upper and right margins of the liver are at the respective margins of the image receptor (Fig. 27.26).
- Contrast media injection rates range from 5 to 10 mL/s for a total volume of 10 to 30 mL.

Splenic arteriogram

The splenic artery branches from the left side of the celiac artery and supplies blood to the spleen and pancreas.

- Position the patient to place the left and upper margins of the spleen at the respective margins of the image receptor (Fig. 27.27).
- Injection of the splenic artery can show the portal venous system on the late venous images.
- To show the portal vein, center the patient to the image receptor.
- Contrast media injection rates range from 5 to 10 mL/s for a total volume of 10 to 30 mL.

Superior mesenteric arteriogram

The superior mesenteric artery (SMA) supplies blood to the small intestine and the ascending and transverse colon. It arises at about the level of L1 and descends to L5–S1.

- To visualize the SMA, center the patient to the midline of the image receptor.
- Direct the central ray to the level of L3 (Fig. 27.28).
- It may be necessary to inject a number of times with overlapping fields of view to visualize the entire area supplied by the SMA.
- Contrast media injection rates range from 5 to 10 mL/s for a total volume of 10 to 35 mL.
- When attempting to visualize bleeding sites, extend the exposure duration to 60 seconds or as requested by the radiologist.

Inferior mesenteric arteriogram

The inferior mesenteric artery (IMA) supplies blood to the splenic flexure, descending colon, and rectosigmoid area. It arises from the left side of the aorta at about the level of L3 and descends into the pelvis.

- To visualize the IMA best, use a 15-degree right anterior oblique (RAO) or left posterior oblique (LPO) that places the descending colon and rectum at the left and inferior margins of the image (Fig. 27.29).
- It may be necessary to inject a number of times with overlapping fields of view to visualize the entire area supplied by the IMA.
- Contrast media injection rates range from 3 to 5 mL/s for a total volume of 9 to 15 mL.

FIG. 27.28 Selective SMA injection.

A superior mesenteric arteriogram shows a catheter passing through the superior mesenteric artery supplying to the small intestine and then to the ascending and transverse colon. It appears radiopaque.

FIG. 27.29 Selective IMA injection.

An inferior mesenteric arteriogram shows a catheter passing through the inferior mesenteric artery supplying to the splenic flexure, descending colon, and rectosigmoid area. It arises from the left side of the aorta at about the level of L 3 and descends into the pelvis.

Renal arteriogram

The renal arteries arise from the right and left side of the aorta between L1 and L2 and supply blood to the respective kidney.

- A renal flush aortogram may be accomplished by injecting 10 to 20 mL/s for a total volume of 20 to 40 mL of contrast media through a multiple–side-hole catheter positioned in the aorta at the level of the renal arteries.
- For a right renal arteriogram, position the patient so that the central ray enters at the level of L2 midway between the center of the spine and the patient's right side.
- For a selective left renal arteriogram, position the patient so that the central ray enters at the level of L1 midway between the center of the spine and the patient's left side (Fig. 27.30).

A representative selective renal injection is 5 mL/s for a 10-mL total volume.

Other arteriograms

Other arteries branching from the aorta may be selectively studied to show anatomy and possible pathology. The positioning for these procedures depends on the area to be studied and the surrounding structures (these may include spinal, bronchial, phrenic, adrenal, and lumbar arteriograms).

Pulmonary Arteriography

Pulmonary arteriography is most commonly performed prior to interventional procedures such as thrombolysis, thrombectomy, embolization, balloon angioplasty, and stent placement. Unlike other arteriograms, pulmonary arteriography is performed using venous access, most commonly the internal jugular, subclavian, or femoral vein. Under fluoroscopic control, a catheter is directed through the vena cava and right side of the heart and into the pulmonary arteries. Depending on location of pathology, catheter placement is either within the main pulmonary arteries or selective for more localized imaging (Fig. 27.31).

- Position the patient in the supine position.
- Image in both AP and oblique views.
- Multiple views may be required to cover apex and base of lung.
- Contrast media injection rates range from 10 to 20 mL/s for a total volume of 20 to 40 mL.
- Make exposures at end of suspending inspiration.

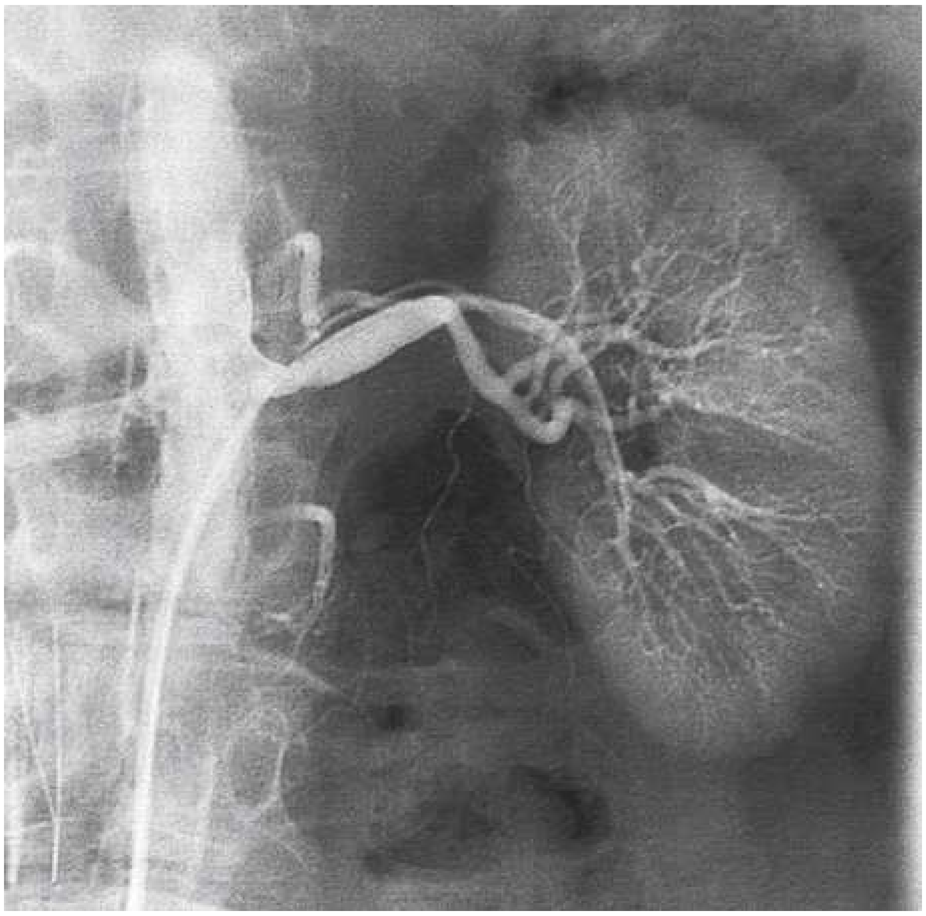


FIG. 27.30 Selective left renal artery injection in early arterial phase.

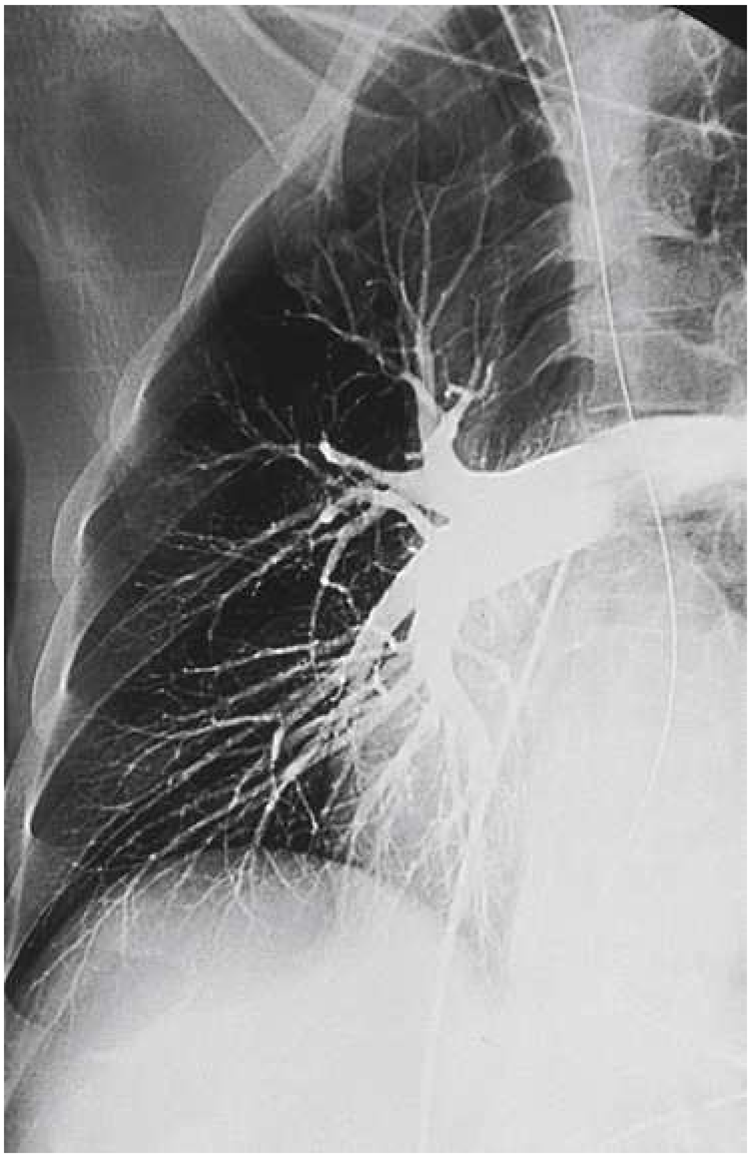


FIG. 27.31 Right pulmonary artery.

A pulmonary arteriography shows the lungs, right pulmonary arteries and the branches. A catheter is directed through the vena cava and right side of the heart and into the pulmonary arteries. It appears radiopaque. The lungs appear radiolucent.

Peripheral Angiography

Lower Limb Arteriograms

Aortofemoral arteriography is usually performed to accurately assess vascular pathology prior to intervention. The catheter tip is positioned superior to the aortic bifurcation so that bilateral arteriograms are obtained simultaneously. When only one leg is to be examined, the catheter tip is placed below the bifurcation, or the contrast media is injected through a catheter or sheath placed in the femoral artery on the side of interest.

- For a bilateral examination, place the patient in the supine position for single-plane AP projections and center the patient to the midline of the image receptor. Images include the area from the renal arteries to the ankles (Fig. 27.32).
- Internally rotate the legs 30 degrees.
- Subtracted or unsubtracted bolus chase selections can be used to follow the contrast media down the legs, or alternately, a number of stationary DSA imaging sequences can be performed to cover the area of interest.
- Make exposures of the opacified lower abdominal aorta and aortic bifurcation with the patient in suspended expiration.
- Examinations of a specific area of the leg such as the popliteal fossa or foot are occasionally performed.
- AP, lateral, or both projections may be obtained with the patient centered to the designated area.
- Contrast media injection rates range from 5 to 10 mL/s for a total of 40 to 60 mL for bolus chase, or from 5 to 10 mL/s for a total of 10 to 30 mL for stationary DSA sequences.


R
Common iliac artery
External iliac artery
Profunda femoris artery
(deep femoral)
Superficial
femoral artery
Popliteal artery
Anterior tibial artery
Peroneal artery
Posterior tibial artery

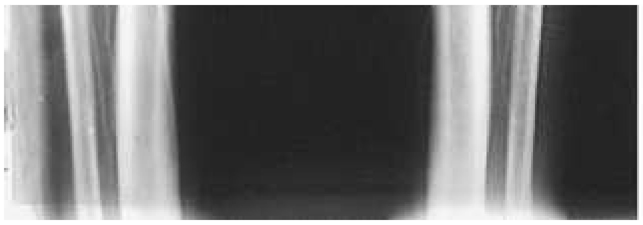


FIG. 27.32 Normal abdominal aortogram and bilateral femoral arteriogram in late arterial phase.

An arteriogram shows the anterior view of a human body from the abdomen to the lower limb. The abdomen area is radiopaque. The parts labeled on the right side are as follows: common iliac artery, external iliac artery, profunda femoris artery (deep femoral), superficial femoral artery, popliteal artery, anterior tibial artery, peroneal artery, posterior tibial artery.

Upper Limb Arteriograms

Upper limb arteriography is most often performed to evaluate traumatic injury, atherosclerotic disease, or other vascular lesions. Arteriograms are obtained by introducing a catheter, most often at a femoral artery site, for selective injection into the subclavian or axillary artery. The contrast media may also be injected at a more distal site through a catheter. The area to be radiographed may be a hand or another selected part of the arm or the entire upper extremity and thorax. When pathology is suspected in the brachiocephalic arteries, an arch aortogram is performed.

FIG. 27.33 Right hand arteriogram (2:1 magnification) showing severe arterial occlusive disease *(arrows)* affecting digits after cold temperature injury.

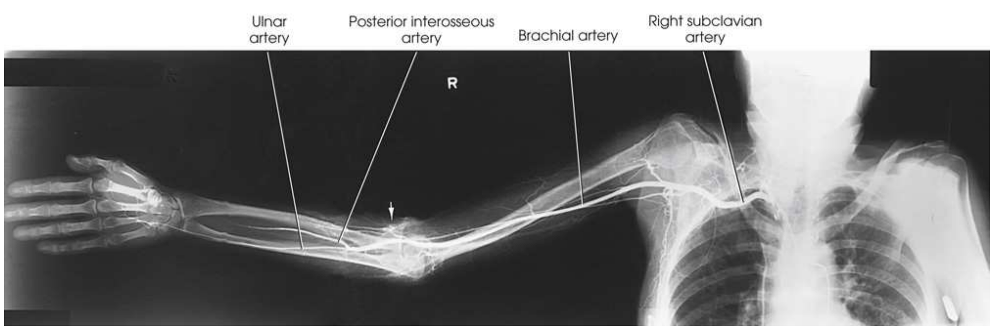


FIG. 27.34 Right subclavian artery injection showing iatrogenic occlusion of radial artery *(arrow)*.

- The recommended projection is a true AP projection with the arm extended and the hand supinated. Hand arteriograms may be obtained in the supine or prone arm position (Figs. 27.33 and 27.34).
- The injection varies from 3 to 4 mL/s through a catheter positioned distally to 10 mL/s through a proximally positioned catheter.

Images are obtained by using a bolus chase technique or by performing serial runs over each segment of the extremity.

Cerebral Angiography

Cerebral Anatomy

Cerebral angiography demonstrates the blood vessels of the brain. The procedure was introduced by Egas Moniz[2] in 1927. It is performed to investigate intracranial vascular lesions such as aneurysms, arteriovenous malformations (AVMs), tumors, atherosclerotic or stenotic lesions, and acute thrombus (blood clot).

The brain is supplied by four trunk vessels or great vessels (Fig. 27.35): the right and left common carotid arteries, which supply the anterior circulation, and the right and left vertebral arteries, which supply the posterior circulation. These paired arteries branch from the arch of the aorta and ascend through the neck.

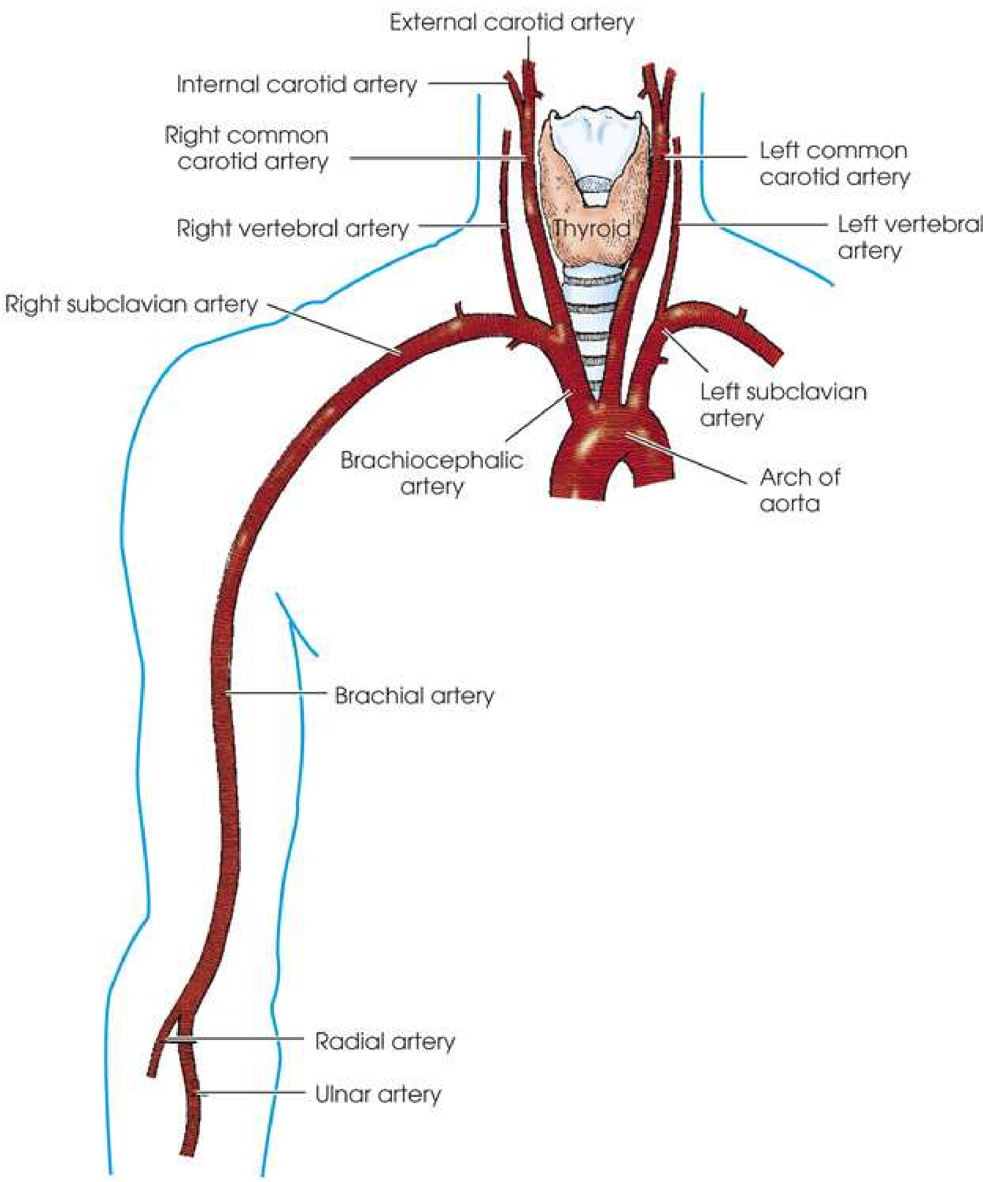


FIG. 27.35 Major arteries of upper chest, neck, and arm.

Diagram shows major arteries in upper chest, neck, and arm. The arteries are highlighted in red that surround thyroid is surrounded by the arteries. The parts labeled are marked in clockwise direction as follows: ulnar artery, radial artery, brachial artery, right subclavian artery, right vertebral artery, right common carotid artery, internal carotid artery, external carotid artery, left common carotid artery, left vertebral artery, left subclavian artery, arch of aorta.

The first branch of the aortic arch is the *innominate artery* or the *brachiocephalic artery*. It bifurcates into the right common carotid artery (CCA) and the right subclavian artery. The second branch of the aortic arch is the left CCA, followed by the left subclavian artery. Each of the vessels originates directly from the aortic arch. Both vertebral arteries most commonly take their origins from the subclavian arteries. Although this branching pattern is common in most patients, there can be some *anomalous* origins of these great vessels. Each CCA passes superiorly and laterally alongside the trachea and larynx to the level of C4 and then divides into internal and external carotid arteries (ECAs). The ECA contributes blood supply to the extracranial and extra-axial circulation. There can be some collateral circulation into the internal carotid circulation in some situations. The internal carotid artery (ICA) enters the cranium through the carotid foramen of the temporal bone and bifurcates into the anterior and middle cerebral arteries (Fig. 27.36). These vessels branch and rebranch to supply the anterior circulation of the respective hemisphere of the brain.

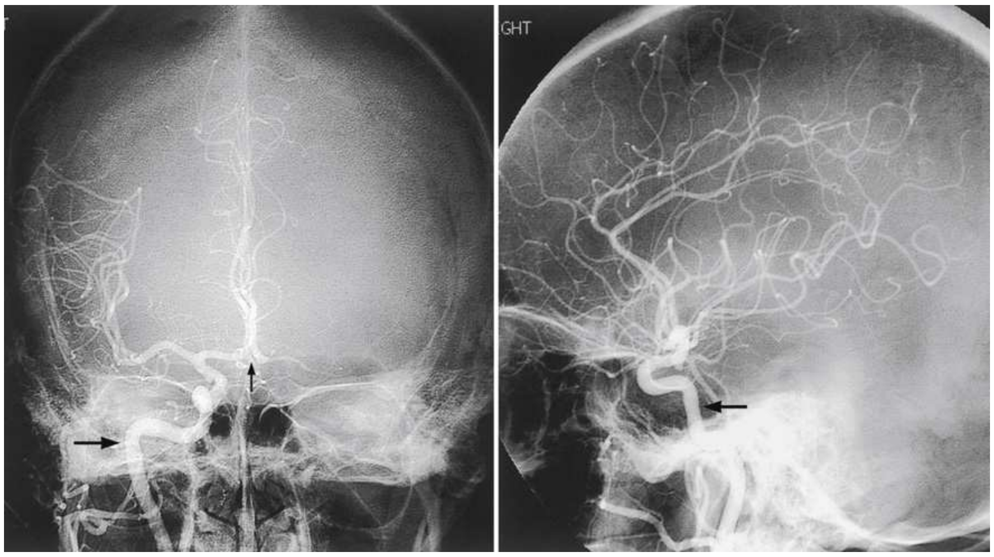


FIG. 27.36 Right common carotid artery injection showing right internal carotid artery *(arrows)* and anterior cerebral blood circulation, including reflux across anterior communicating artery *(small arrow)*.

A radiographic image on the left shows the posterior view of the skull. The right internal carotid artery is indicated by two black arrows. A radiographic image on the right shows the lateral view of the skull. The anterior communicating artery is indicated by a black arrow.

The vertebral arteries ascend through the cervical transverse foramina and pass medially to enter the cranium through the foramen magnum. The vertebral arteries unite to form the basilar artery, which, after a short superior course along the posterior surface of the dorsum sellae, bifurcates into the right and left posterior cerebral arteries. The blood supply to the posterior fossa (cerebellum) originates from the vertebral and basilar arteries (Fig. 27.37).

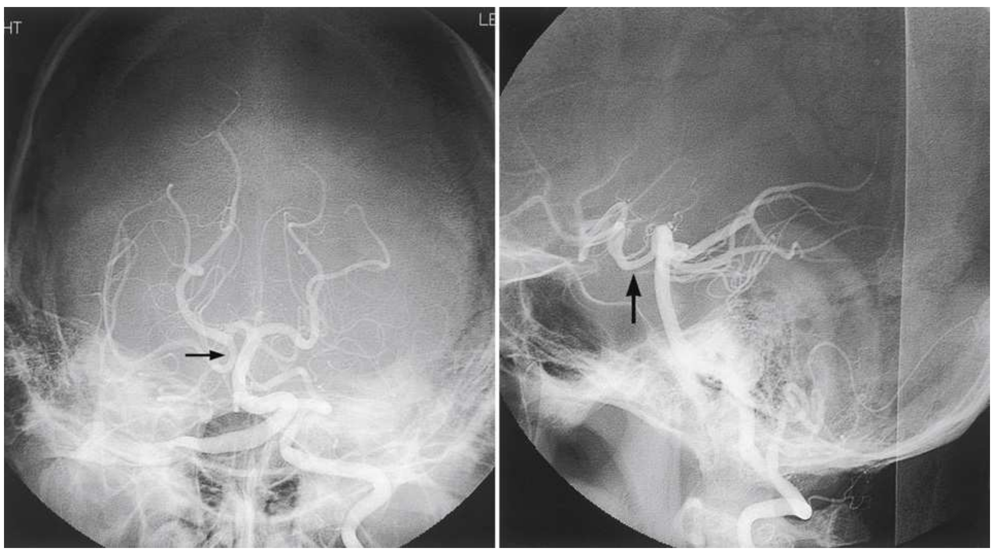


FIG. 27.37 Left vertebral artery injection showing posterior cerebral blood circulation, including reflux into posterior communicating artery *(arrows)*.

A radiographic image on the left shows the posterior view of the skull. The left vertebral artery is indicated by a black arrow. A radiographic image on the right shows the lateral view of the skull. The posterior communicating artery is indicated by a black arrow.

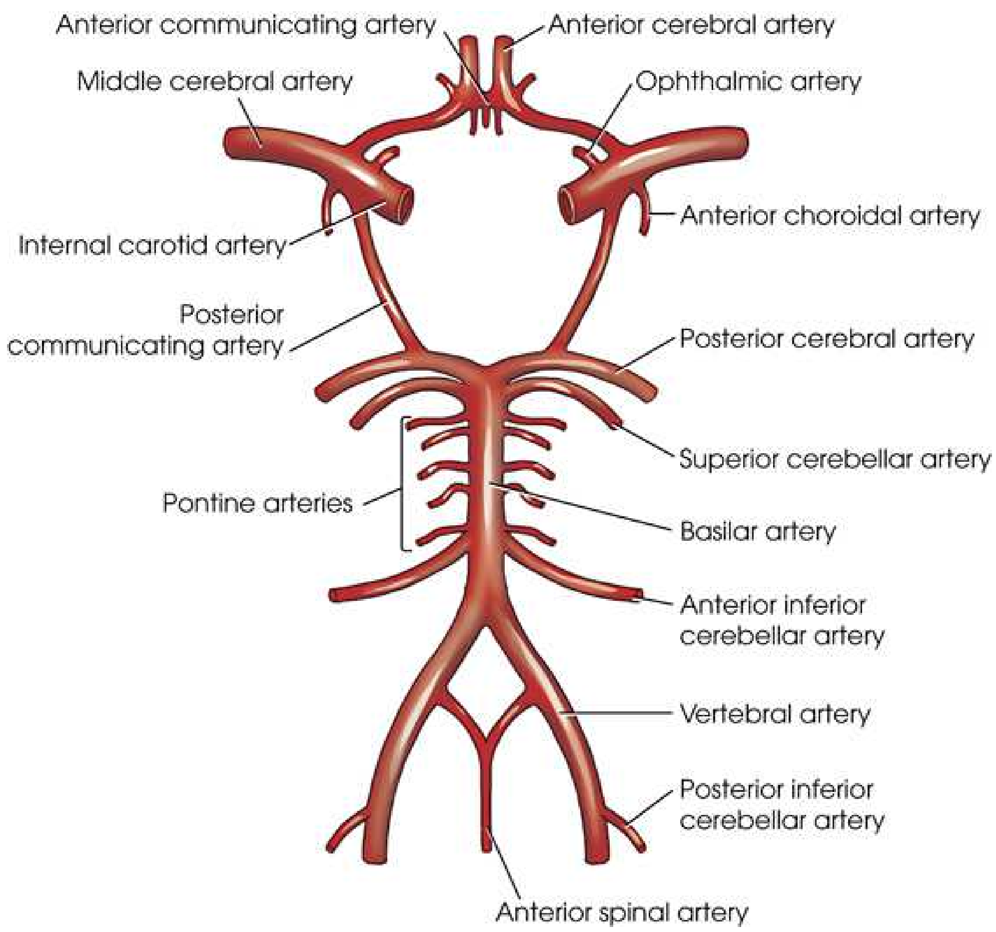


FIG. 27.38 Circle of Willis.

Diagram shows the circle of Willis. The parts labeled are marked in clockwise direction as follows: pontine arteries, posterior communicating artery, internal carotid artery, middle cerebral artery, anterior communicating artery, anterior cerebral artery, ophthalmic artery, anterior choroidal artery, posterior cerebral artery, superior cerebellar artery, basilar artery, anterior inferior cerebellar artery, vertebral artery, posterior inferior cerebellar artery, anterior spinal artery.

The anterior and posterior cerebral arteries are connected by communicating arteries at the level of the midbrain to form the *circle of Willis*. The anterior communicating artery forms an anastomosis between the anterior cerebral arteries, which communicate between the right and left hemispheres. The right and left posterior communicating arteries each form an anastomosis between the ICA and the posterior cerebral artery connecting the anterior and posterior circulation. A chart detailing intracerebral circulation is provided in Figs. 27.38 and 27.39.

Technique

Catheter-directed cerebral angiography should be performed only in facilities equipped to produce studies of high technical quality with minimal risk to the patient. Rapid-sequence biplane imaging with DSA electronically coupled with an automatic injector is employed almost universally in cerebral angiography. Collimating to the area of the head and neck is essential for improving image quality in a non-magnified study.

Cerebral angiography is performed either using a femoral arterial approach or radial arterial approach. Selective catheterization techniques allow the internal and external carotid circulation to be studied separately, which is particularly useful in delineating the blood supply of cerebral tumors and vascular malformations.

The final position of the catheter depends on the information sought from the angiographic study. When atherosclerotic disease of the extracranial carotid, subclavian, and vertebral arteries is being evaluated, injection of the aortic arch with imaging of the extracranial portion of these vessels is an appropriate way to begin.

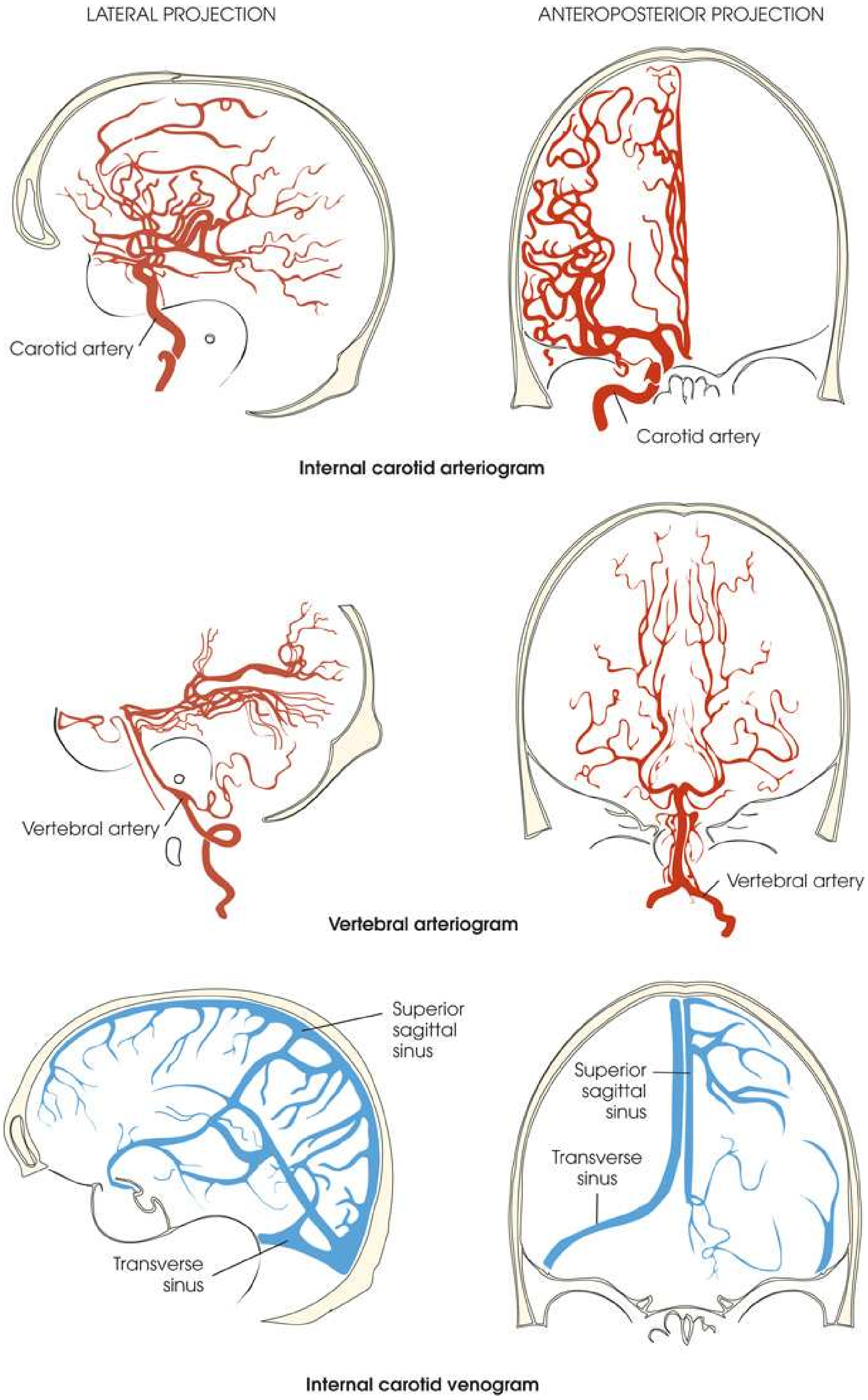


FIG. 27.39 Diagram of intracranial circulation: arterial and venous phase. From Bean BC: A chart of the intracerebral circulation, ed 2. *Med Radiogr Photogr* 34:25, 1958; courtesy Dr. Berton C. Bean and Eastman Kodak Co.

Lateral projection of an internal carotid arteriogram shows the catheter passing through the carotid artery. Anteroposterior projection of an internal carotid arteriogram shows the catheter passing through the carotid artery. Lateral projection of a vertebral arteriogram shows the catheter passing through the carotid artery. Anteroposterior projection of a vertebral arteriogram shows the catheter passing through the carotid artery. Lateral projection of an internal carotid venogram shows the catheter passing through the transverse sinus. Anteroposterior projection of an internal carotid venogram shows the transverse sinus, and superior sagittal sinus.

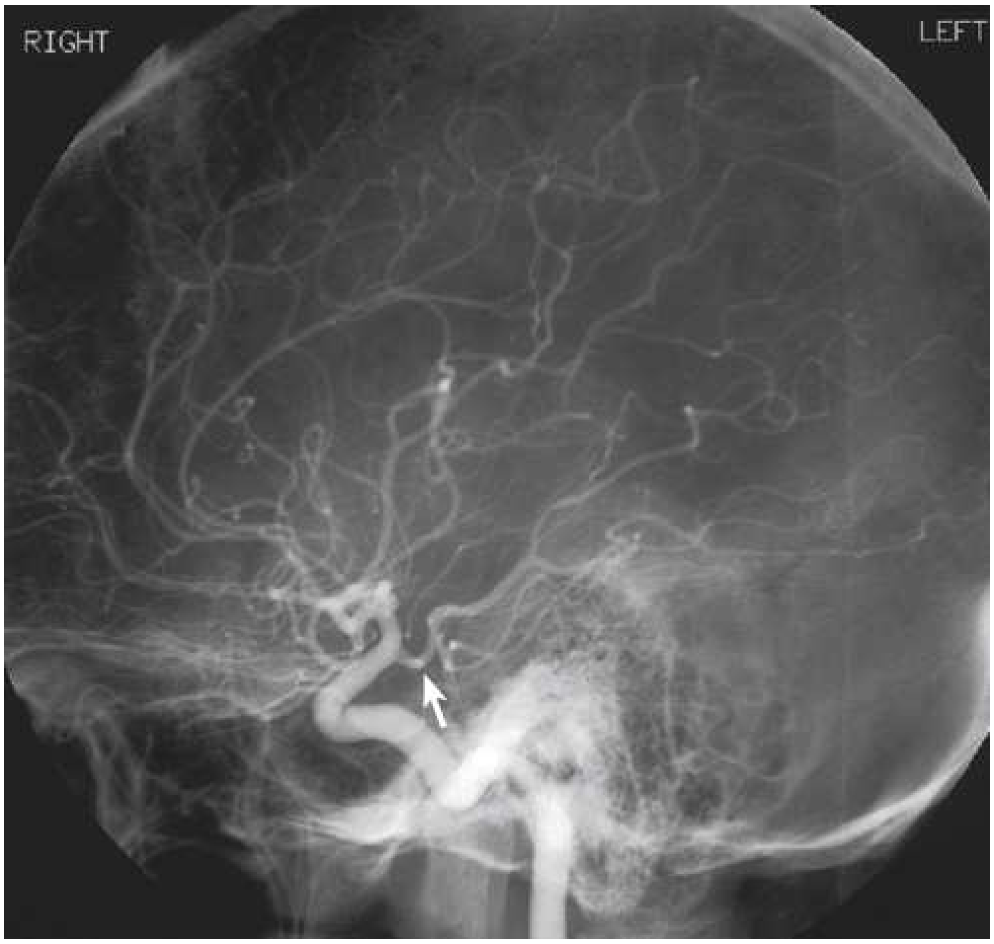


FIG. 27.40 Right internal carotid injection, lateral projection, shows arterial phase of circulation. Note posterior communicating artery *(arrow)*.

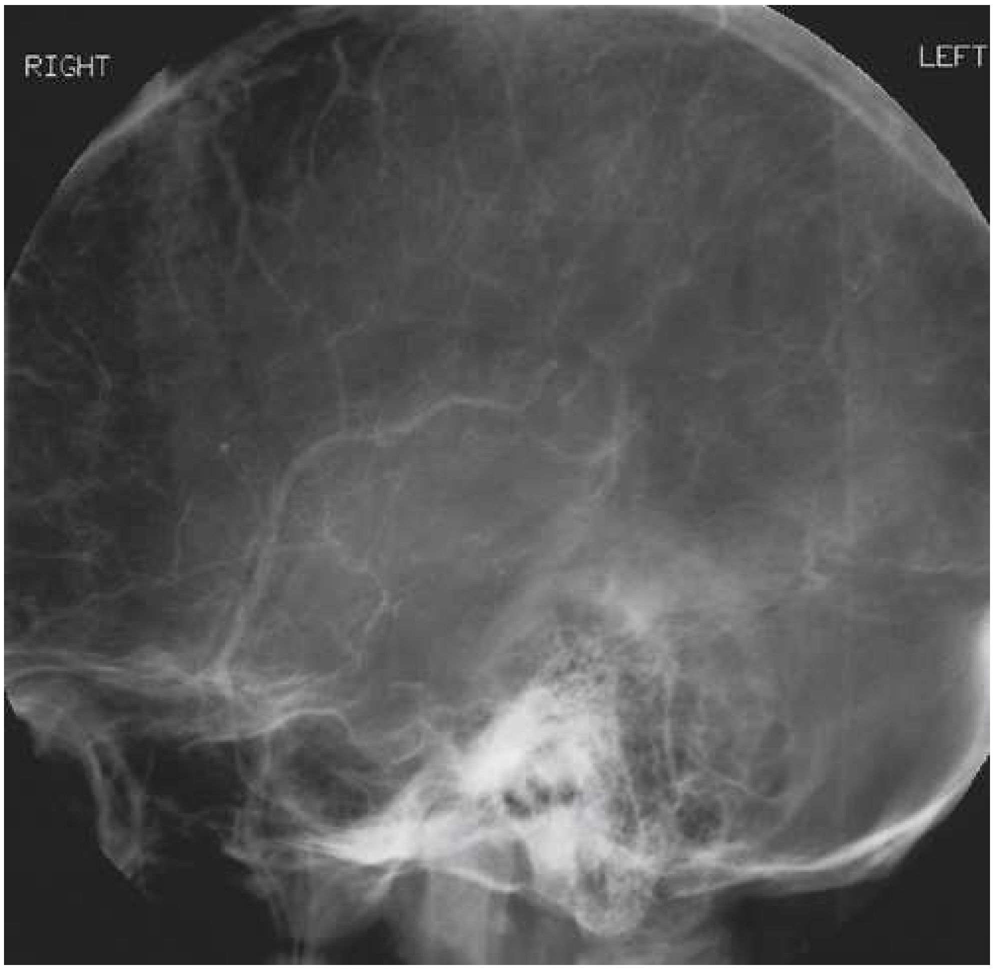


FIG. 27.41 Right internal carotid injection, lateral projection, shows capillary phase of carotid circulation.

Circulation Time And Imaging Program

Egas Moniz[3] stated that the transit time of the cerebral circulation is only 3 seconds for the blood to circulate from the ICA to the jugular vein, with the circulation time being slightly prolonged by the injected contrast solution. Greitz,[4] who measured the cerebral circulation time as "the time between the points of maximum concentration (of contrast media) in the carotid siphon and in the parietal veins," found a normal mean value of 4.13 seconds. Certain pathologic conditions significantly alter the cerebral circulation time. AVMs shorten the transit time; vascular occlusions or arterial vasospasm may cause a considerable delay.

A standard angiographic program should include at least one image taken before the arrival of contrast media to serve as a subtraction mask and then rapid-sequence images at 2 to 4 images per second in the AP and lateral projections during the arterial phase (first 1½ to 2½ seconds) of the arteriogram (Fig. 27.40). After the arterial phase, imaging may be slowed to one image per second for the capillary, or parenchymal, phase (Fig. 27.41) and maintained at one image per second or every other second for the venous phase (Fig. 27.42) of the angiogram. The entire program should cover 7 to 10 seconds, depending on the preference of the angiographer. The imaging program can be tailored to optimally demonstrate the suspected pathologic condition.

Injections at rates of 5 to 9 mL/s for 1 to 2 seconds are most often employed in the cerebral vessels, with variations dependent on vessel size and the patient's circulatory status.

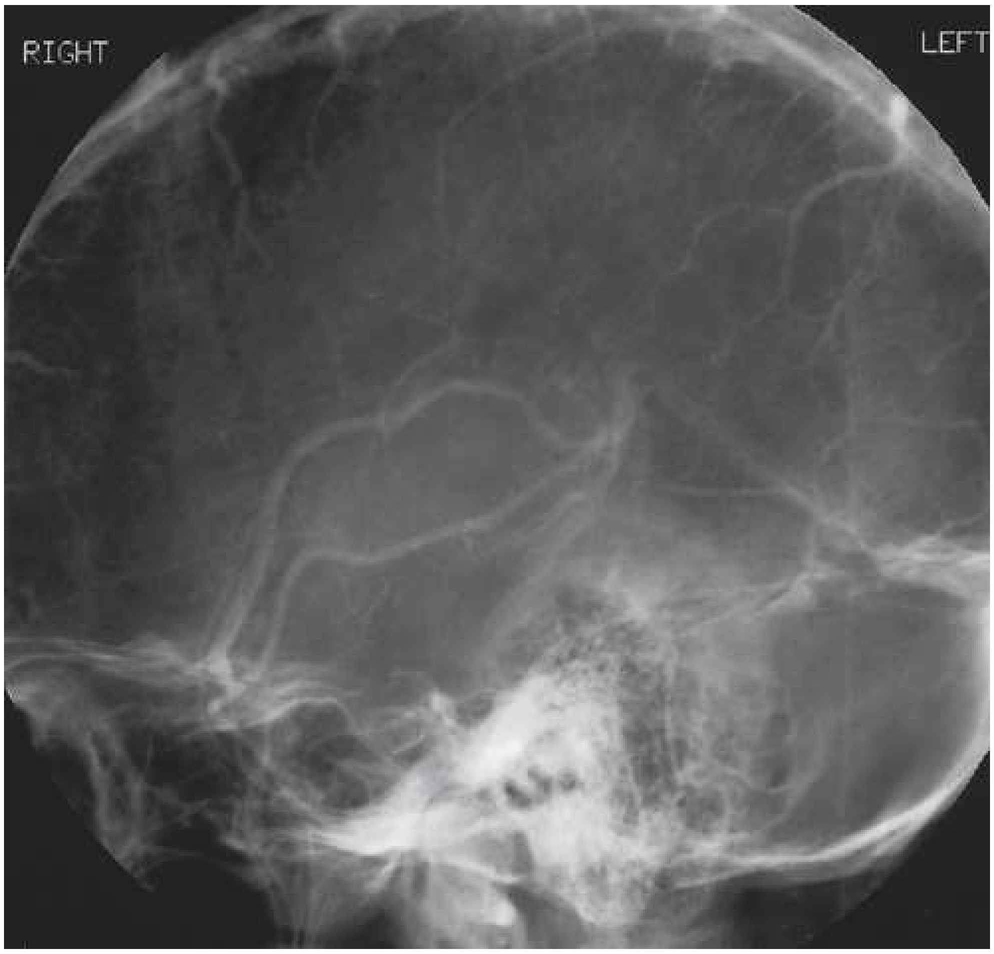


FIG. 27.42 Right internal carotid injection, lateral projection, shows venous phase of circulation.

Position of Head

The centering and angulation of the central ray required to show the anterior circulation differ from those required to show the posterior circulation. The same head position is used for the basic AP and lateral projections of both regions.

- Adjust the patient's head so that it lies symmetrically in the headholder; the midsagittal plane is perpendicular to the horizontal plane.
- Place the infraorbitomeatal line (IOML) perpendicular to the horizontal plane.
- Angle the central ray for caudally inclined AP and AP oblique projections.

This chapter discusses the most frequently employed images and reasonably standard specifications for obtaining them.

The number of radiographs required for satisfactory delineation of a lesion depends on the nature and location of the lesion. Oblique projections or variations in central ray angulation are used to separate the vessels that overlap in the basic positions and to evaluate any existing abnormality.

Aortic Arch Angiogram

An aortic arch angiogram is most commonly obtained to visualize atherosclerotic or occlusive disease of the extracranial or common carotid, vertebral, and subclavian arteries. A multiple–side-hole catheter is positioned in the ascending thoracic aorta so that the subsequent injection fills all of the vessels simultaneously.

Simultaneous Biplane Oblique Projections

For best results, simultaneous biplane oblique projections are produced so that superimposition of vessels is minimized (Fig. 27.43).

- Place the image receptor in a 35-degree LAO position. This position opens the aortic arch and clearly demonstrates the origins of the brachiocephalic, left common carotid, and left subclavian arteries.
- Raise the patient's chin to superimpose the inferior margin of the mandible onto the occiput so that as much of the neck as possible is exposed in the frontal image.
- Move the patient's shoulders inferiorly so that they are removed as much as possible from the lateral image.
- Position the lateral image receptor in a 35- to 45-degree RAO position to better demonstrate the bifurcation of the brachiocephalic and the origin of the left vertebral artery.

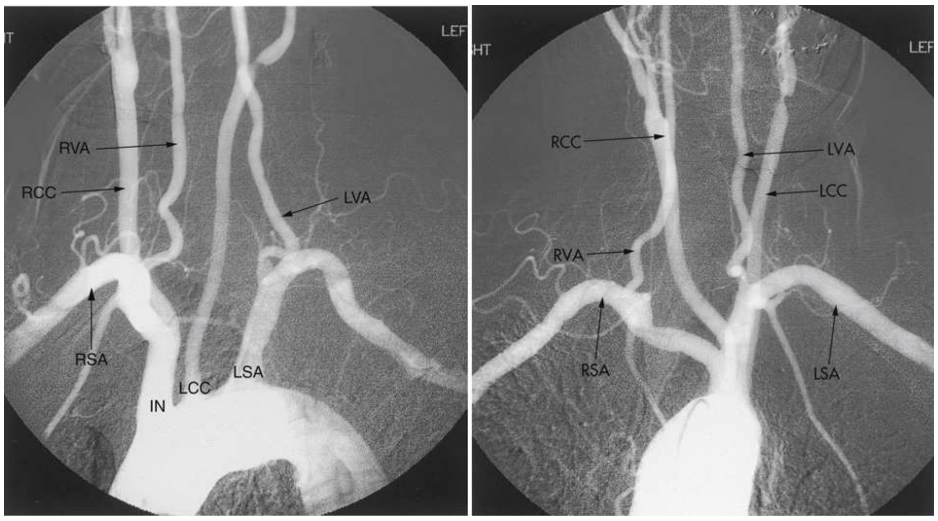


FIG. 27.43 Digital subtracted images of thoracic aortogram showing the origins of the great vessels. *IN,* Innominate; *LSA,* left subclavian artery; *LVA,* left vertebral artery; *RCC,* right common carotid; *RSA,* right subclavian artery; *RVA,* right vertebral artery.

Two thoracic aortagram shows the origin of the great vessels. The aortogram on the left has the following parts labeled on it: left subclavian artery, left vertebral artery, left common carotid, right common carotid, right subclavian artery, right vertebral artery, innominate. The aortogram on the right has the following parts labeled on it: left subclavian artery, left vertebral artery, left common carotid, right common carotid, right subclavian artery, right vertebral artery.

- The image receptor is positioned to include the inferior border of the aortic arch at the bottom of the imaging field.

Extracranial Carotid and Vertebral Arteriography

The most common vascular pathology in the extracranial carotid and vertebral arteries is atherosclerotic disease resulting in stenosis or occlusion. The majority of these stenoses are located at the bifurcation of the CCA or proximal ICA. Risk of stroke in patients with a high-grade stenosis, equal to or greater than 70%, is very high. Angiography of the extracranial carotid and vertebral arteries is often performed to verify the degree of occlusive disease demonstrated on prior non-invasive imaging and to plan appropriate endovascular or surgical intervention. Selective injections are performed at the origin of the right CCA, left CCA, and the vertebral arteries.

Selective catheter angiography of the ECA is performed to demonstrate vascular anatomy and pathology of extracranial branches supplying the neck, face, and scalp.

Common Carotid Arteriography

- Adjust the patient's head so that the head lies symmetrically in the headholder.
- Raise the patient's chin to superimpose the inferior margin of the mandible onto the occiput so that as much of the neck as possible is exposed in the frontal image.
- Move the patient's shoulders inferiorly so that the shoulders are removed as much as possible from the lateral image.
- The CCA is usually visualized with three projections: AP, 45-degree oblique, and lateral.
- A representative injection rate is 5 mL/s for a total of 10 mL.
- It is important for the patient to hold respirations and prevent any movement, including swallowing, during exposures to minimize misregistration of DSA images.

Vertebral Arteriography

- The patient position is the same as common carotid arteriography.
- The extracranial vertebral artery is visualized in the AP and lateral projections.
- Position the central ray more posterior in the lateral plane to include the posterior aspect of the spine.

• A representative injection rate is 5 mL/s for a total of 8 mL.

External Carotid Arteriography

• The patient position is the same as common carotid arteriography.
• The ECA is routinely visualized in the AP and lateral projections.
• Increase the FOV to include the mandible and the soft tissue of the skull.
• Position the central ray more anterior in the lateral plane to include the facial structures.
• Close collimation and additional filters may be necessary to reduce image contrast and prevent image burnout.
• A representative injection rate is 3 mL/s for a total of 6 mL.
• If possible, warn the patient of heat sensation from the contrast media in facial tissue.

Intracranial Anterior Circulation

Lateral Projection

• Adjust the patient's head so that the skull lies symmetrically; the midsagittal plane is perpendicular to the horizontal plane.
• Place the IOML perpendicular to the horizontal plane.

• Perform lateral projections of the anterior, or carotid, circulation with the central ray directed horizontally to a point slightly cranial to the auricle and midway between the forehead and the occiput. This centering allows for patient variation (Figs. 27.44–27.46).
• A representative injection rate for a selected ICA is 6 mL/s for a total of 8 mL.

NOTE: See Fig. 27.39 for assistance in identifying the cerebral vessels in the image.

FIG. 27.44 Cerebral angiogram: Lateral projection as part of a biplane setup.

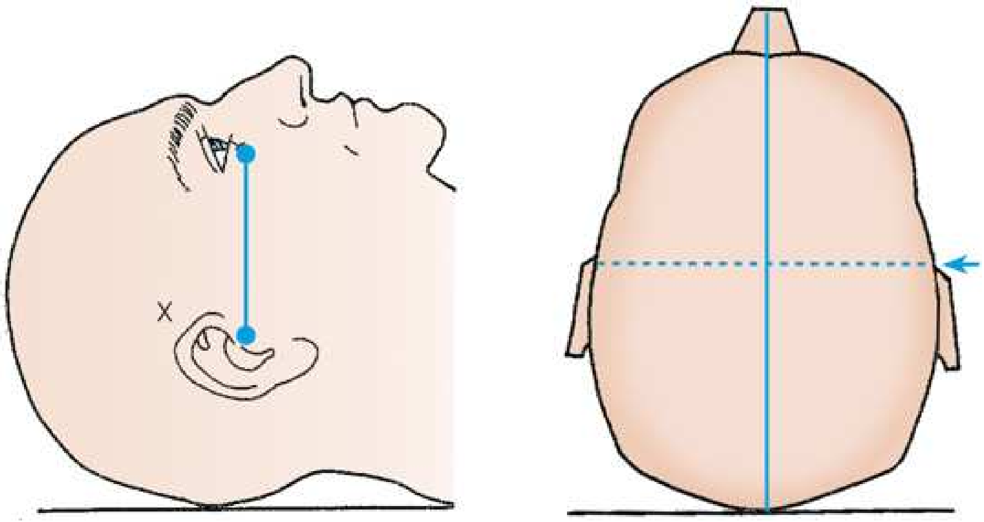


FIG. 27.45 Lateral projection.

Diagram on the left shows the lateral view of the head in a supine position. A line is drawn from the ear to the eye. Diagram on the right shows the top view of the head in a supine position. A horizontal and vertical line divides the head into four quadrants.

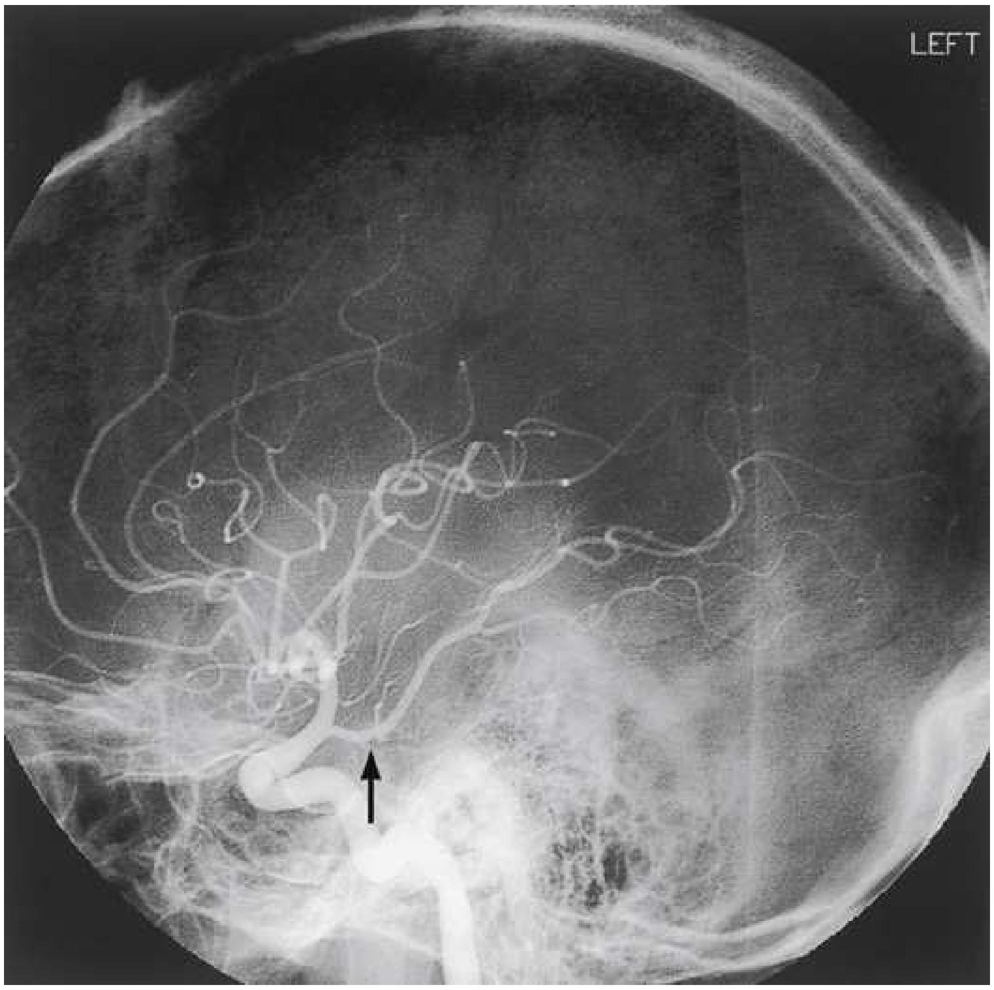


FIG. 27.46 Left internal carotid artery injection. Cerebral angiogram: lateral projection showing anterior circulation. Note posterior communicating artery *(arrow)*.

Ap Axial Projection (Supraorbital)

Patient head position is the same as in common carotid arteriography.

- Keep in mind that achieving the goal in this angiogram requires superimposition of the supraorbital margins on the superior margin of the petrous ridges so that the vessels are projected above the floor of the anterior cranial fossa.
- To obtain this result in most patients, direct the central ray 15 to 20 degrees caudally, directing the central ray through the frontal bone and EAM to the center of the image receptor (Figs. 27.47–27.49).

FIG. 27.47 Carotid angiogram: PA axial (supraorbital) projection.

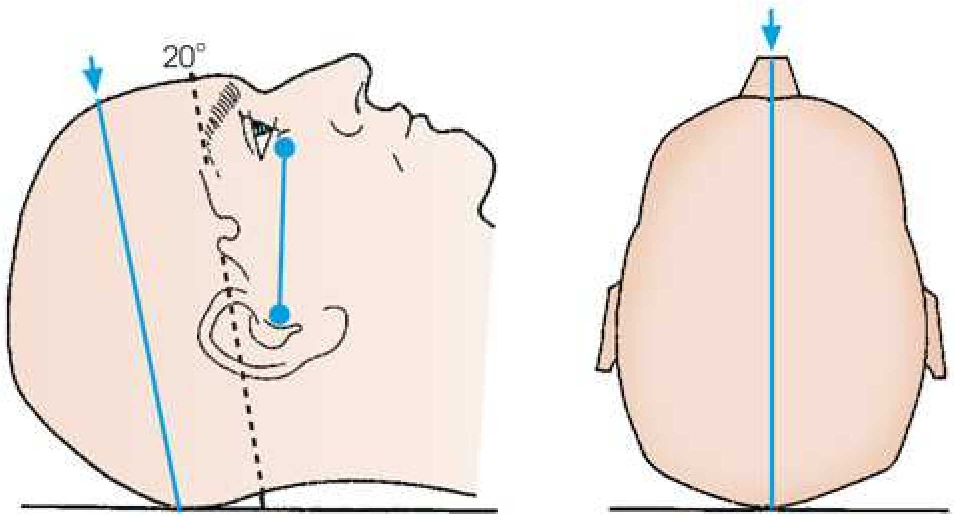


FIG. 27.48 AP axial (supraorbital).

Diagram on the left shows the lateral view of the head in a supine position. A line is drawn from the ear to the eye. The central ray is directed 15 to 20 degrees caudally. Diagram on the right shows the top view of the head in a supine position. A vertical line divides the head into two quadrants.

FIG. 27.49 Left common carotid artery injection showing AP axial (supraorbital) projection. Arterial phase of circulation.

Ap Axial Oblique Projection (Transorbital)

The oblique transorbital projection shows the internal carotid bifurcation and the anterior communicating and middle cerebral arteries within the orbital shadow.

- From the position for the basic AP projection, rotate the patient's head approximately 30 degrees away from the injected side, or angle the central ray 30 degrees toward the injected side.
- Angle the central ray 20 degrees cephalad and center it to the mid-orbit of the injected side (Figs. 27.50 and 27.51).

Posterior Circulation

Lateral Projection

- Adjust the patient's head so that the skull lies symmetrically; the midsagittal plane is perpendicular to the horizontal plane.
- Place the IOML perpendicular to the horizontal plane.
- Perform lateral projections of the posterior, or vertebral, circulation with the central ray directed horizontally to the mastoid process at a point about 1 cm superior to and 2 cm posterior to the EAM.

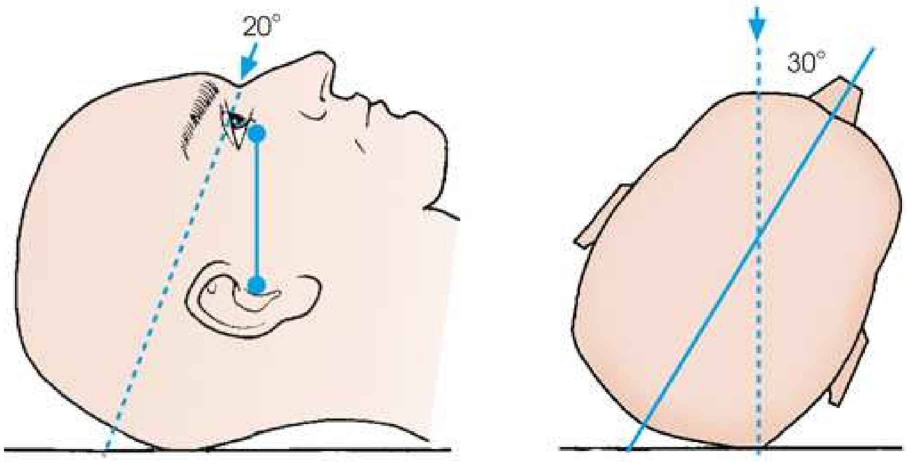


FIG. 27.50 AP axial oblique (transorbital) projection.

Diagram on the left shows the lateral view of the head in a supine position. A line is drawn from the ear to the eye. The central ray is directed 20 degrees cephalad. Diagram on the right shows the top view of the head tilted to the left in a supine position. The central ray is angled 30 degrees.

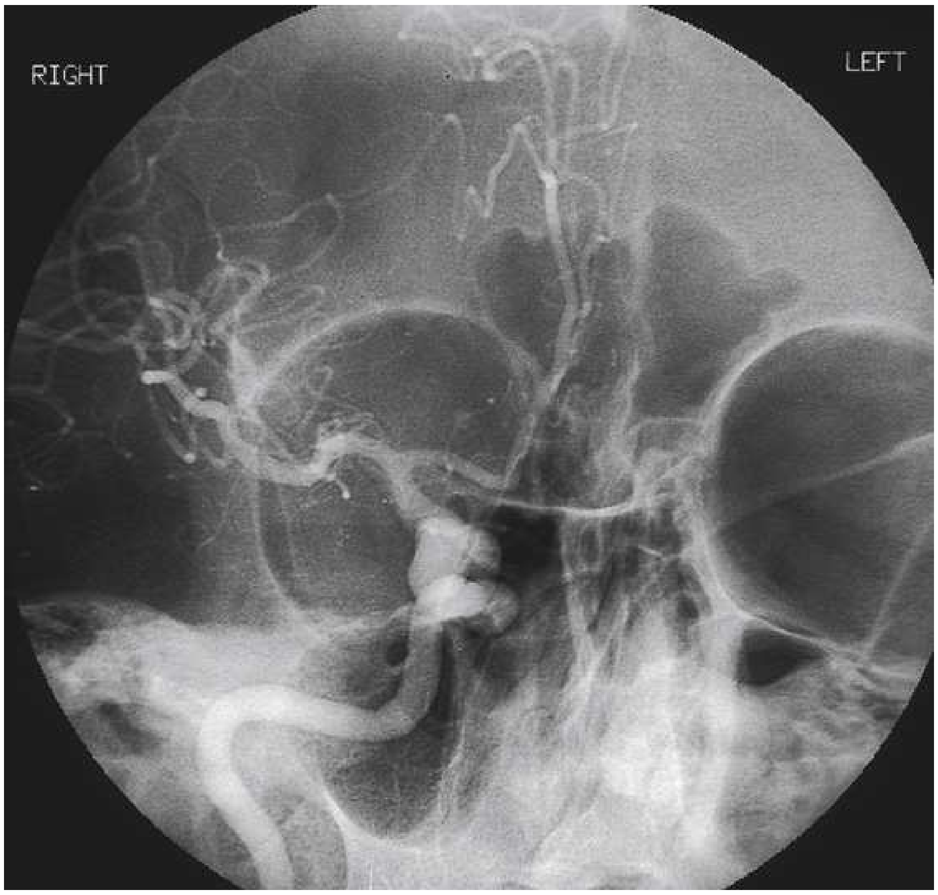


FIG. 27.51 Right internal carotid artery injection showing AP axial oblique (transorbital) projection.

- Restrict the exposure field to the middle and posterior fossae for lateral studies of the posterior circulation (Figs. 27.52 and 27.53). Inclusion of the entire skull is neither necessary nor, from the standpoint of optimal technique, desirable.

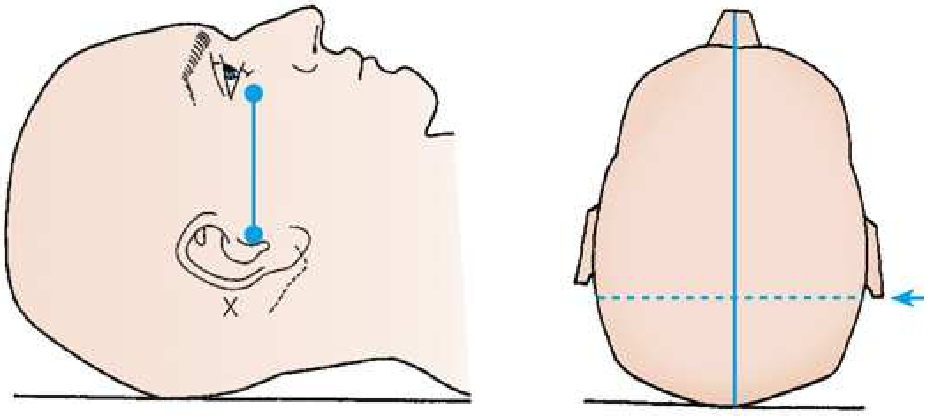


FIG. 27.52 Lateral projection for posterior circulation.

Diagram on the left shows the lateral view of the head in a supine position. A line is drawn from the ear to the eye. Diagram on the right shows the top view of the head in a supine position. A horizontal and vertical line divides the head into four quadrants.

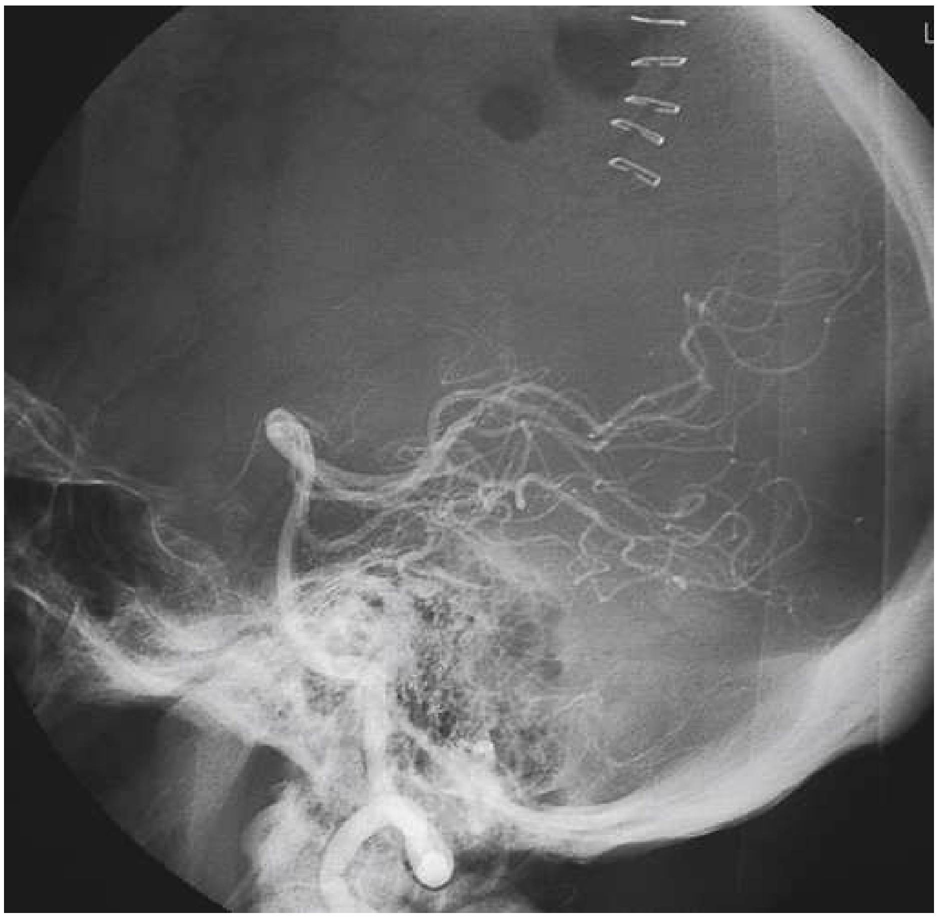


FIG. 27.53 Right vertebral artery injection showing lateral projection of vertebrobasilar system.

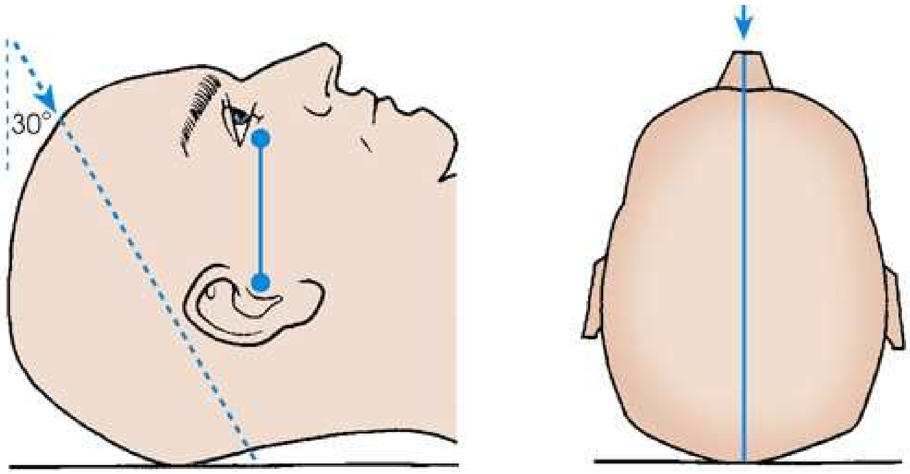


FIG. 27.54 AP axial projection for posterior circulation.

Diagram on the left shows the lateral view of the head in a supine position. A line is drawn from the ear to the eye. The central ray is directed 35 degrees caudad. Diagram on the right shows the top view of the head in a supine position. A vertical line divides the head into two quadrants.

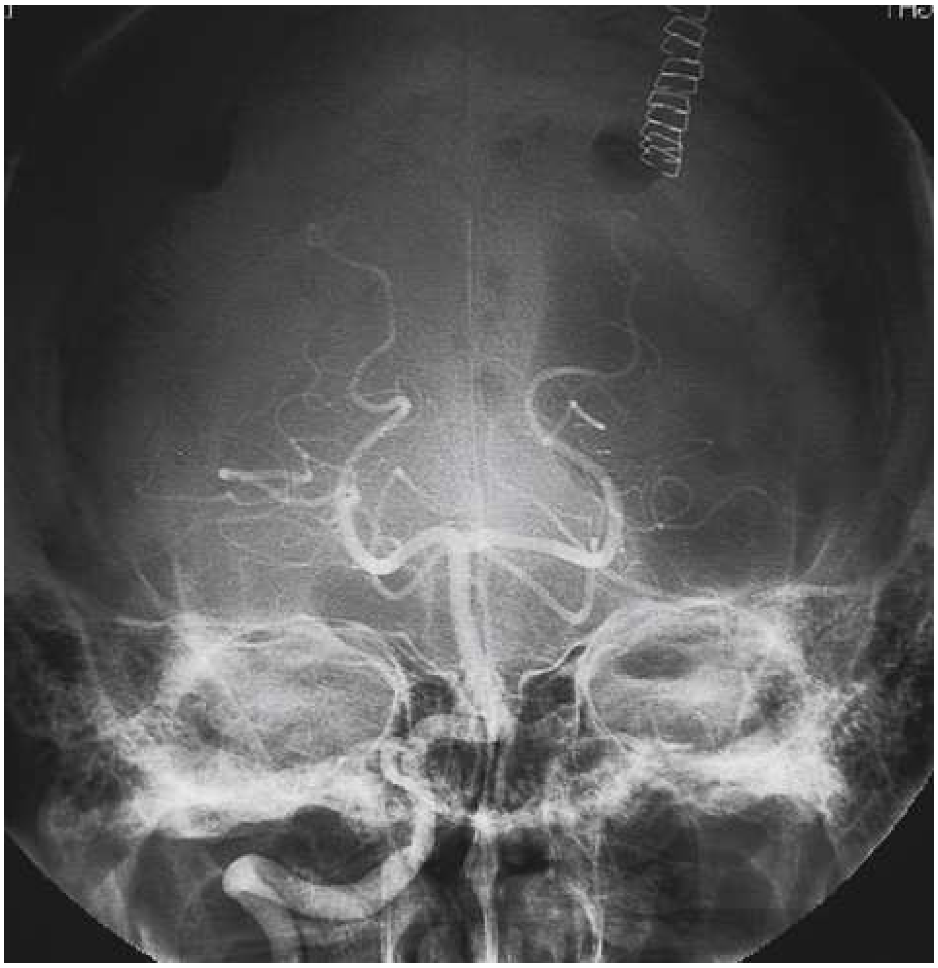


FIG. 27.55 Right vertebral artery injection showing AP axial projection of vertebrobasilar system.

- A representative injection rate is 5 mL/s for a total of 8 mL.

Ap Axial Projection

- Adjust the patient's head so that the skull lies symmetrically; the midsagittal plane is perpendicular to the horizontal plane.
- Place the IOML perpendicular to the horizontal plane.
- Direct the central ray to the region approximately 1½ inches (3.8 cm) superior to the glabella at an angle of 30 to 35 degrees caudad. The central ray exits at the level of the EAM. For this projection, the supraorbital margins are positioned approximately ¾ inch (2 cm) below the superior margins of the petrous ridges (Figs. 27.54 and 27.55).

Venography

Venography

Venous blood in veins flows proximally toward the heart. Injection into a central venous structure may not opacify the peripheral veins that *anastomose* to it. The position of peripheral veins can be indirectly documented, however, by the filling defect from unopacified blood in the opacified central vein. This phenomenon is often used to locate the position of renal veins on an IVC venogram.

Upper Limb Venograms

Upper limb venography is most often performed to look for thrombosis or occlusions. The contrast medium is injected through a needle, IV line, or catheter into a superficial vein at the elbow or wrist. Radiographs should cover the vasculature from the wrist or elbow to the SVC (Fig. 27.56). Contrast media injections are usually performed by hand rather than automatic injection. Injection rates and imaging rates will vary depending on suspected pathology and site of injection.

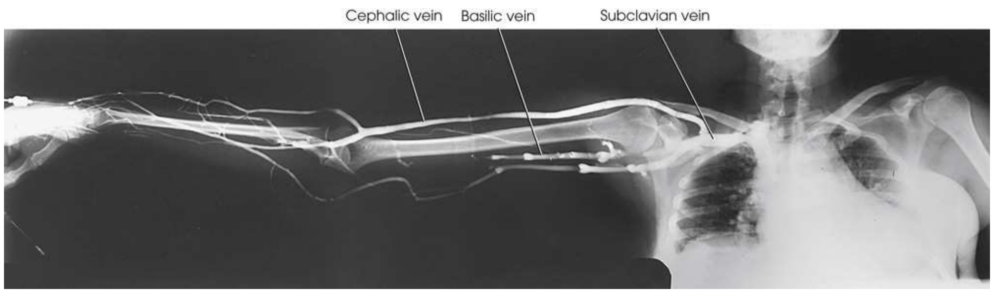


FIG. 27.56 Normal right upper limb venogram.

Lower Limb Venograms

Lower limb venography is performed to accurately visualize thrombosis of the deep veins of the leg prior to intervention. Ultrasound of the legs is the first-line diagnostic tool to diagnose deep vein thrombosis. CT or MR venography can also be performed for noninvasive diagnostic imaging. In cases where interventional procedures are expected to be performed, lower limb venography can also be obtained with contrast media injected through a sheath or catheter placed directly into the popliteal vein with the patient prone (Fig. 27.57).

Superior Venacavogram

Venography of the SVC is performed primarily to rule out the existence of thrombus or the occlusion of the SVC. Superior opacification of the SVC results from injection through a catheter positioned in the axillary, subclavian, or jugular veins. Radiographs should include the opacified subclavian vein, brachiocephalic vein, SVC, and right atrium (Fig. 27.58).

Inferior Venacavogram

Venography of the IVC is performed primarily to identify the location of the renal veins for placement of an IVC filter. The contrast media are injected through a multiple–side-hole catheter inserted through the femoral vein and positioned in the common iliac vein or the inferior aspect of the IVC (Fig. 27.59).

Common
iliac vein
External
iliac vein

FIG. 27.57 Normal left lower limb venogram.

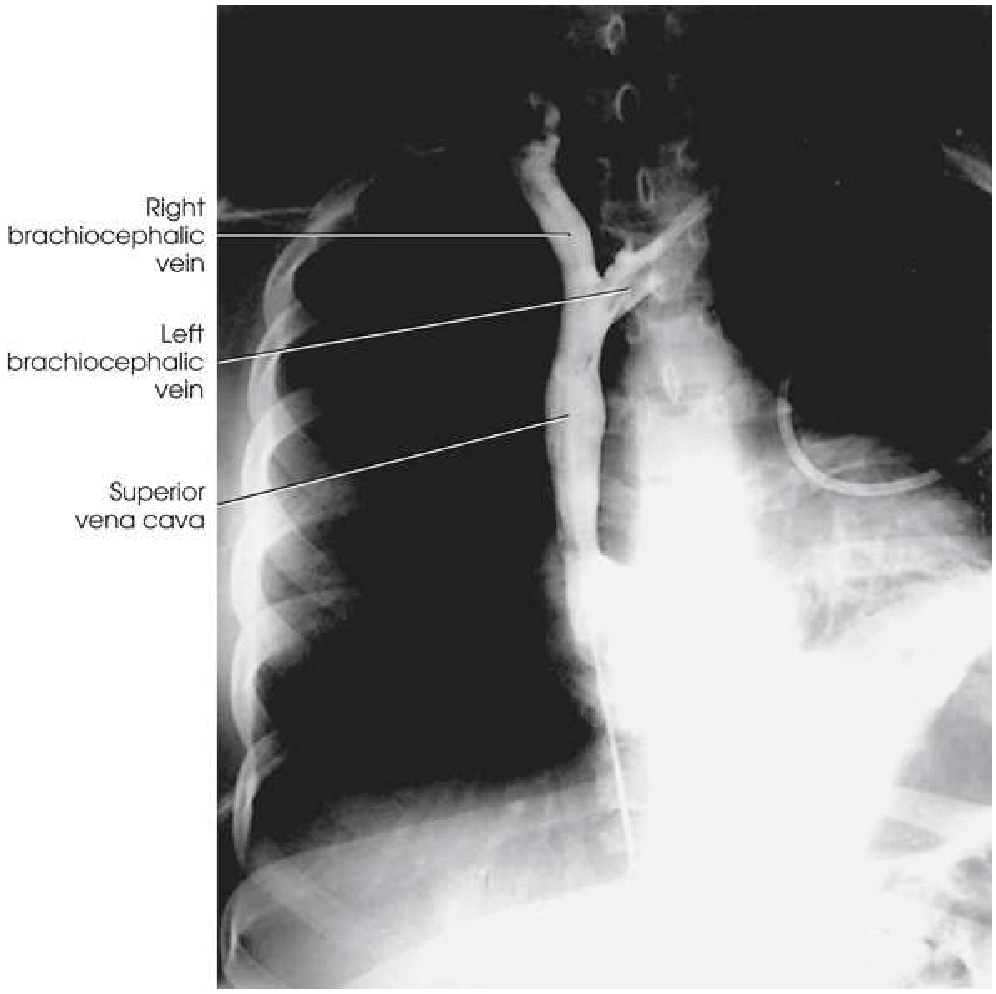


FIG. 27.58 AP superior vena cava.

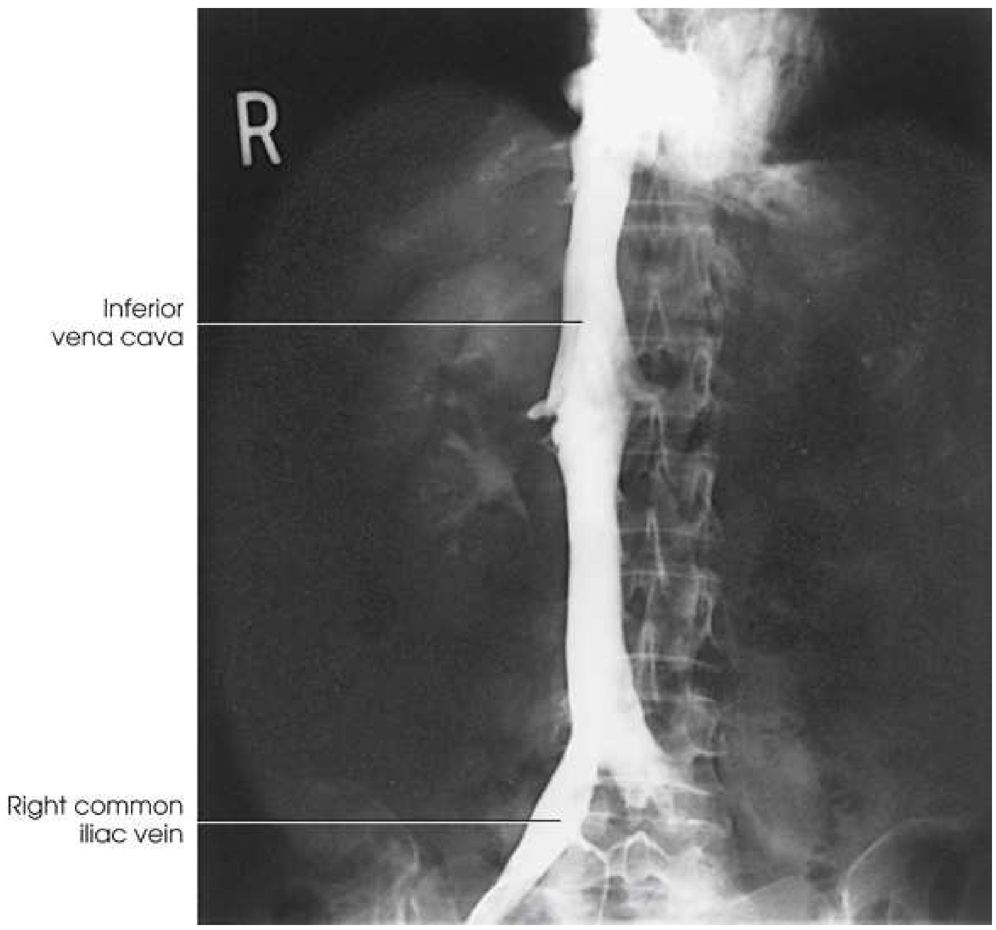


FIG. 27.59 AP inferior vena cava.

Visceral Venography

The visceral veins are often visualized by extending the imaging program of the corresponding visceral arterial injection. The veins that drain the small bowel are normally visualized by extending the imaging program of a superior mesenteric arteriogram. Portal venography (Fig. 27.60) can be performed by injecting the portal vein directly from a percutaneous approach, but it is usually accomplished by late-phase imaging of a splenic artery injection or SMA injection.

Hepatic Venogram

Hepatic venography is usually performed to rule out stenosis or thrombosis of the hepatic veins. These veins can also be catheterized to obtain pressure measurements from the interior of the liver. The hepatic veins carry blood from the liver to the IVC. (The portal vein carries nutrient-rich blood from the viscera to the liver.) The hepatic veins are most easily catheterized from a jugular vein or an upper limb vein approach, but a femoral vein approach may also be used.

- Place the patient in the supine position for AP or PA projections that include the liver tissue and the extreme upper IVC (Fig. 27.61).
- Make exposures at the end of suspended expiration.

Renal Venogram

Renal venography is usually performed to rule out thrombosis of the renal vein. The renal vein is also catheterized for blood sampling, usually to measure the production of renin, an enzyme produced by the kidney when it lacks adequate blood supply. The renal vein is most easily catheterized from a femoral vein approach.

- Place the patient in the supine position for a single-plane AP or PA projection.
- Center the selected kidney to the image receptor, and collimate the field to include the kidney and area of the IVC (Fig. 27.62).
- Make exposures at the end of suspended expiration.

Over the years the role of catheter-directed angiography as a primary diagnostic tool has diminished as non-invasive diagnostic imaging techniques have evolved. The majority of angiography procedures today are vascular interventional procedures; however, conventional angiographic methods, such as vascular access, guidewire and catheter manipulations, and precise imaging, will always be the foundation for vascular interventional procedures.

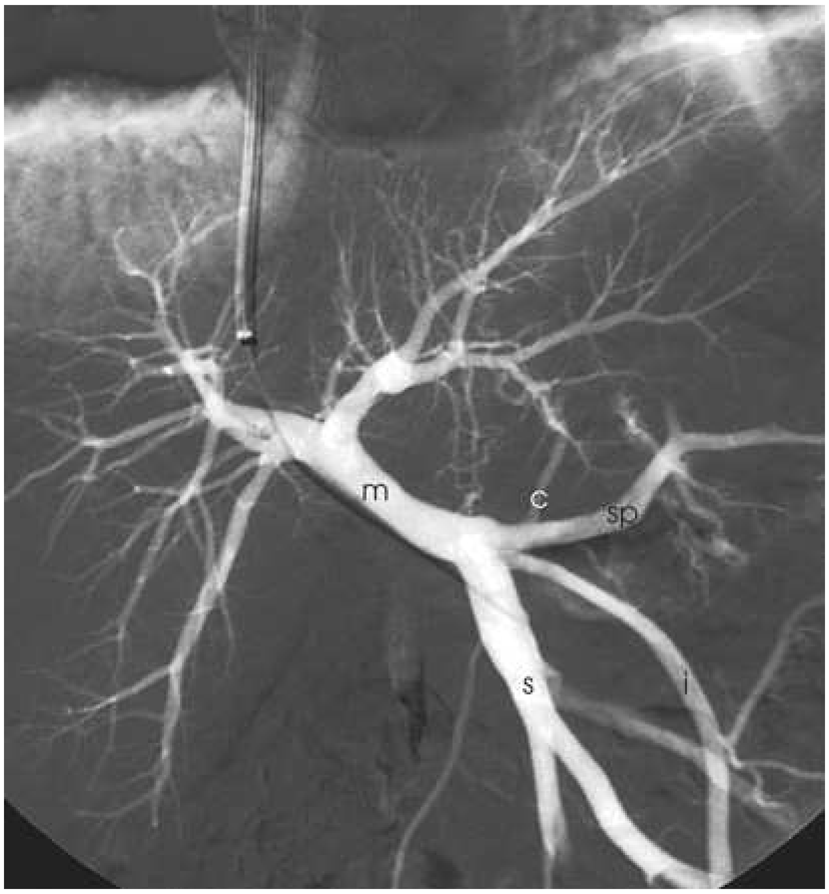


FIG. 27.60 Portal venogram. *c,* Coronary varices; *i,* inferior mesenteric vein; *m,* main portal vein; *s,* superior mesenteric vein; *sp,* splenic vein.

A portal venogram shows the portal vein directly injected. The parts labeled on the venogram are as follows: coronary varices, inferior mesenteric vein, main portal vein, superior mesenteric vein, splenic vein.

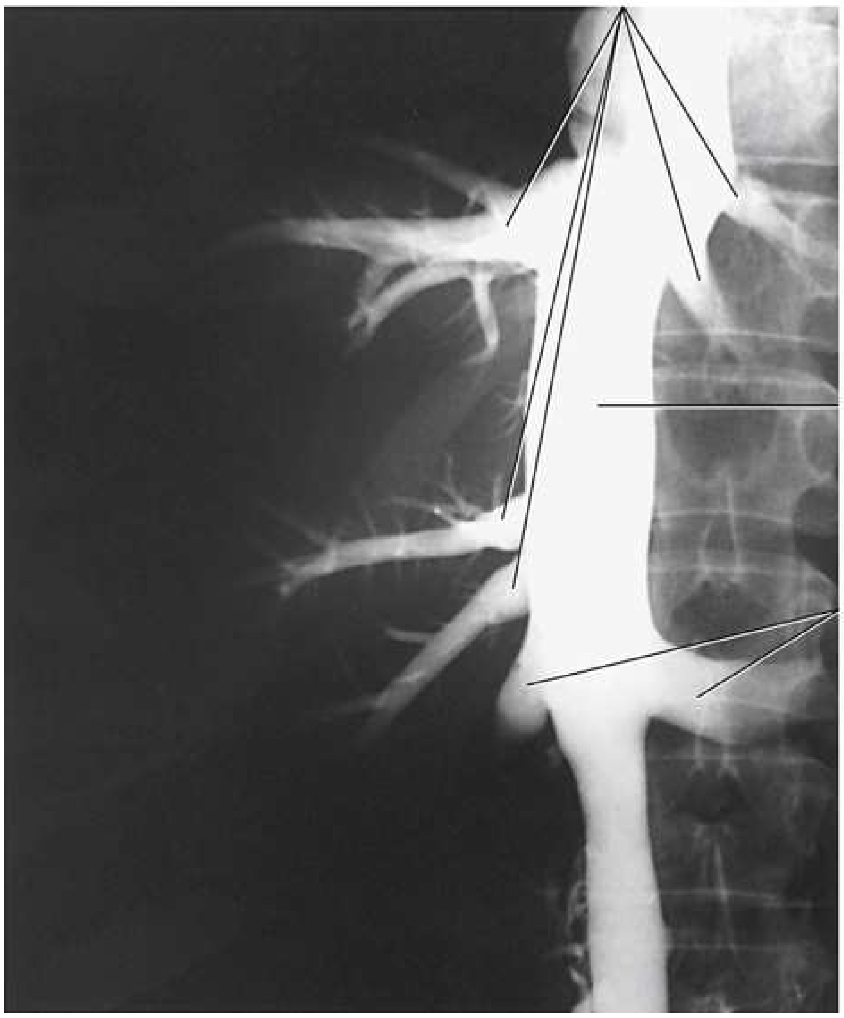


FIG. 27.61 Hepatic vein visualization from reflux from inferior vena cava injection. (Note reflux into bilateral renal veins.)

FIG. 27.62 Selective left renal venogram. AP projection.

Interventional Radiology

Interventional radiology has a therapeutic rather than diagnostic purpose in that it intervenes in, or interferes with, the course of a disease process or other medical condition. Interventional radiologic procedures reduce hospital stays in many patients and help some patients avoid surgery, with consequent reductions in medical costs. Since the conception of this form of radiology in the early 1960s, its realm has become so vast and sophisticated that publishers of periodicals struggle to keep abreast of this rapidly advancing specialty.

Every interventional radiologic procedure must include two integral processes. The first is the interventional or medical side of the procedure, in which a highly skilled interventionalist uses wires, catheters, and special medical devices (e.g., occluding coils, stents) to improve the patient's status or condition. The second process involves the use of fluoroscopy and radiography to guide and document the progress of the steps taken during the first process. A radiologic technologist must receive special education in either vascular interventional or cardiac interventional radiography. This skilled technologist has an important role in assisting the physician in interventional procedures.

The more frequently performed interventional procedures are described in this section. Specific cardiac interventions are described later in the chapter. Resources containing more detailed information are cited in the selected bibliography at the end of the chapter.

Percutaneous Transluminal Angioplasty and Stenting

PTA is a therapeutic radiologic procedure designed to dilate or reopen stenotic or occluded areas within a vessel using a catheter introduced by the Seldinger technique. In 1964, Dotter and Judkins[5] first described PTA using a coaxial catheter method. First, a guidewire is passed through the narrowed area of a vessel. A smaller catheter is then passed over the guidewire through the stenosis to begin the dilation process. Finally, a larger catheter is passed over the smaller catheter to cause further dilation. This method is referred to as the "Dotter method." Although this method can achieve dilation of stenosis, it has the significant disadvantage of creating an arteriotomy as large as the dilating catheters, and it is seldom used as a first-line therapy.

In 1974, Grüntzig and Hopff[6] introduced the double-lumen, balloon-tipped catheter. One lumen allows the passage of a guidewire and fluids through the catheter. The other lumen communicates with a balloon at the distal end of the catheter. When inflated, the balloon expands to a size much larger than the catheter. Double-lumen angioplasty balloon catheters are available in sizes ranging from 3 to 9 Fr, with attached balloons varying in length and expanding to diameters of 2 to 20 mm or more (Fig. 27.63).

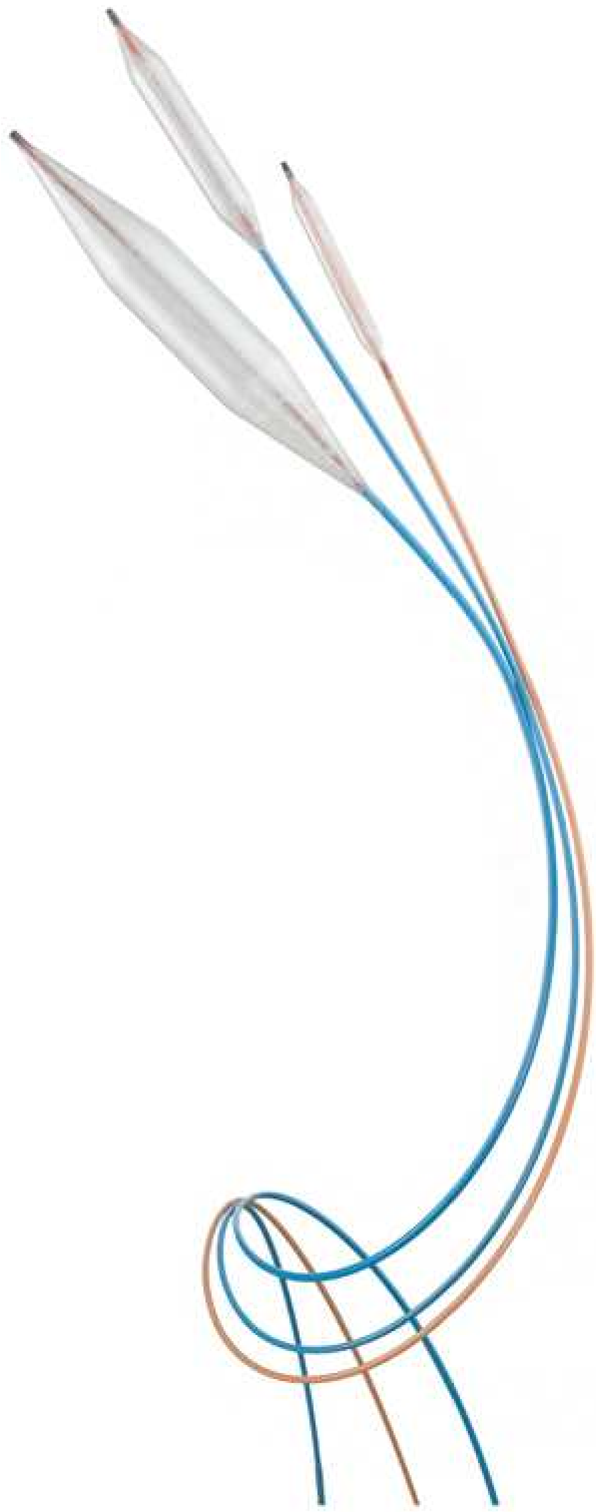


FIG. 27.63 Balloon angioplasty catheters with varied diameters and lengths. 2014 C. R. Bard, Inc. Used with permission. Bard is a registered trademark of C. R. Bard, Inc.

Three balloon angioplasty catheters are of different colors and has different ends. One has a narrow end. The other one has a slightly broad end with a pointy tip and the last one has a very broad end with a pointy tip.

Fig. 27.64 illustrates the process of *balloon angioplasty*. The stenosis is initially identified on a previously obtained angiogram. The balloon diameter used for a procedure is often the measured diameter of the normal artery adjacent to the stenosis. The angioplasty procedure is often performed at the same time and through the same catheterization site as the initial diagnostic examination.

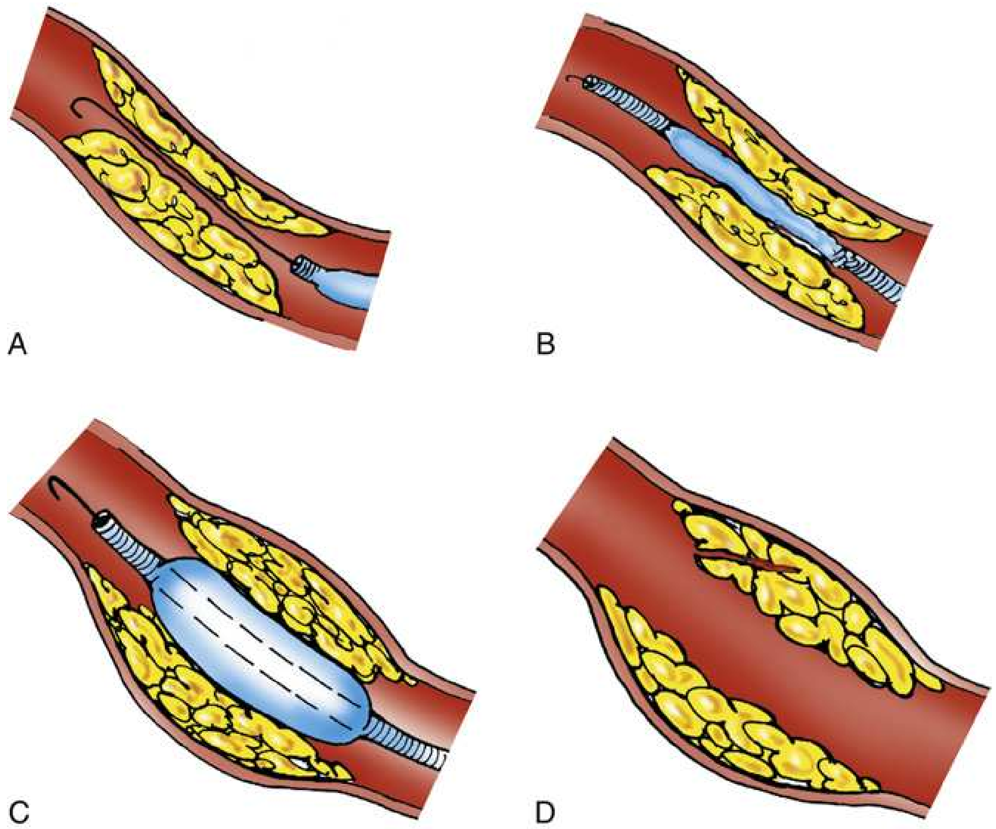


FIG. 27.64 Balloon angioplasty of atherosclerotic stenosis. (A) Guidewire advanced through stenosis. (B) Balloon across stenosis. (C) Balloon inflated. (D) Postangioplasty stenotic area.

Balloon angioplasty of atherosclerotic stenosis. (A) The guidewire is advanced through stenosis. (B) The balloon is inserted across stenosis. (C) The balloon is inflated and is between the yellow region. (D) The postangioplasty stenotic area has yellow regions on either side.

After the guidewire is positioned across the stenosis, the angiographic catheter is removed over the wire. The angioplasty balloon catheter is introduced and directed through the stenosis over the guidewire. The balloon is usually inflated with a diluted contrast media mixture for 15 to 45 seconds, depending on the degree of stenosis and the vessel being treated. The balloon is deflated and repositioned or withdrawn from the lesion. Contrast media can be injected through the angioplasty catheter for a repeat angiogram to determine whether or not the procedure was successful. The success of the angioplasty procedure may also be determined by comparing transcatheter blood pressure measurements from a location distal and a location proximal to the lesion site. Nearly equal pressures indicate a reopened stenosis.

FIG. 27.65 Digital subtracted images of the abdominal aortogram and bilateral iliac arteries. (A) High-grade stenosis of right common iliac artery *(arrow)*. (B) Abdominal aortogram and bilateral iliac arteries, postangioplasty, showing widely patent iliac system.

(A) A radiograph shows the abdominal aortogram and bilateral iliac arteries. The right common iliac artery is indicated by a black arrow. The right common iliac artery and its branches appear radiopaque. (B) A radiograph shows the abdominal aortogram and bilateral iliac arteries.

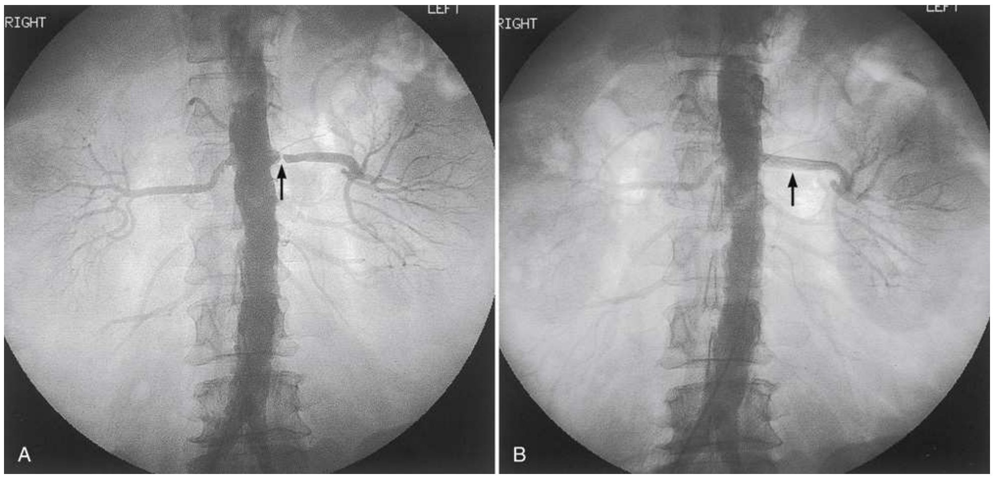


FIG. 27.66 Abdominal aortogram before and after angioplasty of the left renal artery. (A) High-grade stenosis of left renal artery *(arrow)*. (B) Postangioplasty and stent placement within left renal artery *(arrow)*.

(A) A radiograph shows the abdominal aortogram of the renal artery. It appears darker than the surrounding region. The left renal artery is indicated by a black arrow. There is a gap between it. (B) A radiograph shows the abdominal aortogram of the renal artery. It appears darker than the surrounding region. The left renal artery is indicated by a black arrow. There is no gap between it.

Transluminal angioplasty can be performed in virtually any vessel that can be reached percutaneously with a catheter (Figs. 27.65 and 27.66). In 1978, Molnar and Stockum[7] described the use of balloon angioplasty for dilation of strictures within the biliary system. Balloon angioplasty is also conducted in venous structures, ureters, and the gastrointestinal tract.

Balloon angioplasty has been used successfully to manage various diseases that cause arterial narrowing. The most common form of arterial stenosis treated by transluminal angioplasty is caused by atherosclerosis. Dotter and Judkins[5] speculated that this atheromatous material was soft and inelastic and could be compressed against the artery wall. Later research showed, however, that the plaque does not compress. If plaque surrounds the inner diameter of the artery, the plaque cracks at its thinnest portion as the arterial lumen is expanded. Continued expansion cracks the inner layer of the arterial wall, the *intima*, then stretches and tears the middle layer, the *media*, and finally stretches the outer layer, the *adventitia.* The arterial lumen is increased by permanently enlarging the artery's outer diameter. Restenosis, when it occurs, is usually caused by deposits of new plaque rather than arterial wall collapse. Angioplasty involving the arteries of the heart, *percutaneous transluminal coronary angioplasty* (*PTCA*), is generally performed in the cardiac catheterization laboratory. PTCA is discussed later in this chapter.

Another percutaneous treatment of vessel stenoses is the placement of vascular stents. A vascular *stent* is composed of a metal material, stainless steel, or nitinol that can be covered or uncovered with a surgical graft material. The stent is introduced through a catheter system and positioned across a stenosis. When deployed, the stent applies *radial force* to the stenosis to keep the narrowed area spread apart. These devices remain in the vessel permanently (Figs. 27.67 and 27.68).

The success of PTA and/or stent placement in the management of atherosclerosis has made it a significant alternative to surgical procedures in the treatment of this disease. PTA is not indicated in all cases, however. Long segments of occlusion may be best treated by surgery. PTA has a lower risk than surgery but is not totally risk-free. Generally, patients must be able to tolerate the surgical procedure that may be required to repair vessel damage that can be caused by PTA. Unsuccessful transluminal angioplasty and stent procedures rarely prevent or complicate necessary subsequent surgery. In selected cases, the procedure is effective and almost painless and can be repeated as often as necessary, with no apparent increase in risk to the patient. The recovery time is often no longer than the time required to stabilize the arteriotomy site, usually a matter of hours, and general anesthesia is normally not required.

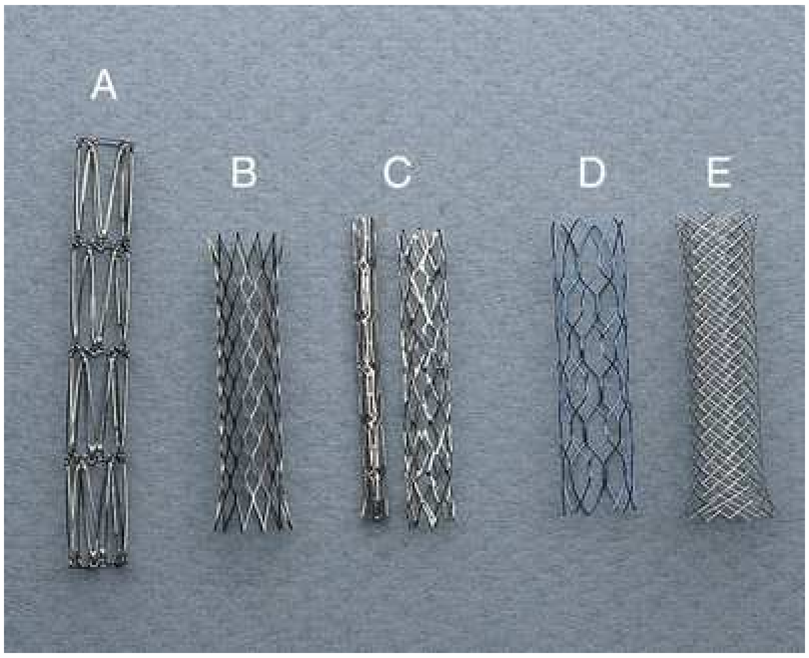


FIG. 27.67 Intravascular stents. (A) Gianturco-Rosch biliary Z-stent. (B) Memotherm. (C) Palmaz; unexpanded and expanded. (D) Symphony. (E) Wallstent.

FIG. 27.68 Stent and balloon for angioplasty shown collapsed and inflated.

Abdominal Aortic Aneurysm Endografts

An interventional therapy started in the late 1990s treats abdominal aortic aneurysms (AAAs) with a transcatheter approach and stenting. AAAs historically have been treated with an open repair of the aneurysm by a vascular surgeon. This approach has risks associated with abdominal surgery and a long hospital stay for recovery of the incision. The stent graft or endograft is a metal stent covered in synthetic graft material that comes in pieces or one intact device depending on the manufacturer (Fig. 27.69). A cutdown approach to bilateral femoral arteries is done, and sheaths and delivery catheters are advanced to deliver the device. A large amount of planning is done before a patient can undergo this approach to treating AAA. Patients preferably should have an AAA that is infrarenal or occurring below the renal arteries. The endograft would occlude any arteries originating from the portion of the aorta being treated. Some newer AAA endograft devices are designed to treat aneurysms that extend to involve the renal artery and even mesenteric artery origins. These fenestrated endografts are usually custom made for each individual patient (Fig. 27.70).

FIG. 27.69 Stent graft or endograft used to repair aneurysm in the aorta and iliac region.

Preliminary abdominal and iliac arteriograms may be obtained using a calibrated catheter that the interventionalist or vascular surgeon can use for measuring (Fig. 27.71). CT is the preferred imaging modality and is used as the primary source for measurements. This procedure is usually performed in a hybrid angiography suite with OR capabilities to reduce the need to move the patient should complications arise requiring open surgery. Alternatively, they are performed in the OR using a portable C-arm with DSA capability.

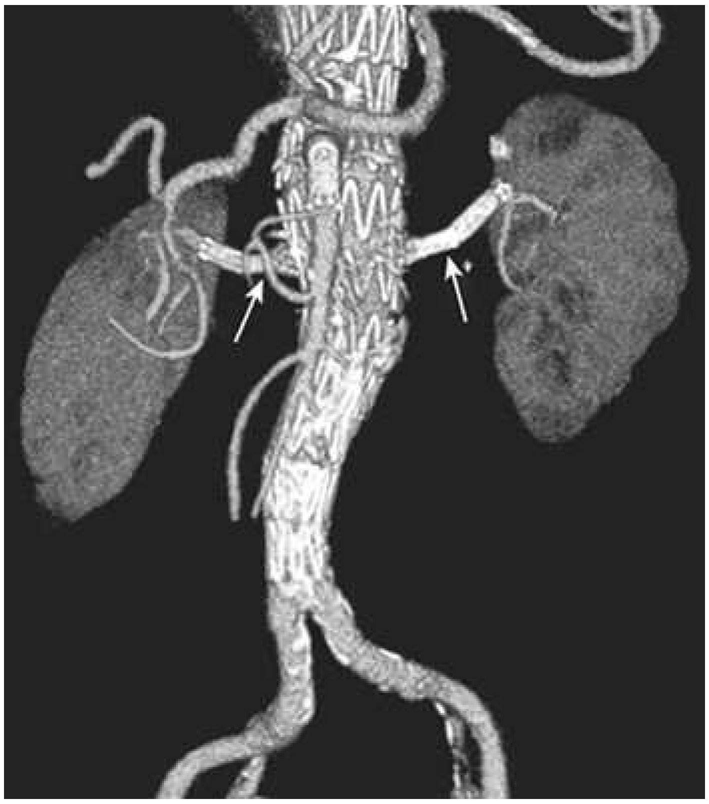


FIG. 27.70 Fenestrated, or branched, endograft. Volume rendering of a computed tomographic angiography showing a fenestrated endograph (Zenith, Cook, Bloomington, IL). There are extensions into both renal arteries *(arrows)*, the superior mesenteric artery, and celiac artery. From Kaufman JA: Abdominal aorta and pelvic arteries. In Kaufman JA, Lee MJ, editors: *Vascular and interventional radiology: the requisites*, ed 2, Philadelphia, 2014, Elsevier. Courtesy Roy Greenberg, MD, Cleveland, OH.

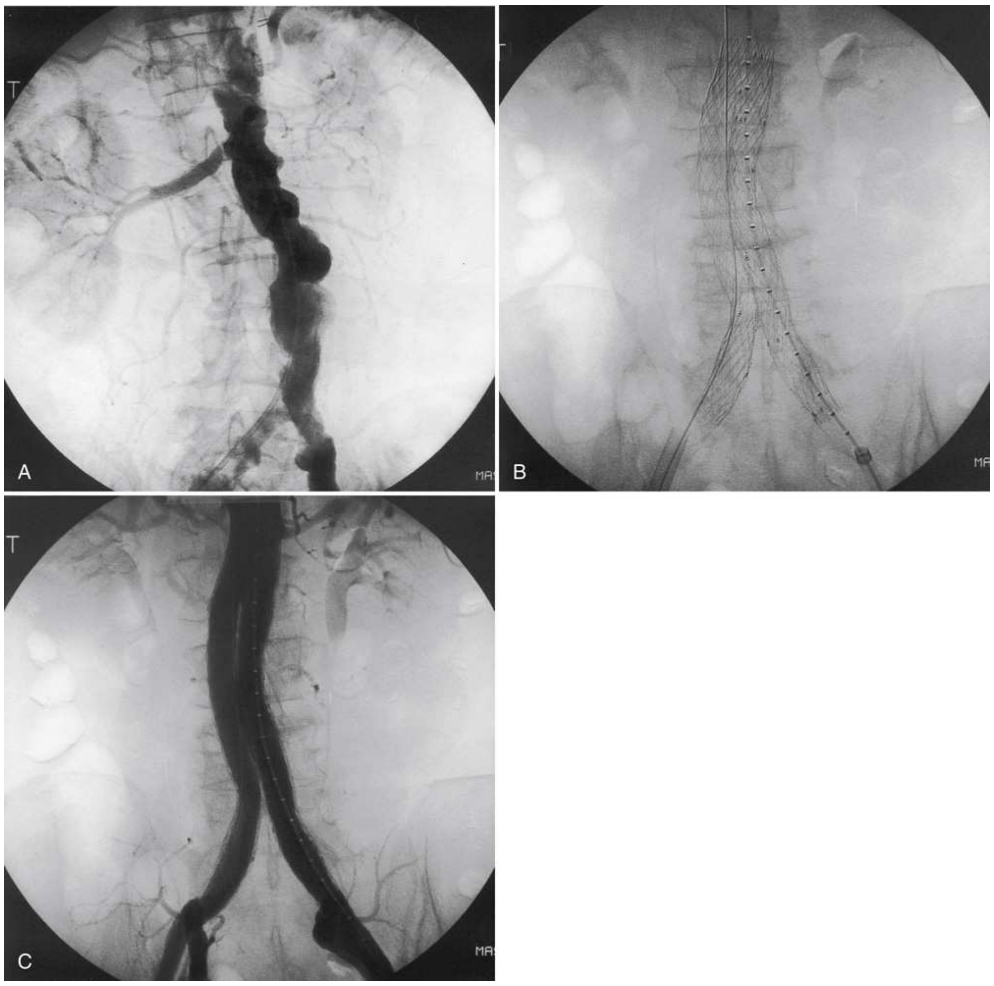


FIG. 27.71 (A) Abdominal aortogram. (B) Placement of endograft. (C) Follow-up aortogram showing repair.

(A) A radiographic image shows a long tubular irregular structure in the middle. (B) A radiographic image shows a net like structure with two branched ends. (C) A radiographic image shows two long tubular structure.

Transcatheter Embolization

Transcatheter embolization was first described by Brooks[8,9] in 1930. He described vessel occlusion for closure of arteriovenous fistula. Transcatheter embolization involves the therapeutic introduction of various substances to occlude or drastically reduce blood flow within a vessel (Box 27.1). The three main purposes for embolization are (1) to stop active bleeding sites, (2) to control blood flow to diseased or malformed vessels (e.g., tumors or AVMs), and (3) to stop or reduce blood flow to a particular area of the body before surgery.

Box 27.1 Lesions amendable to embolization

- Aneurysm
- Pseudoaneurysm
- Hemorrhage
- Neoplasms
  - Malignant
  - Benign
- Arteriovenous malformations
- Arteriovenous fistula
- Infertility (varicocele)
- Impotence owing to venous leakage
- Redistribution of blood flow

The patient's condition and the situation must be considered when choosing an embolic agent. The interventionalist usually identifies the appropriate agent to be used. Embolic agents must be administered with care to ensure that they flow to the predetermined vessel or target without embolizing nontarget vessels. Embolization can be a permanent treatment; the effects on the lesion are irreversible. Many embolic agents are available (Box 27.2), and the choice of agent depends on whether the occlusion is to be temporary or permanent (Table 27.1).

TABLE 27.1

Particulate agent sizes

Agent	Size
Gelfoam powder	40–60 μ
Gelfoam sponges	Pledgets-torpedoes
Avitene	100–150 μ
Polyvinyl alcohol	100–1200 μ
Embosphere	100–1200 μ

Box 27.2 Embolic agents

Particulate agents

- Polyvinyl alcohol
- Embosphere
- Avitene
- Gelfoam

Metal coils

- Gianturco coils
- Metal coils
- Detachable coils
  - Platinum
  - Coated

Vascular occluder plug

- Liquid agents (occluding, sclerosing)
  - Ethanol
  - Thrombin
  - Hypertonic glucose
  - Sodium tetradecyl sulfate
  - Ethibloc
  - EVAL
  - Onyx
- Detachable balloons
  - Latex—Debrun
  - Silicone—Hieshima
- Liquid adhesives
  - *N*-butyl 2-cyanoacrylate
- Autologous material

Temporary agents such as Gelfoam [b] or Avitene may be used as a means to reduce the pressure head of blood to a specific site. These temporary agents reduce flow into a bleeding site so that hemostasis may be achieved. Temporary agents can also be used to prevent inadvertent embolization of normal vessels.

Vasoconstricting drugs can be used to reduce blood flow temporarily. Vasoconstrictors such as vasopressin (Pitressin) drastically constrict vessels, resulting in hemostasis.

When permanent occlusion is desired, as in trauma to the pelvis that causes hemorrhage or when vascular tumors are supplied by large vessels, stainless steel coils may be used. This coil (Fig. 27.72), which functions to produce thrombogenesis, is simply a looped segment of guidewire with Dacron fibers attached to it. The coil is initially straight and is easily introduced into a catheter that has been placed into the desired vessel. This coil is then deployed by being pushed out of the catheter tip with a guidewire. The coil assumes its looping shape immediately as it enters the bloodstream. It is important that the catheter tip be specifically placed in the vessel so that the coil springs precisely into the desired area. Numerous coils can be placed as needed to occlude the vessel. Detachable coils are mounted on a wire and are deployed either manually or with an electrical current to allow for more precise placement. If the placement is not correct, the coil can be removed without being deployed. Newer generations of coils promise more effective embolization by using various coatings on the outside of the coil. One such coil uses a coating that initiates a foreign body/scarring response. Another type of coil is coated with an expansile gel that swells in the presence of blood, occluding the vessel (Fig. 27.73). Another permanent occlusion device is a vascular plug, which is deployed by manually unscrewing the device from the delivery wire when in the desired position within the vessel. The vascular plug is used for large-vessel occlusion.

Fig. 27.74 shows a hypervascular uterine fibroid that was causing significant symptoms. Embolization of this uterine fibroid was successfully accomplished with total occlusion of the lesion. Embolization combined with arterial catheter directed infusion of chemotherapy drugs is known as *chemoembolization.* This is most commonly performed for treatment of primary and metastatic hepatic lesions. In recent years embolic spheres or *microspheres* have been designed to absorb therapeutic agents, such as chemotherapy drugs, to ensure a more controlled and sustained release of the drug.[10] *Radioembolization* is also used to treat hepatic lesions. This procedure uses radioactive microspheres to both cut off blood supply to the tumor and to destroy tumor tissue by emitting powerful, but short, penetrating beta radiation.

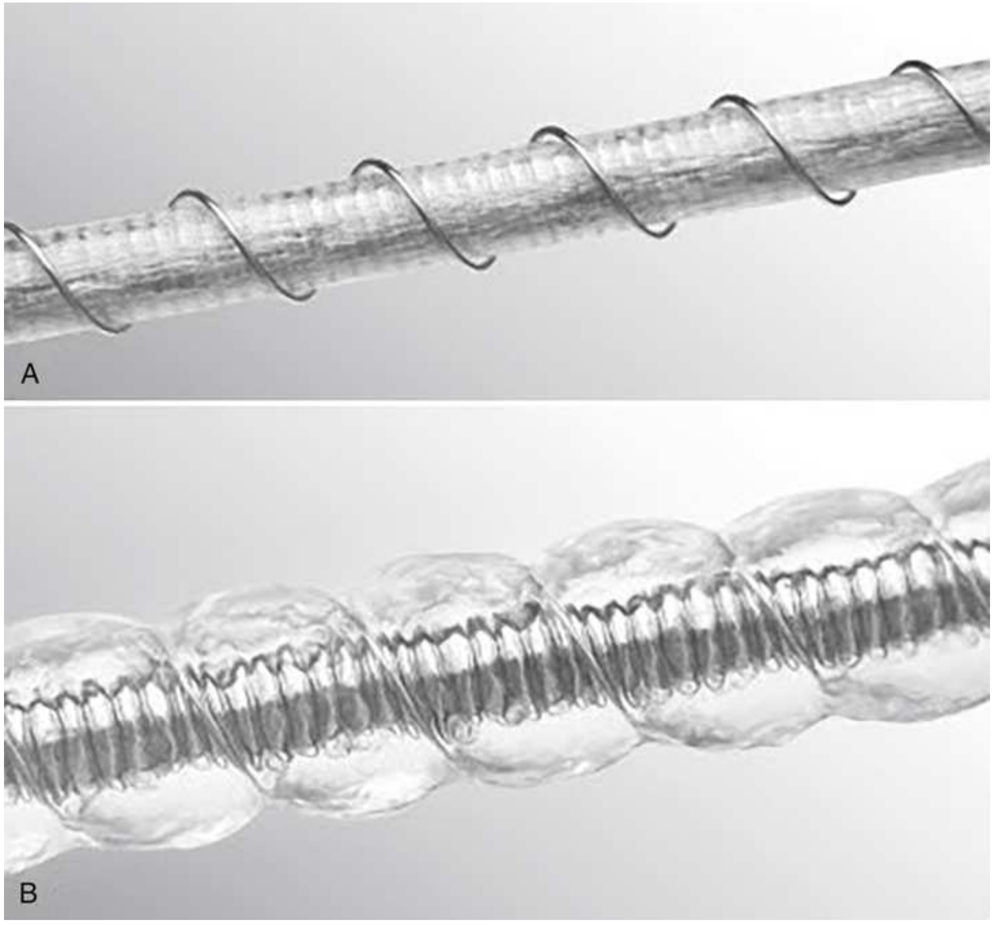


FIG. 27.73 Coil coated with a hydrogel that swells when in contact with blood. (A) Coil as packaged. (B) Coil after hydration. The process requires approximately 20 minutes in the blood to complete. Courtesy MicroVention Inc., Tustin, CA. From Kaufman JA: Vascular interventions. In Kaufman JA, Lee MJ, editors: *Vascular and interventional radiology: the requisites*, ed 2, Philadelphia, 2014, Elsevier.

Transcatheter embolization is also used in the cerebral vasculature of the brain. Vascular lesions, such as aneurysms, AVMs, and tumors, can be managed using multiple embolic agents, PVA, or tissue adhesive. Microcatheters (2 or 3 Fr) are passed through a larger catheter, a coaxial system that is positioned in the cerebral vessels. The smaller catheter is manipulated into the appropriate cerebral vessel, and if possible, into the aneurysm itself. The embolic materials are delivered through the microcatheter until the appropriate embolization is achieved (Fig. 27.75).

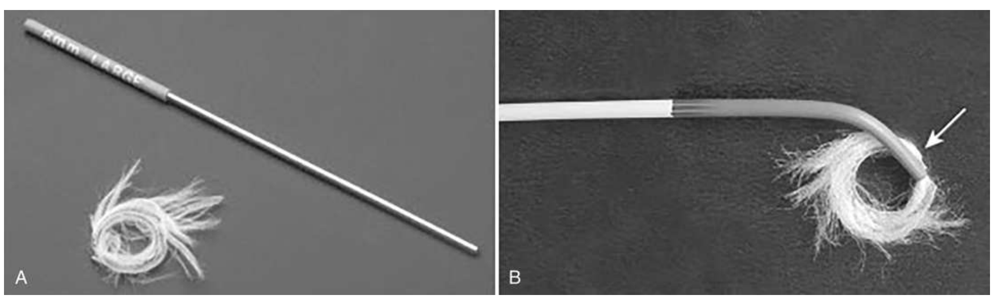


FIG. 27.72 Embolization coils. (A) Coils are packaged preloaded in tubes. Shown is a Gianturco stainless steel coil with polyester fibers. (B) The coil is delivered through a catheter *(arrow)*. The coil can be pushed with a guidewire, or injected. A, Courtesy Cook Group, Bloomington, IN. From Kaufman JA: Vascular interventions. In Kaufman JA, Lee MJ, editors: *Vascular and interventional radiology: the requisites*, ed 2, Philadelphia, 2014, Elsevier.

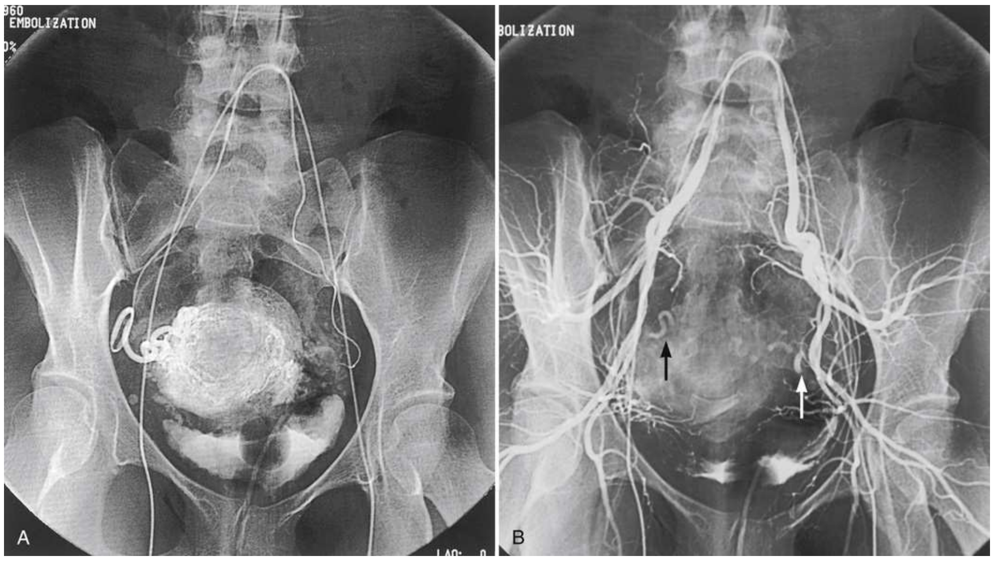


FIG. 27.74 Hypervascular uterine fibroid. (A) Bilateral uterine artery injections using coaxial microcatheters, showing hypervascular uterine fibroid. (B) Bilateral iliac artery injections, postembolization, showing total occlusion of both uterine arteries *(arrows)*.

(A) A radiographic image of the pelvis shows a radiopaque region in the center and microcatheters passing around it. (B) A radiographic image of the pelvis shows the bilateral iliac artery. It appears radiopaque.

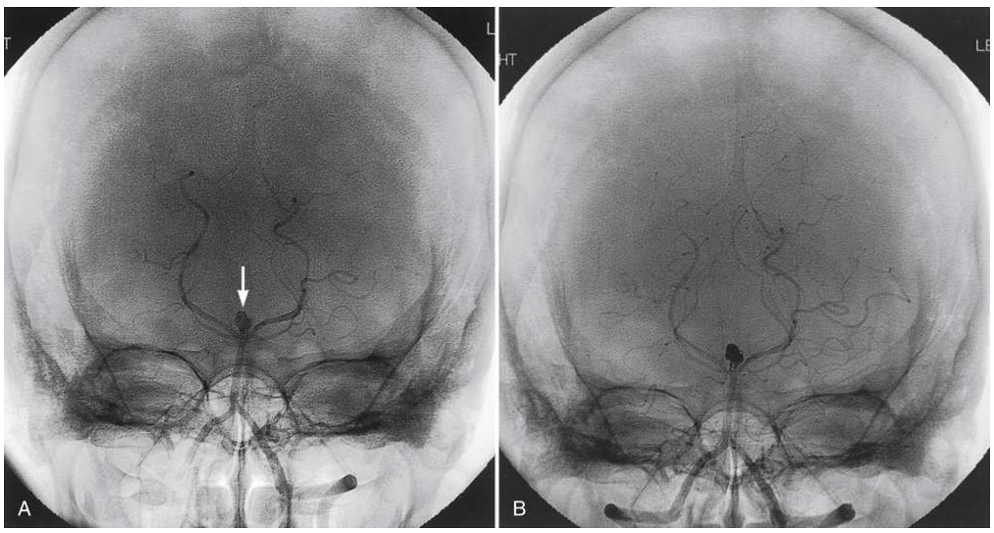


FIG. 27.75 Left vertebral artery injection. (A) Basilar tip aneurysm *(arrow)*. (B) Left vertebral artery injection postembolization with the use of Guglielmi detachable coils (GDCs).

(A) A radiographic image shows a dark circular region near the left vertebral artery. It is indicated by a white arrow. (B) A radiographic image shows a black circular region near the left vertebral artery.

Vena Cava Filter Placement

Vena cava filters are designed to trap venous emboli from migrating to the pulmonary arteries causing a pulmonary embolus (PE). Most commonly, filters are placed in the IVC, although filters can also be placed in the SVC when necessary. A PE is a blood clot that forms as a thrombus and usually develops in the deep veins of the leg. When such a thrombus becomes dislodged and migrates, it is called an *embolus.* An embolus originating in the leg may migrate through the IVC and right side of the heart and finally lodge in the pulmonary arteries. A filter can be percutaneously placed in the IVC to trap such an embolus.

Lower limb vein thrombosis is not an indication for IVC filter placement. Normally, blood-thinning medications are administered to treat deep vein thrombosis. When anticoagulant therapy is contraindicated due to increased risk for hemorrhage, filter placement may be indicated. Filter placement itself has associated risks, including thrombosis of the vein through which the filter is introduced and thrombosis of the vena cava. These risks normally are not life threatening. IVC filter placement is not a treatment for deep vein thrombosis of the leg but a therapy intended to reduce the chance of pulmonary embolism.

The idea of interrupting the pathway of an embolus is not a new one. Surgical interruption of the common femoral vein was first described in 1784, and surgical interruption of the IVC was described in 1868. These procedures and the partial surgical interruption procedures that evolved from them had a high rate of complications, not only owing to the surgical process but also owing to inadequate venous drainage from the lower limbs. Catheterization technology led to the development of detachable balloons for occluding the IVC, but that procedure also resulted in complications because of inadequate venous flow from the lower limbs.

The first true filter designed to trap emboli while maintaining vena cava patency was introduced in 1967 by Mobin-Uddin. It consisted of six metal struts joined at one end to form a conical shape that was covered by a perforated plastic canopy. Because of this filter's striking resemblance to an open umbrella, vena cava filters of all types for many years were referred to as "umbrella filters."

Today IVC filters are available in various shapes. All of these filters are initially compacted inside an introducer catheter delivery system and assume their functional shape as they are released (Fig. 27.76). The introducers are passed through sheaths ranging in size from 6 to 15 Fr.

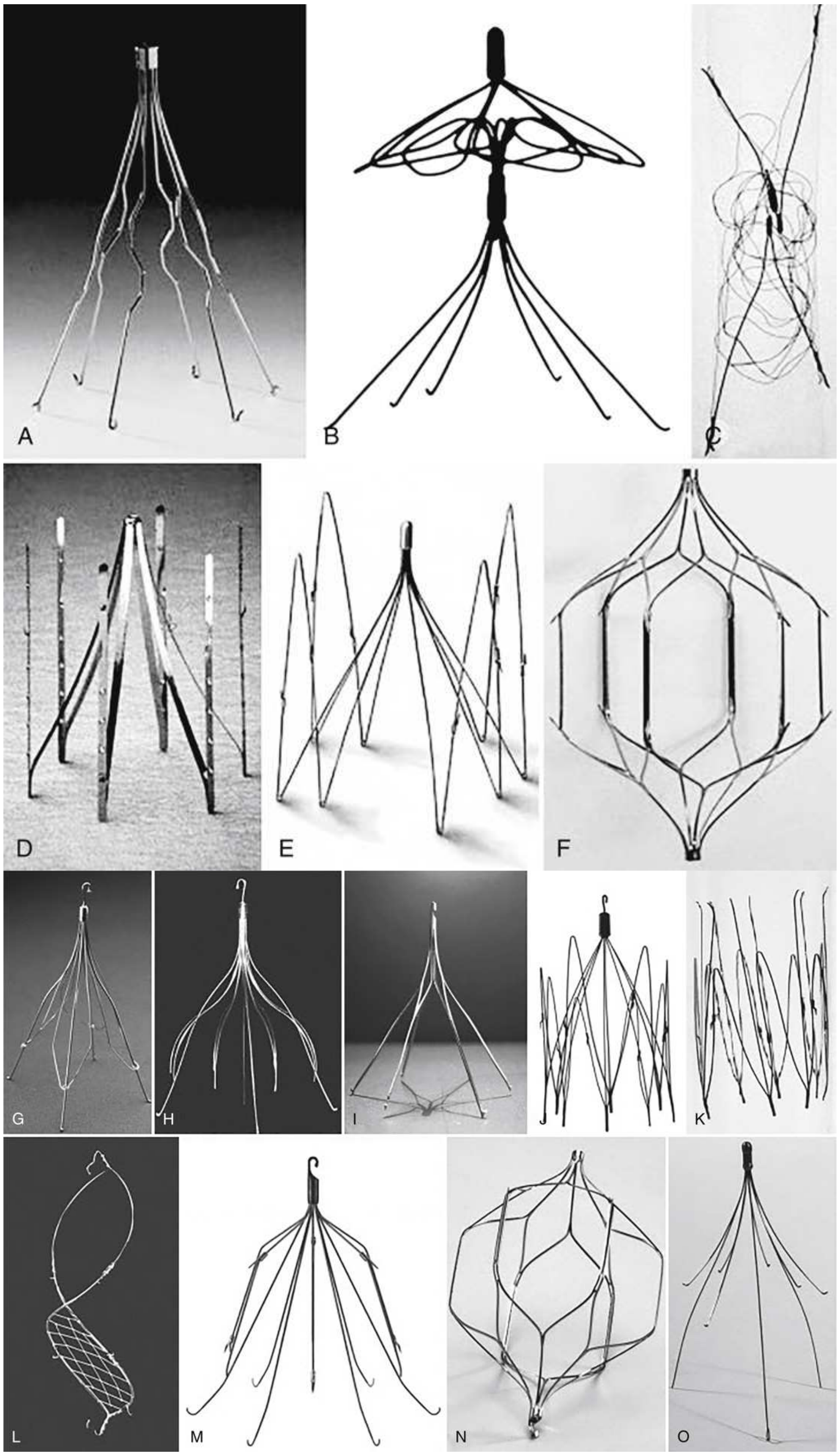


FIG. 27.76 Examples of permanent inferior vena cava (IVC) filters. (A) Greenfield (Boston Scientific); (B) Simon Nitinol (Bard); (C) Bird's Nest (Cook); (D) Vena Tech (B. Braun Medical); (E) Vena Tech LP (B. Braun Medical); (F) TrapEase (Cordis Corporation). Optional IVC filters.(G) Gunther Tulip (Cook); (H) Celect (Cook); (I) Option (Argon Medical); (J) Convertible filter in closed position (B. Braun Medical); (K) Convertible filter with cap removed (B. Braun Medical); (L) Crux filter (Crux BioMedical); (M) Meridian (Bard); (N) OPTEASE (Cordis); (O) ALN (ALN Implants). From Kaufman JA: Inferior vena cava and tributaries. In Kaufman JA, Lee MJ, editors: *Vascular and interventional radiology: the requisites*, ed 2, Philadelphia, 2014, Elsevier.

(A) A permanent inferior vena cava filter has six legs and a conical top. (B) A permanent inferior vena cava filter has six legs and a umbrella like structure on top. (C) A permanent inferior vena cava filter has two pointy strings on the top and at the bottom. (D) A permanent inferior vena cava filter has multiple ends. (E) A permanent inferior vena cava filter. (F) A permanent inferior vena cava filter has a cage like structure. (G) A permanent inferior vena cava filter has four legs. (H) A permanent inferior vena cava filter has six legs and a conical top. (I) A permanent inferior vena cava filter has six legs and a umbrella like structure on top. (J) A permanent inferior vena cava filter has two pointy strings on the top and at the bottom. (K) A permanent inferior vena cava filter has multiple ends. (L) A permanent inferior vena cava filter has the shape of the number 8. One of the side has a net like structure.. (M) A permanent inferior vena cava filter has a cage like structure. (N) A permanent inferior vena cava filter has a cage like structure. (O) A permanent inferior vena cava filter has six legs and a conical top.

Most filters are designed as a conical shape to trap clots in the central lumen. They are designed to be placed in vena cava ranging up to 20 to 30 mm in diameter. Fig. 27.76 shows the currently available IVC filters. Several newer filters are designed to be retrievable within a specified time frame. These are known as optional filters, as physicians have the option to remove the filter or leave the filter in permanently, depending on the risks and benefits to the patient. These retrievable filters have hooks, either at the top or bottom, that allow them to be grasped by a catheter snare device and be removed percutaneously (Fig. 27.77).

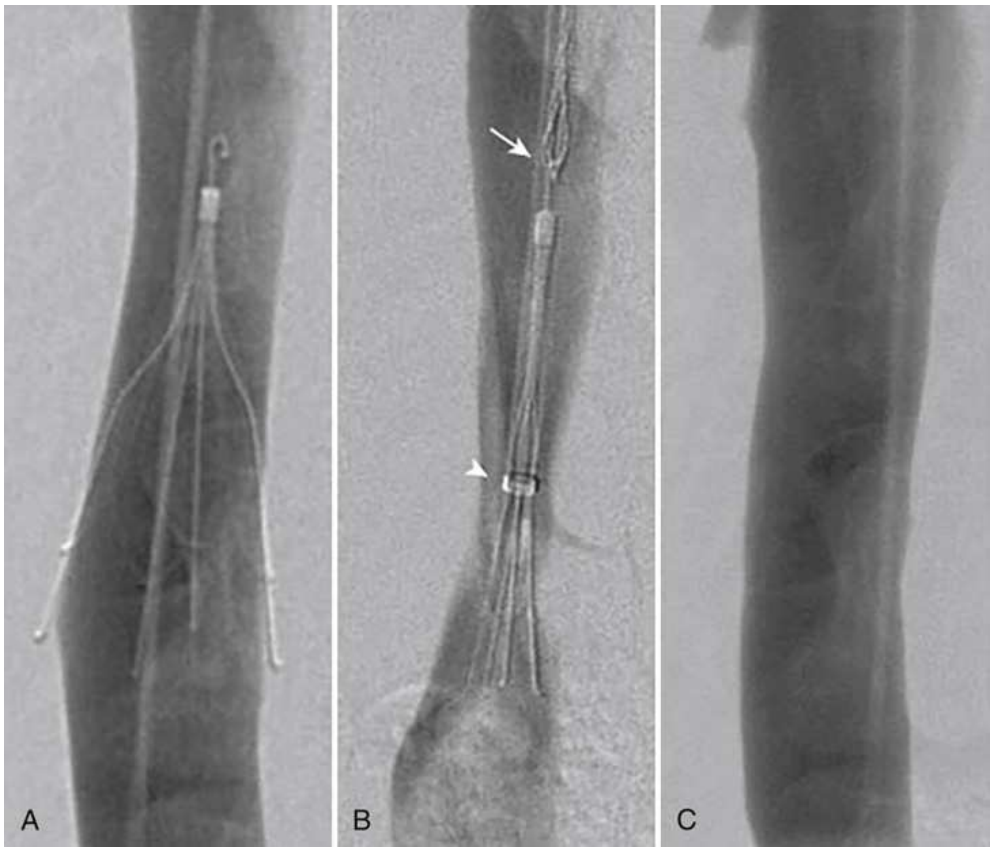


FIG. 27.77 The process of filter retrieval. (A) Initial cavogram confirming patency of the filter and inferior vena cava (IVC) (Gunther Tulip, Cook Medical). (B) The filter has been snared *(arrow)* and the sheath *(arrowhead)* advanced over the filter to constrain it. The sheath is advanced over the feet of the filter for safe removal. (C) Completion cavogram after filter removal showing a normal IVC. From Kaufman JA: Inferior vena cava and tributaries. In Kaufman JA, Lee MJ, editors: *Vascular and interventional radiology: the requisites*, ed 2, Philadelphia, 2014, Elsevier.

(A) A radiographic image shows a permanent inferior vena cava filter is in the inferior vena cave. It has six legs and a conical top. (B) A radiographic image shows a permanent inferior vena cava filter is in the inferior vena cava. (C) A radiographic image shows the inferior vena cava. It is a long tubular structure.

Regardless of whether the filter is permanent or temporary, the purpose is to prevent new onset of PE by trapping venous emboli. These filters do not treat preexisting clots.

The filters are percutaneously inserted through a femoral, jugular, or antecubital vein, usually for placement in the IVC just inferior to the renal veins. Placement inferior to the renal veins is important to prevent renal vein thrombosis, which can occur if the vena cava is occluded superior to the level of the renal veins by a large thrombus in a filter. An inferior vena cavogram is performed using the modified Seldinger technique. The inferior vena cavogram defines the anatomy, including the level of the renal veins, determines the diameter of the vena cava, and rules out the presence of a thrombus (Fig. 27.78). The diameter of the vena cava may influence the choice of filter as each filter has a maximum diameter. If the patient's IVC diameter is larger than the filter's maximum diameter, there is an increased risk of filter migration toward the patient's heart, which could result in serious complications.

Filter insertion from the jugular or antecubital approach may be indicated if a thrombus is present in the iliac veins and/or in the IVC. The filter insertion site is dilated to accommodate the filter introducer. The filter remains sheathed until it reaches the desired level and is released from its introducer by the interventionalist. The introducing system is then removed, and external compression is applied to the venotomy site until hemostasis is achieved. A postplacement image is obtained to document the location of the filter (Fig. 27.79).

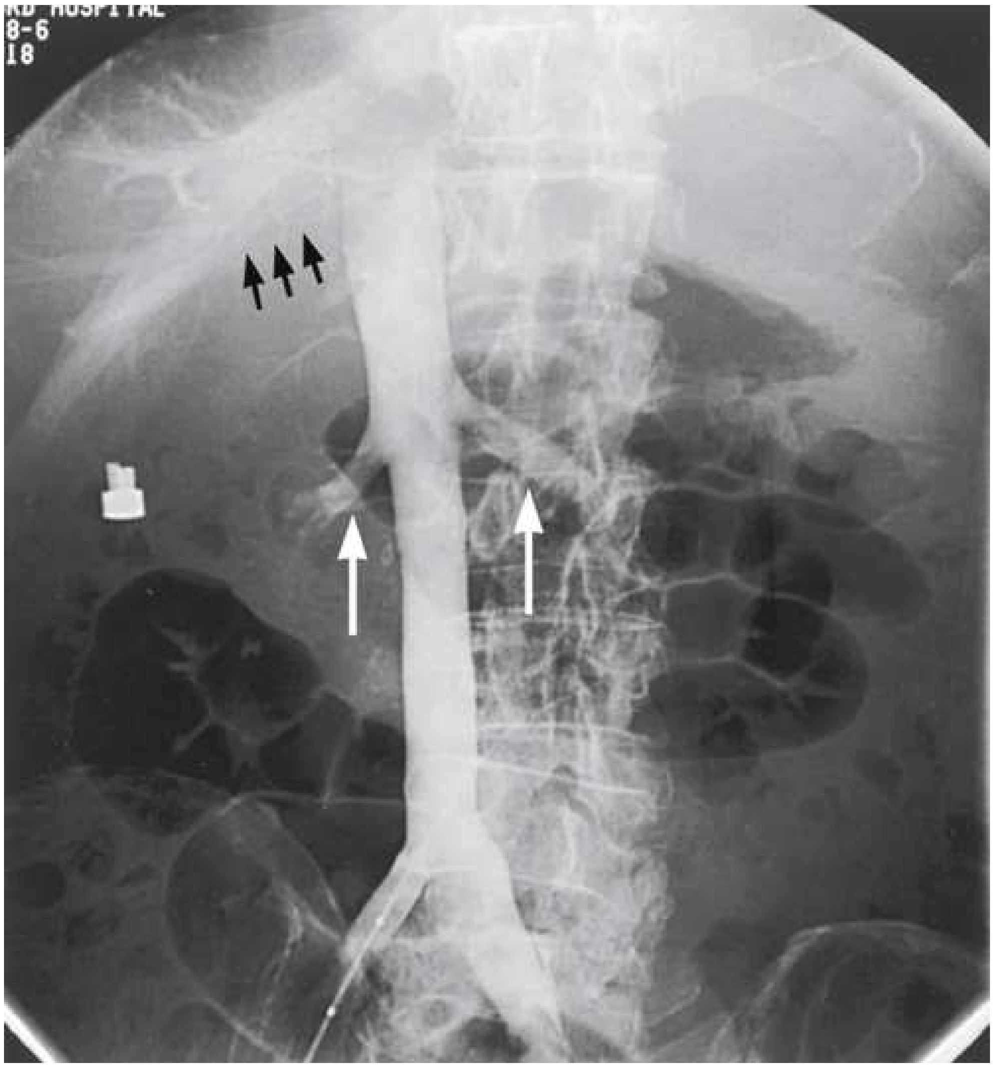


FIG. 27.78 Inferior vena cavogram. Note reflux into renal veins *(white arrows)* and hepatic veins *(black arrows)*.

FIG. 27.79 Postplacement image showing Greenfield filter in place *(arrow)*.

Transjugular Intrahepatic Portosystemic Shunt

The *portal circulation* consists of blood from the digestive organs, which drains into the liver. The portal system consists of the splenic vein, the superior mesenteric vein, and the inferior mesenteric vein. The blood passes through the liver tissue and is returned to the IVC via the hepatic veins. Disease processes can increase the resistance of blood flow through the liver, elevating the blood pressure of the portal circulation—a condition known as *portal hypertension*. It may cause the blood to flow through collateral veins. Venous *varices* are the result and can be life-threatening if they bleed. The creation of a portosystemic shunt can decrease portal hypertension and the associated variceal bleeding by allowing the portal venous circulation to bypass its normal course through the liver. The percutaneous intervention for creating an artificial low-pressure pathway between the portal and hepatic veins is called a *transjugular intrahepatic portosystemic shunt (TIPS)*.

Prior to a TIPS procedure, ultrasonography is used to confirm patency of the portal venous system. Hepatic venography and portography are performed during a TIPS procedure to delineate anatomy. Transcatheter blood pressure measurements are often used to confirm the existence of a pressure gradient between the portal and hepatic veins.

The most common approach for a TIPS procedure is from a right internal jugular venous puncture site to the middle or right hepatic vein. A hepatic venogram may be obtained using contrast material or CO_2 or both. A special long needle is passed into the hepatic vein and advanced through the liver tissue into the portal vein. The needle is exchanged for an angioplasty balloon catheter, and the tract through the liver tissue is dilated. An angiographic catheter may be passed through the tract and advanced into the splenic vein for a splenoportal venogram. An intravascular stent is positioned across the tract to maintain its patency (Figs. 27.80 and 27.81). The tract and stent may be enlarged further with an angioplasty balloon catheter until the desired reduction in pressure gradient between the portal and hepatic veins is achieved. If large gastric or splenic varices persist after the shunt creation, embolization of these varices using coils, sclerosants, or glue may be performed. Once the shunt is created, portal pressures are reduced, and flow through the varices diverted, the sheath is removed from the internal jugular vein, and external pressure is applied until hemostasis at the venotomy occurs.

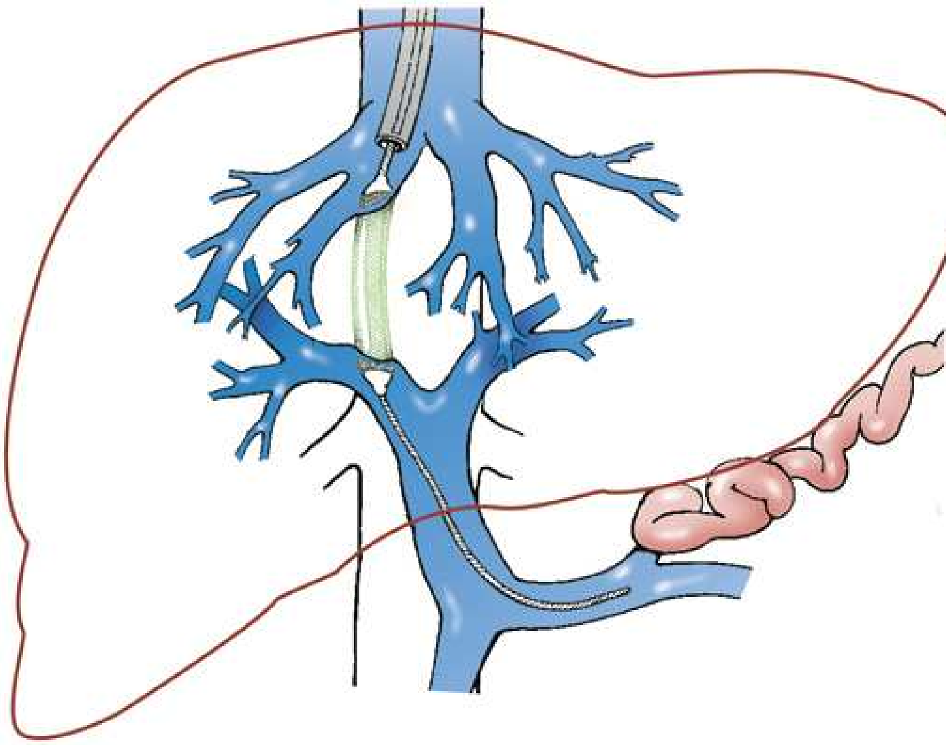


FIG. 27.80 Intravascular stent placement in a TIPS procedure.

Pharmacological Thrombolysis and Mechanical Thrombectomy

When an angiogram shows a thrombus (blood clot) within a vessel, interventional catheters and devices can be used to remove the thrombus and restore blood flow in both arterial and venous systems. These methods are effective in restoring arterial blood flow quickly in acute emergent situations such as large vessel ischemic stroke, limb-threatening ischemia, large PE, and acute myocardial infarction (MI), discussed later in this chapter. Pharmacological thrombolysis uses blood clot–dissolving medications that are infused through an angiographic catheter positioned against the thrombus. Special infusion catheters with side holes are manipulated directly into the clot. Periodic repeat *angiograms* evaluate the progress of *lysis* (dissolution). The catheter may have to be advanced under fluoroscopic control to keep it against or in the clot as lysis progresses. Mechanical thrombectomy uses catheters and/or devices to physically remove the clot. Mechanisms for physical thrombus removal include aspiration, maceration, and fragmentation. Fig. 27.82 demonstrates mechanical thrombectomy in the cerebral arteries using specialized aspiration catheters and a stent retriever device to restore blood flow to brain tissue.

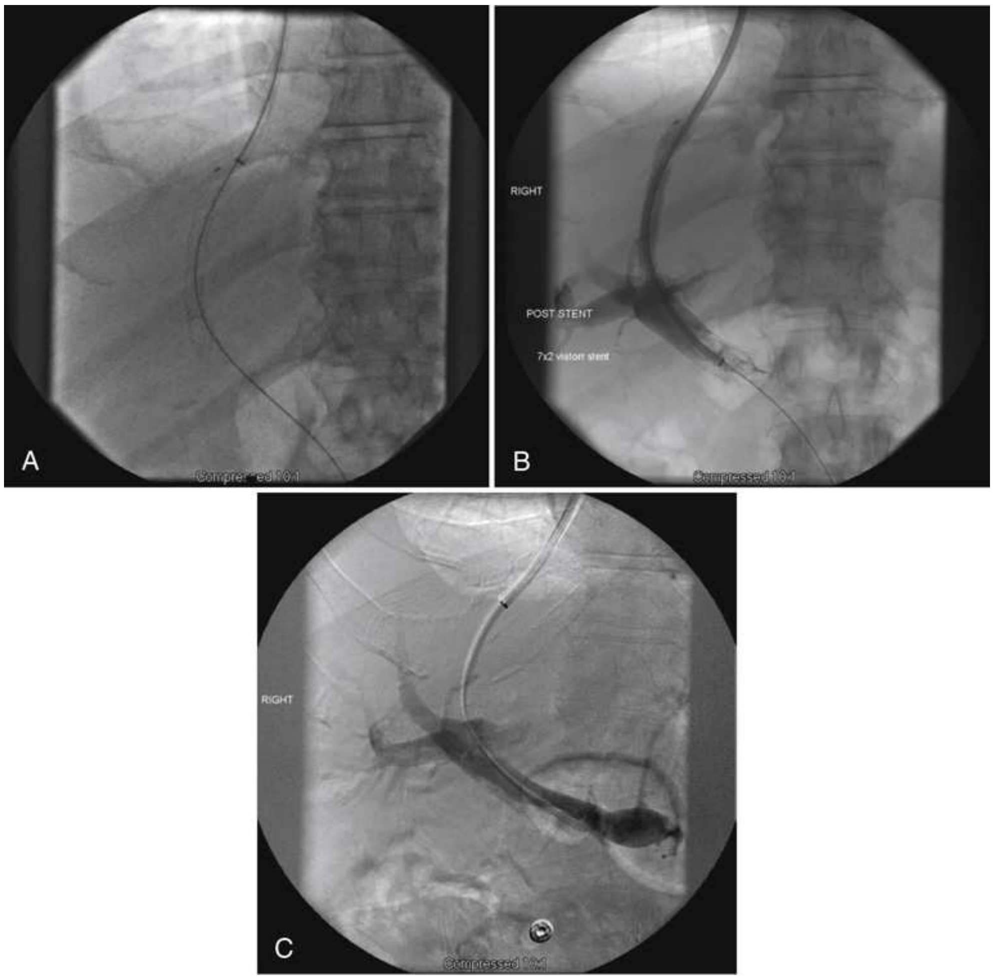


FIG. 27.81 TIPS procedure. (A) Stent placement. (B) Stent with contrast. (C) Initial contrast agent injection.

(A) A radiographic image shows a curve bent to the left. The vertebra and the ribs appear grey behind it. (B) A radiographic image shows a dark curve bent to the left. (C) A radiographic image shows a curve bent to the left. It has a dark region at one side.

Other Procedures

The insertion of vascular access catheters, such as central lines, hemodialysis catheters, tunneled catheters for long-term use, and implantable vascular access devices, such as port-a-caths used for chemotherapy infusion, are often performed in interventional radiology.

Interventional devices can be used to remove foreign bodies, such as catheter fragments or broken guidewires, percutaneously from the vasculature. Various snares can be used for this purpose. A snare catheter introduced using the Seldinger technique is manipulated under fluoroscopic control to grasp the foreign body. The snare and foreign bodies are then withdrawn as a unit.

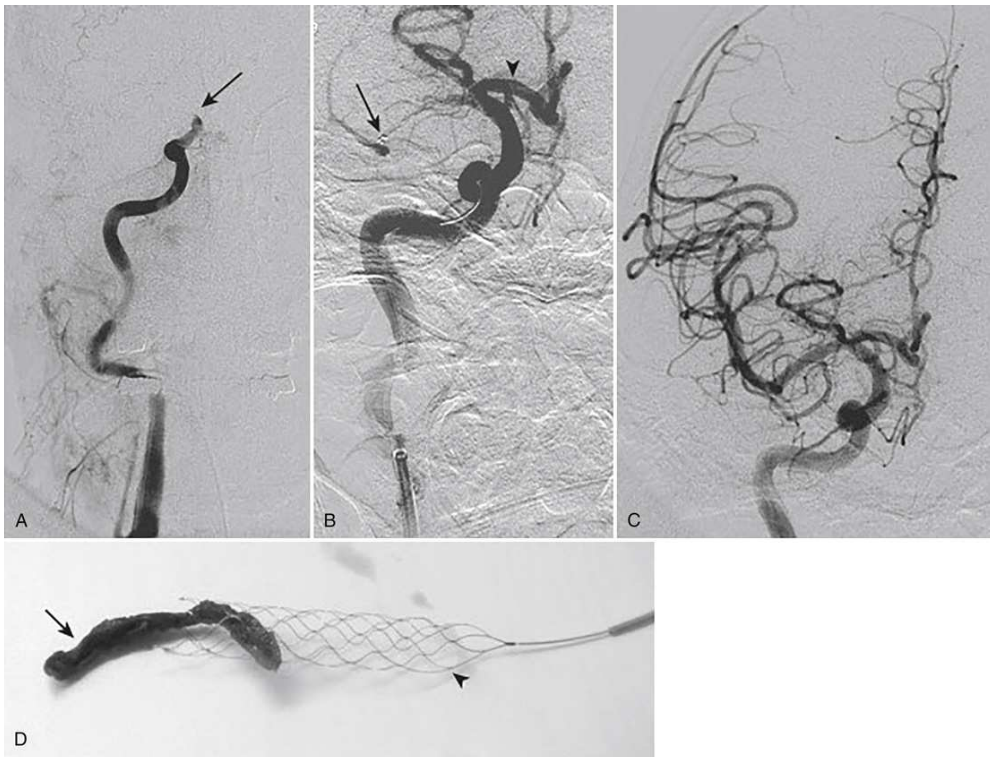


FIG. 27.82 Stroke intervention with a thrombus retrieval device (the Solitaire retrievable stent, Medtronic, Minneapolis, MN). (A) Carotid arteriogram showing abrupt occlusion in right internal carotid artery *(arrow)*. (B) Arteriogram after first pass with stent retriever showing right anterior cerebral is now open *(arrowhead)*. (C) Completion arteriogram showing reperfusion in the right anterior and middle cerebral arteries. (D) The thrombus *(arrow)* removed, trapped in the stent retriever *(arrowhead)*. From Kaufman JA, Nesbit GM: Carotid and vertebral arteries. In Kaufman JA, Lee MJ, editors: *Vascular and interventional radiology: the requisites*, ed 2, Philadelphia, 2014, Elsevier.

(A) A radiograph shows a long dark tubular structure. It is indicated by a black arrow. (B) A radiograph shows a long and broad dark tubular structure. The right anterior cerebral artery is indicated by an arrowhead. The right internal carotid artery is indicated by an arrow. (C) A radiograph shows several long dark tubular structures and branches. (D) A radiograph shows a dark long tube inside a stent. It is indicated by a black arrow. It appears like a net. It is indicated by an arrowhead.

Nonvascular Interventional Procedures

In addition to vascular interventional procedures, there are many nonvascular interventional procedures that are performed in interventional radiology. Technologists are expected to have comprehensive knowledge of anatomy and pathophysiology of the gastrointestinal, biliary, and urinary systems, and demonstrate an understanding of interventional procedures such as needle biopsy, percutaneous drainage, and stent placement. Common nonvascular interventional procedures include, but are not limited to:

- Percutaneous nephrostomy catheter placement: to externally drain urine from the pelvis of the kidney.
- Percutaneous ureteral stent placement: to provide an internal pathway for urine to flow from the kidney to the bladder, through an obstructed or damaged ureter.
- Percutaneous gastrostomy and gastrojejunostomy: to place direct gastrointestinal (GI) feeding tubes and/or drainage tubes into the most appropriate section of the GI tract.
- Percutaneous biliary drainage and/or stent placement: to relieve biliary obstruction, to divert bile in the presence of a bile leak, or to externally drain infected bile.

Vascular and Interventional Radiology: Present and Future

As previously mentioned, the field of interventional radiology is continually and rapidly evolving.

New catheters, guidewires, and medical devices are constantly being introduced with the ultimate aim of improving patient outcomes by performing less invasive procedures. More complex diseases and more critically ill patients are being treated with interventional procedures which have led to incorporating dedicated angiography equipment into the OR, or ensuring the angiography suite is OR compatible, allowing for dedicated anesthesia support and the potential to quickly convert percutaneous procedures to open surgical procedures. These suites are often considered *hybrid suites*. In these suites, interventionalists will often work alongside vascular, cardiothoracic, and neurosurgeons in complicated procedures that use both percutaneous and open surgical techniques. These procedures are highly technical, and a team approach is crucial.[11] The cardiovascular and interventional technologist plays an active role in this multidisciplinary interventional team (Fig. 27.83).

FIG. 27.83 The technologist plays an active role on the interventional team by assisting the interventionalist *(left)* or by circulating within the angiography suite *(right)*.

The imaging capabilities of angiographic equipment have also evolved dramatically. Increased image resolution at lower radiation dose is a primary goal within angiography, and manufacturers are continually developing ways to meet this goal.

Other imaging advancements include incorporating cross-sectional and 3-D imaging in the angiography suite. Most angiographic equipment manufacturers now offer the capability to perform cone beam CT acquisitions using the C-arm. These CT acquisitions allow for high-quality 3-D imaging and advanced image processing without the need for additional imaging equipment. Some larger facilities have integrated CT and even MRI scanners into the angiography suite to assist with image guidance for procedures.

Advances in medical imaging software and applications have allowed for multimodality fusion imaging. This allows images from other modalities to be projected onto and incorporated into the live fluoroscopic image, so that the image moves in conjunction with the fluoroscopy image to assist with catheter placement during interventional procedures.

Currently, research is being conducted into the use of robotics in interventional radiology and cardiovascular interventions. Robotic angiographic instruments have been designed to manipulate needles, guidewires, and medical devices, such as balloon angioplasty catheters. It is thought that the use of these robotics would drastically reduce radiation exposure to the interventionalist, allow easier and safer navigation of tortuous vasculature, and allow for MRI-guided interventions to be faster and more accurate.

Cardiac Catheterization And Interventional Cardiology

Cardiac Catheterization

Cardiac catheterization is a comprehensive term used to describe a minimally invasive, percutaneous procedure involving the introduction of specialized catheters into the heart and surrounding vasculature for the purpose of diagnostic evaluation and intervention associated with various cardiovascular-related disorders in children and adults. Cardiac catheterization is classified as either a diagnostic or an interventional procedure. The primary purpose of diagnostic procedures is to collect data necessary to evaluate the patient's condition. Cardiac interventional procedures involve the application of therapeutic measures through catheter-based systems or other mechanical means to treat disorders of the vascular and conduction systems within the heart.

General Indications

Cardiac catheterization is performed to identify the anatomic and physiologic condition of the heart. The data gathered during catheterization provide the physician with information to develop management strategies for patients who have cardiovascular disorders. *Coronary angiography* is performed to accurately visualize coronary anatomy and pathology. The anatomic information gained from this procedure may include the presence and extent of obstructive coronary artery disease, thrombus formation, coronary artery collateral flow, coronary anomalies, aneurysms, and spasm. Coronary artery size can also be determined. Often the goal of coronary angiography is to evaluate and plan the most appropriate coronary interventional procedure (e.g., PTCA, intracoronary stent, or atherectomy).

TABLE 27.2

AO, Aortography; *BX,* endomyocardial biopsy; *COR,* coronary angiography; *ERGO,* ergonovine provocation of coronary spasm; *ETT,* exercise tolerance test; *LV,* left ventriculography; *R + L,* right and left heart hemodynamics; *RH,* right heart oxygen saturations and hemodynamics (e.g., placement of Swan-Ganz catheter).

From Kern MJ: *The cardiac catheterization handbook,* ed 4, St Louis, 2003, Mosby.

Coronary artery disease is the most common disorder necessitating catheterization of the adult heart. This disease is caused primarily by the accumulation of fatty intracoronary *atheromatous* plaque, which leads to *stenosis* and *occlusion* of the coronary arteries. Coronary artery disease is symptomatically characterized by chest pain (angina pectoris) or a heart attack (MI). Treatment of coronary artery disease includes medical, surgical, and catheter-directed interventions.

Diagnostic cardiac catheterization of an adult patient with coronary artery disease is conducted to assess the appropriateness and feasibility of various therapeutic options. Cardiac catheterization provides *hemodynamic* and *angiographic* data to document the presence and severity of the disease. In selected circumstances, postoperative catheterization is performed to assess the results of surgery.

Diagnostic studies of the adult heart also aid in evaluating a patient who has confusing or obscure symptoms (e.g., chest pain of undetermined cause). These studies are also used to assess diseases of the heart not requiring surgical intervention, such as certain cardiomyopathies.

In children, diagnostic heart catheterization is employed to evaluate congenital and valvular disease, disorders of the cardiac conduction system, and selected cardiomyopathies. Interventional techniques are also performed in children, primarily to alleviate symptoms associated with certain congenital heart defects.

The indications for cardiac catheterization as established by a special task force to the American College of Cardiology and the American Heart Association (ACC/AHA) are summarized in Table 27.2. Commonly performed procedures based on diagnosis are also presented. The ACC/AHA[11] has classified the indications and appropriateness for coronary angiography by placing the previously discussed disease categories into three classifications, as follows:

Class 1: Conditions for which there is general agreement that coronary angiography is justified

TABLE 27.3

CHF, Congestive heart failure; *PTCA*, percutaneous transluminal coronary angioplasty.

From Kern MJ: *The cardiac catheterization handbook,* ed 4, St Louis, 2003, Mosby.

Class 2: Conditions for which coronary angiography is frequently performed, but for which a divergence of opinion exists with respect to its justification in terms of value and appropriateness

Class 3: Conditions for which coronary angiography ordinarily is not justified

Other procedures that may be performed concurrently with coronary angiography are listed in Table 27.3. Some of these procedures are discussed later in the text.

Contraindications, Complications, And Associated Risks

Cardiac catheterization has associated inherent risk factors. Many physicians agree that the only absolute contraindications to this procedure are the refusal of the procedure by a mentally competent person and the lack of adequate equipment or catheterization facilities.

There are few contraindications for cardiac catheterization when the appropriateness of the procedure is based on the benefit-risk ratio. Relative contraindications according to the guidelines of the ACC/AHA[11] include the following:

- Active gastrointestinal bleeding, anemia
- Anticoagulation, or known bleeding disorder
- Electrolyte imbalance
- Infection and fever

- Medication intoxication (digitalis, phenothiazine)
- Pregnancy
- Recent stroke
- Renal failure
- Uncontrolled congestive heart failure
- Uncooperative patient

Some of these conditions may be temporary, or they may be treated and reversed before cardiac catheterization is attempted.

As with any invasive procedure, complications can be expected during cardiac catheterization. The Society for Cardiac Angiography and Interventions (SCA&I) reviewed the catheterizations in more than 300,000 patients from three different time periods and found the major complication rate for the entire group was less than 2%. As the severity of the patient's disease increases, however, so do the risks associated with the procedure.

The risks of cardiac catheterization vary according to the type of procedure and the status of the patient undergoing the procedure. Significantly influencing the outcome of the procedure is the stability of the patient's condition before the procedure. Patients presenting with left main coronary stenosis have a greater than twofold higher risk of complications from coronary angiography than patients who have no left main coronary stenosis. The SCA&I database identified the main predictors of major complications after cardiac catheterization and determined that the following increased the risk of complications:[12]

- Moribund patient (patient with poor response to life-threatening condition)
- Cardiogenic shock
- Acute MI (within 24 hours)
- Renal insufficiency
- Cardiomyopathy

The expected benefits of cardiac catheterization must be weighed against the associated risks when determining whether to perform the procedure.

Supplies And Equipment

Cardiovascular equipment consists of supplies and equipment needed to perform the procedure. In addition to the equipment mentioned previously for vascular angiographic procedures, there are variations in catheter design to accommodate the coronary arteries. Because of the complexity and vast number of different types of procedures performed in a cardiac catheterization laboratory, only a few of the most commonly used items are discussed.

Catheters

The catheters used for left heart cardiac catheterization are similar to the angiographic catheters previously described, except cardiac catheters are specifically shaped for the cardiac vasculature (Fig. 27.84). Left heart catheterization involves accessing the arterial system to locate the coronary arteries and left side of the heart. Right heart catheterizations involve accessing the venous system to locate the right side of the heart and the pulmonary arteries. Specialized catheters are used for right heart catheterization procedures. In contrast to angiographic catheters, the main purpose of which is to serve as a conduit for contrast media, right heart catheters are typically flow-directed catheters that use an inflated balloon on the tip of the catheter to ease passage through the various chambers of the heart. Various types of flow-directed catheters are capable of performing more tasks than the standard angiographic catheter. Depending on the type of procedure to be performed, the cardiologist determines which catheter(s) to use.

Catheters placed in a patient's vasculature can function as a fluid-filled column for hemodynamic data or as a conduit for contrast media, thrombolytic agents, and mechanical devices. Blood samples can be drawn directly from selected cardiac chambers for the purpose of *oximetry* or other laboratory analysis. To perform these and other tasks, three or four valves (*stopcocks*) are combined to form a *manifold*, which is attached to the proximal end of the catheter (Fig. 27.85). Using a manifold allows such functions as drawing blood samples, administering medications, and recording blood pressures without disconnecting from the catheter.

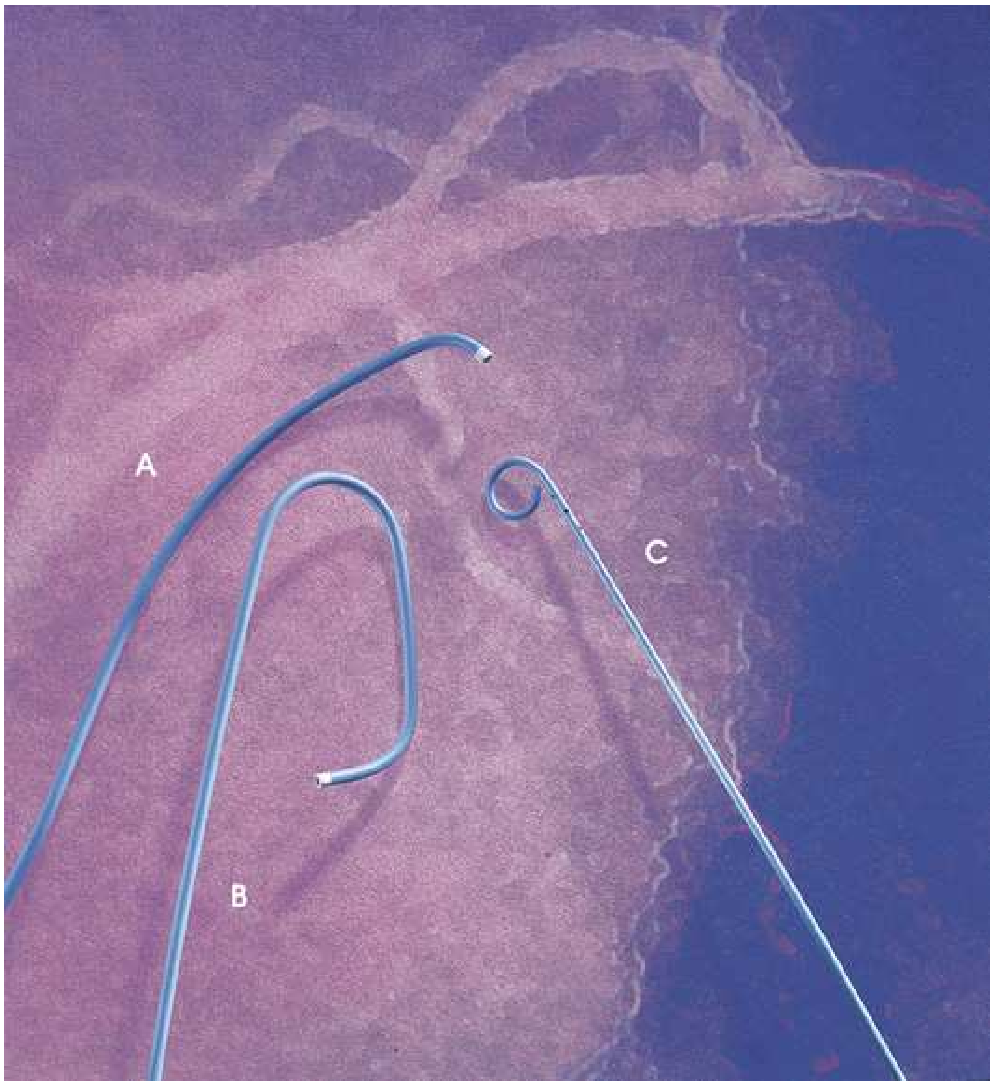


FIG. 27.84 Catheters used during cardiac catheterization. (A) Judkins right. (B) Judkins left. (C) Pigtail. Courtesy Cordis Corp., Miami, FL.

Contrast media

Injection of contrast media is essential for angiographic visualization of the cardiac anatomy. Several iodinated radiographic contrast media are approved for intravascular, intracardiac, and intracoronary use in adults and children. Transient (temporary) ECG changes during and immediately after the injection of contrast media are common.

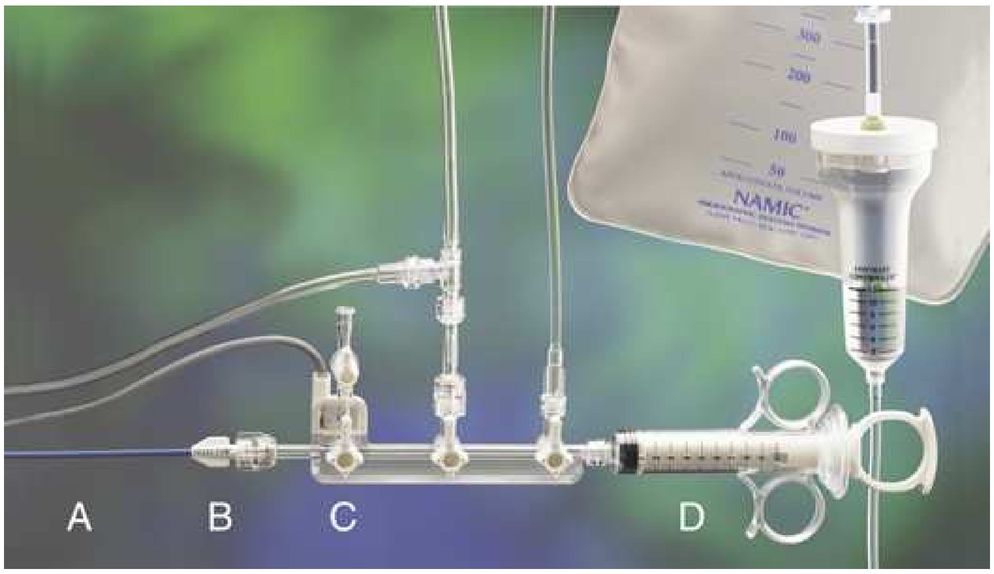


FIG. 27.85 Disposable three-valve Compensator Morse manifold, with a Selector catheter (A), rotating adapter (B), pressure transducer (C), and angiographic control syringe (D). Courtesy SCHNEIDER/NAMIC, Glens Falls, NY.

Pressure injector

The pressure injector for the administration of radiographic contrast media (Fig. 27.86) is also used during cardiac catheterization. During cardiac catheterization, the pressure injector is used to inject a large amount (25 to 50 mL) of contrast material into either the right or the left ventricle (the main pumping chambers of the heart), the aortic root, or the pulmonary vessels. Because the coronary arteries are of small caliber and of low flow rate, administration of contrast media into these structures generally does not require a high-pressure injector. Instead, most physicians opt for manual injection using an angiographic control syringe (see Fig. 27.85).

Equipment

The imaging equipment found in the cardiac catheterization laboratory is essentially the same as the equipment found in the vascular angiography suite. The catheterization laboratory requires a system capable of producing fluoroscopic images with the greatest amount of recorded detail available. Maximum resolution from the optical system is crucial because of the small size of the cardiac anatomy, which must be imaged while in motion. The imaging used for cardiac studies is typically 15 to 30 frames per second, compared with 2 to 6 frames per second used for peripheral imaging. The motion of the heart beating requires this increased frame rate to visualize these small arteries properly. The imaging equipment necessary to produce high-resolution imaging is described in the earlier section on DSA procedures.

Patient positioning

Patients are placed on the examination table in the supine position. Moving the patient during catheterization is undesirable, particularly when catheters have been carefully positioned to show specific anatomic structures or to record certain data. Multiple tube angulations and projections are necessary to clearly demonstrate the coronary arteries as they surround the heart. Each patient's anatomy must be evaluated using fluoroscopy to ascertain the optimal degree of rotation and cranial or caudal angulation necessary to visualize each structure of interest.

FIG. 27.86 The Angiomat (ILLUMENA) high-pressure injector for radiographic contrast media. Courtesy Liebel-Flarsheim, a product of Mallinckrodt, Inc., Cincinnati, OH.

Physiologic equipment

The physiologic monitor is essential to cardiac catheterization procedures. It is used to monitor and record vital patient functions, including electrical activity (ECG) [c] within the heart and blood pressure (hemodynamic) within the various intracardiac chambers (Fig. 27.87). The patient's ECG and hemodynamic pressures are continuously displayed throughout the various types of procedures. Selective samplings of ECG and hemodynamic pressures are recorded for permanent documentation.

FIG. 27.87 Computer-based physiologic monitor used to monitor patient ECG and hemodynamic pressures during cardiac catheterization. Courtesy GE Medical Systems.

For the collection of hemodynamic data during catheterization, the physiologic recorder (receiving information in electrical form) must be connected to the catheter (carrying information as physical fluid pressure). Devices called *pressure transducers* are interfaced between the manifold and the physiologic recorder to convert fluid (blood) pressure into an electrical signal.

For a standard cardiac catheterization procedure, four channels of the physiologic recorder are usually prepared: two for ECG recordings and two for pressure recordings. A physiologic recorder can have as many as 32 *channels*.

Other Equipment

Because of the nature of the patient's condition, the inherent risks of cardiac catheterization, and the types of procedures performed, each catheterization room should have the following equipment available:

- A fully equipped emergency cart. The cart typically contains emergency medications, cardiopulmonary resuscitation equipment, intubation equipment, and other related supplies.
- Oxygen and suction.
- Whole-blood oximeters used to determine the oxygen saturation of the blood samples obtained during adult and pediatric catheterizations (Fig. 27.88).
- Defibrillator, used to treat life-threatening arrhythmias. Ideally, the defibrillator would also have external pacemaking capabilities. Some laboratories have two defibrillators available in case one fails.
- Temporary pacemaker to treat potential asystole or symptomatic bradycardia.
- Pulse oximeter to monitor and assess level of oxygenation noninvasively during sedation.
- Noninvasive blood pressure monitoring capabilities.
- Equipment to perform cardiac output studies.
- Intra-aortic balloon pump used to increase myocardial perfusion and cardiac output during interventional procedures.
- Activated clotting time (ACT) used to monitor treatment of high-dose heparin during procedures.

In addition to the basic coronary angiogram and left and right heart studies, many effective tools are available to diagnose and treat coronary artery disease (Table 27.4).

FIG. 27.88 Oximeter used to measure oxygen saturation in blood.

TABLE 27.4

Tools for diagnosis and treatment of coronary artery disease

Equipment	Use	Diagnostic or therapeutic
Pressure wire	Measures blood flow across lesion to determine severity of stenosis	Diagnostic
IVUS	Internal vessel visualization of stenosis, plaque, stent position	Diagnostic
OCT (optical coherence tomography)	Laser light to image the inside of the vessel wall	Diagnostic
Rotablator	Rotational atherectomy of intraluminal plaque or calcium	Therapeutic
Rheolytic thrombectomy	High-velocity saline spray for thrombectomy	Therapeutic
The Crosser	Study device to chronic total occlusions	Therapeutic

IVUS, Intravascular ultrasound; *OCT*, optical coherence tomography.

Pre-Catheterization Care

Before the catheterization is performed, the procedure is explained, and informed consent is obtained. A pre-procedure checklist is used to ensure all the necessary patient medical history, physical examinations, non-invasive imaging, and laboratory blood tests have been performed and reviewed prior to the procedure.

Various medications are frequently administered for sedation and control of nausea. Typically, patients are not allowed anything to eat or drink for 4 to 6 hours before the procedure. During all catheterizations, a protocol (or detailed record) of every aspect of the procedure is maintained.

Catheter Introduction

The most frequent sites used for cardiac catheterization are the femoral and radial area. The brachial, axillary, jugular (neck), and subclavian (chest) areas may also be chosen.

For catheterization of the artery or vein, the percutaneous approach is employed (see the modified Seldinger technique, which is described and illustrated in Fig. 27.13). On rare occasions, if the percutaneous approach cannot be used, a cutdown technique is employed. This technique requires that a small incision be made in the skin to allow for direct visualization of the artery or vein that the physician wants to catheterize. The skin is aseptically prepared and infiltrated with local anesthetic, and the vessel or vessels are bluntly dissected and exposed. After an opening is created in the desired vessel (arteriotomy or venotomy), the catheter is introduced and advanced toward the heart.

Post-Catheterization Care

When the catheterization procedure is completed, all catheters are removed. If a cutdown approach was used, the arteriotomy or venotomy is repaired as appropriate. If a percutaneous approach was used, multiple techniques can be employed to obtain hemostasis. Manual pressure may be placed on the puncture site until bleeding is controlled. For femoral arteriotomies internal closure devices may be used. These devices are deployed under the skin against the artery wall and include a collagen seal, suture-mediated devices, or a metal clip. For radial arteriotomies, an external pressure device is often used that allows gradual reduction of pressure at the site after a prescribed time, usually over 1 to 2 hours. For venotomies, manual pressure for 5 to 10 minutes is usually sufficient to obtain hemostasis. Once hemostasis is achieved, these wound sites are cleaned and dressed to minimize the risk of infection.

The physician prescribes post-catheterization medications. The puncture site must be observed for hemorrhage or hematoma, and the status of the distal pulse is recorded on the protocol record before the patient leaves the catheterization laboratory. Vital signs should be monitored regularly after the catheterization. The ingestion of fluids should be encouraged, and pain medication may be indicated.

Cardiac catheterization is often performed on an outpatient or same-day treatment basis. The patient is monitored for 4 to 8 hours in a recovery area and then allowed to go home. Instructions for home care recovery procedures are usually given to the patient or a family member before the patient leaves the recovery area.

Diagnostic Cardiac Procedures

Left Heart

Catheterization of the left side of the heart is performed to evaluate heart function, to measure hemodynamic pressures in the left atrium and left ventricle, and to access the right and left coronary arteries. The catheter may be introduced through the radial, brachial, or femoral artery and advanced over a guidewire to the ascending aorta. When in the ascending aorta, the guidewire is removed, and the catheter is aspirated and flushed to prevent migration of any air bubbles.

A normal aortic valve prevents backward flow of contrast media into the left ventricle during injection, whereas an insufficient valve does not (Fig. 27.89). Left ventriculography provides information about valvular competence, interventricular septal integrity, and the efficiency of the pumping action of the left ventricle (ejection fraction) (Fig. 27.90). Mitral regurgitation is another example of valvular incompetence, and angiographically it is seen as the backward flow of contrast media from the left ventricle into the left atrium or pulmonary veins (Fig. 27.91). Computer *planimetry* software calculates how well the ventricle functions (Fig. 27.92). The presence of aortic valve stenosis is determined as the blood pressure measurements are repeated while the catheter is withdrawn across the aortic valve. Normal flow of blood through the aortic valve allows the systolic pressure in the left ventricle to match the systolic pressure in the aorta. When the systolic blood pressure in the left ventricle is greater than the systolic blood pressure in the aorta, aortic stenosis is present.

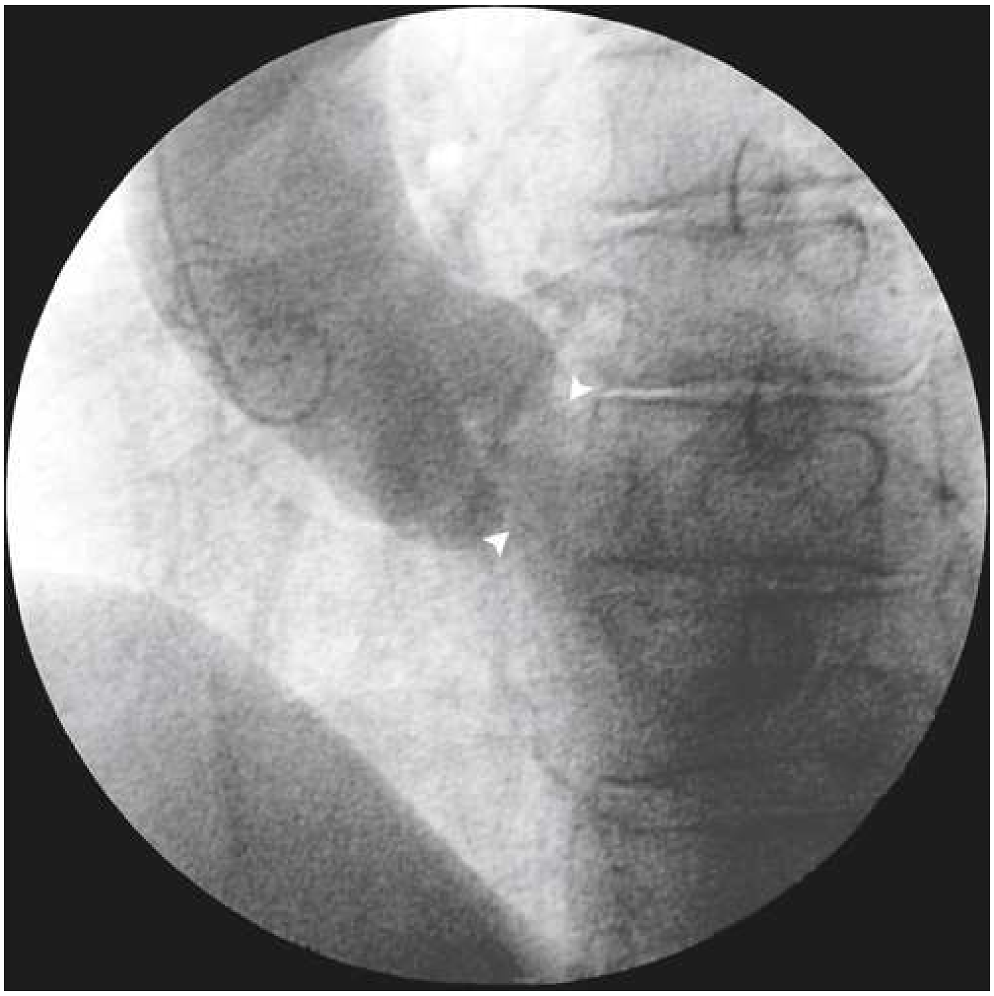


FIG. 27.89 Aortic root injection showing aortic insufficiency with contrast agent flowing back into left ventricle *(arrowheads)*.

FIG. 27.90 Normal left ventriculogram during diastole.

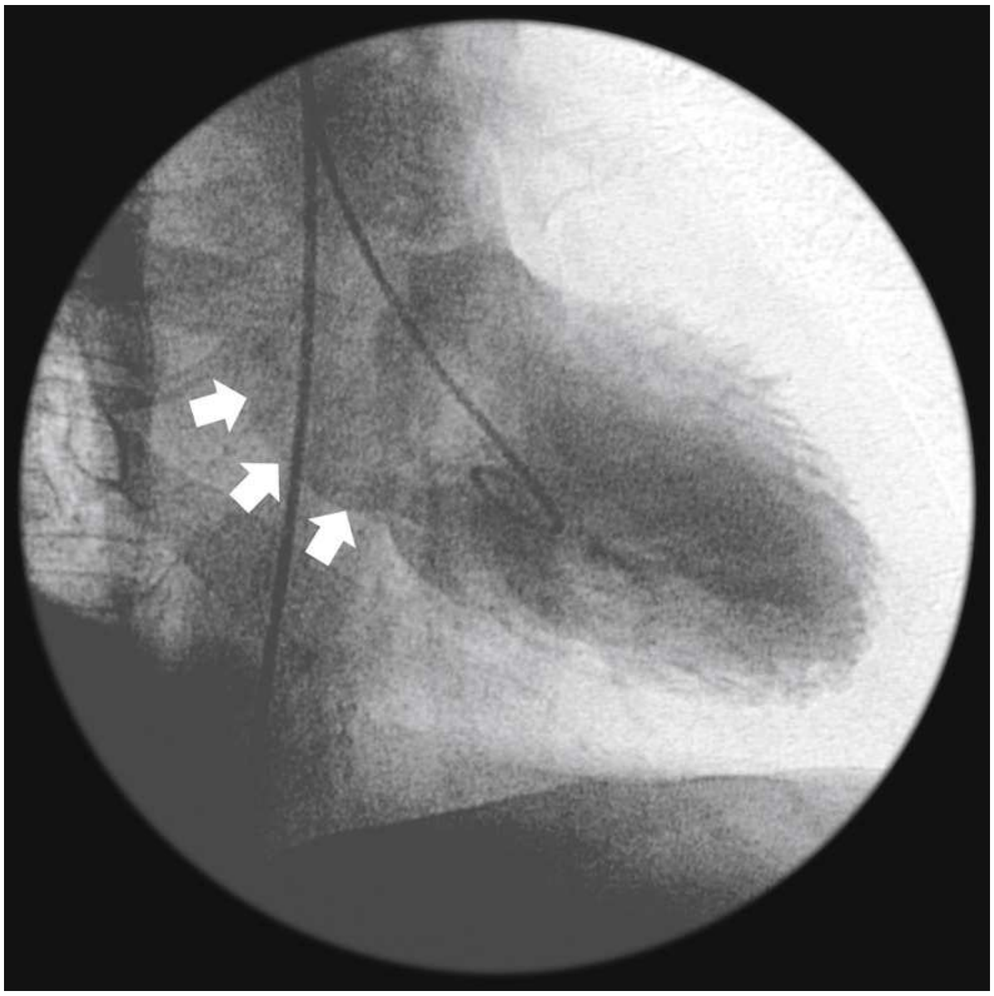


FIG. 27.91 Left ventriculogram showing mitral valve regurgitation.

Selective Coronary Angiography

Selective angiography of the right coronary artery and left coronary artery is performed, with different projections used for each coronary artery to prevent superimposition with overlapping structures. Coronary angiography allows the extent of intracoronary stenosis to be evaluated (Figs. 27.93 and 27.94).

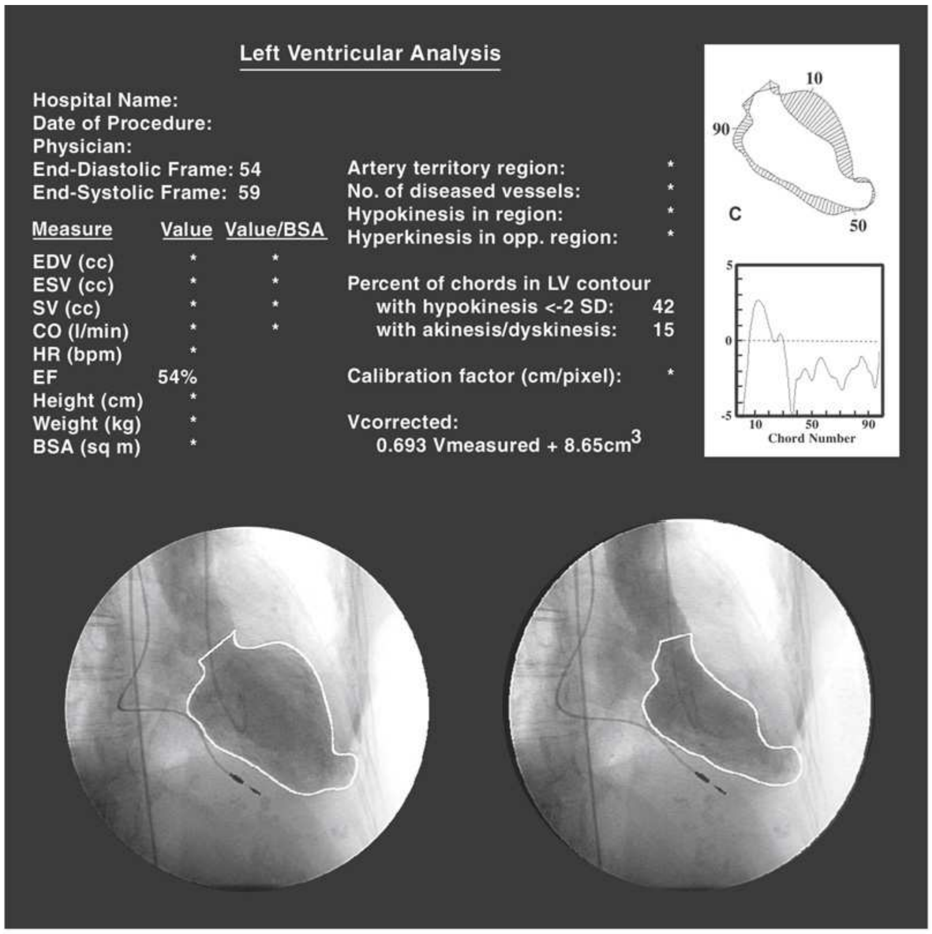


FIG. 27.92 Computerized planimetry for evaluation of left ventricular ejection fraction. (A) Diastolic phase of contraction of the heart. (B) Systolic phase of contraction of the heart. (C) Digital representation of when the diastolic and systolic phases of contraction are superimposed.

A chart with the following data is shown: Left ventricular analysis. Hospital name. Date of procedure. Physician. End-diastolic frame: 54. End -systolic frame: 59. Artery territory region. Number of diseased vessel. Hypokinesis in region. Hypokinesis in opposite region. (A) shows a graph with diastolic phase of contraction of the heart. (B) shows a systolic phase of contraction of the heart. (C) shows a digital representation of the diastolic and systolic phases of contraction superimposed and a graph titled chord number.

Because of the complexity of the anatomy involved, the variations in patient body habitus, and the presence of anomalies, a comprehensive guide for angiographic projections is difficult to establish. Projections commonly used during coronary angiography are listed in Table 27.5. The cardiologist determines the projections that best show the artery of interest. Coronary arteriograms are obtained in nearly all catheterizations of the left side of the heart.

Right Heart

Catheterization of the right side of the heart is another commonly performed procedure. During right heart catheterization, a catheter is inserted into the femoral, antecubital fossa, internal jugular, or subclavian vein, and it is advanced to the vena cava, into the right atrium, across the tricuspid valve, to the right ventricle, and through the pulmonary valve to the pulmonary artery, until it is wedged distally in the pulmonary artery. Pressure measurements and oximetry are performed in each of the heart chambers as the catheter is advanced. The pressure measurements are used to determine the presence of disorders such as valvular heart disease, congestive heart failure, pulmonary hypertension, and certain cardiomyopathies. The oximetry data is used to determine the presence of an intracardiac shunt. DSA is performed as appropriate.

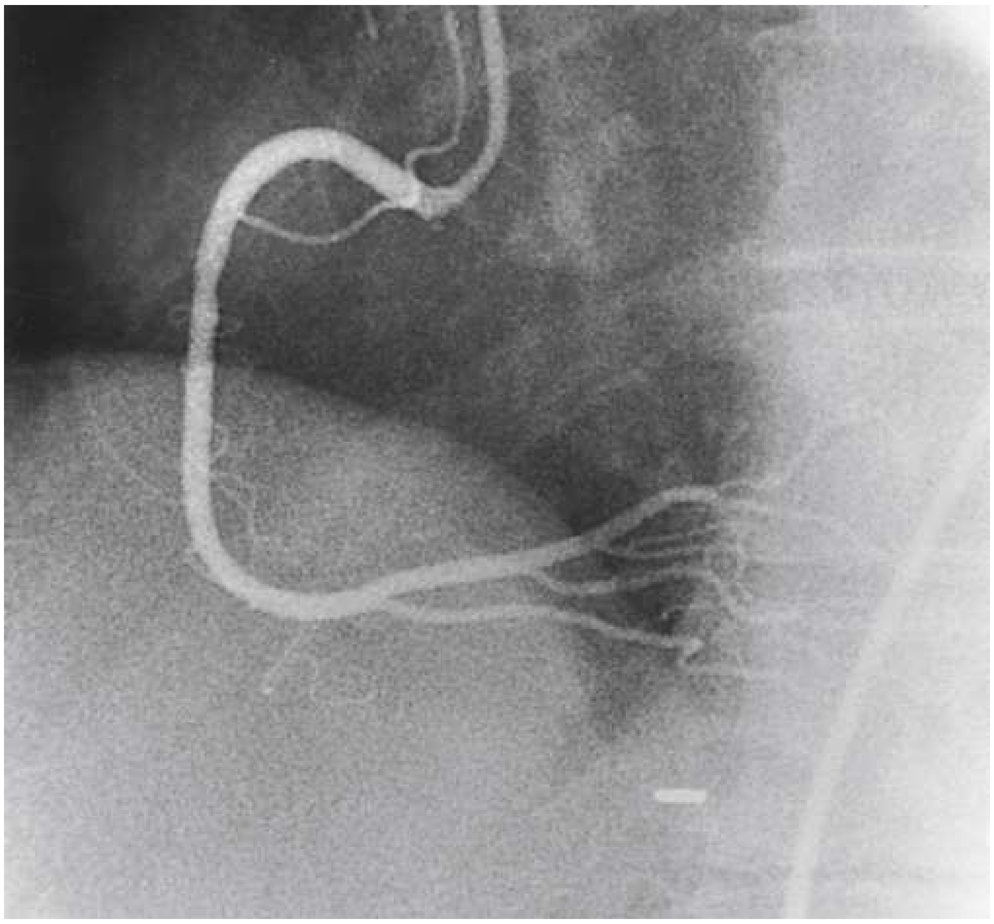


FIG. 27.93 Normal right coronary artery.

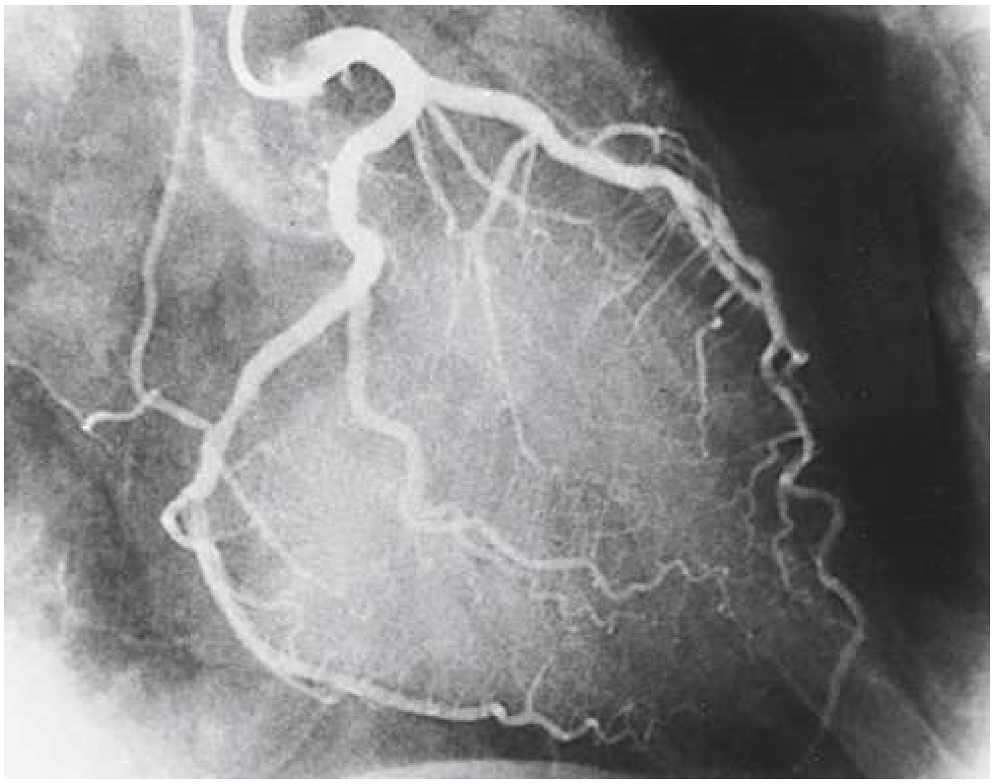


FIG. 27.94 Normal left coronary artery.

TABLE 27.5

Common angiographic angles for specific coronary arteries

Coronary artery	Vessel segment	Projections
Left coronary artery	Left main	PA or RAO 5–15 degrees
	Left anterior descending	LAO 30–40 degrees, cranial 20–40 degrees
		RAO 5–15 degrees, cranial 15–45 degrees
		RAO 20–40 degrees, caudal 15–30 degrees
		RAO 30–50 degrees
		Lateral
	Circumflex	RAO 20–40 degrees, caudal 15–30 degrees
		LAO 40–55 degrees, caudal 15–30 degrees
		LAO 40–60 degrees
Right coronary artery	Middle right	LAO 20–40 degrees
		RAO 20–40 degrees
	Posterior descending	LAO 5–30 degrees, cranial 15–30 degrees

Exercise hemodynamics are often required in the evaluation of valvular heart disease when symptoms of fatigue and dyspnea are present. In such cases, simultaneous catheterization and pressure measurements of the right and left heart are performed at rest and during peak exercise. Exercise may be achieved by the patient pedaling a stationary bicycle ergometer that is placed on top of the examination table, by using an arm ergometer, or by lifting weights. Alternatively, exercise, or stress on the heart, can be induced pharmacologically (with medication) with the use of temporary pacing wires, or with a rapid bolus infusion of fluids. During simultaneous catheterization, a catheter is placed in a vein (femoral or basilic) and an artery (femoral or brachial).

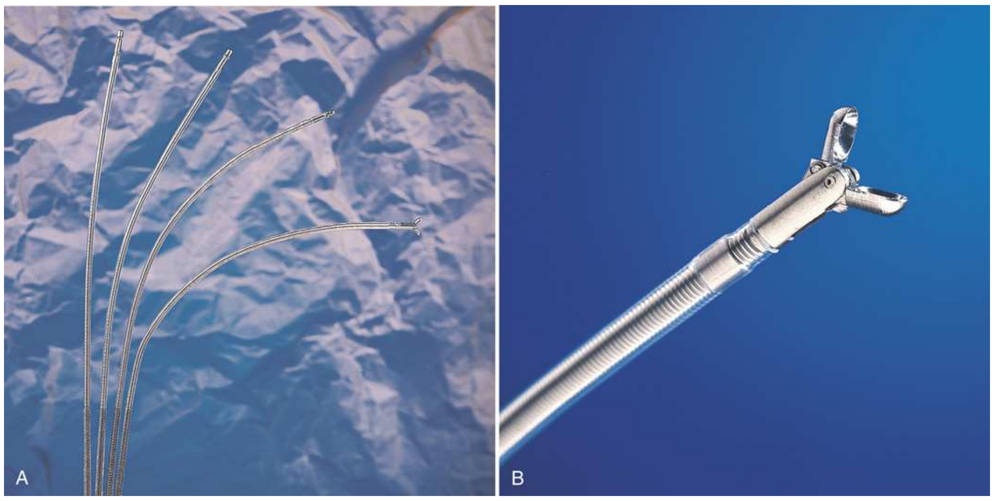


FIG. 27.95 (A) Standard biopsy catheters. (B) Bioptome catheter tip used for myocardial biopsy. The jaws on the tip close and take a "bite" from the inside of the heart muscle. Courtesy Cordis Corp., Miami, FL.

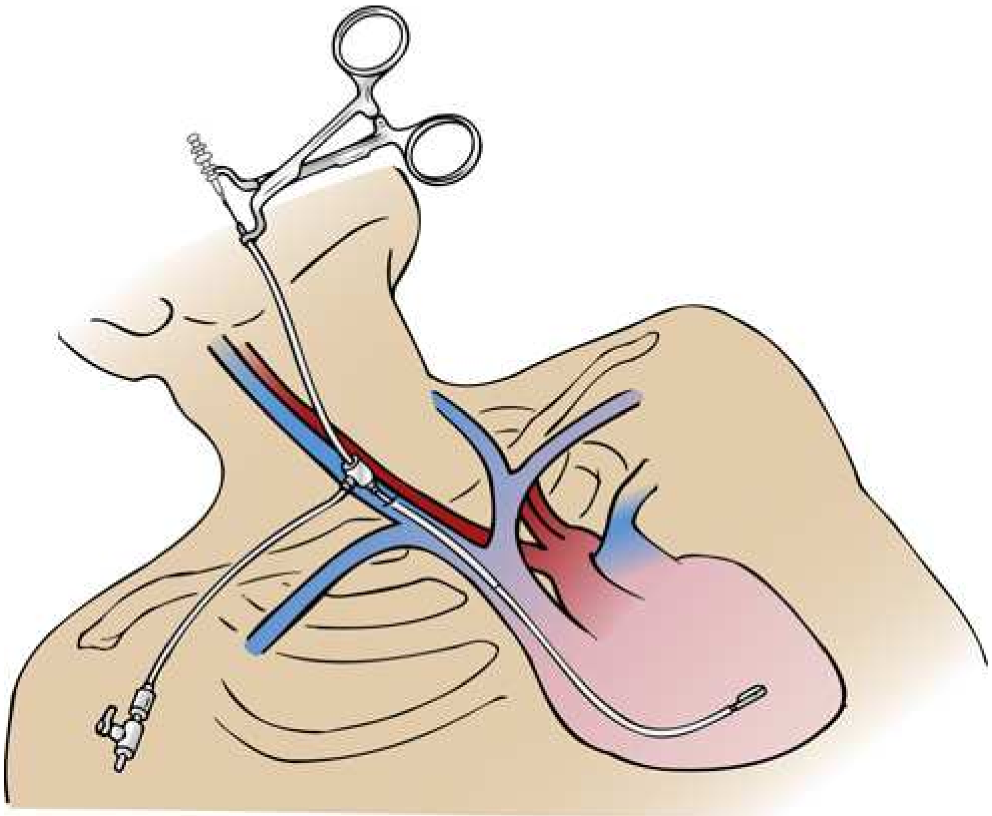


FIG. 27.96 Bioptome tip in the right ventricular apex points toward the ventricular septum.

Diagram shows the anterior view of the human body. The heart and the arteries are highlighted. The bioptome is advanced into the ventricle, the jaws of the device are opened, and the catheter is advanced to the ventricular septum.

Endomyocardial Biopsy

Endomyocardial biopsy is performed to provide a tissue sample for direct pathologic evaluation of cardiac muscle. A special biopsy catheter with a bioptome tip (Fig. 27.95) is advanced under fluoroscopic control from either the jugular or the femoral vein to the right ventricle (Fig. 27.96). After the bioptome is advanced into the ventricle, the jaws of the device are opened, and the catheter is advanced to the ventricular septum. After the bioptome is in contact with the septum, its jaws are closed, and a gentle tugging motion is applied to retrieve the tissue sample. Several biopsy specimens are acquired in this manner. The specimens are immediately fixed in either glutaraldehyde or buffered formalin before being sent for pathologic evaluation. Endomyocardial biopsy is frequently used to monitor cardiac transplantation patients for early signs of tissue rejection and to differentiate between various types of cardiomyopathies.

Interventional Cardiac Procedures

Because of the risks associated with mechanical interventions of the vascular system, open-heart surgical facilities must be immediately available. Coronary occlusion is a major complication requiring emergency surgery in patients undergoing catheter-based mechanical interventions.

Interventional pharmacologic procedures in adults consist of the therapeutic administration of medications that may be given before the patient reaches the cardiac catheterization laboratory. A thrombolytic agent can be used in the early hours of an acute MI in an effort to modify its course. Estimates indicate that thrombotic coronary artery occlusion is present in 75% to 85% of patients with acute MI. If reperfusion of the ischemic myocardium is effective, scarring is reduced. Reperfusion in the early stages of MI offers greater potential for heart muscle salvage. ST segment elevation MI is determined from a 12-lead ECG performed in the field or in the emergency department. These patients are the most critical and typically have a complete or almost complete blockage of a coronary artery. Rapid reperfusion to the heart muscle must be performed to minimize damage.

Angioplasty And Stent Placement

Interventional cardiac catheterization techniques requiring special-purpose catheters have expanded significantly since the late 1970s. PTCA is a technique that employs balloon dilation of a coronary artery stenosis to increase blood flow to the heart muscle. Grüntzig performed the first successful PTCA in 1977.

During PTCA, a specially designed guiding catheter is placed into the orifice of the stenotic coronary artery. (Fig. 27.97). A steerable guidewire is inserted into the balloon catheter and advanced within the guiding catheter (Fig. 27.98). The guidewire is advanced across the stenotic area; it serves as a support platform so that the balloon catheter can be advanced and centered across the stenosis. Controlled and precise inflation of the balloon fractures and compresses the fatty deposits into the muscular wall of the artery. This compression, in conjunction with the stretching of the external vessel diameter, is necessary for successful angioplasty. The balloon is deflated to allow rapid reperfusion of blood to the heart muscle. The inflation procedure, followed by arteriography, may be repeated several times until a satisfactory degree of patency is observed (Fig. 27.99). The limiting factor of PTCA is restenosis, which occurs in approximately 30% to 50% of patients who undergo the procedure. Restenosis of the coronary artery after revascularization is the major factor in failed long-term outcomes. Due to this high restenosis rate, balloon-expandable coronary stent placement, rather than PTCA alone, is now commonly performed. There are several different stent designs. Drug-coated or drug-eluting stents were designed to reduce or inhibit restenosis that occurs after a revascularization procedure. Drugs are chemically bound or coated on a stent. The drug is released in small amounts over time to inhibit restenosis. The various drugs reduce restenosis by limiting the proliferation of smooth muscle cells or reducing the rate at which this occurs. The prevention of restenosis after revascularization remains to be proven.

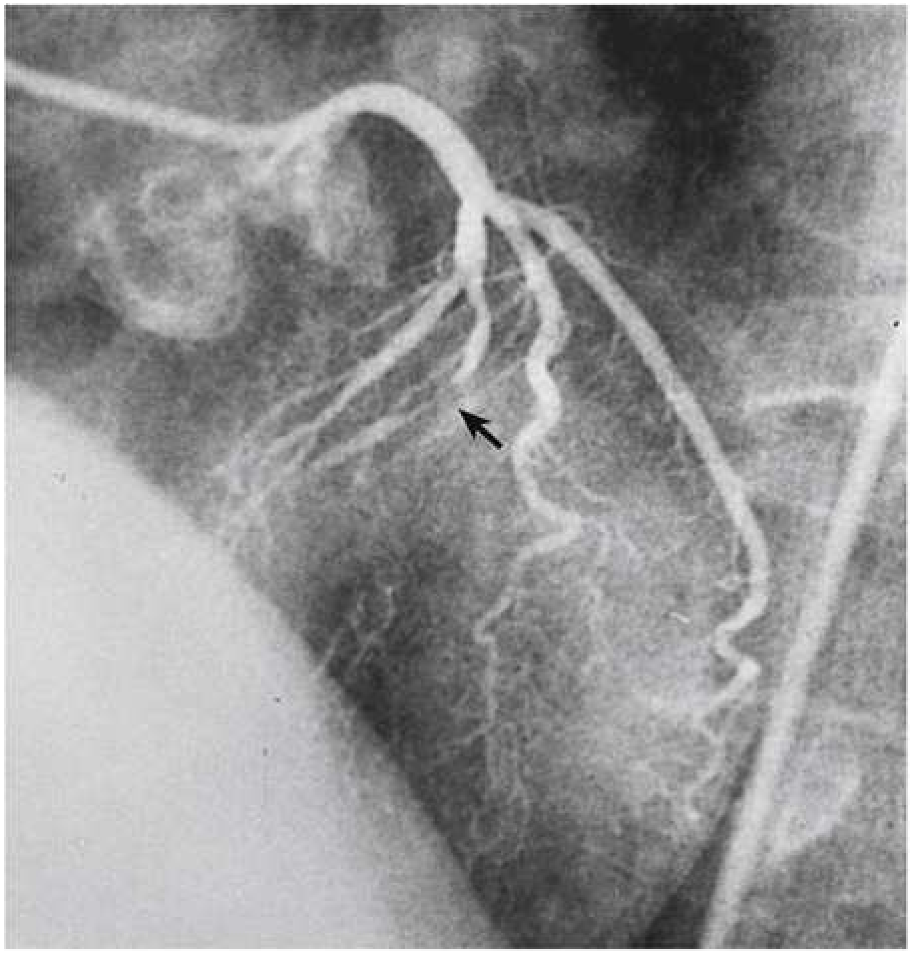


FIG. 27.97 Stenotic coronary artery before PTCA. *Arrow* indicates the stenotic area, estimated at 95%, with minimum blood flow distal to the lesion.

Bare metal stents are used along with or independently of drug-eluting stents. Patient age, cost, and disease are the determining factors. The procedure is similar to PTCA and is performed in the same manner except that a metallic stent is mounted on the angioplasty balloon (Fig. 27.100). For optimal stent deployment, the stent is centered across the entire length of the stenosis. Deployment of the stent is achieved with the inflation and deflation of the angioplasty balloon. After the stent is deployed, the angioplasty balloon is removed, and a high-pressure balloon is advanced within the stent. Inflation of the high-pressure balloon is performed to embed the metallic struts of the stent in the walls of the artery. Restenosis rates are lower in patients receiving intracoronary stents than in patients who undergo conventional angioplasty. Of major concern are dissection at the proximal and distal ends of the stent and complete apposition of the stent against the vessel wall.

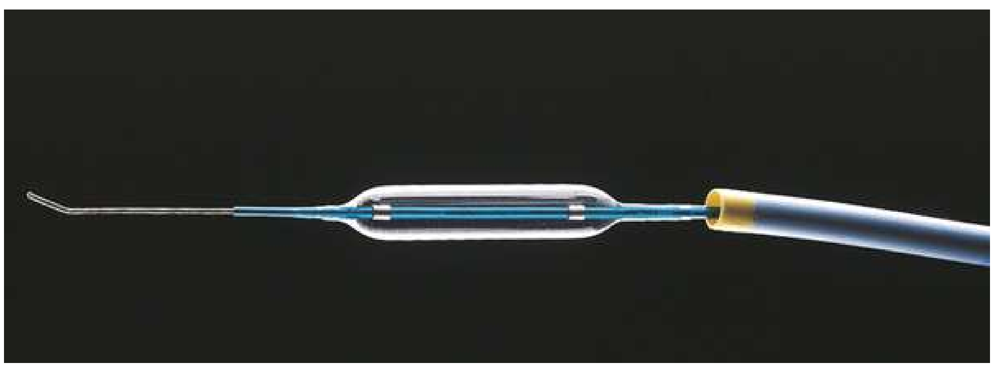


FIG. 27.98 Catheter system for PTCA. The three sections of the system are the outer guiding catheter *(right)*, central balloon catheter *(middle)*, and internal steerable guidewire *(left)*. Courtesy Cordis Corp., Miami, FL.

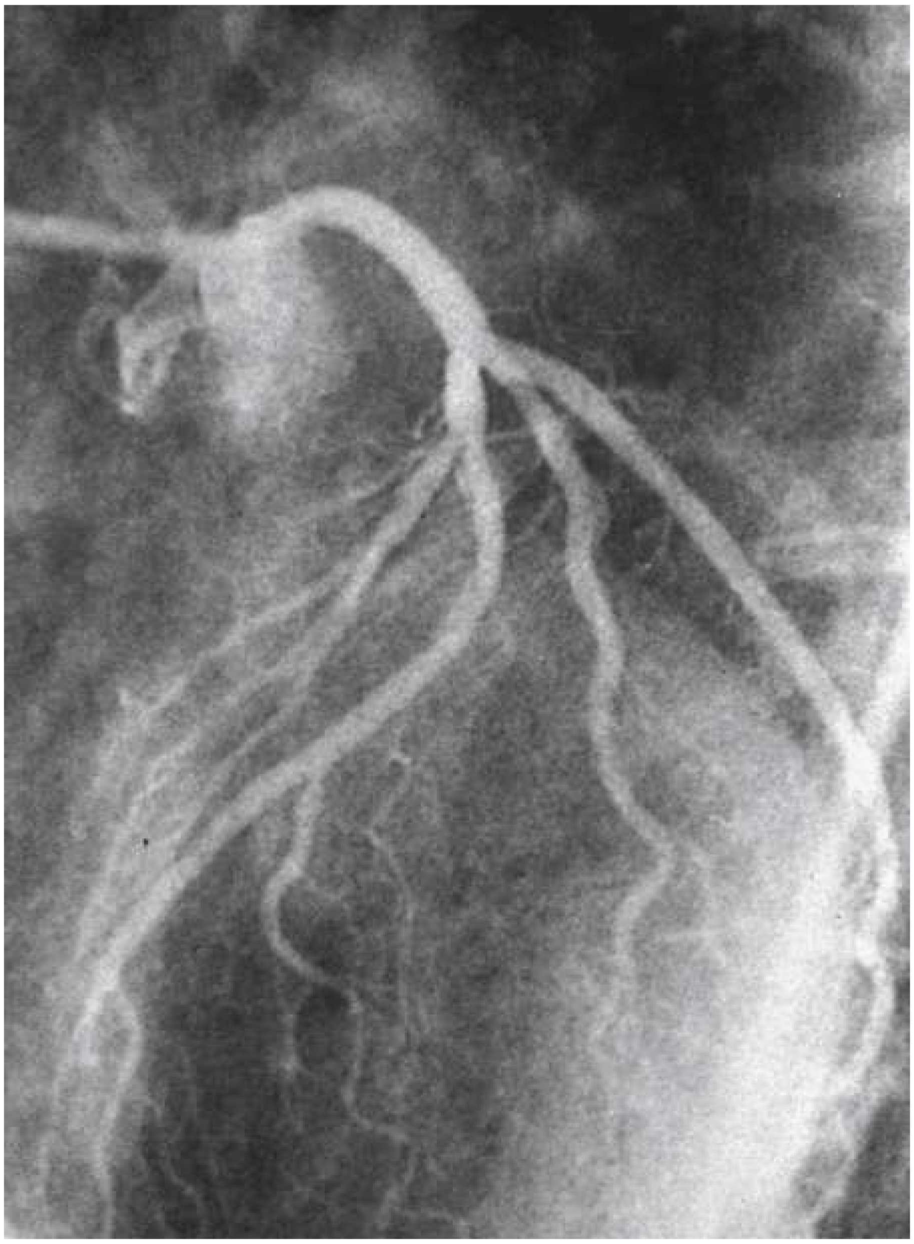


FIG. 27.99 Coronary arteriogram after PTCA in the same patient as in Fig. 27.92. Blood flow is estimated to be 100%.

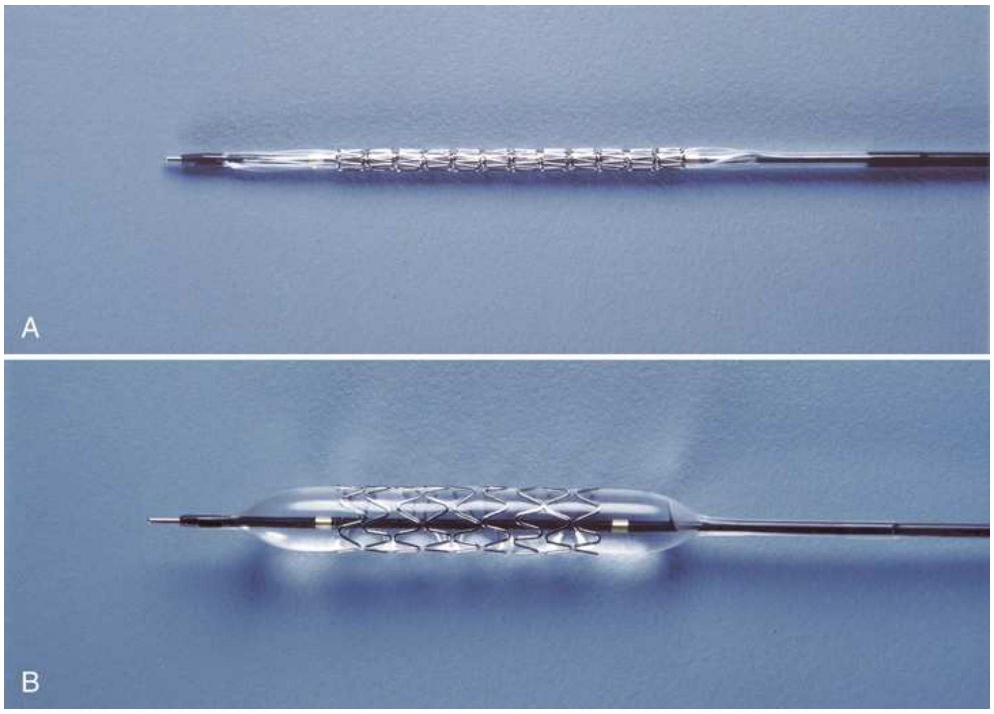


FIG. 27.100 Balloon expandable intracoronary stent. (A) Before stent balloon inflation. (B) After stent balloon inflation.

Atherectomy

Atherectomy devices are used in the treatment of coronary artery disease. In contrast to angioplasty balloons, atherectomy devices remove the fatty deposit or thrombus material from within the artery (Fig. 27.101).

A device called Rotablator has been indicated in the use of atherosclerotic coronary artery disease. Commonly referred to as percutaneous transluminal coronary rotational atherectomy (PTCRA), this procedure can be used in conjunction with PTCA or stenting. The tip of the catheter (1.25 to 2.5 mm in diameter) resembles a football and is embedded with microscopic diamond particles on the front half and is rotated on a special torque guidewire between 160,000 and 200,000 rpm (Figs. 27.102 and 27.103).

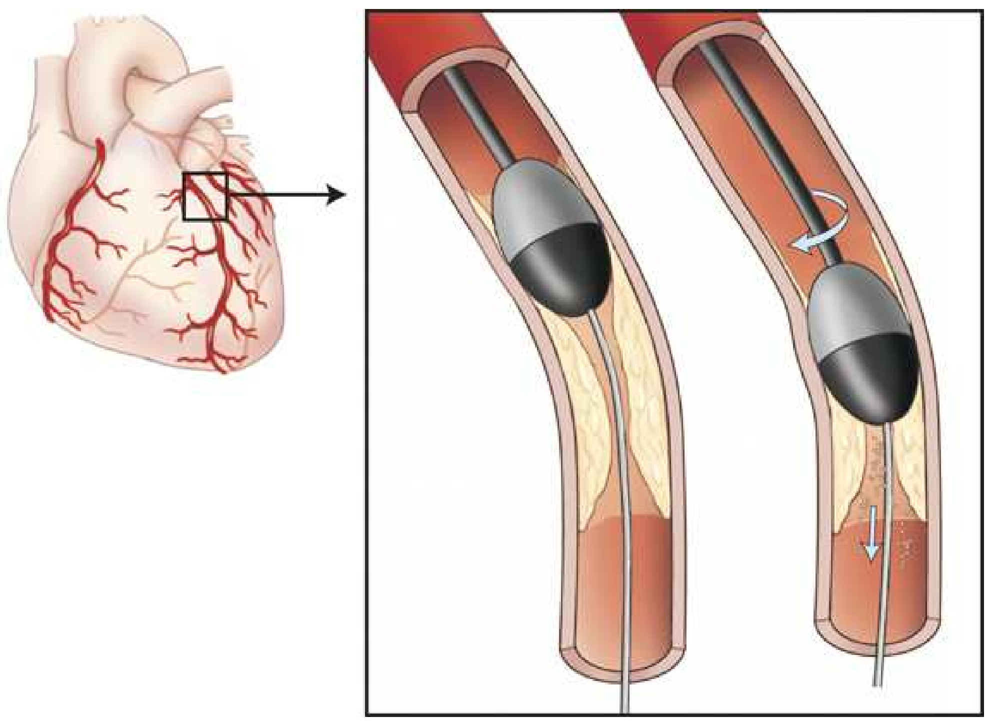


FIG. 27.101 Coronary atherectomy device.

Diagram shows a heart on the left. An arrow from a part highlighted on the heart points at two tubes slightly bent in the middle. The tube on the left has a oval ball on the top. There are yellow colored deposits on either side of the tube beneath the ball. A catheter passes through it. The tube on the right shows the oval ball pushing away the yellow deposits on the tube. A white arrow points downwards.

FIG. 27.102 Rotablator rotational atherectomy catheter with advancer unit. *Insert* shows football-shaped burr. Courtesy Boston Scientific.

FIG. 27.103 Atherectomy catheter burr. Courtesy Boston Scientific.

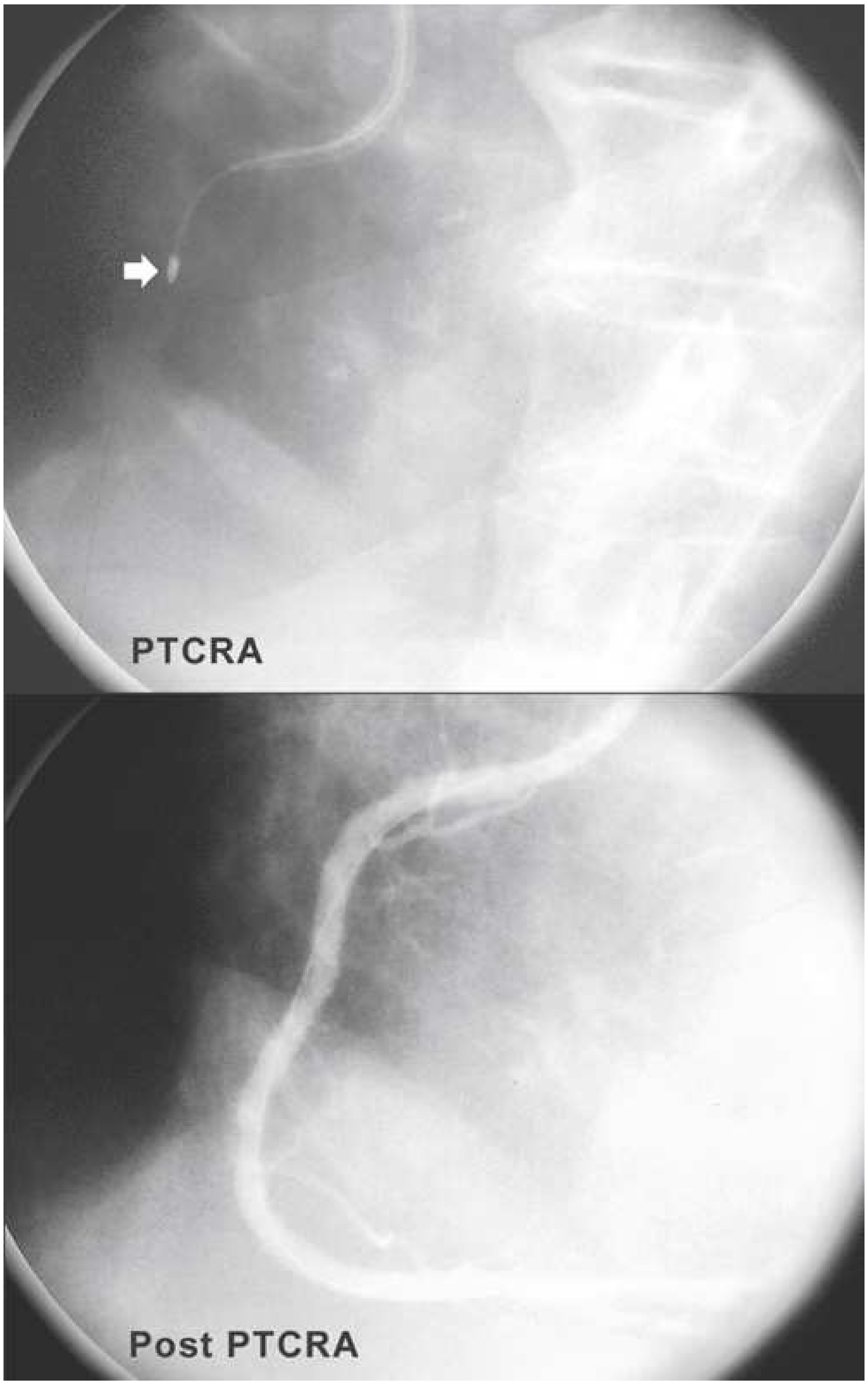


FIG. 27.104 PTCRA. *Arrow* points to burr of catheter. After PTCRA, a widely patent right coronary artery is shown.

A radiographic image on the top shows a pale white spot at the tip of a catheter. It is indicated by a white arrow. A radiographic image at the bottom shows a long slender tubular structure. It appears radiopaque.

FIG. 27.105 IVUS unit. Shown here are the keyboard and monitor. Courtesy Volcano.

Standard angioplasty catheter positioning techniques are used to position a guidewire distal to the targeted lesion. A rotational atherectomy burr size is selected and advanced over the special torque guidewire just proximal to the lesion. At this point, the burr is activated, and the plaque is pulverized and reduced to the size of a blood cell. The pulverized plaque is removed by the reticuloendothelial system. After an adequate amount of plaque is cleared, standard PTCA or stenting techniques are employed to maintain artery patency (Fig. 27.104). PTCRA has proven to be beneficial in the treatment of highly calcified lesions and in-stent restenosis compared with PTCA alone.

Intravascular Ultrasound

Although coronary angiography remains the gold standard for the diagnosis of coronary artery disease, *intravascular ultrasound* (IVUS) offers further diagnostic and interventional information that cannot be appreciated by angiography alone. IVUS allows a full 360-degree circumference visualization of the vessel wall, permits information regarding vascular pathology and longitudinal and volumetric measurements, and facilitates guidance of catheter-based interventions. The intervention-associated potential of IVUS is the ability to optimize the type and size of device being used and to determine proper apposition of the stent after deployment against the artery wall.

Components consist of the ultrasound unit, recording device, transducer, pullback device, and catheter (Fig. 27.105). The intravascular catheters employ 20- to 40-MHz silicon piezoelectric crystals and range in size from 5 Fr on the proximal end of the catheter to 2.9 Fr at the distal end. During the procedure, the IVUS catheter is advanced over the guidewire that was previously placed within the artery being imaged. The IVUS catheter is advanced distal to the targeted lesion, at which time the transducer and recording device are turned on. Slowly, the catheter is withdrawn using the pullback device to maintain a consistent withdrawal of the catheter and to help ascertain the length of the targeted lesion. Documentation of IVUS catheter position can be obtained with angiography. The images are stored on the hard drive of the IVUS system and can be retrieved for the cardiologist to review, take measurements, and print (Figs. 27.106 and 27.107).

At present, IVUS remains an integral part of coronary interventions being performed. With advances in stent designs, brachytherapy, local drug delivery, and future technologies, IVUS will remain a vital source for information in improving the outcomes of percutaneous coronary interventions. The clinical use of IVUS imaging and other improved computerized image enhancements should allow for more precise data collection and more tailored methods of determining the interventional method to use in treating coronary artery disease. A newer diagnostic tool available to visualize intravascular structures is optical coherence tomography (OCT). This technology uses infrared laser light to identify plaque rupture, stent apposition, dissection, and vessel size. This diagnostic tool creates extremely high-resolution images with improved visualization of calcified plaques. The image is obtained while injecting contrast into the vessel of interest, thereby displacing the blood. The only limitation to using this intra-procedure is if a patient has impaired renal function (Fig. 27.108A and B).

Valvuloplasty And Percutaneous Valve Repair And Replacement

Many procedures previously performed by open surgery, such as cardiac valve replacements, are now being performed percutaneously in the catheterization laboratory or in a hybrid angiography/OR suite. Percutaneous valve stenosis treatment, known as valvuloplasty, has been performed for many years, and for mitral valve stenosis, balloon valvuloplasty is considered the initial mechanical treatment. The mitral valve is accessed by passing a needle from the right atrium across the septum into the left atrium (transseptal access). A specially designed balloon catheter, called an Inoue balloon, is then passed into the left atrium and manipulated to cross the mitral valve. The mitral valve is then carefully dilated, in multiple stages, under continual trans mitral pressure gradient and echocardiographic monitoring.

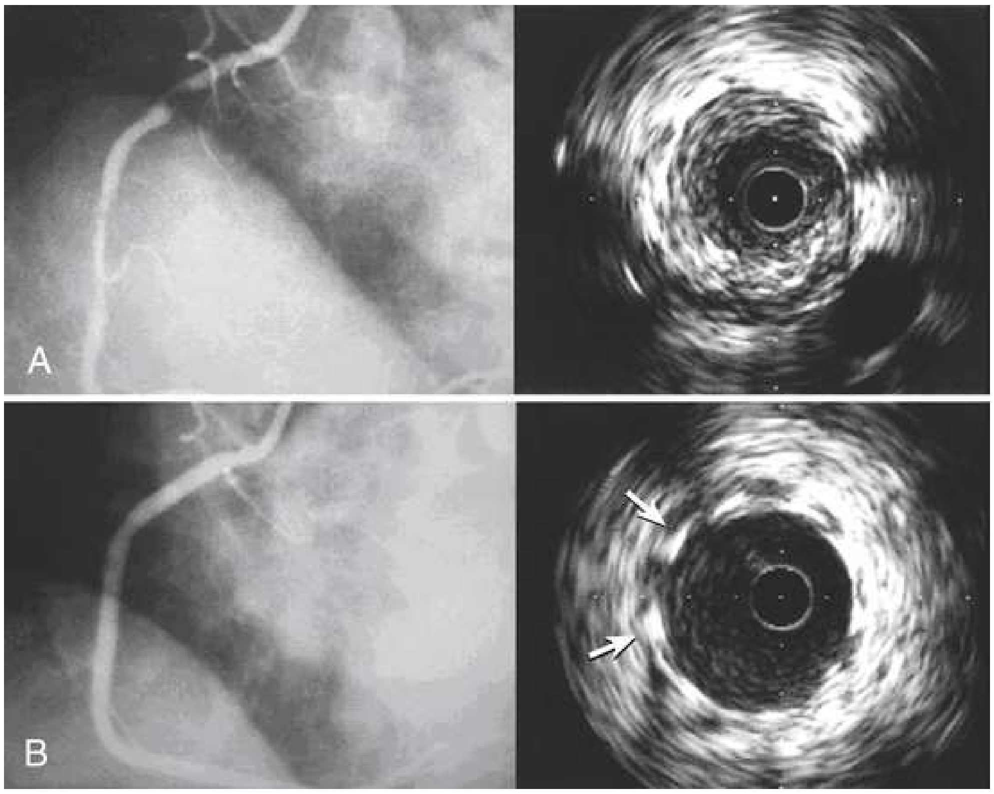


FIG. 27.106 IVUS images shown on the right correlated with angiography images on the left. *Arrows* in B show the echogenicity of the stent struts during IVUS.

(A) A radiographic image shows a long slender tubular structure. It has a gap in the middle and it appears radiopaque. A radiographic image next to it shows a circle with a definite white border in the middle surrounded by many radiopaque circular regions. (B) A radiographic image shows a long slender tubular structure. It appears radiopaque. A radiographic image next to it shows a circle with a definite white border in the middle surrounded by a radiopaque circular region. A radiolucent region is in between it. It is indicated by two white arrows.

FIG. 27.107 IVUS Artery Images.

For mitral valve regurgitation, a percutaneously placed clip can be used to repair the valve. Using transseptal puncture, the clip is attached to the mitral valve to enable the valve to close more effectively, reducing or eliminating mitral regurgitation.

Cardiothoracic surgeons and specially trained cardiac interventionalists can now perform transcatheter valve replacements, the most common of which is the transcatheter aortic valve replacement (TAVR) (Fig. 27.109). This procedure requires using multiple imaging modalities, such as fluoroscopy and transesophageal echocardiogram (TEE) to accurately assess valvular anatomy and function and is usually performed in the cardiothoracic OR, or in a hybrid angiography/OR suite, to quickly convert percutaneous procedure to an open heart surgery if required.

Congenital Defects

A primary indication for diagnostic catheterization studies in children is the evaluation and documentation of specific anatomy, hemodynamic data, and selected aspects of cardiac function associated with congenital heart defects. Methods and techniques used for catheterization of the heart vary depending on age, heart size, type and extent of defect, and other coincident pathophysiologic conditions.

Pediatric cardiac catheters are often introduced percutaneously into the femoral vein and, in older children, sometimes into the femoral artery. In very young patients, it may be possible to pass a catheter from the right atrium to the left atrium (allowing access to the left side of the heart) through either a patent foramen ovale (PFO) or a preexisting atrial septal defect. If the atrial septum is intact, temporary access to the left atrium may be obtained using a transseptal catheter system. (Fig. 27.110). With the transseptal catheter system, a long introducer and needle are used to puncture the right atrial septum of the heart to gain access to the left atrium if access cannot be attained as previously described.

Patent Ductus Arteriosus, Patent Foramen Ovale, And Atrial Septal Defect Closure

A patent ductus arteriosus is sometimes evident in a newborn. In utero, the pulmonary artery shunts blood flow into the aorta through the ductus arteriosus, which normally closes after birth. Patent ductus arteriosus occurs when this channel fails to close spontaneously. In some instances, closure can be induced with medication. If this measure is unsuccessful, and the residual shunt is deemed significant, surgical closure (ligation) of the vessel is appropriate.

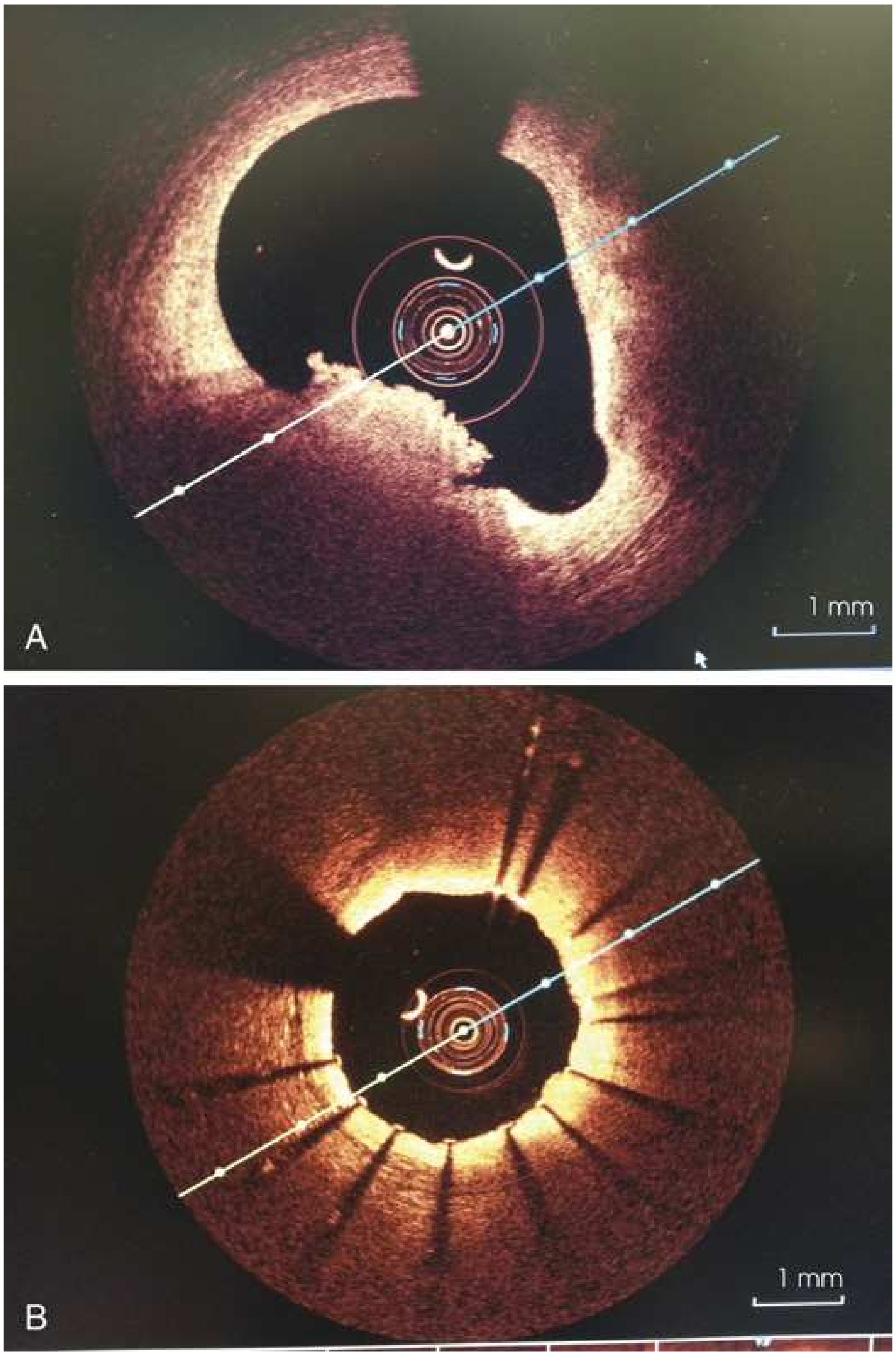


FIG. 27.108 (A) OCT demonstrating plaque burden inside a coronary artery. (B) OCT of coronary artery post stent deployment.

(A) A radiographic image shows multiple red circles in the middle surrounded by a reddish brown circle with a gap between the ends. A line passes through the center of all the circles. (B) A radiographic image shows multiple red circles in the middle surrounded by a reddish brown circle.

For some patients, occlusion of a patent ductus arteriosus can be accomplished in the catheterization laboratory. A catheter containing an occlusion device, such as an umbrella, is advanced to the ductus. After the position of the lesion is confirmed by angiography, the occluder is released. Subsequent clotting and fibrous infiltration permanently stop the flow and subsequent mixing of blood. Similarly, specific transcatheter closure devices are available to close a PFO, an opening between the right and left atria, and other atrial septal defects. PFO can be the cause of stroke in the adult patient. Occluder devices have shown positive results in treatment of the PFO.

Balloon Septostomy

Balloon septostomy may be used to enlarge a PFO or preexisting *atrial septal defect*. Enlargement of the opening enhances the mixing of right and left atrial blood, thereby improving the level of systemic arterial oxygenation. Transposition of the great arteries is a condition for which atrial septostomy is performed.

Balloon septostomy requires a catheter similar to the type used in PTCA. The balloon is passed through the atrial septal opening into the left atrium, inflated with contrast media, and snapped back through the septal orifice. This maneuver causes the septum to tear. Often the technique must be repeated until the septal opening is sufficiently enlarged to allow the desired level of blood mixing as documented by oximetry, intracardiac pressures, and angiography.

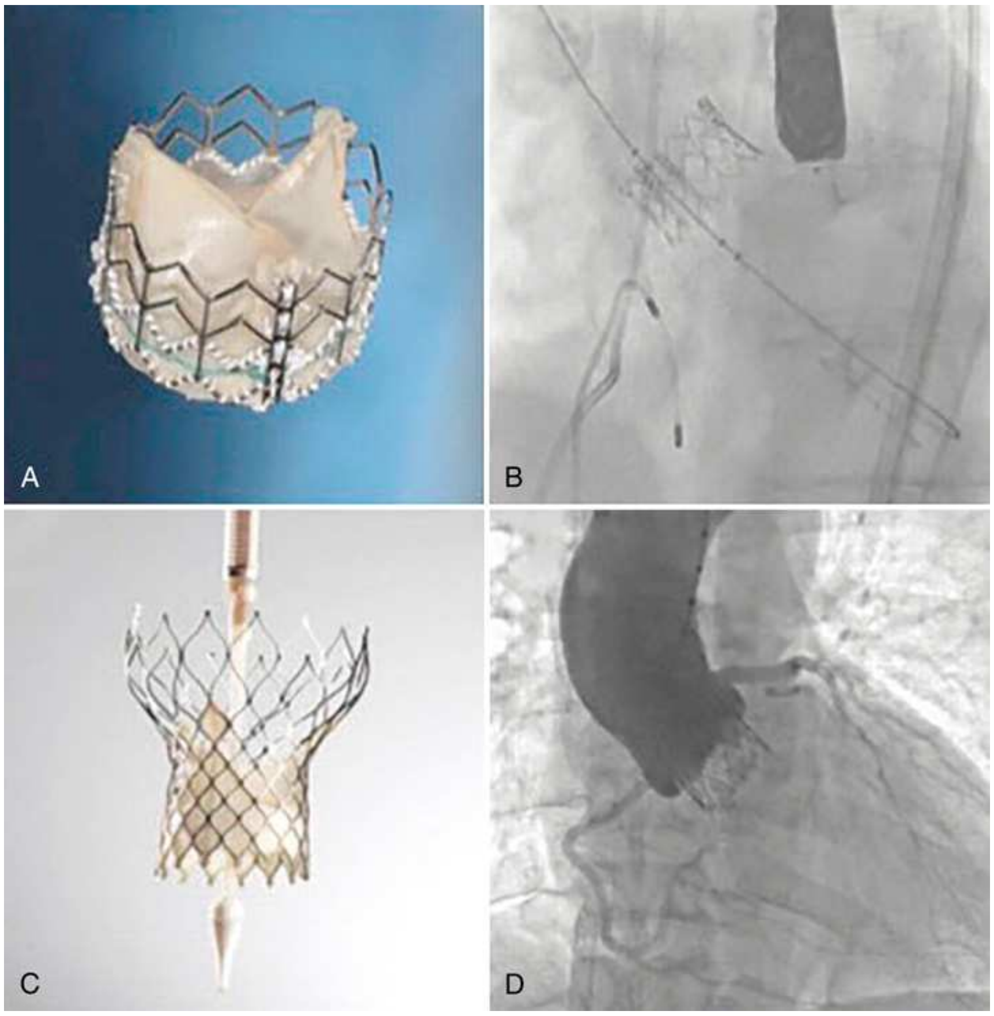


FIG. 27.109 Percutaneous aortic valves: (A) Edwards SAPIEN (Edwards Lifesciences Corp., Irvine, CA). (B) Fluoroscopic image of Edwards SAPIEN device in place. (C) CoreValve (Medtronic, Minneapolis, MN). (D) Aortogram of CoreValve in place. From Steinberg DH, Staubach S, Franke J, Sievert H: Defining structural heart disease in the adult patient: current scope, inherent challenges and future directions. *Eur Heart J Suppl* 12[E]:E2–E9, 2010.

(A) A circular percutaneous aortic valve with spikes on top. (B) A radiographic image shows a circular percutaneous aortic valve with spikes on top. (C) A circular percutaneous aortic valve with spikes on top and a broad end. (D) A radiographic image shows a circular percutaneous aortic valve with spikes on top and a broad end is in a radiolucent tubular structure.

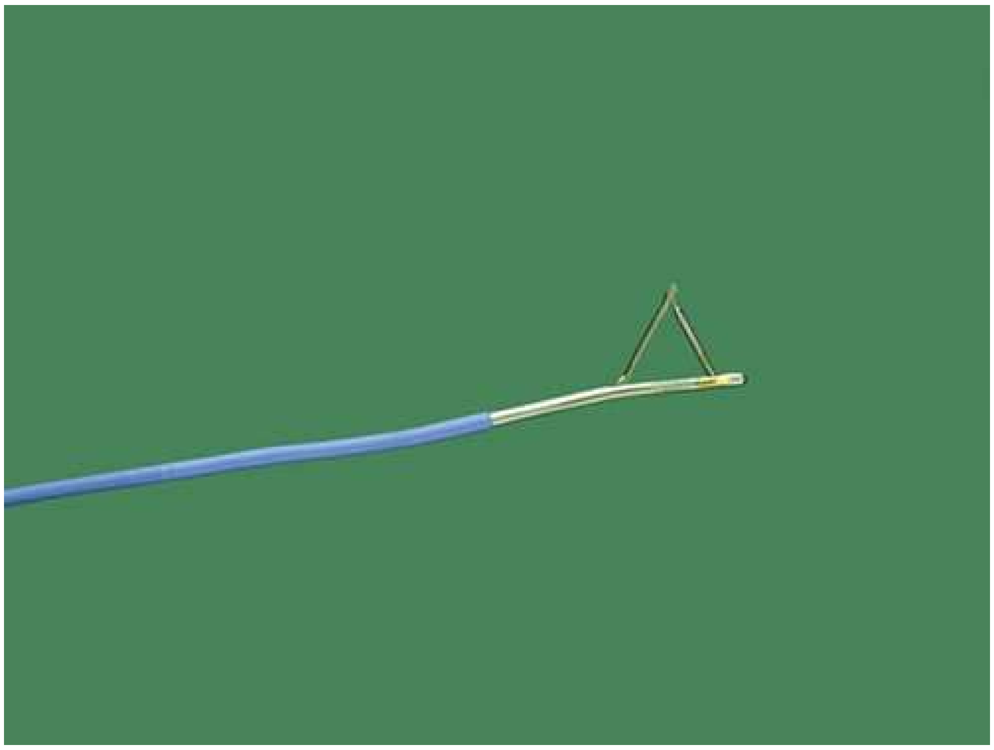


FIG. 27.110 Blade on catheter tip used to incise septal walls in pediatric interventional procedures.

Electrical Conduction System

Diagnostic Procedures

Electrophysiology (EP) procedures involve the collection of sophisticated data to facilitate detailed mapping of the electrical conduction system within the heart. The procedures involve placement of numerous multipolar electrode catheters in areas of the SA node, AV node, and/or bundle branches (Fig. 27.111). EP studies are used to analyze the conduction system, induce and evaluate arrhythmias, and determine the effects of therapeutic measures in treating arrhythmias.

Electrode catheters are introduced into the femoral vein, internal jugular vein, or subclavian vein. Because several catheters are used, multiple access sites are needed. It is common to have three introducer sheaths placed within the same vein. The catheters consist of several insulated wires, each of which is attached to an electrode on the catheter tip that serves as an interface with the intracardiac surface. The arrangements of the electrodes on the catheter allow its dual function of recording the electrical signals of the heart (intracardiac electrograms) and pacing the heart. The pacemaker function is performed to introduce premature electrical impulses to determine possible arrhythmias. After the precise defect is characterized, an appropriate course of therapy can be undertaken. Cardiac ablation, pacemaker, and internal cardiac defibrillator are the most common treatments for arrhythmias. In some cases, surgical intervention is required.

Interventional Conduction Procedures

Pacemaker and defibrillator

Permanent implantation of an antiarrhythmic device is another interventional procedure performed in cardiac catheterization laboratories (Fig. 27.112). Antiarrhythmic devices include pacemakers for patients with bradyarrhythmias or disease of the electrical conduction system of the heart and implantable cardioverter defibrillators (ICDs) for patients with lethal ventricular tachyarrhythmias originating from the bottom of the heart.

Pacemaker implantation can be performed successfully under local anesthesia in selected adult and pediatric patients. ICD implantation requires conscious sedation or general anesthesia, depending on the type of testing required at the time of implantation. Insertion of either a pacemaker or an ICD involves accessing the subclavian or cephalic vein and introducing leads (electrically insulated wires with distal electrodes). The leads are manipulated so that their tips are in direct contact with the right ventricular or right atrial endocardium, or both. The leads are tested for stimulation and sensing properties to ascertain proper functioning before they are attached to the pulse generator. During ICD implantation, defibrillation threshold testing is performed to determine the amount of energy required to defibrillate a patient from ventricular tachycardia or fibrillation. After testing is completed, the proximal end of the lead is attached to a battery (pacemaker or ICD) and implanted in a subcutaneous or subpectoral pocket created in the thorax (Fig. 27.113). Current pacemakers have longevity of 5 to 10 years, and ICDs have longevity of 6 to 8 years. Newer pacemaker technologies allow the elimination of pacemaker leads, although at present they are only available as an alternative to single lead pacemakers. A small pacemaker device is delivered through a catheter and embedded directly into the right ventricle. This leadless pacemaker is intended for patients with atrial fibrillation or other dangerous arrhythmias, such as bradycardia-tachycardia syndrome.

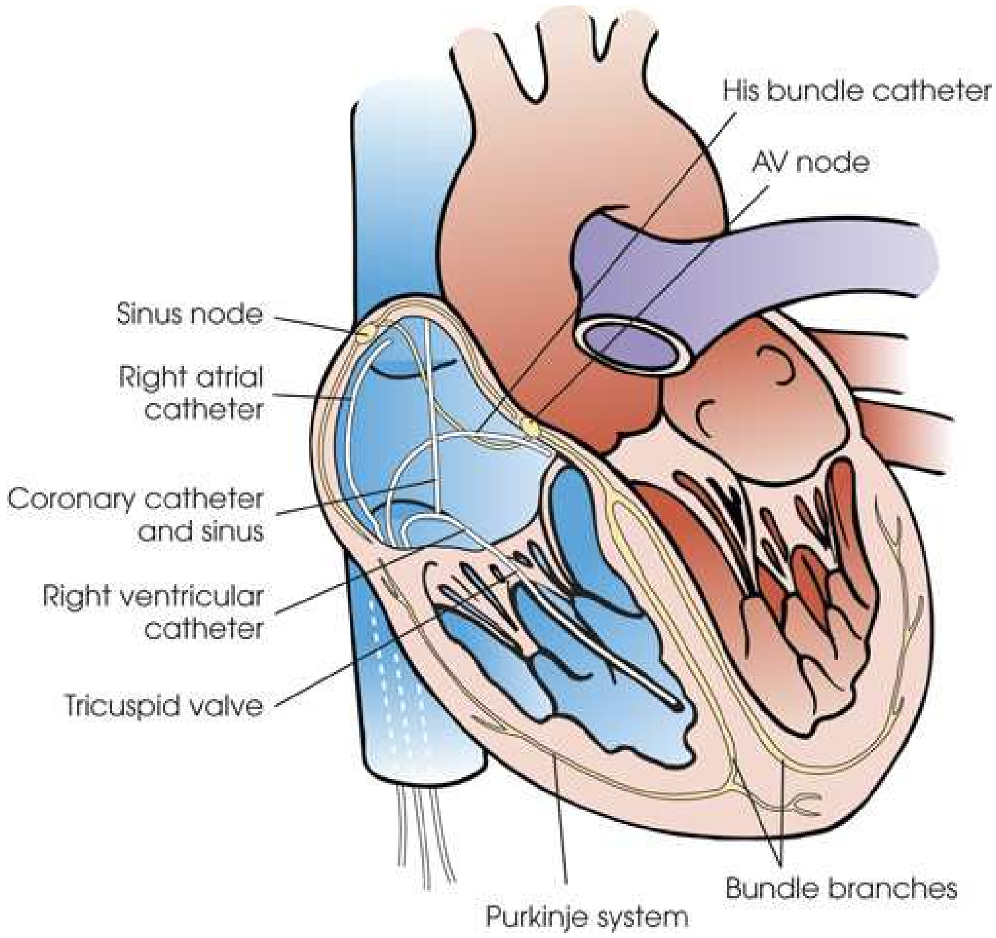


FIG. 27.111 Catheter positions for routine electrophysiologic study. Multipolar catheters are positioned in the high right atrium near the sinus node, in the area of the atrioventricular apex, and in the coronary sinus.

Diagram shows the catheter position of a heart. The position labeled on the diagram in clockwise direction are as follows: tricuspid valve, right ventricular catheter, coronary catheter and sinus, right atrial catheter, sinus node, his bundle catheter, A V node, bundle branches, Purkinje system.

Radiofrequency ablation

Another interventional procedure to treat disorders of the conduction system is radiofrequency (RF) ablation. Several different arrhythmias previously treated with ICD implantation or drug therapy can now be treated with RF ablation. The procedure is normally performed at the time of the diagnostic EP study if an underlying mechanism or arrhythmogenic focus is identified.

RF ablation is achieved by delivering a low-voltage, high-frequency alternating current directly to the endocardial tissue through a specially designed ablation catheter. The current desiccates the underlying abnormal myocardial conduction tissue and creates a small, discrete burn lesion. Localized RF lesions create areas of tissue necrosis and scar, subsequently destroying the arrhythmogenic focus. Several RF lesions may be necessary to eliminate the abnormal conduction circuit.

Follow-up electrophysiologic testing is performed to document the resolution of the arrhythmia. RF ablation of the atrioventricular node and pacemaker insertion is quickly becoming the preferred treatment for chronic atrial fibrillation with rapid, irregular responses. The atrioventricular junction is destroyed intentionally; consequently, the rapid, irregular electrical impulses from the atrium are not conducted into the ventricle. A pacemaker is implanted, and a more consistent, regular heart rate is achieved.

FIG. 27.112 (A) Single-chamber ICD. (B) Dual chamber pacemaker. Used with permission of Boston Scientific Corporation. Boston Scientific Corporation 2013 or its Affiliates. All rights reserved.

Interventional Cardiology: Present and the Future

Existing and new interventional procedures will continue to provide patients with viable, relatively low-risk, financially reasonable alternatives to open-heart surgery. The area of transcatheter guidance in structural heart interventions, such as valve replacement, is growing rapidly. These procedures, while minimally invasive for the patient, are technically complex and require multimodality imaging, both for planning for procedure and in performing the procedure. Advances in 3-D/4-D transesophageal echocardiography (TEE) and cardiac CTA have assisted in procedure planning. The ability to use cardiac *fusion imaging* software in the angiographic suite has greatly improved visualization during the procedure. Cardiac fusion imaging software overlays both CTA and TEE images onto the live fluoroscopy image. The images can also be incorporated into the live fluoroscopy image, so that the image moves in conjunction with the fluoroscopy image to assist with catheter and device manipulation.

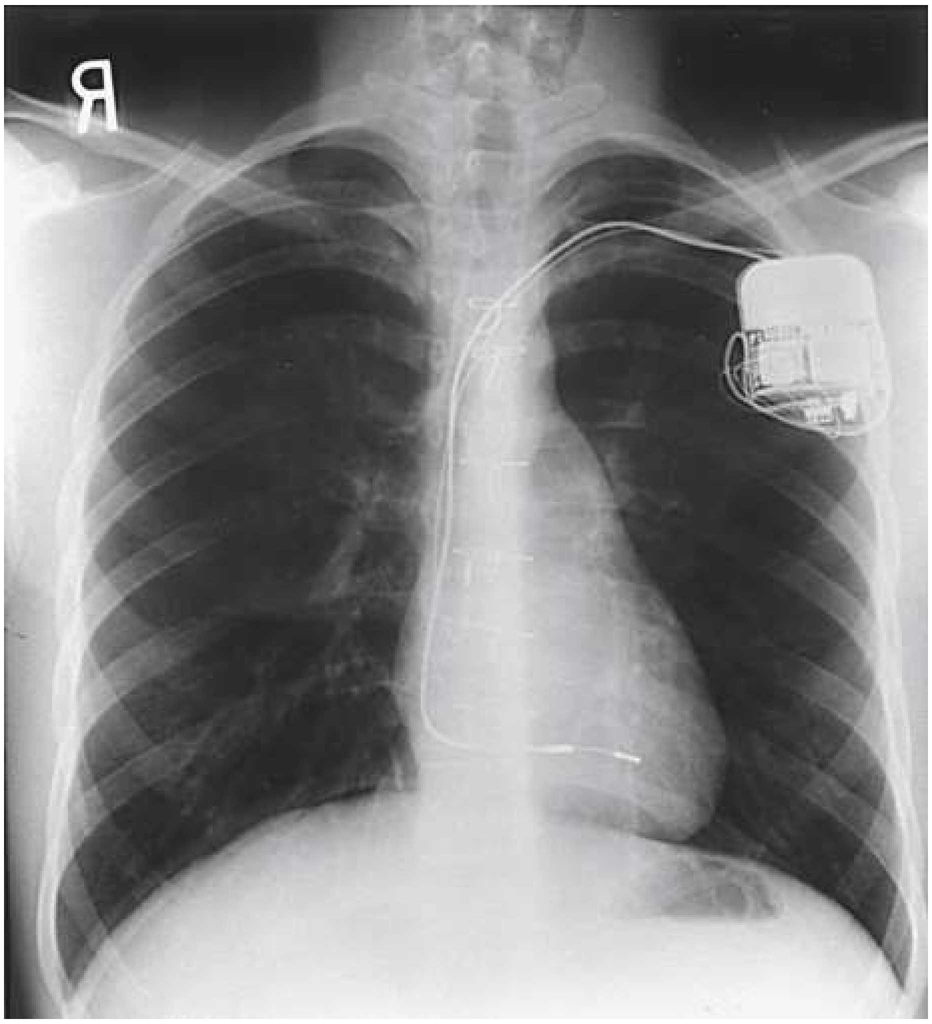


FIG. 27.113 Chest radiograph of a patient with a permanent pacemaker implanted. Note the pacemaker location in the superior and anterior chest wall, with the distal leads located in the right ventricle and right atrium of the heart.

An x-ray view of the chest shows a radiopaque device with a wire connected to the heart. It is located in the superior and anterior chest wall, with the distal leads located in the right ventricle and right atrium of the heart.

As the practice of interventional cardiology evolves to include more complex and therefore longer procedures, innovative technology is being explored to reduce radiation exposure to both patients and staff, and to make the cardiac catheterization laboratory more ergonomically friendly. The use of remote-controlled robotics in percutaneous coronary intervention is thought to be a way to reduce some of the occupational hazards to interventional radiologists. Research is currently being conducted to evaluate patient safety and the technical and clinical performance of these robotic systems in manipulating needles, guidewires, catheters, and stents. Despite changes in cardiovascular technology and medical techniques, cardiac catheterization laboratories continue to provide the essential patient care services necessary for the diagnosis and treatment of a vast number of cardiovascular-related diseases.

Best Practices in Vascular, Cardiac, and Interventional Radiology

Vascular and cardiac interventional technologists have a fundamental role in vascular and cardiac angiographic procedures. The technologist prepares the angiographic room, assists the physician with angiographic imaging, ensures necessary supplies are readily available, and is often a scrub assistant to the physician. The technologist is actively involved in patient education, patient positioning, preparing angiographic and medical equipment, maintaining a sterile field during procedures, and ensuring radiation protection and safety measures are followed. Cardiac interventional technologists also receive additional training for monitoring and documenting hemodynamic data during cardiac procedures. Often technologists perform these tasks under emergent and stressful conditions, when time is a critical factor in improving patient outcomes. The following best practices provide some guidelines for the vascular and cardiac interventional technologists.

1. ***Effective communication and teamwork:*** In critical medical situations, such as during angiographic and interventional procedures, it is vital to communicate effectively with fellow team members. Technologists should practice the following: verify pertinent information and ensure expectations are aligned, ask for clarification where necessary, ask for assistance where necessary, be prepared to assist when possible, and prioritize patient safety measures.

2. ***Preparation:*** When preparing the room for the procedure, technologists should verify the expected procedure, the expected supplies to be used, and the patient's condition with the physician. Preparing the room as much as possible before the patient arrives in the procedural room will allow for effective use of procedural time.

3. ***Attention to department protocol and scope of practice:*** The technologist should know the department protocols and practice them within his or her own competence and abilities.

4. ***Universal protocol:*** All angiographic team members are responsible for ensuring the three steps of the universal protocol are adhered to (where applicable) prior to any invasive procedure. These steps include preprocedural verification checklist, site marking, and "time-out" procedure.

5. ***Informed consent and documentation:*** All angiographic team members are responsible for ensuring informed consent is given prior to invasive procedures. Technologists must be knowledgeable of facility policies regarding the informed consent process, including documentation and alternative decision-maker issues, as well as expectational circumstances, such as ST-Elevation Myocardial Infarction (STEMI).
6. ***Infection control:*** The interventional suite should be treated as an OR environment. Access should be limited to essential personnel only. Personnel must wear proper attire and be trained to follow strict aseptic practices. The procedure room, patient devices, and angiographic equipment must be cleaned thoroughly between cases. Surgical hand scrub should be performed immediately before putting on sterile gown and gloves. Maximum sterile barrier precautions should be utilized. All staff must ensure the sterile field is maintained and not contaminated. Packaging for sterile supplies must be checked for expiration dates and signs of damage before opening.
7. ***Radiation safety:*** All angiographic procedures should be performed while keeping radiation dose as low as reasonably achievable (ALARA). All personnel in the procedure room should wear personal radiation protective equipment including lead aprons, radiation badges, thyroid shields, and leaded glasses for those nearest the radiation source. Technologists should be mindful of and remind visiting personnel, such as anesthesia or respiratory staff, the importance of time, intensity, distance, and shielding with fluoroscopy procedures.
8. *Certification training and continuous education:* Ideally, technologists should obtain Vascular Interventional (VI), Cardiac Interventional (CI), or Registered Cardiovascular Invasive Specialist (RCIS) certification and comply with continuing education requirements for these certifications. Additional training and education pertaining to angiographic equipment, imaging applications, patient monitoring devices, angiographic and interventional devices, and new procedures are essential to function effectively in the fields of interventional radiology and cardiovascular interventions. Technologist competency documentation should be reviewed and updated regularly to reflect additional training. Technologists should also be encouraged to join professional organizations, attend national meetings, and be actively involved in staying current in their field.

Definition of Terms

acquisition rate: The rate at which angiographic images are taken; measured in frames per second (f/s).
adventitia: The outer most layer of connective tissue that surrounds a blood vessel.
afferent lymph vessel: Vessel carrying lymph toward a lymph vessel.
anastomose: Join.
aneurysm: Sac formed by local enlargement of a weakened artery wall.
angina pectoris: Severe form of chest pain and constriction near the heart; usually caused by a decrease in the blood supply to cardiac tissue; most often associated with stenosis of a coronary artery as a result of atherosclerotic accumulations or spasm. Pain generally lasts for a few minutes and is more likely to occur after stress, exercise, or other activity resulting in increased heart rate.
angiography: Radiographic demonstration of blood vessels after the introduction of contrast media.
anomaly: Variation from the normal pattern.
aortic dissection: Tear in inner lining of the aortic wall that allows blood to enter and track along the muscular coat.
aortography: Radiographic examination of the aorta.
arrhythmia: Variation from normal heart rhythm.
arrhythmogenic: Producing an arrhythmia.
arteriography: Radiologic examination of arteries after injection of a radiopaque contrast medium.
arteriole: Very small arterial vessel.
arteriosclerotic: Indicative of a general pathologic condition characterized by thickening and hardening of arterial walls, leading to general loss of elasticity.
arteriotomy: Surgical opening of an artery.
arteriovenous malformation: Abnormal anastomosis or communication between an artery and a vein.
artery: Large blood vessel carrying blood away from the heart.
atherectomy: Excision of atherosclerotic plaque.
atheromatous: Characteristic of degenerative change in the inner lining of arteries caused by the deposition of fatty tissue and subsequent thickening of arterial walls that occurs in atherosclerosis.
atherosclerosis: Condition in which fibrous and fatty deposits on the luminal wall of an artery may cause obstruction of the vessel.
atrium: One of the two upper chambers of the heart.
balloon angioplasty: See percutaneous transluminal angioplasty (PTA).
bifurcation: Place where a structure divides into two branches.
biplane: Two x-ray exposure planes 90 degrees from one another, usually frontal and lateral.
blood vascular system: Vascular system comprising arteries, capillaries, and veins, which convey blood.
bradyarrhythmia: Irregular heart rhythm in conjunction with bradycardia.
bradycardia: Any heart rhythm with an average heart rate of less than 60 beats/min.
capillary: Tiny blood vessel through which blood and tissue cells exchange substances.
cardiac output: Amount of blood pumped from the heart per given unit of time; can be calculated by multiplying stroke volume (amount of blood in milliliters ejected from the left ventricle during each heartbeat) by heart rate (number of heartbeats per minute). A normal, resting adult with a stroke volume of 70 mL and a heart rate of 72 beats/min has a cardiac output of approximately 5 L/min.

cardiomyopathies: Relatively serious group of heart diseases typically characterized by enlargement of the myocardial layer of the left ventricle and resulting in decreased cardiac output; hypertrophic cardiomyopathy is a condition often studied in the catheterization laboratory.
cinefluorography: Same as cineradiography; the production of a motion picture record of successive images on a fluoroscopic screen.
claudication: Cramping of the leg muscles after physical exertion because of chronically inadequate blood supply.
coagulopathy: Any disorder that affects the blood-clotting mechanism.
collateral: Secondary or accessory.
diastole: Relaxed phase of the atria or ventricles of the heart during which blood enters the chambers; in the cardiac cycle at which the heart is not contracting (at rest).
dyspnea: Labored breathing.
efferent lymph vessel: Vessel carrying lymph away from a node.
ejection fraction: Measurements of ventricular contractility expressed as the percentage of blood pumped out of the left ventricle during contraction; can be estimated by evaluating the left ventriculogram; normal range is 57% to 73% (average 65%). A low ejection fraction indicates failure of the left ventricle to pump effectively.
embolization: The artificial or natural formation of an embolus
embolus: Foreign material, often thrombus, that detaches and moves freely in the bloodstream.
endocardium: Interior lining of heart chambers.
epicardium: Exterior layer of heart wall.
ergometer: Device used to imitate the muscular, metabolic, and respiratory effects of exercise.
extravasation: Escape of fluid from a vessel into the surrounding tissue.
fibrillation: Involuntary, chaotic muscular contractions resulting from spontaneous activation of single muscle cells or muscle fibers.
French size: Measurement of catheter sizes; 1 French = 0.33 mm; abbreviated Fr.
guidewire: Tightly wound metallic wire over which angiographic catheters are placed.
hematoma: Collection of extravasated blood in an organ or a tissue space.
hemodynamics: Study of factors involved in circulation of blood. Hemodynamic data typically collected during heart catheterization are cardiac output and intracardiac pressures.
hemostasis: Stopping of blood flow in a hemorrhage.
iatrogenic: Caused by a therapeutic or diagnostic procedure.
intima: Inner most endothelia layer of a blood vessel.
innominate or brachiocephalic artery: First major artery of the aortic arch supplying the cerebral circulation.
in-stent restenosis: Renarrowing of an artery inside a previously placed stent.
intervention: Therapeutic modality—mechanical or pharmacologic—used to modify the course of a disease process.
interventricular septal integrity: Continuity of the membranous partition that separates the right and left ventricles of the heart.
intracoronary stent: Metallic device placed within a coronary artery across a region of stenosis.
introducer sheath: Plastic tubing placed within the vasculature through which other catheters may be passed.
ischemic: Indicative of a local decrease of blood supply to myocardial tissue associated with temporary obstruction of a coronary vessel, typically as a result of thrombus (blood clot).
lesion: Injury or other damaging change to an organ or tissue.
lymph: Body fluid circulated by the lymphatic vessels and filtered by the lymph nodes.
lymph vessels: See afferent and efferent lymph vessel.
lysis: Decomposition, destruction, or breakdown
mandrel: Inner metallic core of a spiral wound guidewire.
meninges: Three membranes that envelop the brain and spinal cord.
minimally invasive: Minimizing surgical incisions to reduce trauma to the body.
misregistration: Occurs when the two images used to form a subtraction image are slightly displaced from one another.
myocardial infarction (MI): Acute ischemic episode resulting in myocardial damage and pain; commonly referred to as a heart attack.
myocardium: Muscular heart wall.
neointimal hyperplasia: Hyperproliferation of smooth muscle cells and extracellular matrix secondary to revascularization.
nephrotoxic: Chemically damaging to the kidney cells.
noninvasive imaging: Imaging that does not require the introduction of instruments into the body.
nonocclusive: Not completely closed or shut; allowing blood flow.
occlusion: Obstruction or closure of a vessel, such as a coronary vessel, as a result of foreign material, thrombus, or spasm.
oximetry: Measurement of oxygen saturation in blood.
oxygen saturation: Amount of oxygen bound to hemoglobin in blood, expressed as a percentage.
patency: State of being open or unobstructed.
patent foramen ovale: Opening between the right atrium and left atrium that normally exists in fetal life to allow for the essential mixing of blood. The opening normally closes shortly after birth.
percutaneous: Introduced through the skin.
percutaneous transluminal angioplasty (PTA): Surgical correction of a vessel from within the vessel using catheter technology.
percutaneous transluminal coronary angioplasty (PTCA): Manipulative interventional procedure involving the placement and inflation of a balloon catheter in the lumen of a stenosed coronary artery for the purpose of compressing and fracturing the diseased material, allowing subsequent increased distal blood flow to the myocardium.
percutaneous transluminal coronary rotational atherectomy (PTCRA): Manipulative interventional procedure involving a device called a Rotablator to remove atherosclerotic plaque from within the coronary artery using a high-speed rotational burr.
percutaneously: Performed through the skin.
pericardium (pericardial sac): Fibrous sac that surrounds the heart.
planimetry: Mechanical tracing to determine the volume of a structure.

pledget: Small piece of material used as a dressing or plug.
portal circulation (portal system): System of vessels carrying blood from the organs of digestion to the liver.
postprocessing: Image processing operations performed when reviewing an imaging sequence.
pressure transducer: See transducer.
pulmonary circulation: System of vessels carrying blood from the heart to the lungs and back to the heart.
pulse: Regular expansion and contraction of an artery that is produced by ejection of blood from the heart.
pulse oximetry: Measurement of oxygen saturation in the blood via an optic sensor placed on an extremity.
radial force: A force exerted from the center of a radius, used in endovascular stents
reperfusion: Reestablishment of blood flow to the heart muscle through a previously occluded artery.
restenosis: Narrowing or constriction of a vessel, orifice, or other type of passageway after interventional correction of primary condition.
rotational burr atherectomy: Ablation of atheroma through a percutaneous transcatheter approach using a high-speed rotational burr.
serial imaging: Acquisition of images in rapid succession.
stenosis: Narrowing or constriction of a vessel, an orifice, or another type of passageway.
stent: Wire mesh or plastic conduit placed to maintain flow.
systemic circulation: System of vessels carrying blood from the heart out to the body (except the lungs) and back to the heart.
systole: Contraction phase of the atria or ventricles of the heart during which blood is ejected from the chambers; point in the cardiac cycle at which the heart is contracting (at work).
tachyarrhythmia: Irregular heart rhythm in conjunction with tachycardia.
tachycardia: Any heart rhythm having an average heart rate in excess of 100 beats/min.
targeted lesion: Area of narrowing within an artery where a revascularization procedure is planned.
thrombogenesis: Formation of a blood clot.
thrombolytic: Capable of causing the breakup of a thrombus.
thrombosis: Formation or existence of a blood clot.
thrombus: Blood clot obstructing a blood vessel or cavity of the heart.
transducer: Device used to convert one form of energy into another. Transducers used in cardiac catheterization convert fluid (blood) pressure into an electrical signal displayed on a physiologic monitor.
transposition of the great arteries: Congenital heart defect requiring interventional therapy. In this defect, the aorta arises from the right side of the heart, and the pulmonary artery arises from the left side of the heart.
valvular competence: Ability of the valve to prevent backward flow while not inhibiting forward flow.
varices: Irregularly swollen veins.
vasoconstriction: Temporary closure of a blood vessel using drug therapy.
vein: Vessel that carries blood from the capillaries to the heart.
venography: Radiologic study of veins after injection of radiopaque contrast media.
venotomy: Surgical opening of a vein.
ventricle: One of two larger pumping chambers of the heart.
venule: Any of the small blood vessels that collect blood from the capillaries and join to become veins.

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[a] Almost all italicized words on the succeeding pages are defined at the end of this chapter.

[b] Gelfoam is the trademark for a sterile, absorbable, water-insoluble, gelatin-based sponge.

[c] Interpretation of ECG is beyond the scope of this chapter.

28: Diagnostic Medical Sonography

Susanna L. Ovel

OUTLINE

Principles of Diagnostic Ultrasound

Diagnostic medical sonography [a] is a general term used to encompass abdominal, breast, cardiac, gynecologic, obstetric, and vascular sonography. *Registered diagnostic medical sonographers* (RDMSs) specialize in abdominal sonography, obstetrics/gynecology imaging, breast sonography, musculoskeletal imaging, or pediatric sonography. *Registered diagnostic cardiac sonographers* (RDCSs) specialize in fetal, pediatric, or adult echocardiography. *Registered vascular technologists* (RVTs) specialize in abdominal vasculature imaging, as well as imaging of arteries and veins of the upper and lower extremities, imaging of extracranial arteries and veins, transcranial duplex sonography, and physiologic vascular testing in pediatric and adult patients. One overall physics examination, encompassing sonographic principles, hemodynamics, and instrumentation, is required for all of these specialties.

Diagnostic medical sonography employs high-frequency transducers ranging from 2 to 50 MHz. The transducer emits short pulses of ultrasound (pulse waves) into the human body. The transducer receives real-time reflections or frequency shifts from structures or vessels along the sound waves path, and they are displayed as a grayscale, color Doppler, spectral, or duplex image. Velocity of the red blood cells can be calculated using the Doppler technique. Pulse wave, continuous wave, and color Doppler techniques show blood flow direction, flow resistance and turbulence within the vessel, and regurgitation of the cardiac chamber.

Diagnostic medical sonography has evolved into a unique imaging tool. Sonography was previously thought to be a completely noninvasive technique. However, with the introduction of intracavity and intraluminal transducers, the collection of diagnostic data of the pelvic and cardiovascular regions has been shown to improve patient management and care.

Characteristics of Diagnostic Medical Sonographers

The diagnostic medical sonographer uses complicated equipment, independent judgment, and systematic problem-solving skills to acquire quality images and technical data for assistance in a patient's diagnosis, management, and care. Integrity and honesty are important qualities in all medical professionals. In sonography, these character traits are crucial because almost 90% of observed data are discarded. After each examination, the sonographer provides the reading physician with a technical report detailing the size and description of normal and abnormal anatomy or hemodynamics, along with possible differential diagnostic considerations.

Similar to radiography, diagnostic medical sonography has national standardized protocols for each examination. The sonographer has the ability to expand on basic examination protocols when additional information is needed without fear of ionizing radiation. In-depth knowledge of pathophysiology, laboratory values, and other medical imaging modalities (i.e., computed tomography [CT] or magnetic resonance imaging [MRI]) are important parts of sonography education.

Physical requirements play an additional role in sonography. Sonographers must be able to aid in moving patients and medical equipment. Attention to the use of proper body mechanics is essential (Fig. 28.1). Repetitive usage injury or syndrome of the neck, shoulder, elbow, wrist, and back has been documented. The sonographer should be in good physical, emotional, and nutritional health, and should possess a dedication to continual learning. The career can be exciting and rewarding, as well as stressful, demanding, frustrating, and, occasionally, depressing.

Resource Organizations

Resource organizations devoted exclusively to ultrasound include the American Society of Echocardiography (ASE), the Society of Diagnostic Medical Sonography (SDMS), the American Institute of Ultrasound in Medicine (AIUM), the Society of Radiologists in Ultrasound (SRU), and the Society of Vascular Ultrasound (SVU). The International Foundation for Sonography Education and Research (IFSER) is a unique organization devoted to the educators of ultrasound.

Historical Development

Ultrasound began with the discovery of the piezoelectric effect in 1880 by Jacques and Pierre Curie. This discovery allowed for the future construction of transducers to generate and receive sound waves in water. In 1915, the first sonar-type device was developed by Paul Langevin to locate submarines. After World War II, research was conducted on medical applications of ultrasound. Between 1940 and 1962, various medical applications were researched and developed. In 1962, the first compound B-scanner was developed under the support of the US Public Health Services and the University of Colorado. Medical imaging using ultrasound was launched in 1963 with a handheld articulated arm compound B-mode (brightness mode) scanner. The original imaging was bi-stable (black and white only) until 1973, when grayscale imaging was developed by a group in Australia. By 1980, the digital scan converter, allowing 64 shades of gray in the ultrasound image, was developed. In the mid-1980s, ultrasound could be imaged in real time. Not only could sonographers image more reflected intensities, but they could also view live motion of the human anatomy.

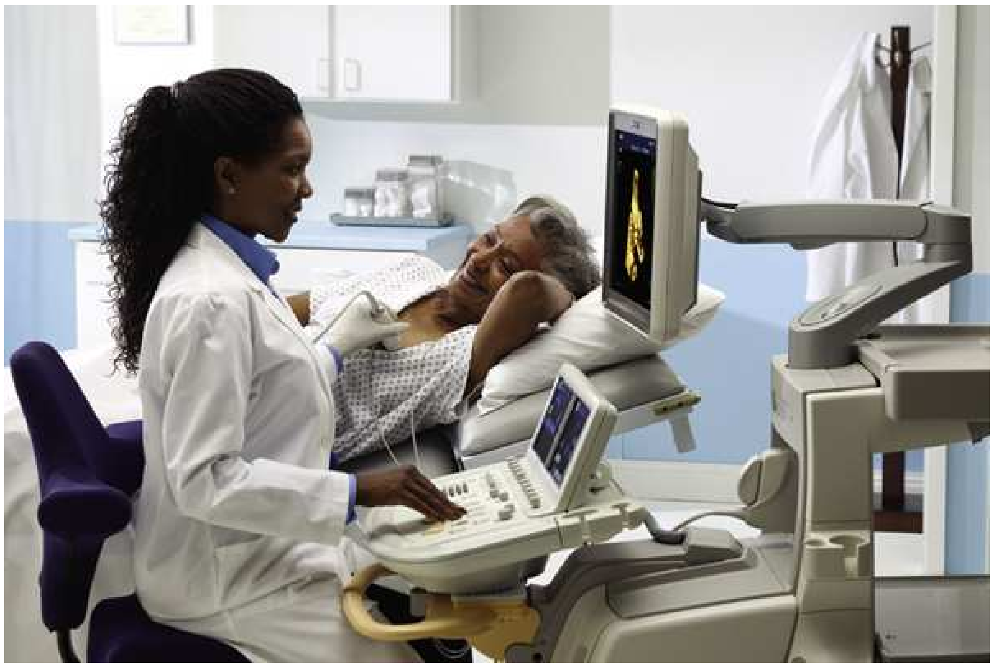

FIG. 28.1 Sonographer performing an ultrasound examination. Courtesy Philips Medical Systems.

Christian Andreas Doppler described the changes in the frequency of transmitted waves when relative motion occurred between the source of the wave and an observer. The first Doppler ultrasound device for medical use was created in the late 1950s in Japan. A prototype of a continuous wave Doppler soon followed, with the reported ability to assess blood flow using the Doppler frequency shift. In the mid-1960s, Dr. Eugene Strandness, at the University of Washington, began research on the use of Doppler ultrasound to detect vascular disease. The first pulsed Doppler technique was developed in 1974 by engineer Donald Baker. Color Doppler was established in 1983 in Japan. However, it was not until 1987 that color Doppler launched in the United States.

For the present-day general sonographer, it may be inconceivable that a diagnosis could be made using only bi-stable and static grayscale scanners to image human anatomy and the presence of abnormalities. The present-day vascular and cardiac sonographers would likely feel the same with the lack of color Doppler to aid in assessing vessel pathology and hemodynamics in vascular and cardiac imaging. Technological advances have benefited medical ultrasound with the use of high-frequency, multihertz, intracavity, and intraluminal transducers, together with three-dimensional, four-dimensional, and panoramic imaging. New technologies, such as elastography, fusion imaging, parallel processing, and contrast enhanced ultrasound imaging, are allowing the diagnosis of pathology without the risks of ionizing radiation and invasive procedures. Most recently, an ultrasound transducer can be attached to a smartphone or tablet, allowing imaging in areas remote from the medical setting.

Diagnostic ultrasound, when used as a clinical imaging tool, has not been associated with any harmful biological effects and is generally accepted as a safe imaging modality.

Physical Principles

Properties of Sound Waves

Sound waves are traveling variations of pressure, density, and particle motion. Matter must be present for sound to travel; it cannot travel through a vacuum. Sound carries energy, not matter, from one place to another. Vibrations from one molecule carry to the next molecule along the same axis. These oscillations continue until friction causes the vibrations to cease.

Ultrasound refers to sound waves beyond the audible range (>20 kHz). Diagnostic medical sonography can use frequencies of up to 50 MHz.

Acoustic impedance

Sound travels through tissues at different speeds, depending on the density and stiffness of the medium. Acoustic impedance of a medium determines how much of the wave transmits to the next medium (Fig. 28.2).

Velocity of sound

Propagation speed is the speed at which a sound wave travels through a medium. It is determined by the density and stiffness of a medium. In soft tissue, the propagation speed of sound is 1540 m/s. Bone shows a very high propagation speed (4080 m/s), whereas air shows the lowest propagation speed (330 m/s).

Transducer Selection

Diagnostic ultrasound transducers operate on the principle of piezoelectricity. The *piezoelectric effect* states that some materials produce a voltage when deformed by an applied pressure. Diagnostic ultrasound transducers convert electrical energy into acoustic energy during transmission, and acoustic energy into electrical energy for reception. Transducers routinely operate in a frequency range of 2 to 20 MHz for diagnostic applications. Transducers may be linear, convex, sector, or vector in construction (Fig. 28.3). Higher frequencies are used in intracavity and intraluminal transducers, as well as for visualizing the extremities or superficial structures. Lower frequencies are needed for deeper structures of the thoracic cavity, abdomen, and pelvis. Lower frequencies provide necessary penetration depth, as well, but this is at the expense of *detail resolution*.

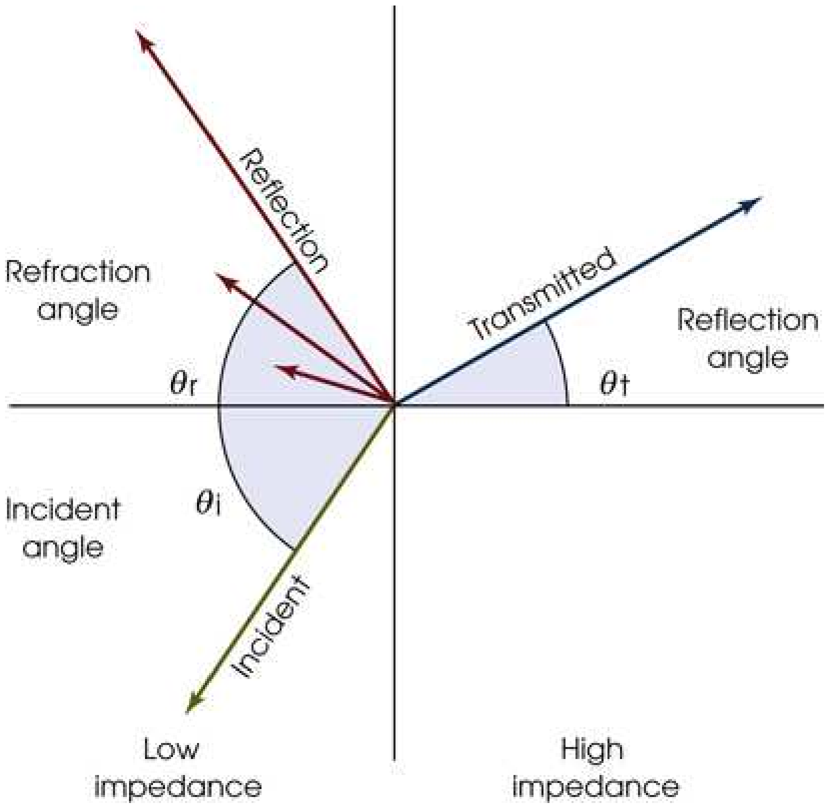

FIG. 28.2 Relationship among incident, reflected, and transmitted waves.

Relationship of incident, reflected, and transmitted waves is shown using a rectangular coordinate system. The transmitted wave is a increasing line in the first quadrant. The reflected wave is a increasing line in the second quadrant and the incident wave is a decreasing line in the third quadrant.

Pulse wave transducers transmit pulses of sound and receive returning echoes, producing a grayscale ultrasound image. A continuous wave transducer produces a continuous wave of sound and is composed of a separate transmit and receive element within a single transducer assembly. Continuous wave transducers do not produce an image.

Volume Scanning And Three-Dimensional And Four-Dimensional Imaging

Volume scanning allows for quick "sweeps" of specific areas of the body or fetus. These sweeps give volume data that can be rendered even after the patient has left the ultrasound department. Three-dimensional imaging systems allow the sonographer to acquire volume data. The sonographer can reconstruct these data into a three-dimensional image on the ultrasound machine or at a workstation. With four-dimensional imaging, the ultrasound system can acquire and display three-dimensional images in real time.

FIG. 28.3 Various ultrasound transducers. Courtesy Philips Medical Systems.

Anatomic Relationships and Landmarks

The use of anatomic landmarks to define specific areas of the human body is an important part of the imaging and orientation skills of the sonographer. The middle hepatic vein is a sonographic landmark used to locate the division between the left and right hepatic lobes (Fig. 28.4A). The main lobar fissure is used to locate the gallbladder fossa (see Fig. 28.4B). The ovaries are located medial and anterior to the iliac vessels (see Fig. 28.4C). The use of anatomic landmarks is a routine part of many sonographic examinations.

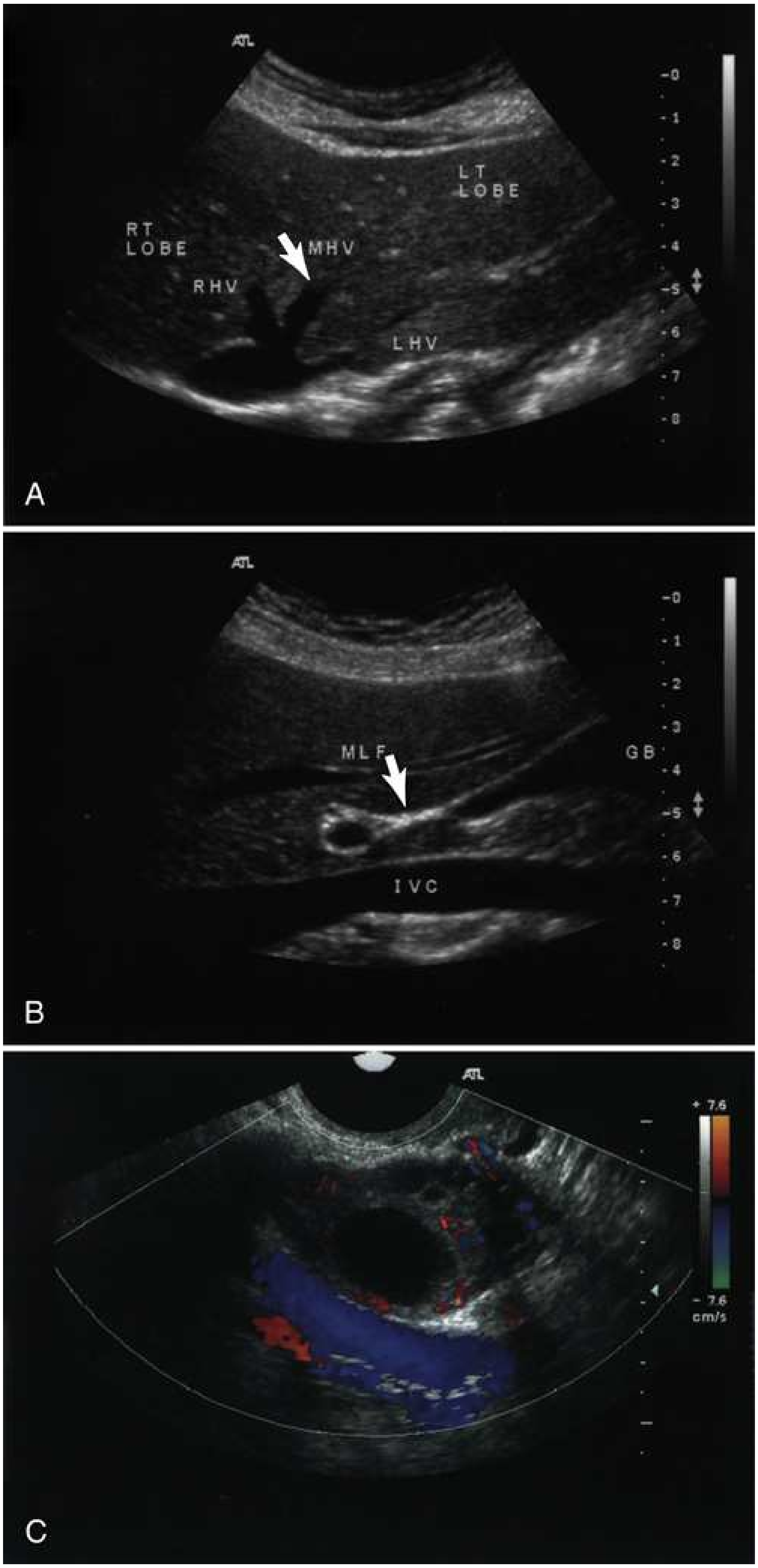

FIG. 28.4 (A) Transverse sonogram of liver showing middle hepatic vein *(MHV)* dividing left and right hepatic lobes. (B) Sagittal image of main lobar fissure *(MLF)* and its relationship to gallbladder *(GB)*. (C)

Sagittal color Doppler image of right ovary lying anterior and medial to iliac vessels. *LHV,* Left hepatic vein; *RHV,* right hepatic vein. Courtesy Paul Aks, BS, RDMS, RVT.

(A) Transverse sonogram of liver shows middle hepatic vein (M H V) dividing left and right hepatic lobes. It is indicated by a white arrow. (B) Sagittal image of main lobar fissure (M L F) and its relationship to gallbladder (G B). It is indicated by a white arrow. (C) Sagittal color Doppler image of right ovary lying anterior and medial to iliac. It is highlighted in red and blue.

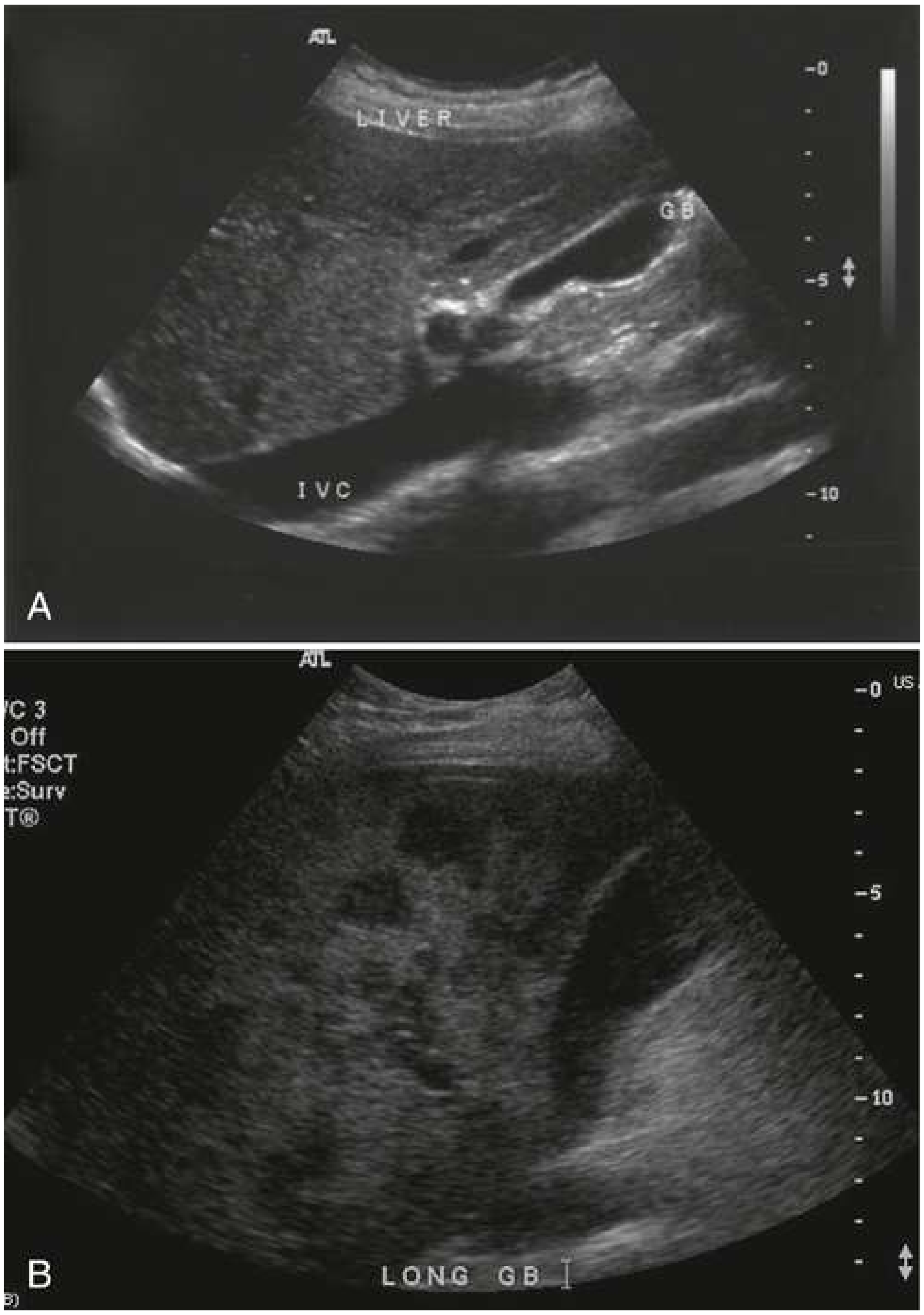

FIG. 28.5 (A) Sagittal sonogram of normal homogeneous liver. (B) Longitudinal sonogram of heterogeneous hepatic lobe in a patient with a history of breast carcinoma.

Clinical Applications

Characteristics of The Sonographic Image

The sonographer uses specific terms to characterize the sonographic image. If the echo pattern is similar throughout a structure or mass, it is termed *homogeneous* (Fig. 28.5A). If the echo pattern is dissimilar throughout a structure or mass, it is termed *heterogeneous* (see Fig. 28.5B). Internal composition of a structure or mass is described using the terms *anechoic* (without internal echoes), *echogenic* (with internal echoes), and *complex* (containing anechoic and echogenic regions) (Fig. 28.6). The sonographer also uses descriptive terms to describe the borders of a mass. Are the borders smooth or irregular, thin or thick, calcified or dilated?

Imaging artifacts are an additional concern for the sonographer. Acoustic artifacts include reflections that are missing; not real; improperly positioned; or of improper brightness, number, shape, or size (Fig. 28.7). By understanding the physical principles of sound waves and the ultrasound system, the sonographer can better comprehend the real-time images.

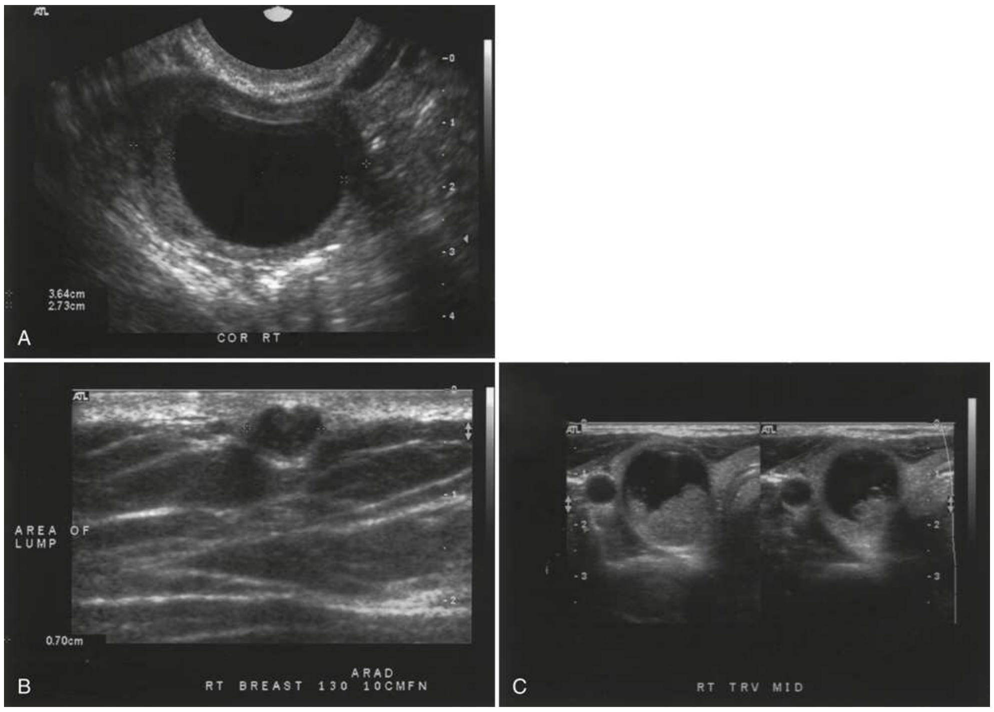

FIG. 28.6 (A) Endovaginal sonogram of anechoic ovarian cyst. (B) Echogenic mass is measured in upper inner quadrant of right breast. (C) Transverse sonogram of complex thyroid mass. Courtesy Paul Aks, BS, RDMS, RVT.

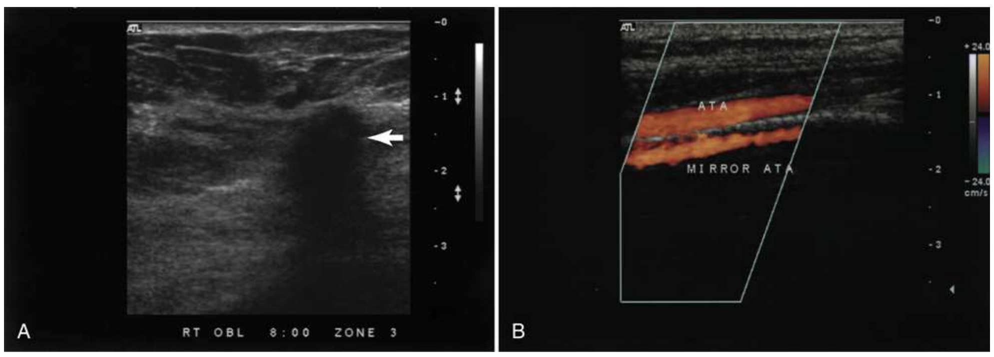

FIG. 28.7 (A) Breast carcinoma showing posterior acoustic shadowing *(arrow)*. (B) Mirror image of anterior tibial artery.

Abdomen And Retroperitoneum

The abdominal ultrasound examination generally includes a survey of the liver, pancreas, gallbladder, spleen, great vessels, and kidneys in the sagittal and transverse planes (Figs. 28.8 and 28.9). Specific protocols are followed to image size, shape, and echogenicity of the organ *parenchyma* and anatomic relationships of the surrounding structures. Doppler flow patterns of the upper abdominal blood vessels may be included. Patients are examined in two different body positions (i.e., supine and decubitus). The use of two positions shows the mobility of gallstones and repositions interfering bowel gas. Air reflects most of the sound wave, making visualization of the abdominal and retroperitoneal structures difficult. Abdominal examinations are typically scheduled in the morning, with the patient fasting 6 to 8 hours before the sonogram.

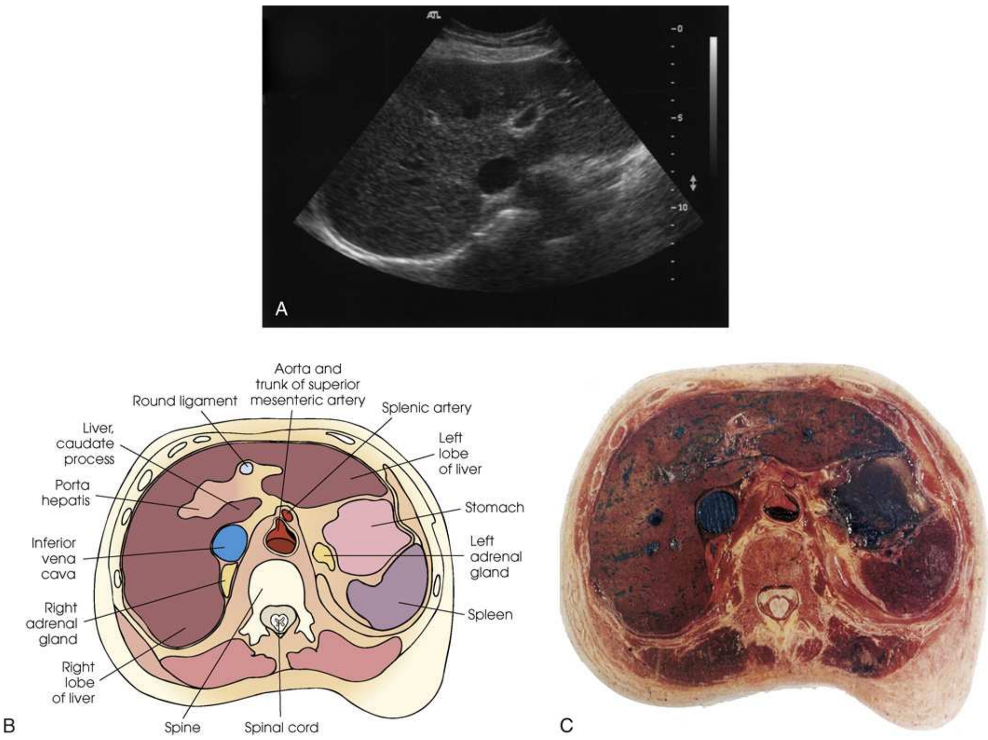

FIG. 28.8 (A) Transverse sonogram of right upper quadrant over right lobe of liver. (B) Line drawing of gross anatomic section. (C) Gross anatomic section at approximately same level as A.

(A) A sonogram shows a few radiolucent regions surrounded by white borders. (B) Diagram of gross anatomic section of a spinal cord has the following parts labeled on it in clockwise direction: spine, right lobe of liver, right adrenal gland, inferior vena cava, porta hepatis, liver, caudate process, round ligament, aorta and trunk of superior mesenteric artery, splenic artery, left lobe of liver, stomach, left adrenal gland, spleen, spinal cord. (C) shows a gross anatomic section of the abdomen.

The retroperitoneal ultrasound examination includes a survey of the great vessels, kidneys, and bladder in the sagittal and transverse planes before and after voiding. Specific protocols are followed to image the size, shape, cortical thickness, and echogenicity of the renal parenchyma. Anterior-posterior diameters of the inferior vena cava, aorta, and common iliac arteries are measured and documented. Doppler flow patterns of the great vessels and kidneys may be included. Retroperitoneum examinations can be scheduled in the morning or afternoon, with the patient drinking 8 to 16 oz. of water 1 hour before the sonogram.

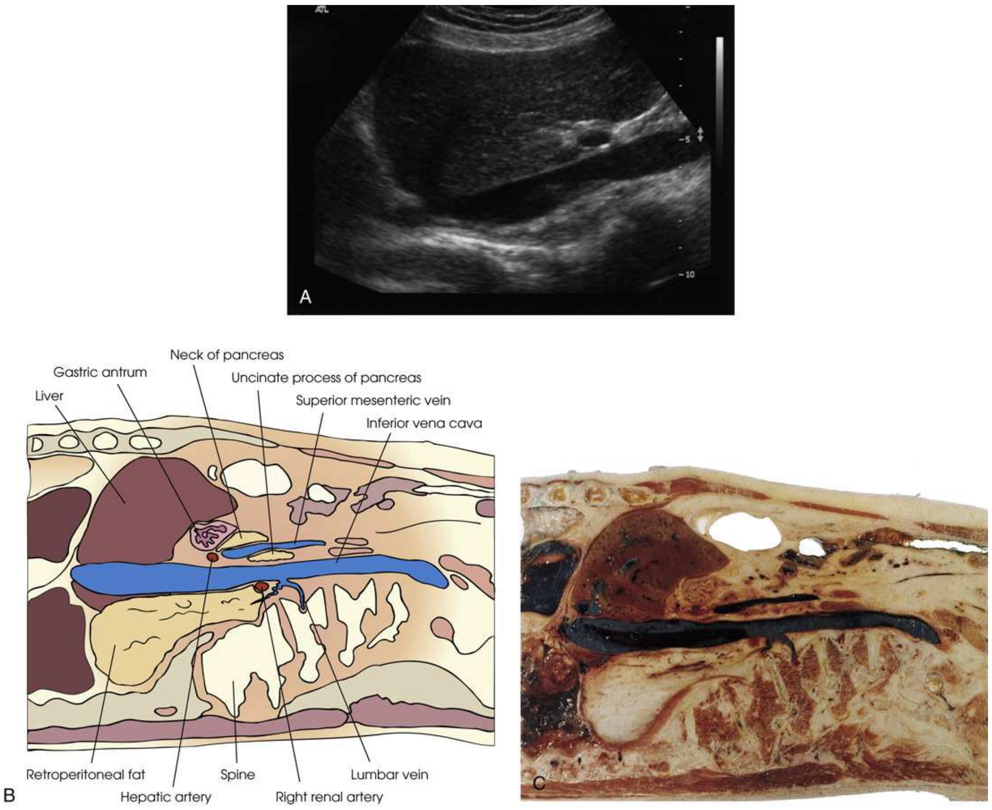

FIG. 28.9 (A) Sagittal sonogram of right upper quadrant over medial segment of left lobe of the liver, hepatic vein, and inferior vena cava. (B) Line drawing of gross anatomic section. (C) Gross anatomic section at approximately same level as A.

(A) A sonogram shows a rectangular radiolucent region on the left leading to the center. (B) Diagram of gross anatomic section of left lobe of the liver has the following parts labeled on it in clockwise direction: hepatic artery, retroperitoneal fat, liver, gastric antrum, neck of pancreas, uncinate process of pancreas, superior mesenteric vein, inferior vena cava, lumbar vein, right renal artery, spine. (C) shows a gross anatomic section of the retroperitoneum.

To produce an adequate survey of the abdominal and retroperitoneal cavities, the sonographer must fully understand the patient's clinical history. Although ultrasound cannot diagnose the specific pathology of a lesion or condition, a complete clinical picture may lead to more specific differential diagnostic considerations.

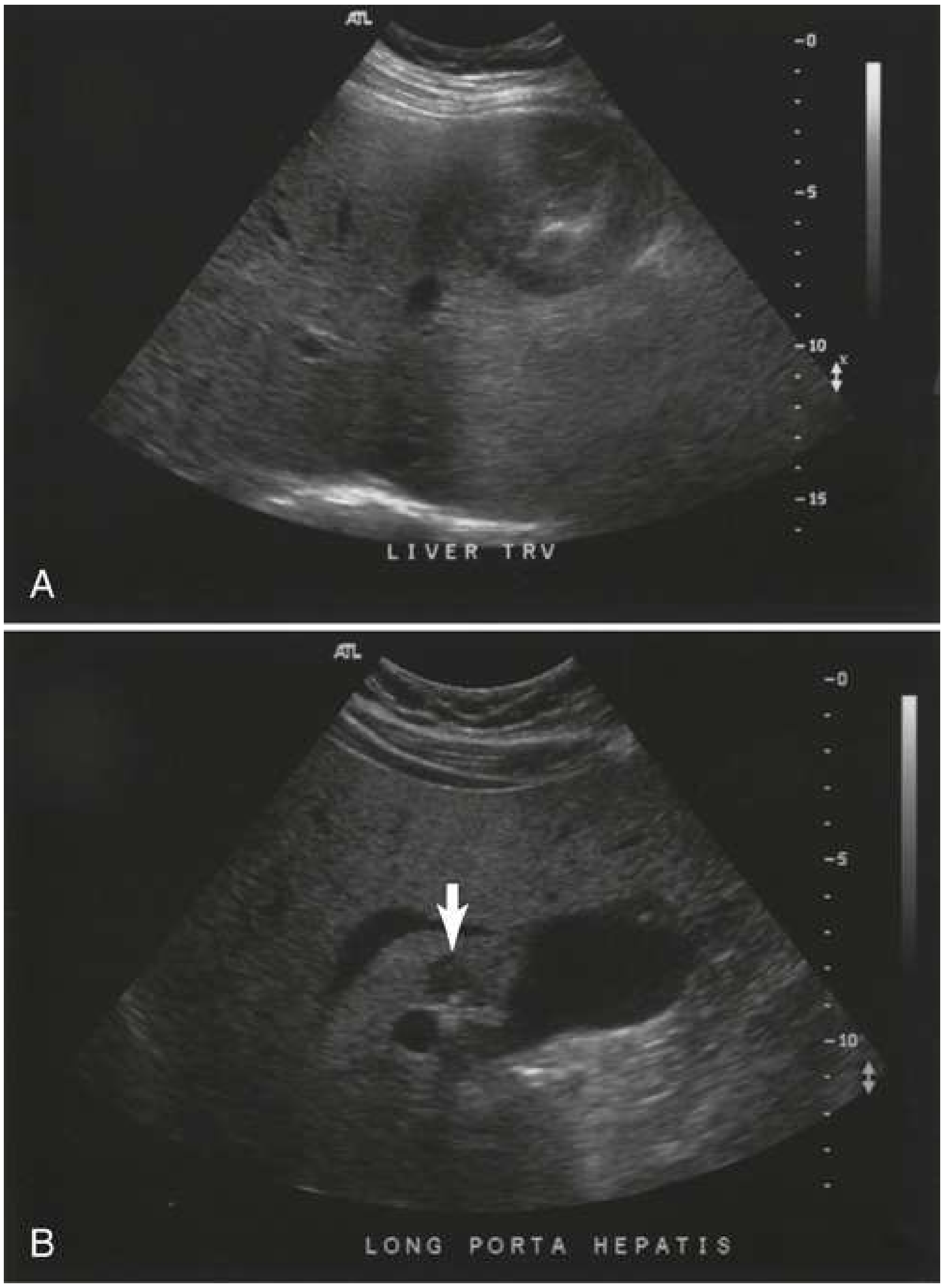

FIG. 28.10 (A) Transverse sonogram of liver shows a complex mass in the left lobe. (B) Sonogram of liver shows fatty infiltration with small area of normal liver parenchyma anterior to porta hepatis *(arrow)*.
A, Courtesy Paul Aks, BS, RDMS, RVT.

(A) A sonogram shows a few radiolucent regions and a huge mass on the left side. (B) A sonogram shows a few radiolucent regions in the middle. The one on the right is huge and there are two circular regions next to it. It is indicated by a white arrow.

Liver and biliary tree

Sonographic examinations of the liver and biliary tree are generally requested in patients with right upper quadrant pain or elevations in liver function laboratory tests. The liver is assessed for size and echogenicity of the parenchyma. Under normal circumstances, the liver parenchyma appears moderately echogenic and homogeneous. Some types of liver pathologies shown on ultrasound include fatty hepatic steatosis, cirrhosis, cavernous hemangioma, and hepatoma (Fig. 28.10). Doppler evaluation of the hepatic artery, hepatic veins, and portal veins is included with a patient history or suspicion of cirrhosis, portal hypertension, portal vein thrombosis, and Budd-Chiari syndrome.

The biliary tree includes the gallbladder, as well as the intrahepatic and extrahepatic bile ducts. The gallbladder is evaluated for size, wall thickness, and absence of internal echoes. Under normal circumstances, the gallbladder is a pear-shaped anechoic structure located in the gallbladder fossa on the posterior surface of the liver (Fig. 28.11). The intrahepatic biliary ducts converge near the *porta hepatis,* forming the common hepatic duct. The cystic duct joins the common hepatic duct to form the extrahepatic common bile duct. The biliary tree is evaluated for size and evidence of intraductal stones or masses. Some abnormalities of the biliary tree shown on ultrasound include intrahepatic and extrahepatic biliary obstruction, cholelithiasis, and cholecystitis (Fig. 28.12).

FIG. 28.11 Sagittal sonogram of normal gallbladder (*GB*).

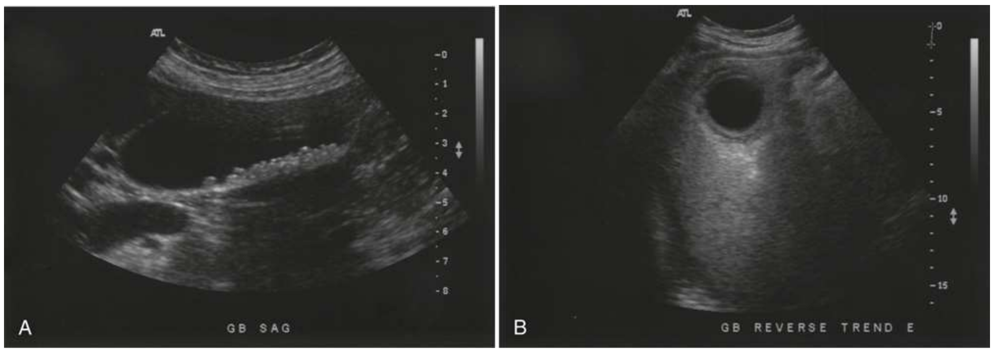

FIG. 28.12 (A) Sagittal sonogram of gallbladder showing multiple small gallstones with posterior acoustic shadowing. (B) Transverse sonogram of acute cholecystitis.

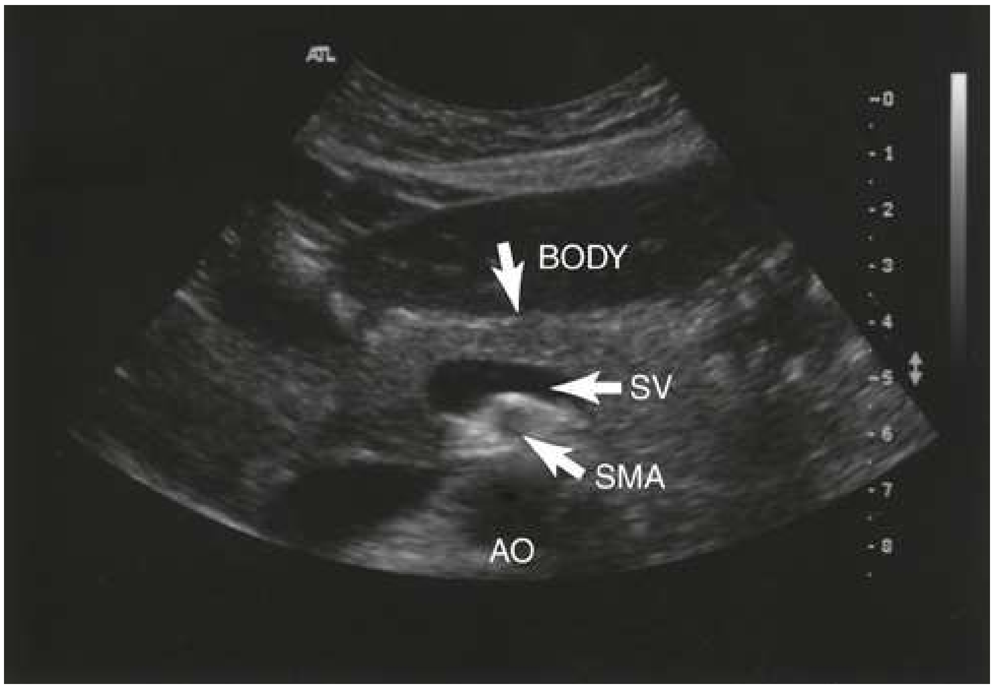

FIG. 28.13 Transverse sonogram of normal pancreas. The body of the pancreas lies anterior to splenic vein *(SV)*, superior mesenteric artery *(SMA)*, and aorta *(AO)*.

A sonogram shows a radiolucent region on the left leading to the center. It is labeled as body. Another radiolucent region is below it. It is labeled as splenic vein. A radiopaque region beneath it is labeled as superior mesenteric artery.

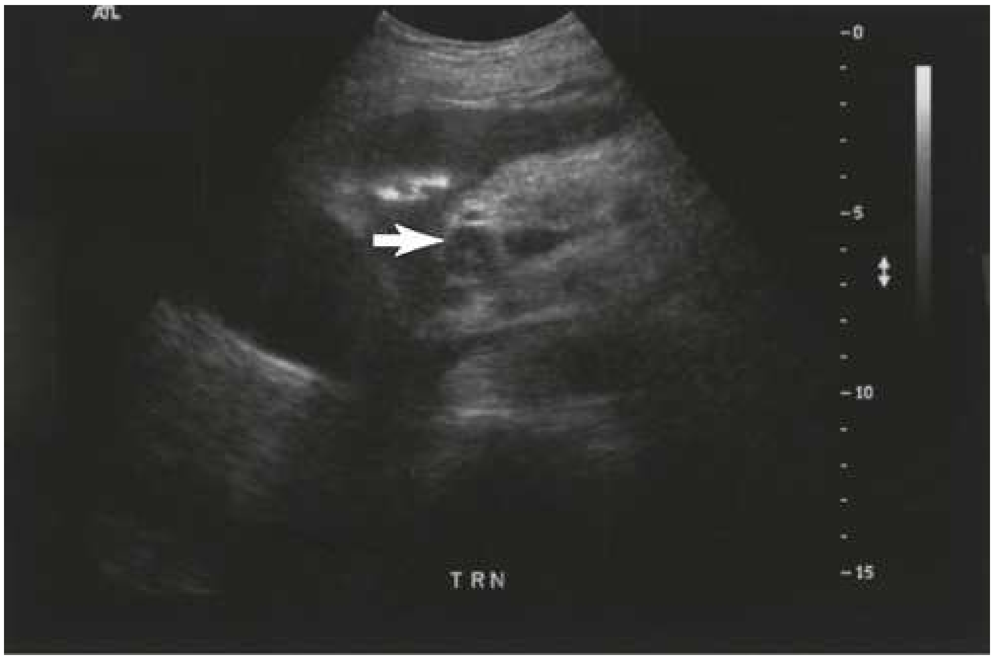

FIG. 28.14 Transverse sonogram shows hypoechoic mass in head of the pancreas *(arrow)*.

Pancreas

The pancreas is an elongated organ oriented in a transverse *oblique plane* in the epigastric and left hypochondriac regions of the retroperitoneal cavity. The head of the pancreas lies in the descending portion of the duodenum and is lateral to the superior mesenteric artery. The body is the largest portion, lying anterior to the superior mesenteric artery and splenic vein (Fig. 28.13). The tail is the superior most portion lying posterior to the antrum of the stomach and generally extends toward the splenic hilum. The echogenicity of the pancreas varies depending on the amount of fat but should appear homogeneous throughout the organ. Ultrasound examinations of the pancreas are requested in patients with a history of unexplained weight loss, epigastric pain, and elevation in pancreatic enzymes or liver function laboratory tests. The pancreas is evaluated for size and echogenicity of the parenchyma. The distal common bile duct is routinely measured in the posterior lateral portion of the head of the pancreas. Some abnormalities of the pancreas shown on ultrasound include inflammation, calcifications, tumor, or abscess formation (Fig. 28.14).

Spleen

The spleen is the predominant organ in the left upper quadrant, located inferior to the diaphragm and anterior to the left kidney. Ultrasound examinations of the spleen are requested in patients with a history of abdominal trauma, chronic liver disease, and leukocytosis. An increase in hepatic pressures from liver disease may cause an abnormal increase in the size of the spleen (Fig. 28.15). The normal spleen appears moderately echogenic, similar to the normal liver parenchyma. The spleen is evaluated for size and echogenicity of the parenchyma. Some abnormalities of the spleen shown on ultrasound include splenomegaly, splenic rupture, calcifications, or abscess formation. Doppler evaluation of the splenic artery and vein is included with a patient history or suspicion of portal hypertension.

FIG. 28.15 Sagittal sonogram of enlarged spleen measuring >15 cm in length (splenomegaly).

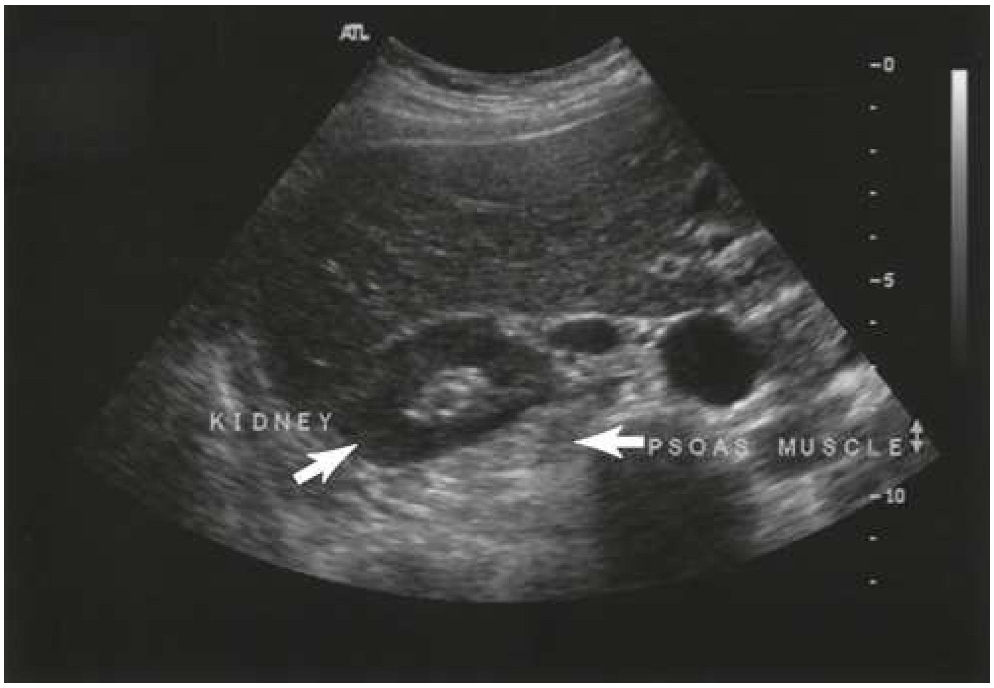

FIG. 28.16 Transverse sonogram of right kidney lying posterior to the liver and lateral to the psoas muscle.

A sonogram shows an irregular radiolucent region with a white patch in the middle of it. It is indicated by a white arrow and is labeled as kidney. Another white arrow next to it is labeled as psoas muscle.

Kidneys and bladder

The kidneys are bean-shaped structures lying in a *sagittal* oblique plane lateral to the psoas muscles in the retroperitoneal cavity (Fig. 28.16). Ultrasound examinations of the kidneys and bladder are requested in patients with a history of urinary tract infection, flank pain, hematuria, and an increase in creatinine levels. The normal adult renal cortex shows a moderate- to low-level echo pattern, *hypoechoic,* to the liver and spleen. The renal sinus is the most echogenic portion of the kidney and considered *hyperechoic* to the surrounding structures. The kidneys are evaluated for contour, size, cortical thickness, dilation of calyces (hydronephrosis), and echogenicity of the renal parenchyma. Ultrasound guidance is used to localize the kidney during renal biopsy procedures and to evaluate for any post-biopsy complications.

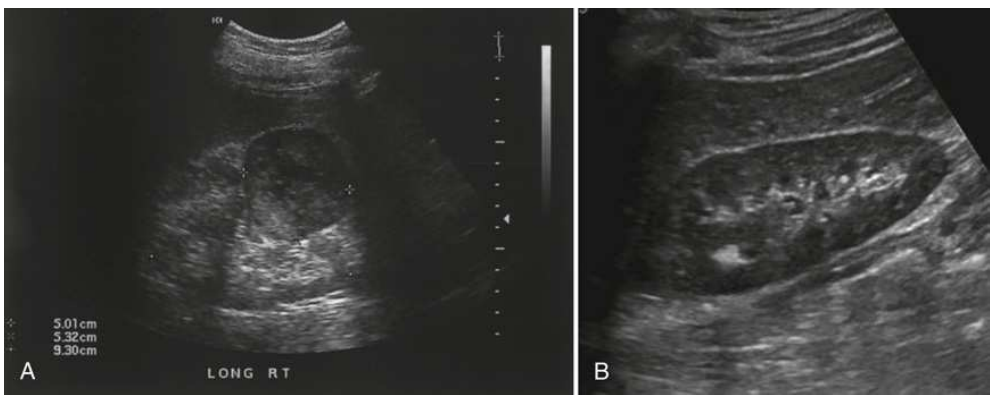

FIG. 28.17 (A) Sagittal sonogram shows hypoechoic mass in anterior right kidney. (B) Sagittal sonogram of right kidney shows hyperechoic kidney stone. Courtesy of Susanna Ovel RT, RDMS, RVT.

Ultrasound is a useful imaging tool to monitor a renal transplant. The transplant is typically placed superficially in the right iliac fossa. Sonograms of the transplant include grayscale images to evaluate size, contour, echogenicity, and cortical thickness. The renal artery and vein are evaluated with Doppler, checking for intimal thickening, stenosis, and thrombosis.

A partially distended urinary bladder is evaluated for wall thickness, contour, and evidence of neoplasm. Post-void imaging is included to evaluate the amount of residual urine and competence of the ureteral valves. Abnormalities of the kidneys and bladder shown on ultrasound include urinary obstruction, nephrolithiasis, abscess formation, cortical thinning, and benign and malignant neoplasms (Fig. 28.17).

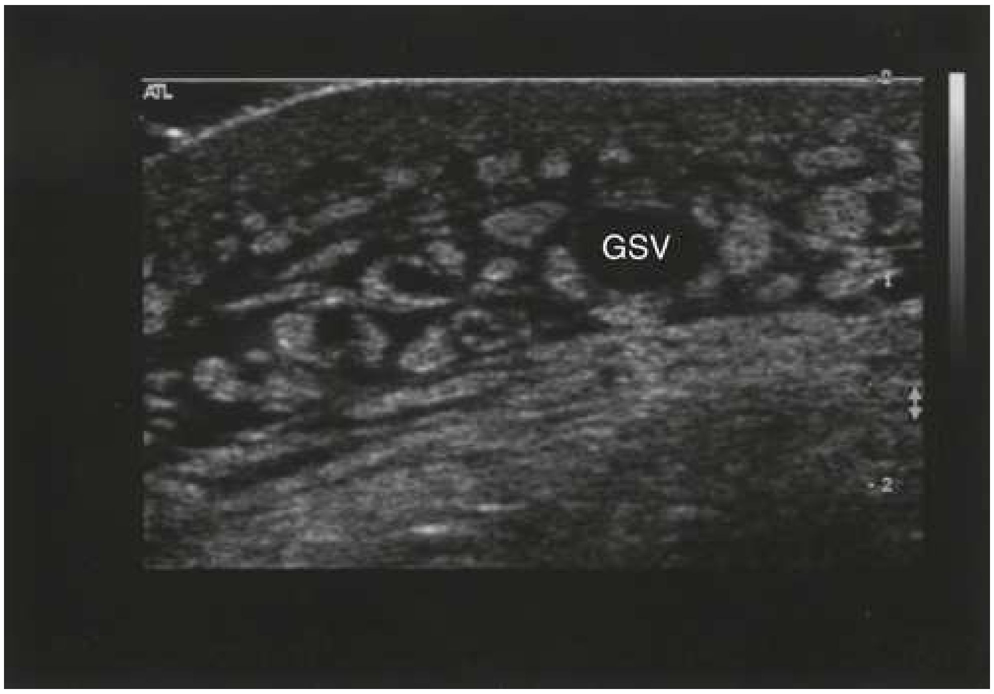

FIG. 28.18 Transverse sonogram of medial thigh shows tissue edema surrounding great saphenous vein *(GSV)*.

Musculoskeletal Structures

The musculoskeletal system provides movement of the body parts and organs. Ultrasound examinations of the musculoskeletal structures are requested in patients with a history of trauma, palpable mass, and chronic pain. On ultrasound, normal muscles show a low to medium shade of gray echo pattern with hyperechoic striations throughout. Tendons appear homogeneous with hyperechoic linear bands. Some abnormalities of the musculoskeletal system shown on ultrasound include muscle or tendon tears, inflammation, hematoma, and edema (Fig. 28.18).

Superficial Structures

Superficial structures image well with ultrasound and include soft tissues, thyroid glands, breast, scrotum, and the abdominal wall. The echogenicity of the thyroid glands and testes is similar, showing a moderately echogenic parenchymal pattern. Breast tissue varies depending on the amount of fat content. In sonography, all breast tissues are compared with the medium level echo pattern of normal breast fat. Abdominal wall ultrasound examinations may be requested to rule out evidence of herniation or hematoma. Soft tissue ultrasound examinations are generally requested to evaluate a specific mass. Abnormalities of the superficial structures shown on ultrasound include inflammation, herniation, hematomas, and benign and malignant neoplasms (Figs. 28.19 and 28.20).

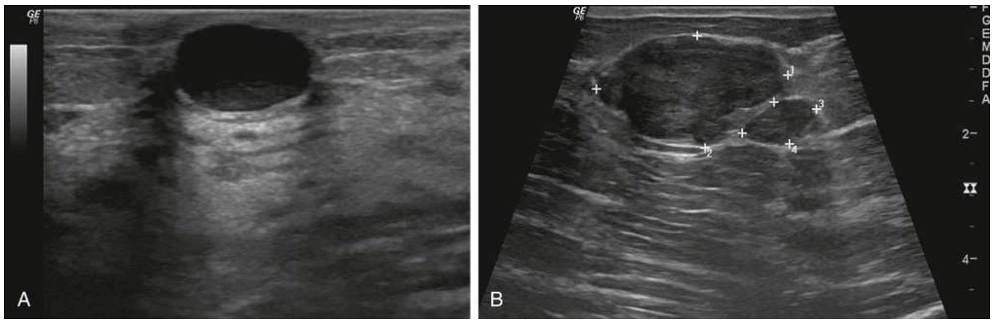

FIG. 28.19 (A) Breast cyst with debris is shown demonstrating well-defined borders, fluid-fluid level, and increased through transmission. (B) Fibroadenomas *(calipers)* demonstrate well-defined borders and may have some increased transmission; however, the internal echo pattern is solid and homogeneous. Benign lesions typically demonstrate a mass wider rather than tall.

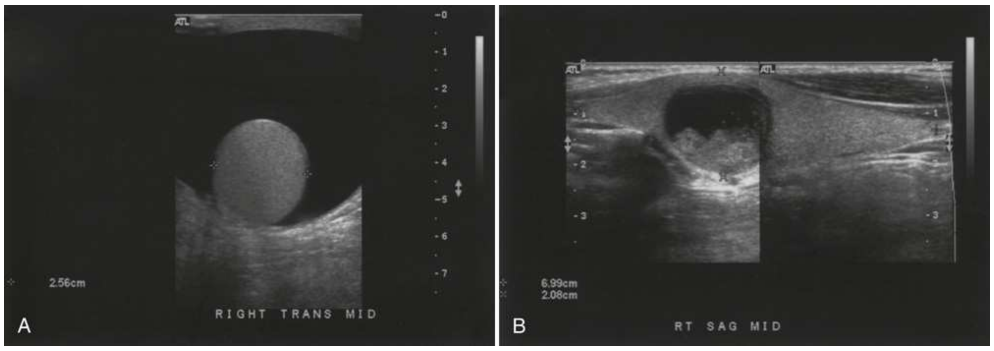

FIG. 28.20 (A) Transverse sonogram of right testis surrounded by anechoic fluid (hydrocele). (B) Sagittal image of complex thyroid mass. Courtesy Paul Aks, BS, RDMS, RVT.

(A) A sonogram shows a grey circular area in a radiolucent region. A scale on the right has calibrations raging from negative 7 to 0. (B) A sonogram shows a radiolucent circular region in the middle. The region below it appears white.

Pediatric Sonography

The goal of pediatric imaging is to perform a study with the lowest amount of radiation and the least amount of sedation. Ultrasound is becoming one of the most widely used imaging modalities, and it is frequently the initial imaging modality in infants and children. A specialty examination to include all general pediatric examinations was implemented in 2015 to replace the existing neonatal neurosonography specialty.

Normal sonographic appearance of anatomy in infants and children can differ from that of the adult patient. This new specialty examination covers the abdomen, pelvis, and small parts, along with pediatric-specific examinations. Examples of pediatric-specific examinations include the gastrointestinal tract for pyloric stenosis and intussusception (Fig. 28.21), infant spine for tethered cord, infant hips for developmental dysplasia of the hip (Fig. 28.22), and neonatal brain for hydrocephalus and intraventricular hemorrhage (Fig. 28.23).

Infants and children pose a challenge to the sonographer. A detailed understanding of the normal and abnormal sonographic appearances of pediatric anatomy is necessary to accurately assess and quickly image the pediatric patient.

FIG. 28.21 Sagittal image of the pylorus in a case of pyloric stenosis. Courtesy Susanna Ovel, RT, RDMS, RVT.

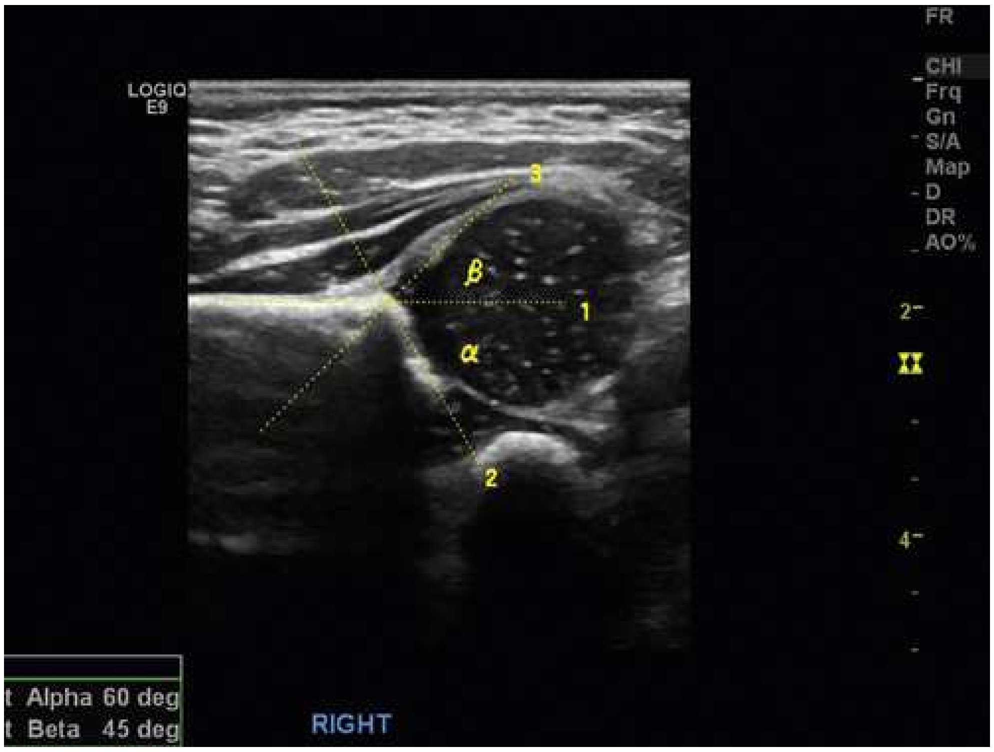

FIG. 28.22 Coronal image demonstrating the Graf angles in a normal infant hip. Courtesy Susanna Ovel, RT, RDMS, RVT.

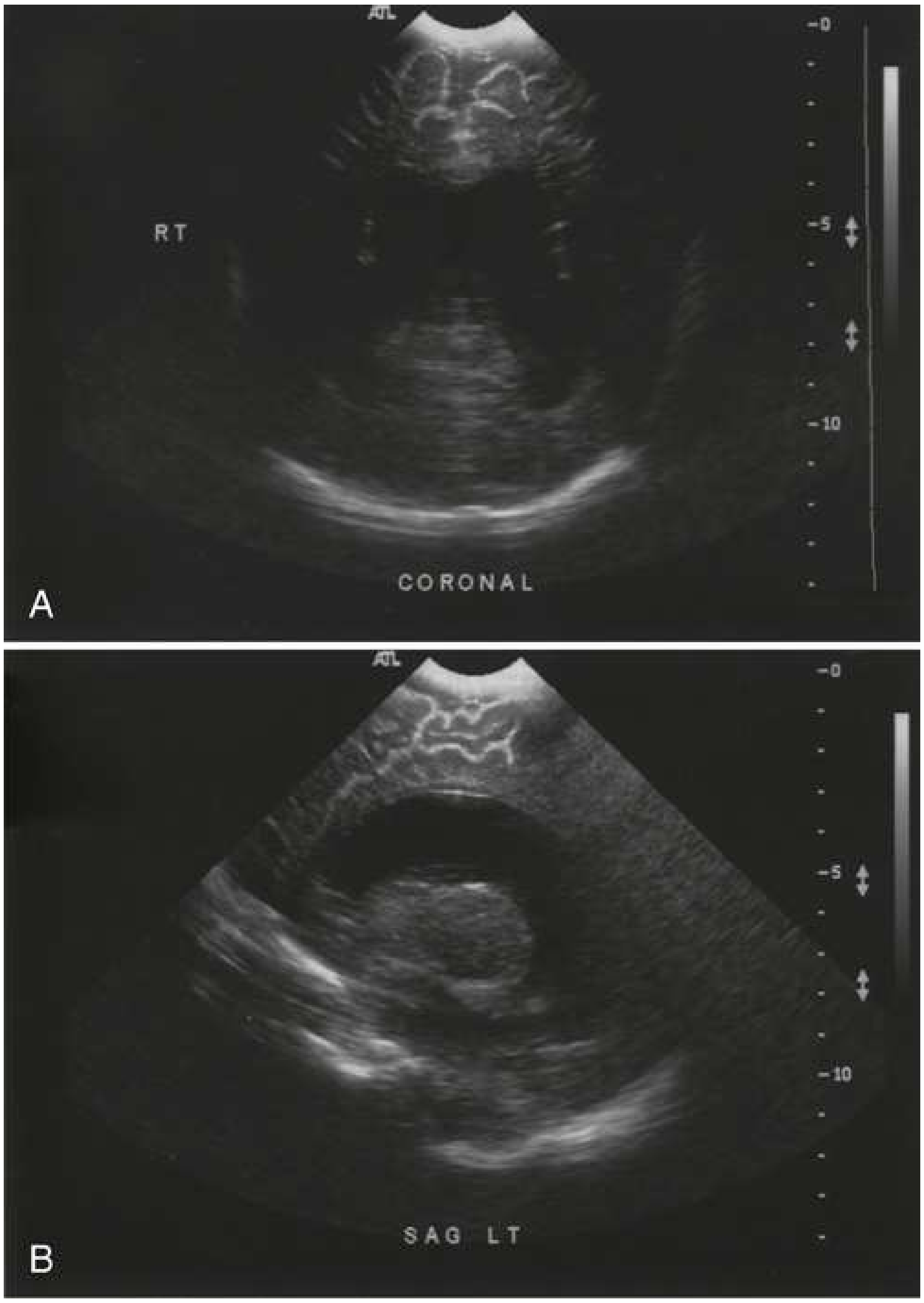

FIG. 28.23 (A) Coronal sonogram in a neonate showing bilateral ventriculomegaly. (B) Sagittal sonogram of left lateral ventricle showing ventriculomegaly.

Gynecologic Applications

Anatomic features of the pelvis

The pelvis is divided into the true and false pelvis by the *iliopectineal line*. The *false pelvis* contains loops of bowel and is bound by the abdominal wall, the ala of the iliac bones, and the base of the sacrum. The *true pelvis* contains the female reproductive organs, urinary bladder, distal ureters, and bowel (Fig. 28.24). It is bound by the symphysis pubis, sacrum, and coccyx. The pelvic floor is formed by ligaments and the levator ani, piriformis, and coccygeus muscles.

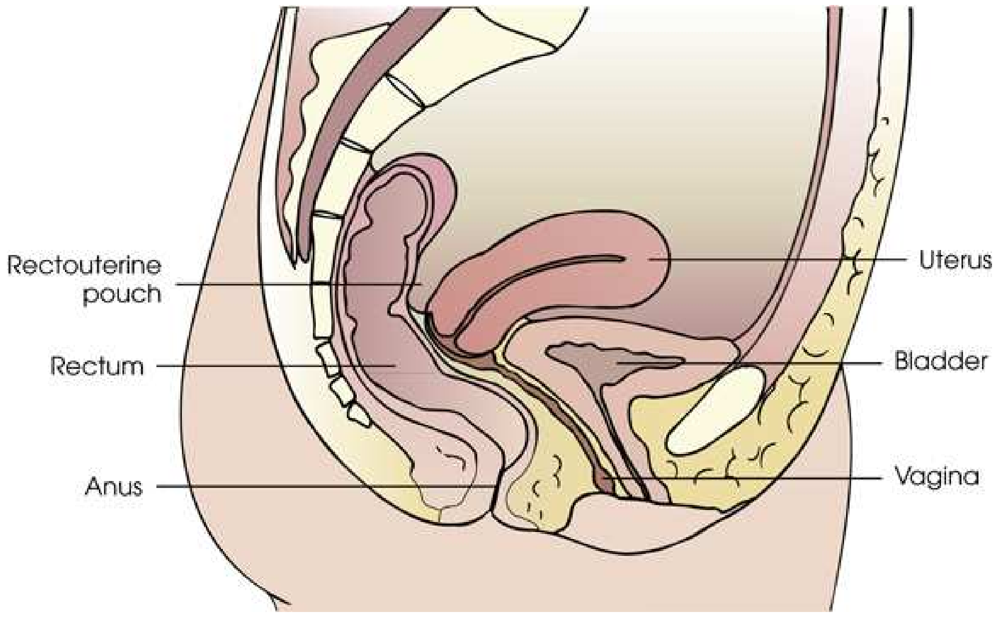

FIG. 28.24 Sagittal line drawing of female pelvis.

The *retrouterine pouch or pouch of Douglas* lies between the uterus and the rectum. Free fluid routinely accumulates in this area. All pelvic recesses should be imaged on all transabdominal and endovaginal sonograms.

Sonography of the female pelvis

Sonography of the female pelvis is clinically useful in the premenarche, menarche, and postmenopausal periods. Pelvic ultrasound examinations are requested for assessment of a pelvic mass, pelvic pain, or abnormal uterine bleeding; infertility monitoring; and localization of an intrauterine device.

A complete transabdominal examination of the female pelvis includes evaluation and documentation of the distended urinary bladder, uterus, cervix, endometrial canal, vagina, ovaries, adnexal regions, pelvic recesses, and supporting pelvic musculature. The full bladder helps to reposition the intestines laterally into the false pelvis. The urinary bladder serves as an *acoustic window* and anechoic landmark in transabdominal imaging. Real-time imaging allows the sonographer to evaluate the entire pelvic area for pathology and peristalsis of the bowel (Fig. 28.25).

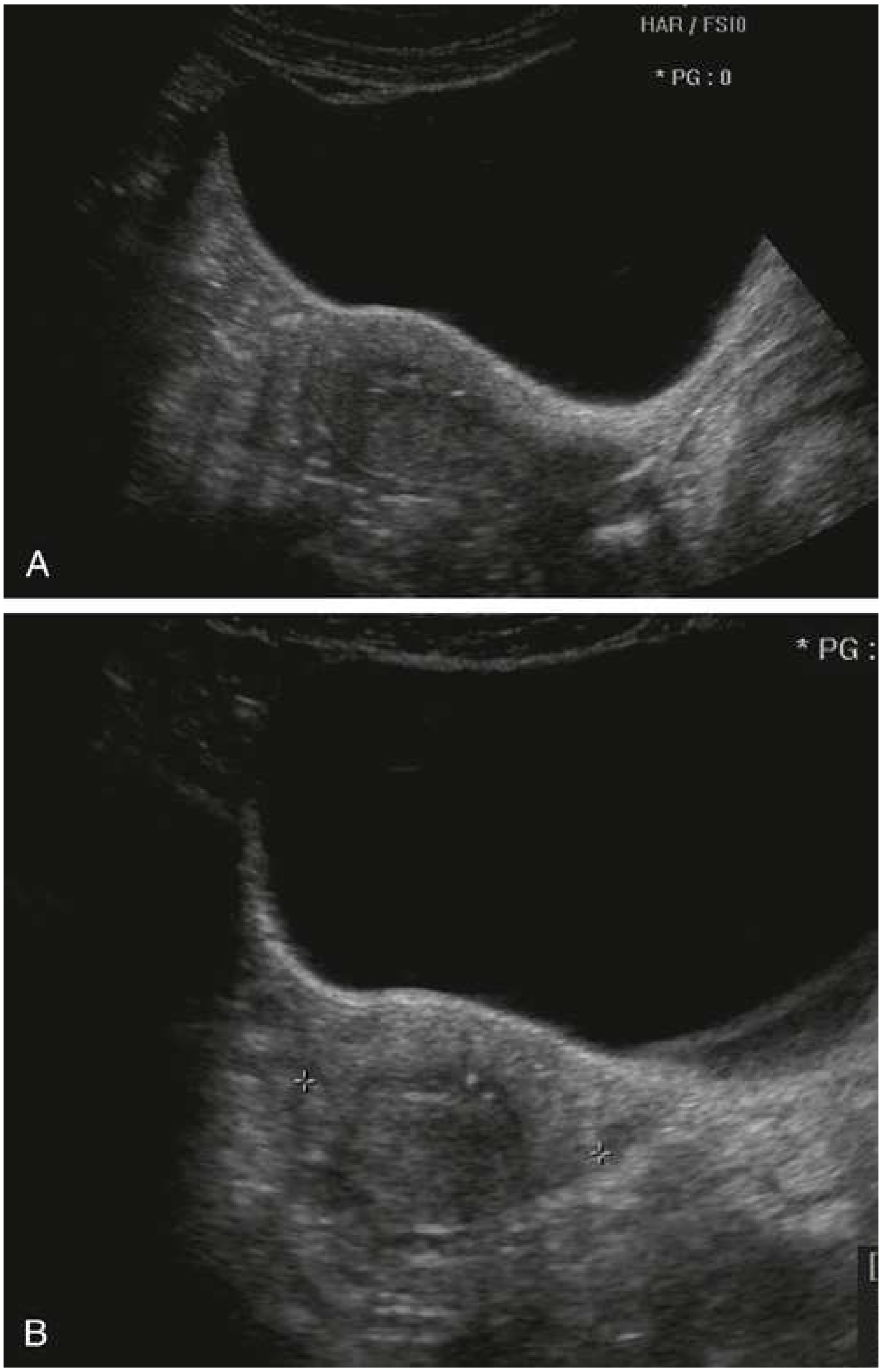

FIG. 28.25 (A) Transabdominal sagittal sonogram of uterus. (B) Transabdominal transverse sonogram of uterus with measurements.

Endovaginal transducers show excellent detail resolution of the uterine endometrium at the expense of penetration depth and acoustic windows (Fig. 28.26). Endovaginal sonography should be used in conjunction with a transabdominal pelvic examination. A high-frequency transducer is inserted into the vaginal canal to evaluate the uterus, endometrium, ovaries, adnexal regions, and pelvic recesses in the sagittal and coronal planes (Fig. 28.27).

The normal adult uterine myometrium appears homogeneous and moderately echogenic on ultrasound. The echogenicity and thickness of the normal endometrium vary with the menstrual cycle but should not exceed 14 mm in anteroposterior diameter. Normal ovaries appear moderately echogenic, with small functional cysts (follicles) of varying size and number. Monitoring the number and size of *follicular cysts* is a common practice in infertility treatment. Ultrasound is used to aid the gynecologist in determining when the ovum is ready for stimulation with high doses of human chorionic gonadotropin. Some abnormalities of the female pelvis shown on ultrasound include congenital malformation, leiomyoma, endometrial polyp, ovarian cyst, and tubal ovarian abscess (Fig. 28.28).

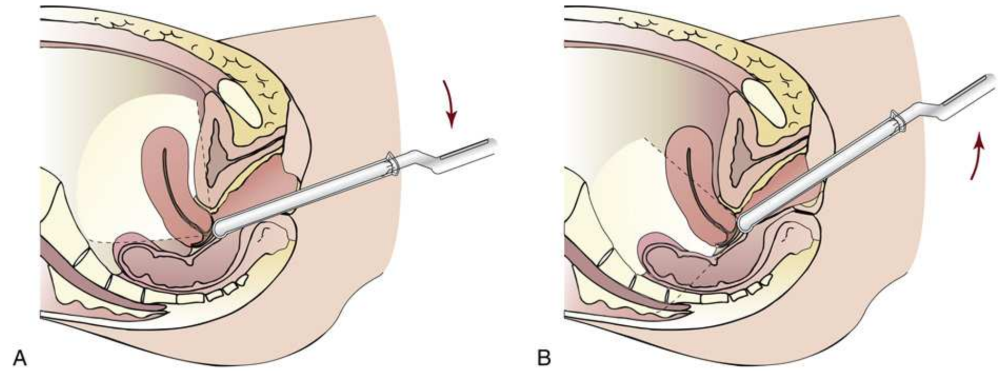

FIG. 28.26 (A) Transvaginal sagittal scan with anterior angulation to visualize better the fundus of normal anteflexed uterus. (B) Transvaginal sagittal scan with posterior angulation to visualize better cervix and rectouterine recess.

(A) A high-frequency transducer is inserted into the vaginal canal and into the fundus of normal anteflexed uterus. A downward arrow is marked near the transducer. (B) A high-frequency transducer is inserted into the vaginal canal and into the fundus of normal anteflexed uterus. An upward arrow is marked near the transducer.

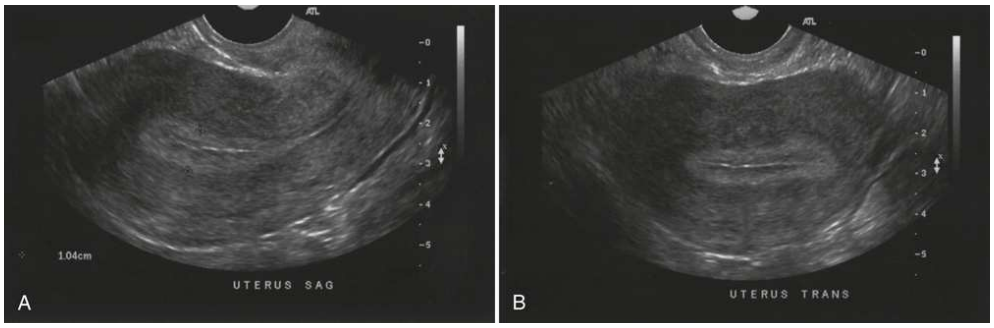

FIG. 28.27 (A) Endovaginal sagittal sonogram of uterus. (B) Coronal sonogram of uterus.

Obstetric Applications

Obstetric sonography is probably the most well-known ultrasound examination. An obstetric sonogram allows the obstetrician to view and monitor the developing *embryo* and *fetus*. Routine screening examinations are requested between 16 and 24 *gestational weeks* to measure *gestational age,* evaluate fetal anatomy, localize placental placement, assess amniotic fluid, and evaluate cervical competence. Evaluation of the fetus is relatively easy because the fetus occupies a fluid-filled *gestational sac,* an excellent acoustic window for ultrasound.

In the first trimester, endovaginal imaging is more likely to image an early gestational sac, yolk sac, amniotic cavity, and embryo (Figs. 28.29 and 28.30). The number of viable embryos is easily diagnosed with a first-trimester sonogram. The gestational sac may be visualized at 4.5 gestational weeks, and embryo cardiac activity can be identified at 5.5 gestational weeks with endovaginal sonography. By the ninth gestational week, the cerebral hemispheres and limb buds are evident. By the 12th gestational week, the fetus has a skeletal body.

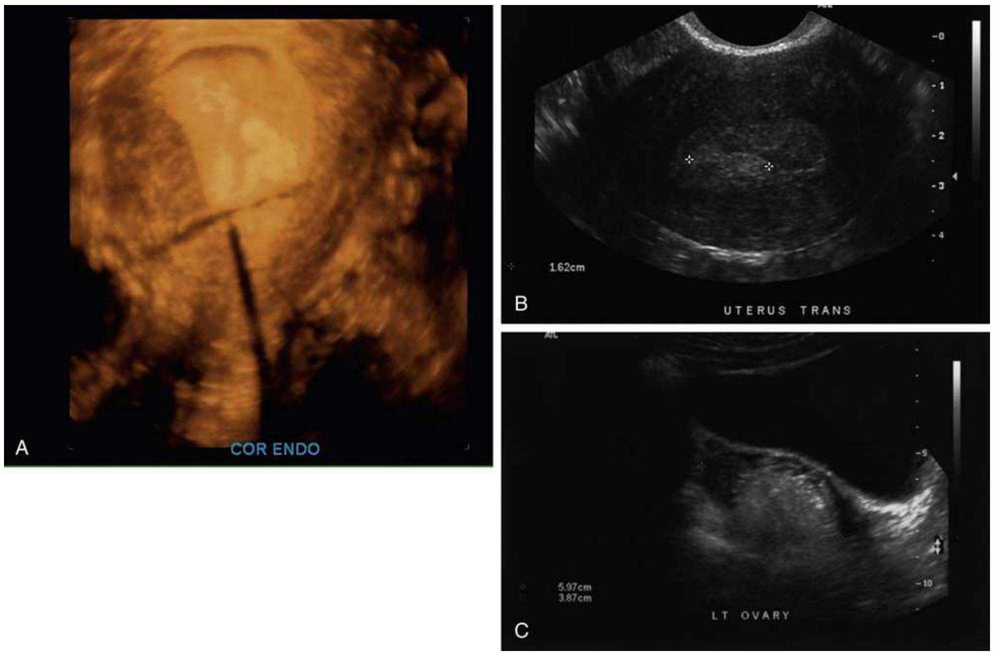

FIG. 28.28 (A) Volumetric coronal sonogram of uterine cervix showing improper location of an intrauterine device. (B) Coronal image of the endometrium showing a hyperechoic neoplasm (calipers). (C) Sagittal image of complex left ovarian mass. A and C, Courtesy Paul Aks, BS, RDMS, RVT.

(A) A coronal sonogram of uterine cervix appears orange. (B) A coronal image of the endometrium shows a two calipers on either side of a grey region. (C) A sonogram shows a radiolucent region on the top. The region below it appears white and grey

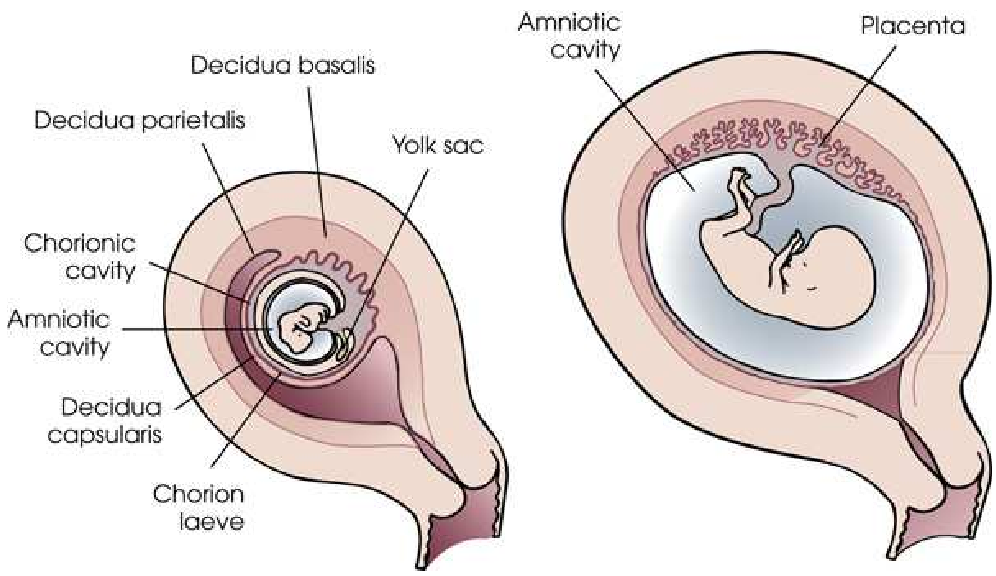

FIG. 28.29 First-trimester representations of developing embryo and yolk sac within amniotic and chorionic cavities of the uterus.

Diagrams of developing embryo and yolk sac in amniotic and chorionics cavities of the uterus. The parts labeled on the first diagram in clockwise direction are as follows: chorion leave, decidua capsularis, amniotic cavity, chorionic cavity, decidua parietalis, decidua basalis, yolk sac. the parts labeled on the second diagram are amniotic cavity and placenta.

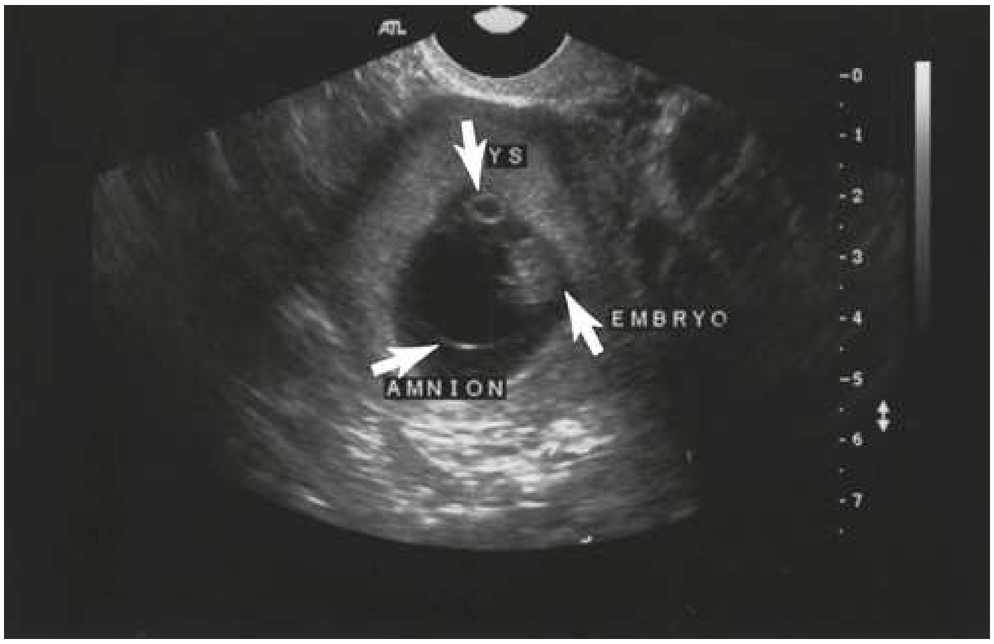

FIG. 28.30 Endovaginal sonogram of first-trimester pregnancy. Yolk sac *(YS)*, embryo, and amnion are easily visualized within fluid-filled gestational sac. Courtesy Sharon Ballestero, RT, RDMS.

During the second trimester (13 to 28 gestational weeks), detailed anatomy of the fetus is identified. Structures such as the brain, face, limbs, spine, abdominal wall, stomach, kidneys, bladder, and heart are evaluated and documented. Measurements of the biparietal diameter, circumference of the fetal head, abdominal circumference, and femur length are used to determine gestational age and are termed *biometric measurements* (Fig. 28.31). Documentation of the placenta, amniotic fluid, cervical length, and fetal position is also included.

In the third trimester (29 to 40 gestational weeks), the fetus grows an additional 4 inches in length and gains 2000 to 2800 g in weight (4 to 6 lb.). Third-trimester ultrasound examinations are generally requested to evaluate fetal growth and position, amniotic fluid volume, and placental placement.

FIG. 28.31 (A) Biparietal diameter *(BPD)* is measured perpendicular to falx cerebri in a plane that passes through the third ventricle and thalami. (B) Fetal head circumference is measured in a plane that must include the cavum septi pellucidi *(CSP)* and tentorial hiatus. (C) Abdominal circumference is a cross-sectional measurement slightly superior to cord insertion at junction of left and right portal veins and shows a short length of umbilical vein and left portal vein. (D) Femur length *(FL)* is measured parallel to femoral shaft at level of femoral head cartilage and distal femoral condyle. Courtesy Sharon Ballestero, RT, RDMS.

(A) A sonogram shows a radiolucent circular region in the middle surrounded by a white border. The parts labeled as C S P and T H. It is indicated by two white arrows. (B) A sonogram shows a grey circular region in the middle surrounded by a white border. (C) A sonogram shows a grey circular region in the middle surrounded by a white border. (D) A sonogram shows a narrow radiolucent region above a grey and white region.

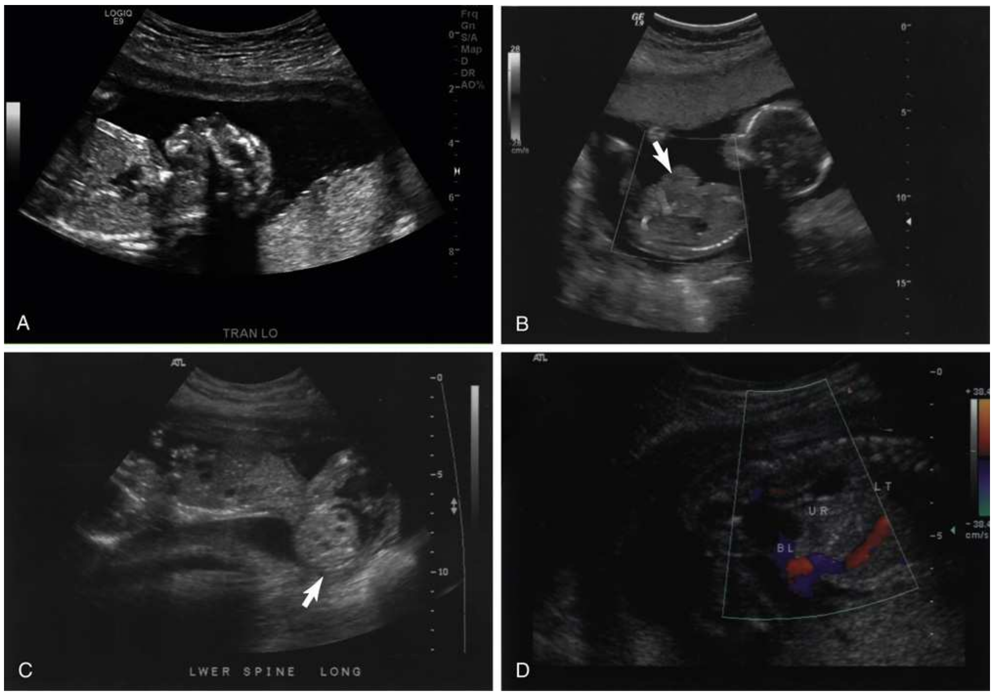

FIG. 28.32 (A) Early second-trimester sonogram of the fetal facial profile showing anencephaly. (B) Sagittal image of early second-trimester fetus showing gastroschisis. (C) Sagittal image of second-trimester fetus showing sacral teratoma *(arrow)*. (D) Sagittal image of left kidney showing hydronephrosis. A, Courtesy of Susanna Ovel RT, RDMS, RVT; B, courtesy Sharon Ballestero, RT, RDMS; C, courtesy B. Alex Stewart, RT, RDMS.

(A) A sonogram shows a radiolucent circular region in the middle surrounded by a white border. (B) A sonogram shows a grey circular region in the middle surrounded by a white border. It is indicated by a white arrow. (C) A sonogram shows a grey circular region in the middle surrounded by a white border. It is indicated by a white arrow. (D) A sonogram shows red and blue regions. The parts labeled are U R and B L.

Obstetric sonography is a safe imaging modality for evaluating normal and abnormal development of embryologic and fetal anatomy. A detailed ultrasound examination can assess complications of pregnancy, such as ectopic pregnancy, fetal demise, neural tube defects, nuchal cord, skeletal or limb anomalies, cardiac defects, gastrointestinal and genitourinary defects, and head anomalies (Fig. 28.32). Evaluation of the fetus using three-dimensional and four-dimensional imaging is not presently a routine part of obstetric screening examinations (Fig. 28.33).

FIG. 28.33 Three-dimensional sonogram of second-trimester fetal face. Courtesy Jeanette Burlbaw, BS, RDMS, FSDMS, FAIUM.

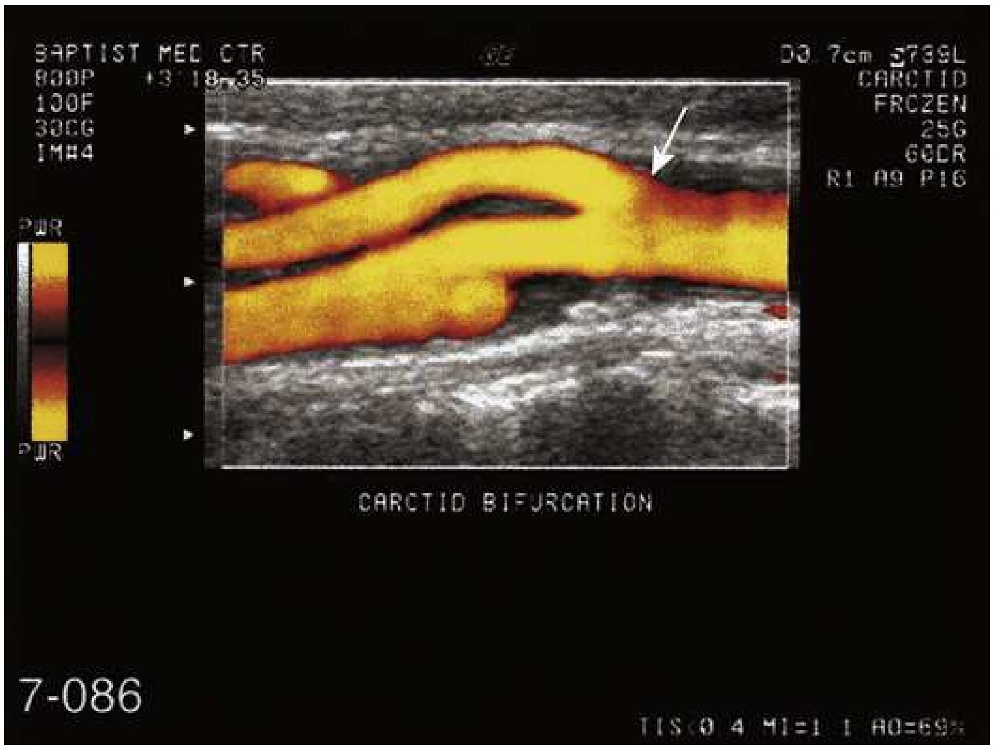

FIG. 28.34 Sagittal sonogram of carotid artery and bifurcation *(arrow)* into internal and external carotid arteries.

Vascular Applications

Sonography applications for evaluating the hemodynamics and anatomy of vascular structures continue to increase. Color Doppler imaging and spectral analysis can evaluate blood flow characteristics of the vascular structures in the neck, upper and lower extremities, abdomen, and pelvis. RVTs have specialized education and training in arterial and venous anatomy, hemodynamics, arterial and venous abnormalities, and additional physiologic vascular testing (i.e., pulse volume recording).

Abdominal duplex examinations are requested in patients with a history or suspicion of portal hypertension, mesenteric ischemia, renal artery stenosis, and portal vein thrombosis. Spectral analysis of blood flow velocity and direction is evaluated and documented. Specific criteria are used to diagnose the degree of arterial narrowing shown on the spectral analysis.

The extracranial carotid arteries are evaluated using duplex sonography (Fig. 28.34). Arterial patency, blood flow velocity, resistance, direction, and evidence of turbulence are evaluated with color Doppler and spectral analysis. The highest flow velocities in the common carotid, internal carotid, external carotid, vertebral, and subclavian arteries are recorded. The velocity difference between the common and internal carotid arteries is used to diagnose the degree or percentage of stenosis (i.e., 50%) (Fig. 28.35).

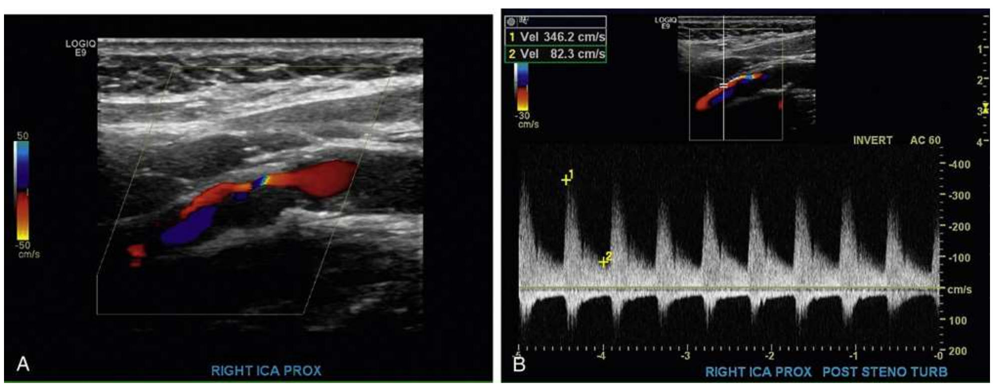

FIG. 28.35 (A) Sagittal image of carotid artery with high-grade stenosis in proximal internal carotid artery. (B) Color Doppler and spectral analysis show increases in flow velocity in stenotic internal carotid artery.

(A) A sagittal image of carotid artery with high-grade stenosis in proximal internal carotid artery. It is highlighted in red and blue. (B) A color Doppler and spectral analysis show increases in flow velocity in stenotic internal carotid artery.

Duplex sonograms of the lower extremity arterial arteries are requested in patients with symptoms of claudication, rest pain, a decrease in palpable pedal pulse, and bypass graft surveillance. Patients with a clinical history of hypertension, cigarette smoking, and diabetes mellitus have an increased risk of developing peripheral arterial disease. Duplex examination of the lower extremities begins at the distal aorta. The common and external iliac arteries are examined for any inflow abnormalities. The common femoral, deep femoral, popliteal, anterior tibial, posterior tibial, and peroneal arteries are evaluated in grayscale with color Doppler and spectral analysis for patency, plaque formation, increases in flow velocity, and, when applicable, degree of stenosis. Upper extremity arterial duplex examinations are requested in patients with arm or hand pain, asymmetric blood pressures, and changes in skin pallor. Using duplex sonography, the subclavian, axillary, brachial, ulnar, and radial arteries are evaluated for patency, plaque formation, increase in flow velocities, and, when applicable, degree of stenosis.

Duplex sonographic examination of the lower extremity veins is an inexpensive imaging modality to evaluate for deep vein thrombosis and venous insufficiency. Acute or chronic leg pain, edema, changes in skin pigmentation, and varicose veins are indications for a lower extremity venous duplex sonogram.

When evaluating for deep vein thrombosis, the deep system is evaluated for patency and phasic flow. Incompetence of the venous valve is the most common cause of varicose vein development. When evaluating for venous insufficiency, the deep venous system is evaluated for patency and valve competency. The small and great saphenous veins are measured and evaluated for patency, valve competency, and association with varicosities. Visible perforator veins are also evaluated for patency and valve competency. The sonographer provides a technical report to the reading physician detailing the findings regarding evidence of lower extremity deep vein thrombosis, venous insufficiency, and possible source of varicosities (Fig. 28.36). Upper extremity venous examinations are requested in patients with indwelling catheters, arm or hand swelling, and arm pain. The internal jugular, subclavian, axillary, brachial, cephalic, and basilic veins are evaluated for patency and *phasic flow*.

Additional physiologic testing is used to evaluate peripheral arterial and venous flow. The ankle/brachial index (ABI), venous return time, and pulse volume recording are examples of nonimaging vascular testing.

Cardiologic Applications

Real-time echocardiography of the fetal, neonatal, pediatric, and adult heart has proven to be a tremendous diagnostic aid for the cardiologist and internist. Multiple imaging windows are used to image cardiac anatomy in detail, including the four chambers of the heart, four heart valves (mitral, tricuspid, aortic, and pulmonic), interventricular and interatrial septa, muscular wall of the ventricles, papillary muscles, and chordae tendineae cordis. Difficult cases can be imaged using a transesophageal technique in which the transducer is passed from the mouth, through the esophagus, and then to the orifice of the stomach.

Procedure For Echocardiography

The echocardiographic examination begins with the patient in a left lateral decubitus position. This position allows the heart to move away from the sternum and fall closer to the chest wall, providing a better cardiac "window," or open area, for the sonographer to image. The transducer is placed in the third, fourth, or fifth intercostal space to the left of the sternum. The protocol for a complete echocardiographic examination includes images in the long axis, short axis, apical, and suprasternal windows (Fig. 28.37). Contrast agents improve visualization of viable myocardial tissue.

Cardiac Pathology

Echocardiography is used to evaluate many cardiac conditions. Atherosclerosis or previous rheumatic fever may lead to scarring, calcification, and thickening of the valve leaflets. With these conditions, valve tissue destruction continues, causing stenosis and regurgitation of the leaflets and subsequent chamber enlargement.

The effects of sub-bacterial endocarditis can also be evaluated with echocardiography. With this infectious process, multiple small vegetations form on the endocardial surface of the valve leaflets, causing the leaflets to tear or thicken, with resultant severe regurgitation into subsequent cardiac chambers. The echocardiogram of a patient with congestive cardiomyopathy shows generalized four-chamber enlargement, valve regurgitation, and the threat of thrombus formation along the nonfunctioning ventricular wall. The pericardial sac surrounds the ventricles and right atrium, and may fill with fluid, impairing normal cardiac function.

Analysis of ventricular function and serial evaluation of patients after a myocardial infarction are accomplished with two-dimensional echocardiography and, in some cases, stress dobutamine echocardiography. Complications of myocardial infarction include rupture of the ventricular septum, development of a left ventricular aneurysm in the weakest area of the wall, and coagulation of thrombus in the akinetic or immobile apex of the left ventricle (Fig. 28.38).

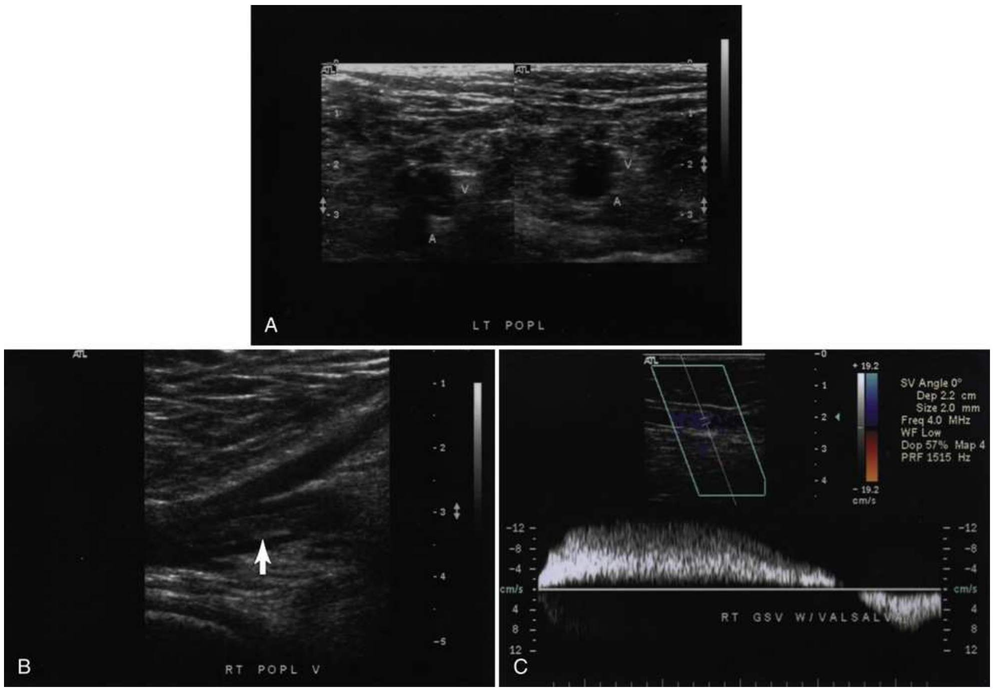

FIG. 28.36 (A) Transverse sonograms of popliteal artery and vein without compression *(left image)* and with compression *(right image)* showing a deep vein thrombosis. (B) Sagittal sonogram of popliteal vein showing echogenic thrombus *(arrow)*. (C) Spectral analysis of great saphenous vein shows venous reflux during Valsalva maneuver signifying venous incompetence at this level.

(A) The transverse sonograms of popliteal artery and vein without compression and with compression shows a deep vein thrombosis. (B) The sagittal sonogram of popliteal vein shows echogenic thrombus. It is indicated by a white arrow. (C) The spectral analysis of great saphenous vein shows venous reflux during valsalva maneuver.

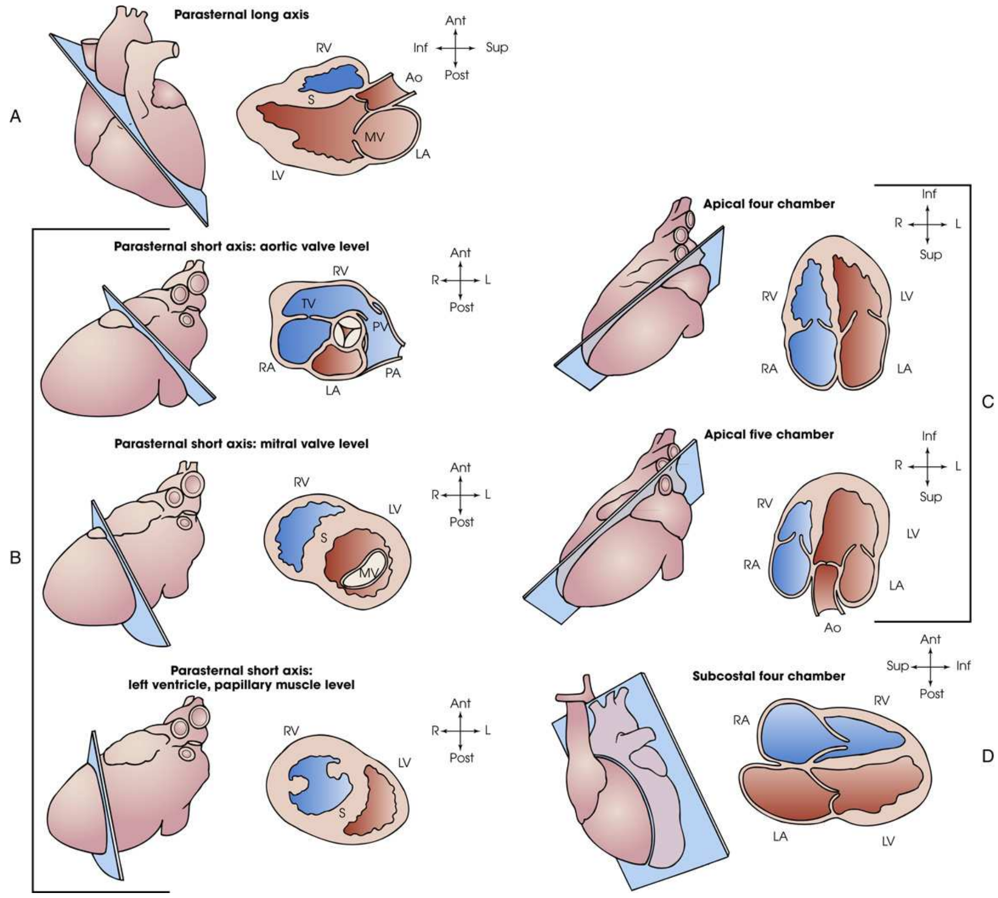

FIG. 28.37 (A) Parasternal long-axis drawing. (B) Parasternal short-axis drawings at various levels: aortic valve level; mitral valve level; and left ventricle, papillary muscle level. (C) Apical four-chamber image and apical five-chamber image. (D) Subcostal four-chamber image. *Ao,* Aorta; *LA,* left atrium; *LV,* left ventricle; *MV,* mitral valve; *PA,* pulmonary artery; *PV,* pulmonic valve; *RA,* right atrium; *RV,* right ventricle; *S,* septum; *TV,* tricuspid valve.

(A) shows the parasternal long-axis drawing. (B) shows the parasternal short-axis drawings at various levels: aortic valve level, mitral valve level, and left ventricle, papillary muscle level. (C) shows the apical four-chamber image and apical five-chamber image. (D) shows the subcostal four-chamber image. Aorta, left atrium, left ventricle, mitral valve, pulmonary artery, pulmonic valve, right atrium, right ventricle, septum, tricuspid valve.

Congenital heart lesions

Echocardiography has been used to diagnose congenital lesions of the heart in fetuses, neonates, and young children. The cardiac sonographer is able to assess abnormalities of the four cardiac valves, determine the size of the cardiac chambers, assess the interatrial and interventricular septum for the presence of shunt flow, and identify the continuity of the aorta and pulmonary artery with the ventricular chambers to look for abnormal attachment relationships.

A premature infant has an improved chance of survival if the correct diagnosis is made early. If the neonate is cyanotic, congenital heart disease or respiratory failure may be rapidly diagnosed with echocardiography. Critical cyanotic disease in a premature infant may include hypoplastic left heart syndrome, transposition of the great vessels with pulmonary atresia, or severe tetralogy of Fallot.

Best Practices In General Sonography

The following best practices are guidelines for performing sonographic examinations. Ultrasound uses high-frequency sound waves instead of potentially harmful radiation. Real-time imaging and cine loop technology make it easier to accommodate patient movement. Cine loop technology saves the last several seconds of real-time imaging. The sonographer can scroll back and document the best image.

1. ***Interaction with the patient:*** When interacting with the patient, the sonographer's vocabulary, body language, and tone of voice should reflect a calming environment. Fear is the most likely cause of uncooperative behavior. Decreasing or eliminating the patient's unease is essential for sonography, especially in the pediatric patient.
2. ***Speed:*** Due to the possible short attention span of younger pediatric patients and pain or discomfort in the adult patient, the sonographer must accurately document imaging protocols. Most protocols require specific measurements, which should be made and recorded after completion of the exam.
3. *Accuracy:* Knowledge in normal anatomy, congenital anomalies, pathologies, and normal appearance of pediatric anatomy is essential. Understanding sonography physics and instrumentation is crucial. Continuing education is essential to retain imaging accuracy.
4. ***Positioning:*** Maintaining a specific or steady position is not as crucial in sonographic imaging. Ingenuity is handy for pediatric positioning. Having a parent hug their child when scanning the kidneys may give the child a sense of security.
5. ***Practice standard precautions:*** The sonographer should practice standard precautions before, during, and after every ultrasound examination. Examination tables, pillow(s), the ultrasound machine, and transducers should be disinfected after every patient. Proper

personal protective equipment (PPE) should be used with every examination.

6. ***Professionalism:*** The sonographer needs to possess ethical conduct and professionalism with all patients. Interacting with the pediatric patient is unique. Not only is the sonographer interacting with the patient, but he/she is also interacting with the parent(s). The perception of the sonographer's professionalism by family members is relevant when interacting with all patients.

Conclusion

The contribution of diagnostic ultrasound to clinical medicine has been assisted by technologic advances in instrumentation and transducer design, an increased ability to process the returned echo information, and an improved methodology for three-dimensional reconstruction of images. The development of high-frequency *endovaginal, endorectal,* and *transesophageal transducers* with endoscopic imaging has aided the visualization of previously difficult areas. Improved computer capabilities and advances in teleradiography have enabled the sonographer to obtain more information and process multiple data points to obtain a comprehensive report from the ultrasound study. Color-flow Doppler has made it possible for the sonographer to distinguish the direction and velocity of arterial and venous blood flow from vascular and other pathologic structures in the body. Doppler has allowed the sonographer to determine the exact area of obstruction or leakage present, and to precisely determine the degree of turbulence within a vessel or cardiac chamber.

Modifications in transducer design have improved resolution in superficial structures, muscles, and tendons. Advancements in equipment and transducer design have also improved the results of ultrasound examinations in neonates and children. Increased sensitivity allows the sonographer to define the texture of organs and glands with more detail and greater tissue differentiation. Improvements in resolution have aided the visualization of small cleft palate defects, abnormal development of fingers and toes, and small spinal defects. The ability to image the detail of the fetal heart has assisted the early diagnosis of congenital heart disease.

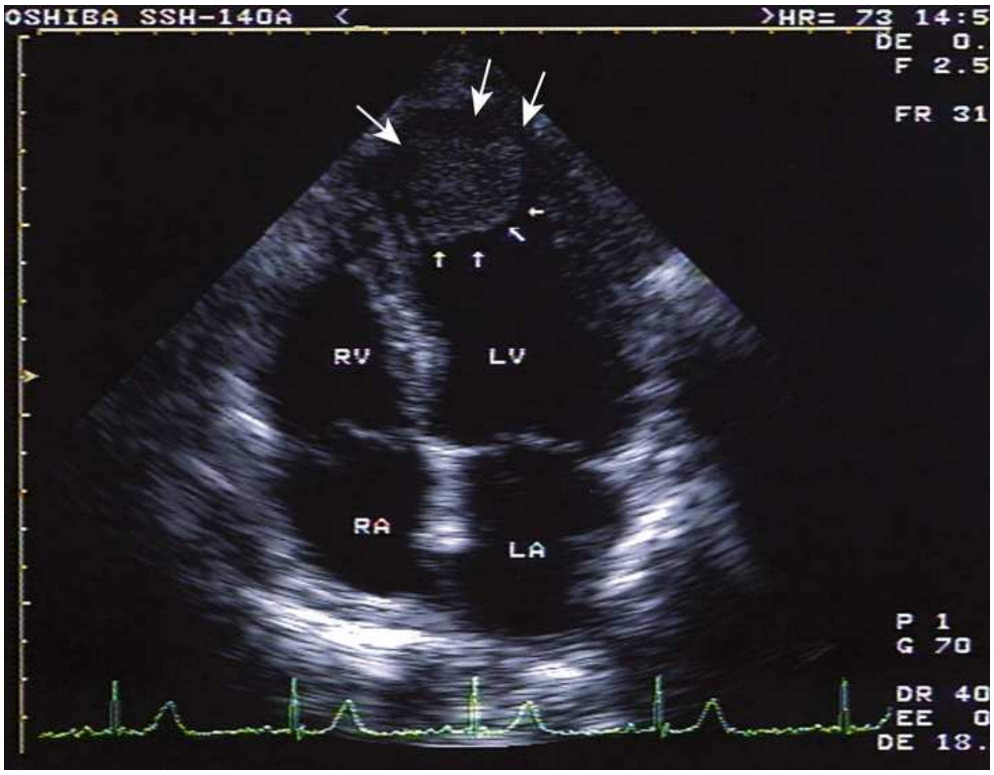

FIG. 28.38 Apical four-chamber image with large apical thrombus. This thrombus *(arrows)*, which is distinguished from an artifact because of its location in a region with abnormal wall motion, is attached to the apical endocardium, has well-defined borders, and moves in the same direction as the apex. *LA,* Left atrium; *LV,* left ventricle; *RA,* right atrium; *RV,* right ventricle.

Advanced research and development of computer analysis and tissue characterization of echo reflections should contribute further to the total diagnostic approach using ultrasound. Various abdominal contrast agents continue to be investigated to improve visualization of the stomach, the pancreas, and the small and large intestines. Cardiac contrast agents are already being used to improve the visualization of viable myocardial tissue within the heart. Saline and other contrast agents are being injected into the endometrial cavity to outline the lining of the endometrium for the purpose of distinguishing polyps and other lesions from the normal endometrium.

Ultrasound has rapidly emerged as a powerful, inexpensive, diagnostic imaging modality with various applications in patient management and care. Expected advancements include further developments in transducer design, image resolution, tissue characterization applications, color-flow sensitivity, and four-dimensional reconstruction of images.

Definition of Terms

acoustic window: Ability of sonography to visualize a particular area. The full urinary bladder is a good acoustic window to image the uterus and ovaries in a transabdominal sonogram. The intercostal margins may be a good acoustic window to image the liver parenchyma.

anechoic: Property of being free of echoes or without echoes.

ankle/brachial index (ABI): Ratio of ankle pressure to brachial pressure to provide a general guide to help determine the degree of disability of the lower extremity.
attenuation: Weakening of the sound wave as it propagates through a medium.
axial resolution: Ability to distinguish two structures along a path parallel to the sound beam.
biometric measurements: Fetal measurements to include biparietal diameter, head circumference, abdominal circumference, and femur length to assess fetal age and growth.
biparietal diameter (BPD): Largest dimension of the fetal head perpendicular to the midsagittal plane; measured by ultrasonic visualization and used to measure fetal development.
color-flow Doppler: Velocity in each direction is quantified by allocating a pixel to each area; each velocity frequency change is allocated a color.
complex: Containing anechoic and echogenic areas.
continuous wave ultrasound: Wave in which cycles repeat indefinitely; consists of a separate transmit and receive transducer housed within one assembly.
coronal image plane: Anatomic term used to describe a plane perpendicular to the sagittal and transverse planes of the body.
detail resolution: Includes axial and lateral resolution.
Doppler effect: Shift in frequency or wavelength, depending on the conditions of observation; caused by relative motions among sources, receivers, and medium.
Doppler ultrasound: Application of Doppler effect to ultrasound to detect movement of a reflecting boundary relative to the source, resulting in a change of the wavelength of the reflected wave.
duplex imaging: Combination of grayscale real-time imaging and color or spectral Doppler.
echogenic: Refers to a medium that contains echo-producing structures.
embryo: Term used for a developing zygote through the 10th week of gestation.
endometrium: Inner layer of the uterine canal.
endorectal transducer: High-frequency transducer that can be inserted into the rectum to visualize the bladder and prostate gland.
endovaginal transducer: High-frequency transducer (and decreased penetration) that can be inserted into the vagina to obtain high-resolution images of the pelvic structures.
false pelvis: Region above the pelvic brim.
fetus: Term used for the developing embryo from the 11th gestational week until birth.
follicular cyst: Functional or physiologic ovulatory cyst consisting of an ovum surrounded by a layer of cells.
frequency: Number of cycles per unit of time, usually expressed in hertz (Hz) or megahertz (MHz) (a million cycles per second).
gestational sac: Fluid-filled structure normally found in the uterus containing the pregnancy.
gestational weeks: Length of time calculated from the first day of the last menstrual period; also known as gestational age.
grayscale: Range of amplitudes (brightness) between white and black.
heterogeneous: Having a mixed composition.
homogeneous: Having a uniform composition.
hyperechoic: Producing more echoes than normal.
hypoechoic: Producing less echoes than normal.
iliopectineal line: Bony ridge on the inner surface of the ileum and pubic bones that divides the true and false pelvis.
isoechoic: Having a texture nearly the same as that of the surrounding parenchyma.
lateral resolution: Ability to distinguish two structures lying perpendicular to the sound beam.
noninvasive technique: Procedure that does not require the skin to be broken or an organ or cavity to be entered (e.g., taking the pulse).
oblique plane: Slanting direction or any variation that is not starting at a right angle to any axis.
parenchyma: Functional tissue or cells of an organ or gland.
phasic flow: Normal venous respiratory variations.
piezoelectric effect: Conversion of pressure to electrical voltage or conversion of electrical voltage to mechanical pressure.
porta hepatis: Region in hepatic hilum containing common duct, proper hepatic artery, and main portal vein.
posterior acoustic enhancement: Increase in reflection amplitude from structures that lie behind a weakly attenuating structure (i.e., cyst).
posterior acoustic shadowing: Reduction in reflection amplitude from reflectors lying behind a strongly reflecting or attenuating structure.
pulse wave ultrasound: A transducer emits short pulses of ultrasound into the human body and receives reflections from the body before emitting another pulse of sound.
real-time imaging: Teleradiograph with rapid frame rate visualizing moving structures or scan planes continuously.
reflection: Redirection (return) of a portion of the sound beam back to the transducer.
refraction: Phenomenon of bending wave fronts as the acoustic energy propagates from the medium of one acoustic velocity to a second medium of differing acoustic velocity.
resolution: Measure of ability to display two closely spaced structures as discrete targets.
retrouterine pouch: Pelvic space located anterior to the rectum and posterior to the uterus; also known as pouch of Douglas.
sagittal: Plane that travels vertically from the top to the bottom of the body along the *y* axis.
scattering: Diffusion or redirection of sound in several directions on encountering a particle suspension or rough surface.
sound wave: Longitudinal waves of mechanical energy propagated through a medium.
transducer: Device that converts energy from one form to another.
transverse: Plane that passes through the width of the body in a horizontal direction.
true pelvis: Region of the pelvis found below the pelvic brim.
ultrasound: Sound with a frequency >20 kHz.
velocity of sound: Speed with direction of motion specified.

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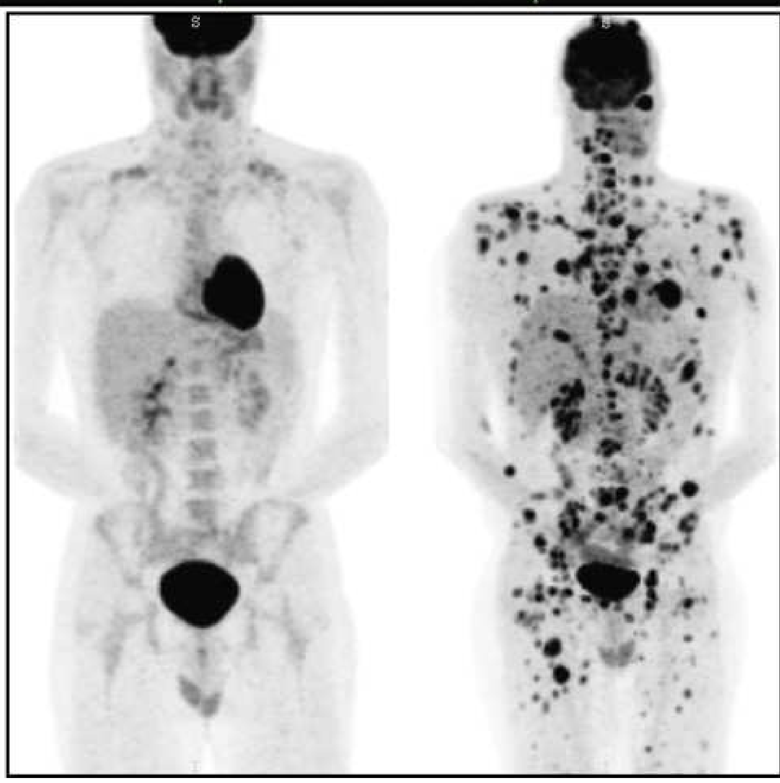
[a] Almost all italicized words on the succeeding pages are defined at the end of this chapter.

29: Nuclear Medicine And Molecular Imaging



Raymond J. Johnson

Outline

Principles of Nuclear Medicine

Nuclear medicine is an imaging modality that focuses on the use of radioactive materials called *radiopharmaceuticals*. [a] Radiopharmaceuticals are used for diagnosis, therapy, and medical research. In contrast to typical radiographic procedures that determine the presence of disease based on structural appearance, nuclear medicine explores the physiologic function of organs and/or tissues.

For a nuclear medicine procedure, the radiopharmaceutical, commonly referred to as a *radiotracer* or *tracer,* is primarily introduced into the body through a multitude of ways. These include but are not limited to, injection (intravenous, intradermal, intramuscular, or intrathecal), ingestion, or inhalation. Different radiotracers are used to study different parts of the body. Specific tracers are selected based on their ability to localize in specific organs and/or tissues. Radiotracers undergo radioactive decay to produce gamma-ray emissions that allow for the detection of the tracer's presence within the body. A special piece of equipment, known as a *gamma* or *scintillation camera,* is used to transform these emissions into images that provide information about the function and anatomy of the organ or system being studied. Physicians attempt to prescribe the lowest amount of radiotracer in each exam to reduce the radiation exposure to the patient without compromising the image quality.

Nuclear medicine procedures are performed by a team of specially educated professionals: a nuclear medicine physician, a specialist with extensive education in the basic and clinical science of medicine who is licensed to use radioactive materials; a nuclear medicine technologist, who performs the tests and is educated in the theory and practice of nuclear medicine procedures; a medical physicist, who is experienced in the technology of nuclear medicine and the care of the equipment; and a radiopharmacist, who is qualified to prepare the necessary radioactive pharmaceuticals.

Historical Development

John Dalton is considered the father of the modern theory of atoms and molecules. In 1803, Dalton, an English schoolteacher, stated that all atoms of a given element are chemically identical, unchanged by chemical reaction, and combine in a ratio of simple numbers. Dalton measured atomic weights in reference to hydrogen, to which he assigned the value of 1 (the atomic number of this element).

The discovery of x-rays by Wilhelm Conrad Roentgen in 1895 was a great contribution to physics and the care of the sick. A few months later, another physicist, Antoine Henri Becquerel, discovered naturally occurring radioactive substances. In 1898, Marie Curie discovered two new elements in the uranium ore pitchblende. Curie named these trace elements polonium (after her homeland, Poland) and radium. Curie also coined the terms *radioactive* and *radioactivity*.

General Nuclear Medicine

In 1923, George de Hevesy, often called the "father of nuclear medicine," developed the tracer principle. He coined the term "radioindicator" and extended his studies from inorganic to organic chemistry. The first radioindicators were naturally occurring substances such as radium and radon. The invention of the *cyclotron* by Ernest Lawrence in 1931 made it possible for de Hevesy to expand his studies to a broader spectrum of biologic processes by using ^{32}P (phosphorus-32), ^{22}Na (sodium-22), and other cyclotron-produced (synthetic) radioactive tracers.

Radioactive elements began to be produced in *nuclear reactors* developed by Enrico Fermi and colleagues in 1946. The nuclear reactor greatly extended the ability of the cyclotron to produce more radioactive tracers. A key development was the introduction of the *gamma camera* by Hal Anger in 1958. In the early 1960s, Edwards and Kuhl made the next advancement in nuclear medicine with the development of a crude single photon emission computed tomography (SPECT) camera known as the MARK IV. With this new technology, it was possible to create three-dimensional images of organ function instead of the two-dimensional images created previously. It was not until the early 1980s, when computers became fast enough to acquire and process all of the information successfully, that SPECT imaging could become a standard practice.

One of the first organs to be examined by nuclear medicine studies using *external radiation detectors* was the thyroid. In the 1940s, investigators found that the rate of incorporation of radioactive iodine by the thyroid gland was greatly increased in hyperthyroidism (the overproduction of thyroid hormones) and greatly decreased in hypothyroidism (the underproduction of thyroid hormones). Over the years, tracers and instruments were developed to allow almost every major organ of the body to be studied by application of the tracer principle. Subsequently, images were made of structures such as the liver, spleen, brain, and kidneys. Currently, the emphasis of nuclear medicine studies is more on function and pathology than anatomic structure.

Positron Emission Tomography

With the development of more suitable *scintillators,* such as sodium iodide (NaI), and more sophisticated nuclear counting electronics, positron coincidence localization became possible. In 1951, Wrenn demonstrated the use of positron-emitting radioisotopes for the localization of brain tumors. Gordon Brownell further developed instrumentation for similar studies. The next major advancement came in 1967 when Sir Godfrey Hounsfield demonstrated the clinical use of computed tomography (CT). The mathematics of positron emission tomography (PET) image *reconstruction* is similar to that used for CT reconstruction techniques. Instead of x-rays from a point source traversing the body and being detected by a single or multiple detector(s) as in CT, PET imaging uses two opposing detectors to count pairs of 511-keV photons simultaneously that originate from a single positron–electron annihilation event.

From 1967 to 1974, significant developments occurred in computer technology, scintillator materials, and *photomultiplier tube* (PMT) design. In 1975, the first closed-ring transverse positron emission tomograph was built for PET imaging by Michel M. Ter-Pogossian and Michael E. Phelps.

Developments now continue on two fronts that have accelerated the use of PET. First, scientists are approaching the theoretic limits (1 to 2 mm) of PET scanner resolution by employing smaller, more efficient, scintillators, and PMTs. Microprocessors tune and adjust the entire ring of *detectors* that surround the patient. Each ring in the PET tomograph may contain 1000 detectors, and the tomograph may be composed of 30 to 60 rings. The second major area of development is in the design of new radiopharmaceuticals. Agents are being developed to measure blood flow, metabolism, protein synthesis, lipid content, receptor binding, and many other physiologic parameters and processes.

During the mid-1980s, PET was used predominantly as a research tool. However, by the early 1990s, clinical PET centers had been established, and PET was routinely used for diagnostic procedures on the brain, heart, and tumors. In the mid- to late 1990s, three-dimensional PET systems that eliminated the use of interdetector *septa* were developed. This development allowed the injected dose of the radiopharmaceutical to be reduced by approximately 6- to 10-fold. New image reconstruction methods have been developed to better characterize the distribution of annihilation photons from these three-dimensional systems.

HYBRID IMAGING: PET/CT, AND PET/MRI

Beginning in 2000, major nuclear medicine camera manufacturers developed combined PET and CT systems that can simultaneously acquire PET functional images and CT anatomic images. Both modalities are co-registered or exactly matched in size and position. The success of these camera systems led to the development of combined SPECT and CT systems, as well. Significant benefits are expected for diagnosing metastatic disease because precise localization of the tumor site and function can now be determined. In addition to anatomic registration, CT has allowed for improved attenuation correction (AC) in PET and SPECT. By more accurately mapping the different densities in the body, more accurate correction of the different gamma attenuators can be applied to PET and SPECT image data. Rapid enhancements and developments are anticipated to continue with this technology over the next several years.

TABLE 29.1

Modality information	PET	SPECT	MRI	CT
Measures	Physiology	Physiology	Anatomy (physiology)[a]	Anatomy
Resolution	3–5mm	8–10mm	0.5–1mm	1–1.5mm
Technique	Positron annihilation	Gamma emission	Nuclear magnetic resonance	Absorption of x-rays
Harmful	Radiation exposure	Radiation exposure	None known	Radiation effects exposure
Use	Research and clinical	Clinical	Clinical (research)[a]	Clinical
No. examinations per day	4–12	5–10	10–15	15–20

[a] Secondary function.

In addition to the hybrid fusion of PET and CT, the first PET/magnetic resonance imaging (MRI) system was approved by the U.S. Food and Drug Administration (FDA) for customer purchase in 2011. The integration of PET and MRI is not straightforward and challenges the technical design of both systems. PET/MRI merges the metabolic ability of PET imaging with the morphologic imaging of MRI (see Chapter 26) to generate diagnostic images for oncologic, cardiologic, and neurologic purposes.

Comparison With Other Modalities

Nuclear medicine is predominantly used to measure human cellular, organ, or system function. A parameter that characterizes a particular aspect of human physiology is determined from the measurement of the radioactivity emitted by a radiopharmaceutical in a given volume of tissue. In contrast, conventional radiography measures the structure, size, and position of organs or human anatomy by determining x-ray transmission through a given volume of tissue. X-ray attenuation by structures interposed between the x-ray source and the radiographic image receptor provides the contrast necessary to visualize an organ. CT creates cross-sectional images by computer reconstruction of multiple x-ray transmissions (see Chapter 25). The characteristics of radiologic imaging modalities are compared in Table 29.1.

SPECT is a conventional nuclear imaging technique that is used to determine tissue function. Because SPECT employs collimators and lower energy photons, it is less sensitive (by 10^1 to 10^5) and less accurate than PET. Generally, PET resolution is better than SPECT resolution by a factor of 2 to 10. PET easily accounts for photon loss through attenuation by performing a *transmission scan*. This is difficult to achieve and not routinely done with SPECT imaging; however, newly designed SPECT instrumentation that couples a low-output x-ray CT to the gamma camera for the collection of attenuation information is now being used to correct for gamma attenuation. Software approaches are also being investigated that assign known *attenuation coefficients* for specific tissues to segmented regions of images for analytic AC of SPECT imaging data.

The differences between the various imaging modalities can be highlighted using a study of brain blood flow as an example. Without an intact circulatory system, an intravenously injected radiotracer cannot make its way into the brain for distribution throughout the brain's capillary network, ultimately diffusing into cells that are well perfused. For radiographic procedures, such as CT, structures within the brain may be intact, but there may be impaired or limited blood flow to and through major vessels within the brain. Under these circumstances, the CT scan may appear almost normal despite reduced blood flow to the brain. If the circulatory system at the level of the capillaries is not intact, a PET scan can be performed, but no perfusion information is obtained because the radioactive water used to measure blood flow is not transported through the capillaries and diffused into the brain cells.

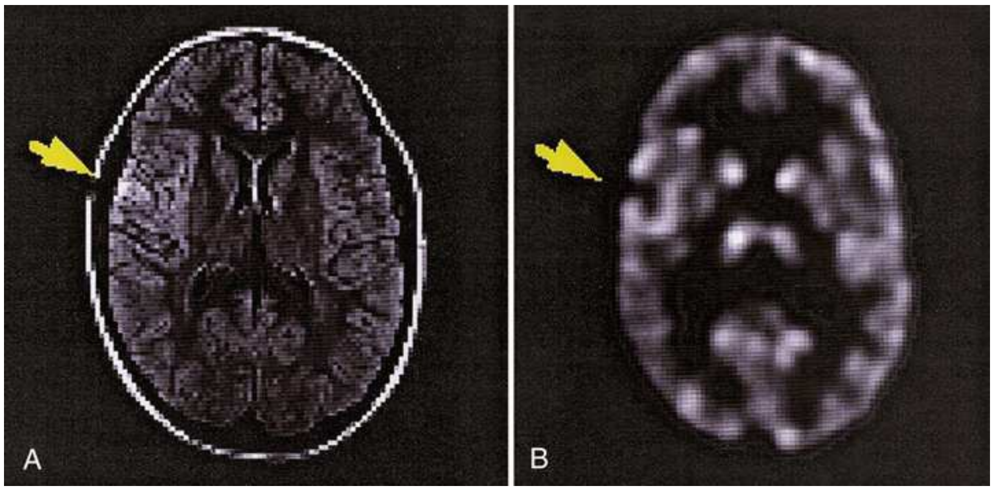


FIG. 29.1 Coregistered MRI and PET scans. *Arrows* indicate an abnormality on the anatomic image (A, MRI scan) and the functional image (B, PET scan). ^{18}F-FDG PET image depicts hypometabolic area of seizure focus *(arrow)* in a patient with a diagnosis of epilepsy.

(A) An M R I of the brain shows a white outer covering with a gap on the left. It is indicated by a yellow arrow. The brain is purple colored. (B) An M R I of the brain shows a yellow colored arrow pointing at a purple colored brain.

The image-enhancing contrast agents used in many radiographic studies may cause a toxic reaction (a warm uncomfortable feeling all over the body or even a severe allergic reaction). The x-ray dose to the patient in these radiographic studies is greater than the radiation dose in nuclear imaging studies. An additional benefit is that the radiotracers used in PET studies are similar to the body's own biochemical constituents and are administered in very small amounts. This biochemical compatibility of the tracers within the body minimizes the risks to the patient because the tracers are not found to be toxic. At the same time, trace amounts minimize any alterations of the body's *homeostasis.*

An imaging technique that augments CT and PET is MRI (see Chapter 26). Images obtained with PET and MRI are shown in Fig. 29.1. MRI is used primarily to measure anatomy or morphology. In contrast to CT, which derives its greatest image contrast from varying tissue densities (bone from soft tissue), MRI better differentiates tissues by their proton content and the degree to which the protons are bound in lattice structures. The tightly bound protons of bone make it virtually transparent to MRI.

CT, MRI, and other anatomic imaging modalities provide complementary information to nuclear medicine imaging and PET. These imaging modalities benefit from *image coregistration* with CT and MRI by pinpointing physiologic function with precise anatomic locations. Greater emphasis is being placed on multimodality image coregistration between PET, CT, SPECT, and MRI for brain research and tumor localization throughout the body (Fig. 29.2). All new PET imaging systems are fused with a CT scanner for AC and anatomic positioning information. Many SPECT imaging systems incorporate CT technology for the same purposes.

Physical Principles of Nuclear Medicine

An understanding of radioactivity must precede an attempt to grasp the principles of nuclear medicine and how images are created using radioactive compounds. The term *radiation* is taken from the Latin word *radii,* which refers to the spokes of a wheel leading out from a central point. The term *radioactivity* is used to describe the radiation of energy in the form of high-speed *alpha* or *beta particles* or waves (gamma rays) from the nucleus of an atom.

Basic Nuclear Physics

The basic components of an atom include the nucleus (which is composed of varying numbers of protons, and neutrons) and the orbiting electrons (which revolve around the nucleus in discrete energy levels). Protons have a positive electrical charge, electrons have a negative charge, and neutrons are electrically neutral. Protons and neutrons have masses nearly 2000 times the mass of the electron; thus the nucleus is responsible for most of the mass of an atom (~99%). The Bohr atomic model (Fig. 29.3) can describe this configuration. The total number of protons, neutrons, and electrons in an atom determines its characteristics, including its stability.

The term *nuclide* is used to describe an atomic species with a particular arrangement of protons and neutrons within the nucleus. Elements with the same number of protons but a different number of neutrons are referred to as *isotopes.* Isotopes have the same chemical properties as one another because the total number of protons and electrons are the same. They differ simply in the total number of neutrons contained in the nucleus. The neutron-to-proton ratio in the nucleus determines the stability of the atom. At certain ratios, atoms may become unstable, and a process known as spontaneous *decay* can occur as the atom attempts to regain stability. Energy is released in various ways during this decay process, or as it returns to its *ground state.*

Radionuclides decay by the emission of alpha, beta, and/or gamma radiation. For most radionuclides to reach their ground state, it usually requires multiple steps and various decay processes. This can include any array of the following: alpha, beta, positron, or *electron capture;* and several other methods. These decay methods determine the type of particles or gamma rays given off as the radionuclide decays.

To explain this process better, investigators have created decay schemes to show the details of how a *parent* nuclide decays to its *daughter* and/or eventually ground state (Fig. 29.4A). A decay scheme is a simple illustration depicting how a radionuclide decays. Each radionuclide has its own unique decay scheme, similar to a fingerprint, which identifies the type(s) of decay, the energy associated with each process, the probability of a particular decay process occurring, and the rate of change to the ground state element (see Fig. 29.4B).

FIG. 29.2 Combined single photon emission computed tomography/computed tomography camera for a blending of imaging function and form.

Radioactive decay is considered a purely random and spontaneous process that can be mathematically defined by complex equations and represented by average decay rates. The term *half-life* is used to describe the time it takes for a quantity of a particular radionuclide to decay to one half of its original activity or one half of the original number of atoms through spontaneous disintegration. The rate of decay has an exponential function, which can be plotted on a linear scale (see Fig. 29.4C). If plotted on a semilogarithmic scale, the decay rate would be represented as a straight line. Radionuclide half-lives can range anywhere from milliseconds to years. The half-lives of most radionuclides used in nuclear medicine range from several seconds to several days.

Nuclear Pharmacy (Radiopharmacy)

Naturally occurring radionuclides have very long half-lives (i.e., thousands of years). These natural radionuclides are unsuitable for nuclear medicine imaging because of limited availability and the high-absorbed dose the patient would receive. The radionuclides used in nuclear medicine (general and PET) are produced in nuclear reactors, generators, or *particle accelerators (cyclotrons)*. Radionuclides can be created in nuclear reactors either by inserting a target element into the reactor core where it is irradiated or by separating and collecting the *fission* byproducts. One of these byproducts is molybdenum-99 (^{99}Mo), which is used in the production of technetium-99m (^{99m}Tc) through a *generator system*. The radionuclides for nuclear medicine are produced in a particle accelerator or cyclotron through nuclear reactions created between a specific target chemical and high-speed charged particles. The number of protons in the target nucleus is changed when it is bombarded by the high-speed charged particles, and a new element or radionuclide is produced.

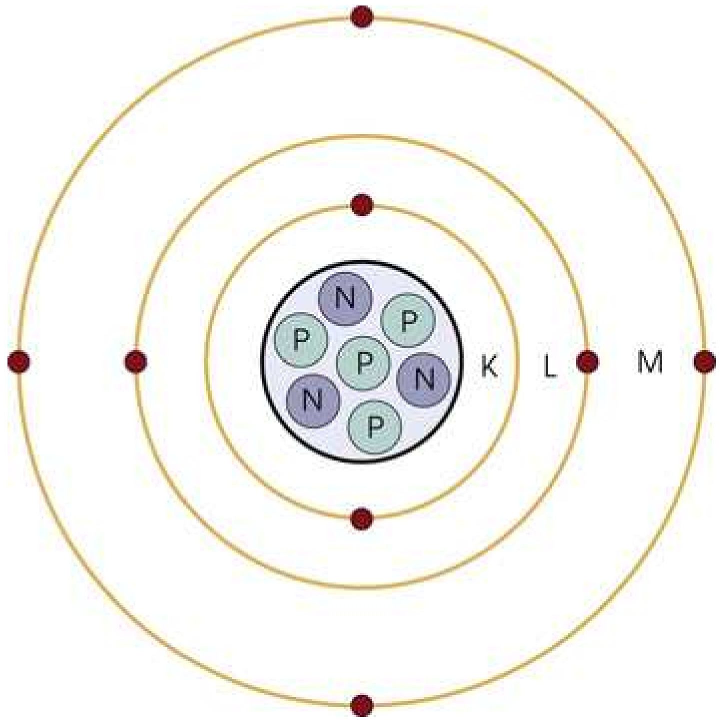


FIG. 29.3 Diagram of Bohr atom containing a single nucleus of protons (*P*) and neutrons (*N*) with surrounding orbital electrons of varying energy levels (e.g., *K, L, M*).

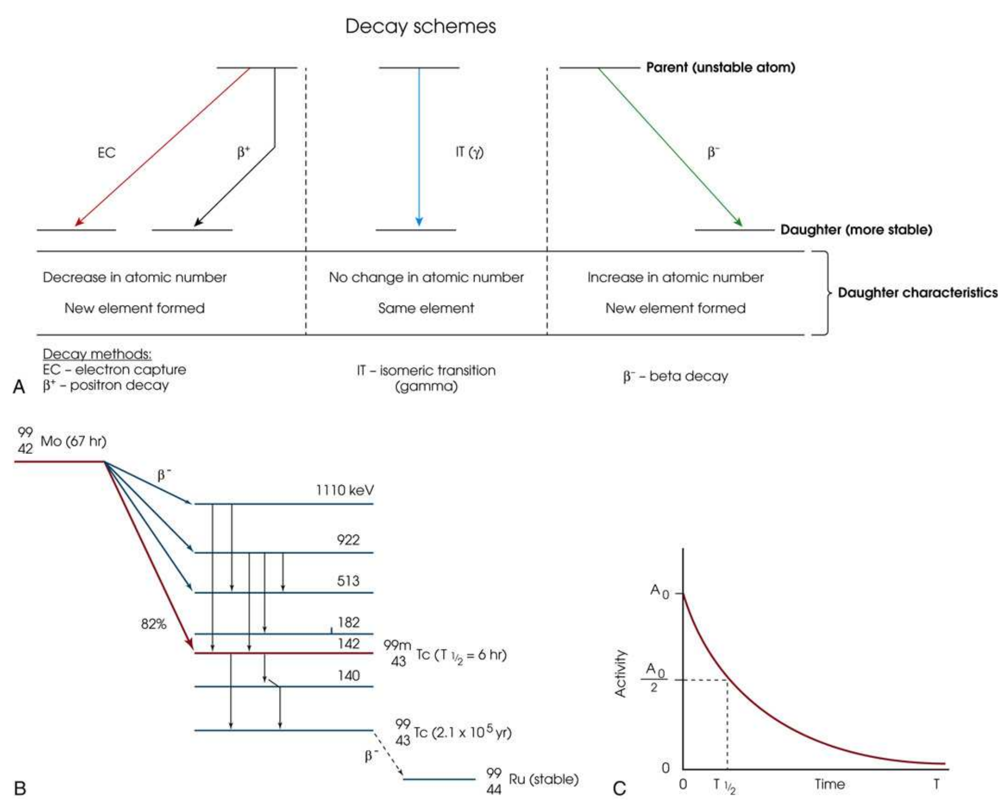


FIG. 29.4 (A) Four types of decay schemes and pathways. (B) Decay scheme illustrating the method by which radioactive molybdenum (^{99}Mo) decays to radioactive technetium (^{99m}Tc), one of the most commonly used radiopharmaceuticals in nuclear medicine. (C) Graphic representation showing the rate of physical decay of a radionuclide. The *y (vertical)* axis represents the amount of radioactivity, and the *x (horizontal)* axis represents the time at which a specific amount of activity has decreased to one-half of its initial value. Every radionuclide has an associated half-life that is representative of its rate of decay.

(A) shows four types of decay schemes and pathways. (B) The decay scheme illustrates that each radionuclide has its own unique decay scheme, similar to a fingerprint, which identifies the type of decay, the energy associated with each process, the probability of a particular decay process occurring, and the rate of change to the ground state element (C) The graphic representation shows the rate of physical decay of a radionuclide. The y (vertical) axis represents the amount of radioactivity, and the x (horizontal) axis represents the time at which a specific amount of activity has decreased to one-half of its initial value. Every radionuclide has an associated half-life that is representative of its rate of decay.

Radionuclides used for general nuclear medicine procedures include ^{99m}Tc, ^{123}I (iodine), ^{131}I (iodine), ^{111}In (indium), ^{201}Tl (thallium), and ^{67}Ga (gallium). Labeled compounds with these high atomic weight radionuclides often do not mimic the physiologic properties of natural occurring substances found in the body. This is due to their size, mass, and different chemical properties. Compounds labeled with traditional nuclear medicine radionuclides are also found to be poor radioactive *analogs* for other natural substances. Imaging studies with these agents are qualitative and emphasize nonbiochemical properties.

Radionuclides used in PET include ^{11}C (carbon), ^{13}N (nitrogen), and ^{15}O (oxygen). The elements hydrogen, carbon, nitrogen, and oxygen are the predominant constituents of natural compounds found in the body. Different from common nuclear medicine radionuclides, these emit positrons, have low atomic weight, and can directly replace their stable isotopes in substrates, metabolites, drugs, and other biologically active compounds. This is also achieved without disrupting any bodily biochemical mechanisms and processes. For example, the most commonly used PET radionuclide, ^{18}F (fluorine), can replace hydrogen in many molecules, providing an even greater assortment of biologic analogs.

The most commonly used radionuclide in nuclear medicine is ^{99m}Tc, which is produced in a generator system. This apparatus makes available desirable short-lived radionuclides (the *daughters*), which are formed by the decay of relatively longer-lived radionuclides (the *parents*). The generator system uses ^{99}Mo as the parent; ^{99}Mo has a half-life of 66.7 hours and decays (86% of the time) to a daughter product known as *metastable* ^{99m}Tc. Because ^{99m}Tc and ^{99}Mo are chemically different, they can easily be separated through an ion-exchange column. ^{99m}Tc exhibits nearly ideal characteristics for use in nuclear medicine examinations, including a relatively short physical half-life of 6.04 hours and a high-yield yield of low-energy gamma photons (98.6% at 140-keV) (see Fig. 29.4B).

FIG. 29.5 A radionuclide is chosen based on the characteristics of its gamma emission and ability to tag to a specific pharmaceutical; the pharmaceutical is chosen based on its ability to localize to a specific organ or function. When combined, a radiopharmaceutical, *or tracer*, is formed.

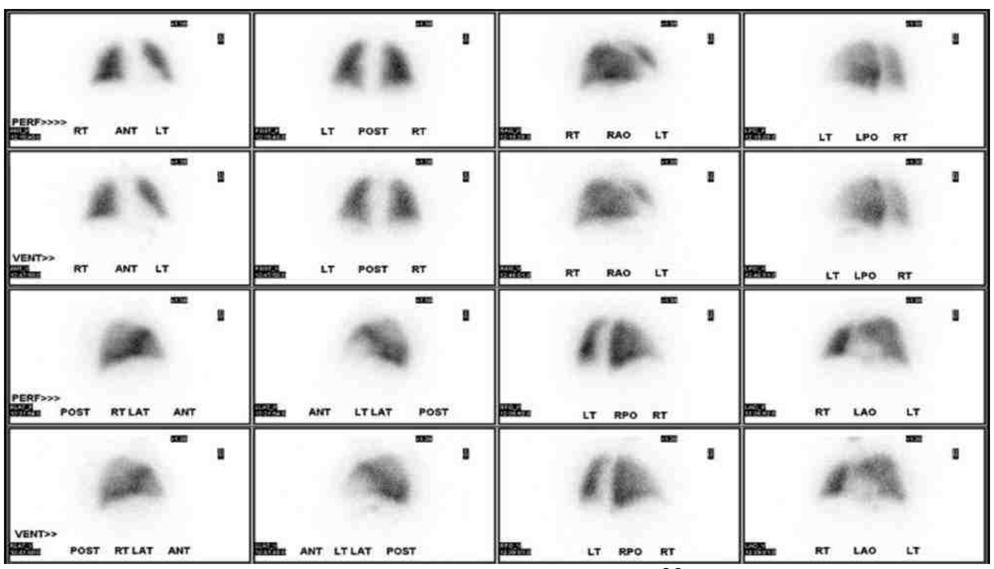


FIG. 29.6 Normal ventilation/perfusion lung scan using 40 mCi of ^{99m}Tc-diethylenetriamine pentaacetic acid (DTPA) (ventilation) and 5 mCi of ^{99m}Tc tagged to a macroaggregated albumin (*^{99m} Tc macroaggregated albumin [MAA] perfusion*) on a large field-of-view gamma camera. Ventilation imaging is provided in the first and third rows. Perfusion imaging is displayed in the second and fourth rows.

The normal ventilation or perfusion lung scan using 40 m C i of 99 m T c-diethylenetriamine pentaacetic acid (D T P A) (ventilation) and 5 m C i of 99 m T c tagged to a macroaggregated albumin (99 m T c macroaggregated albumin [M A A] perfusion) on a large field-of- view gamma camera. Ventilation imaging is provided in the first and third rows. The perfusion imaging is displayed in the second and fourth rows.

A radiopharmaceutical generally has two components: a radionuclide and a *pharmaceutical.* The pharmaceutical is a biologically active compound chosen on the basis of its preferential localization or participation in the physiologic function of a given organ. A radionuclide is the radioactive material used to tag the pharmaceutical, which allows for the localization of the compound within the body (Fig. 29.5). After the radiopharmaceutical is administered, the target organ is localized by means of the physiologic pharmaceutical distribution, and the radiation emitted from it can be detected by imaging instruments or gamma cameras.

The following characteristics are desirable in an imaging radiopharmaceutical:

- Ease of production, low cost, and ready availability
- Lowest possible radiation dose to the patient
- Primary photon energy between 100 and 400 keV
- Physical half-life greater than the time required to prepare the material, deliver it, and use it
- Effective half-life longer than the examination time
- Suitable chemical forms for rapid localization
- Different uptake in the structure to be detected than in the surrounding tissue
- Low toxicity in the chemical form administered to the patient
- Stability or near-stability

Because most radiopharmaceuticals are administered intravenously, they need to be sterile and *pyrogen-free.* They also need to undergo all of the quality control measures required of conventional drugs.

A commonly used radiopharmaceutical is ^{99m}Tc tagged to a macroaggregated albumin (MAA). After intravenous injection, this substance follows the pathway of blood flow to the lungs where it is distributed throughout and trapped in the small pulmonary capillaries (Fig. 29.6). Blood clots along the pathway prevent this radiopharmaceutical from distributing in the area beyond the clot. As a result, the image shows a void or clear area, often described as *photopenia* or a *cold spot.* More than 30 different radiopharmaceuticals are used in nuclear medicine (Table 29.2).

TABLE 29.2

Radionuclide	Symbol	Physical half-life	Chemical form	Diagnostic use
Carbon	^{11}C	20.4min	Sodium acetate	Oncology and myocardial imaging
			Choline	Oncology imaging
Fluorine	^{18}F	110min	Fluorodeoxyglucose	Oncology and myocardial hibernation
			Sodium fluoride	Bone imaging
Gallium	^{67}Ga	77h	Gallium citrate	Inflammatory process and tumor imaging
Indium	^{111}In	67.4h	DTPA	Cerebrospinal fluid imaging
			Ibritumomab tiuxetan	Localization of tumor
			OctreoScan (pentetreotide)	Neuroendocrine tumors
			Oxine	White blood cell/abscess imaging
Iodine	^{123}I	13.3h	Sodium iodide	Thyroid function and imaging
	^{131}I	8 days	Sodium iodide	Thyroid function, imaging, and therapy
Nitrogen	^{13}N	10min	Ammonia	Myocardial perfusion
Oxygen	^{15}O	2.03min	Water [^{15}O]H_2O	Oncology and myocardial blood flow agent
			Gas	Cerebral blood flow imaging
Rubidium	^{82}Rb	75s	Rubidium chloride	Cardiovascular imaging
Technetium	^{99m}Tc	6h	Sodium pertechnetate	Imaging of brain, thyroid, scrotum, salivary glands, renal perfusion, and pericardial effusion; evaluation of left-to-right cardiac shunts
			Sulfur colloid	Imaging of liver and spleen and renal transplants, lymphoscintigraphy
			Macroaggregated albumin	Lung imaging
			Sestamibi	Cardiovascular imaging, myocardial perfusion
			DTPA	Brain and renal imaging
			DMSA	Renal imaging
			MAG3	Renal imaging
			Diphosphonate	Bone imaging
			Pyrophosphate	Bone and myocardial imaging
			Red blood cells	Cardiac function imaging
			HMPAO	Functional brain imaging and white blood cell/abscess imaging
			Neurolite (Bicisate)	Brain imaging
			Myoview (Tetrofosmin)	Myocardial perfusion
			Cardiolite (Sestamibi)	Myocardial perfusion
Thallium	^{201}T1	73.5h	Thallous chloride	Myocardial imaging
Xenon	^{133}Xe	5.3 days	Xenon gas	Lung ventilation imaging

DMSA, Dimercaptosuccinic acid; *DTPA,* diethylenetriamine pentaacetic acid; *HMPAO,* hexamethylpropyleneamine oxime; *MAG3,* mertiatide.

Radioactivity is measured using either the *becquerel* (Bq), which corresponds to the decay rate, expressed as 1 disintegration per second (dps), or as the *curie* (Ci), which equals 3.73×10^{10} dps, relative to the number of decaying atoms in 1 g of radium.

Radiopharmaceutical Dosing

Prescribed radiopharmaceutical doses vary depending on the radionuclide used, the examination to be performed, the pathology involved, the size (kg), and the age of the patient. A radiologist or authorized user will usually set an acceptable dose range to administer an adult patient based on the factors listed above. Pediatric patients only receive a fraction of the adult dose. Currently, there are several formulas used to calculate an appropriate pediatric dose (Fig. 29.7). All pediatric doses provided in this chapter reference the *North American Consensus Guidelines for Pediatric Administered Radiopharmaceutical Activities*.

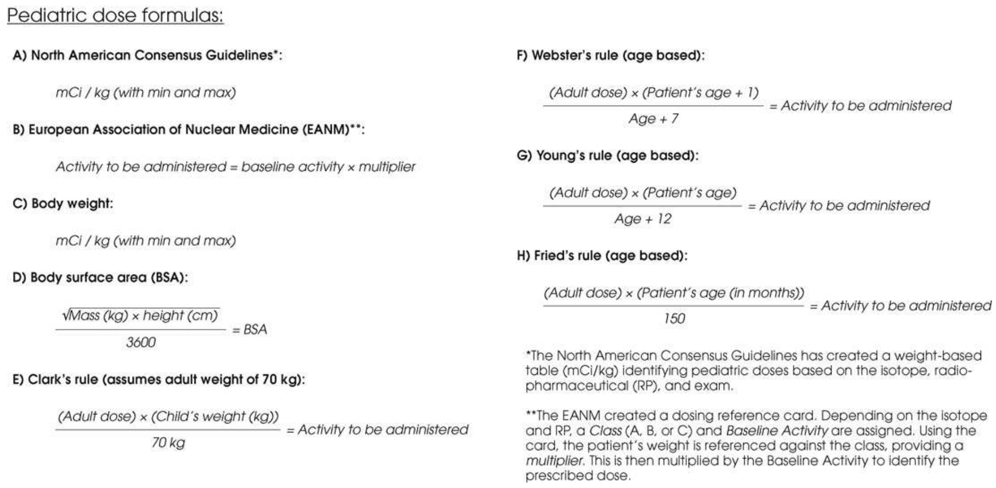


FIG. 29.7 Pediatric dose formulas.

Pediatric dose formulas. (A) North American consensus guidelines: millicuire per kilogram. (B) European Association of Nuclear Medicine: activity to be administered equals baseline activity times multiplier. (C) Body Weight: millicuire per kilogram. (D) Body surface area: start fraction root of mass in kilogram times height in centimeters over 3600 end fraction equals B S A. (E) Clark's rule (assumes adult weight of 70 kilogram): start fraction Adult dose times Child's weight in kilogram over 70 kilogram equals activity to be administered. (F) Webster's rule (age based): start fraction (Adult dose) times (Patient's age + 1) over age plus 7 equals Activity to be administered. (G) Young's rule (age based): start fraction (Adult dose) times (Patient's age) over age plus 12 equals Activity to be administered. (H) Fried's rule (age based): start fraction (Adult dose) times (Patient's age in months) over 150 equals Activity to be administered.

Radiation Safety in Nuclear Medicine

The radiation protection requirements in nuclear medicine differ from the general radiation safety measures used for diagnostic radiography. The radionuclides employed in nuclear medicine are in liquid, solid, or gaseous form. Because of the nature of radioactive decay, these radionuclides continuously emit radiation (in contrast to diagnostic x-rays, which can be turned on and off mechanically). Thus, special radiation safety precautions are required.

Technologists and nuclear pharmacists are required to wear appropriate radiation monitoring (dosimetry) devices, such as radiation badges and thermoluminescent dosimetry (TLD) rings, to monitor radiation exposure to the body and hands. The *ALARA* (as low as reasonably achievable) principle/program applies to all nuclear medicine personnel at all times.

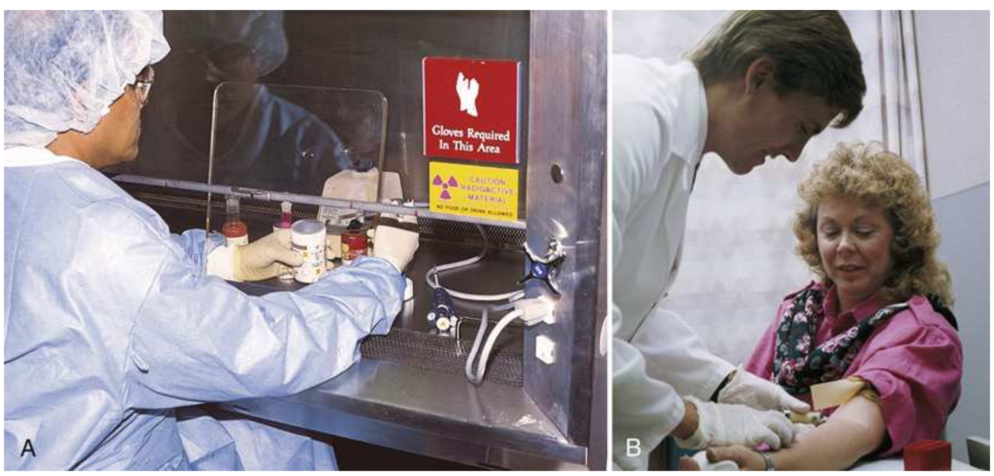


FIG. 29.8 (A) Area in a radiopharmacy in which doses of radiopharmaceuticals are prepared in a clean and protected environment. (B) Nuclear medicine technologist administering a radiopharmaceutical intravenously using appropriate radiation safety precautions, including gloves and a syringe shield.

Generally, the quantities of radioactive tracers used in nuclear medicine present no significant hazard. Nonetheless, care must be taken to reduce unnecessary exposure. The high concentrations or activities of the radionuclides used in a nuclear pharmacy necessitate the establishment of a designated preparation area. These elected rooms are called *hot labs* and usually contain isolated ventilation, protective lead, or leaded glass shielding for vials and syringes, absorbent materials, and gloves. The handling and administration of diagnostic doses to patients warrants the use of gloves and a lead or tungsten syringe shield, which is especially effective for reduction of exposure to the technologist's hands and fingers (Fig. 29.8).

Any spilled radioactive material continues to emit radiation and must be cleaned up and contained immediately. Because radioactive material that contacts the skin can be absorbed and may not be easily washed off, it is very important to wear appropriate personal protective equipment (e.g., lab coat and gloves) when handling radiopharmaceuticals.

Instrumentation in Nuclear Medicine

Modern-Day Gamma Camera

The term *scintillate* means to emit light photons. Becquerel discovered that ionizing radiation caused certain materials to glow. A scintillation material is a sensitive element that emits light photons after being exposed to ionizing radiation. When a light-sensitive device is affixed to this material, the flash of light can be converted into small electrical impulses. Together, this is known as a *scintillation detector*. The electrical impulses are amplified and counted to determine the amount and nature of radiation striking the scintillating materials. Scintillation detectors were used in the development of the first-generation nuclear medicine scanner—the rectilinear scanner—which was built in 1950.

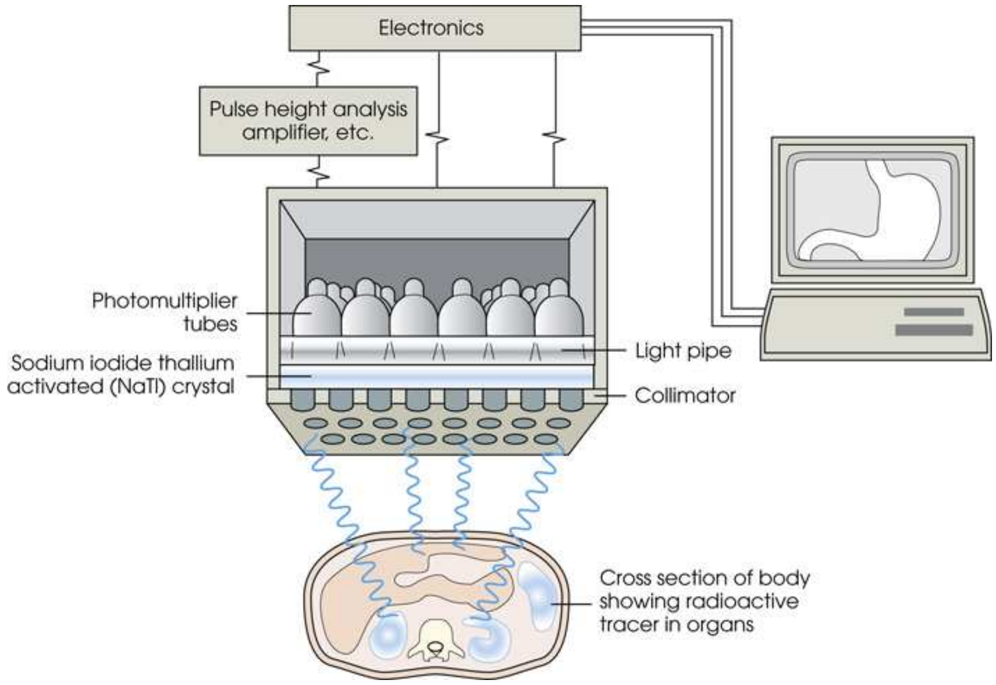


FIG. 29.9 Typical gamma camera system, which includes a processing station and electronic mechanical components for acquiring nuclear medicine images.

A gamma camera system has the following parts: sodium iodide thallium activated (N a T L) crystal, photomultiplier tubes, pulse height analysis amplifier, etcetera, electronics, light pipe, collimator, cross section of body showing radioactive tracer in organs.

Scanners have evolved into complex imaging systems known today as *gamma cameras* (because they detect gamma rays). The gamma camera has many components that work together to produce an image (Fig. 29.9). These cameras are scintillation detectors that use a thallium-activated sodium iodide crystal to detect and transform radioactive emissions into light photons. Through a complex process, these light photons are amplified, and their locations are electronically recorded to produce an image that is displayed on computer output systems. Scintillation cameras today use single or multiple crystals.

Collimator

Located at the face of the detector, where photons from radioactive sources first enter the camera, is the *collimator*. The collimator is used to filter gamma rays not perpendicular to the camera and keep scattered rays from reaching the scintillation crystal. *Resolution* and *sensitivity* are terms used to describe the physical characteristics of collimators. Collimator sensitivity is determined by the fraction of photons that are transmitted through the collimator and strike the face of the camera crystal. Spatial resolution refers to the system's ability to separate two points on an image.

Collimators are usually made of a material with a high atomic number, such as lead, which absorbs scattered gamma rays. Depending on the desired level of sensitivity and resolution, different collimators are used for different types of examinations (Fig. 29.10).

Crystal, light pipe, and PMT

The scintillation crystals commonly used in gamma cameras are made of sodium iodide with trace quantities of thallium added to increase light production. This crystal composition is effective for stopping most common gamma rays emitted from the radiopharmaceuticals used in nuclear medicine.

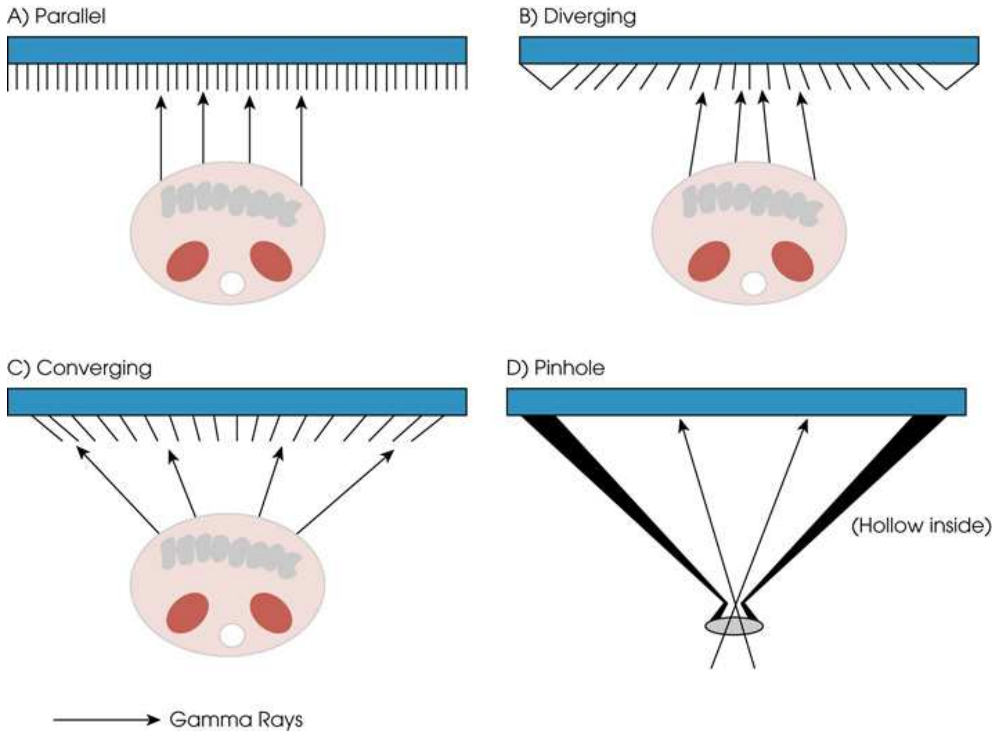


FIG. 29.10 Collimator designs: (A) Parallel collimators are used to visualize organs as is, usually with no or very little zoom. (B) Diverging collimators are used to shrink or minimize large organs or organ systems. (C and D) Converging and pinhole collimators magnify small organs so they can be better visualized.

The thickness of the crystal varies from ¼ inch to ½ inch (0.6 to 1.3 cm). Thicker crystals are better for imaging radiopharmaceuticals with higher energies (>180 keV) but have decreased resolution because of the decreased ability of the electronics to localize the exact location of the photon absorption within the thicker crystal. Thinner crystals provide improved resolution but cannot efficiently image photons with a higher kiloelectron voltage (keV) because of the inability of the thinner crystals to stop the higher-energy photons from passing through the crystal without being absorbed.

A *light pipe* may be used to attach the crystal to the PMTs. The light pipe is a disk of optically transparent material that helps direct photons from the crystal into the PMTs.

Attached to the back of the crystal or light pipe is an array of PMTs that are used to detect and convert light photons emitted from the crystal into an electronic signal. The PMT also amplifies the original photon signal by a factor of up to 10^7. A typical gamma camera detector head contains 80 to 100 PMTs. The PMTs send the detected signal through a series of processing steps, which include determining the location *(x, y)* of the original photon and its amplitude or energy *(z)*. The *x* and *y* values are determined by where the photon strikes the face of the crystal. Electronic circuitry known as a *pulse height analyzer* is used to eliminate the *z* signals that are of the appropriate energy based on the particular radionuclide being used. It is also used for rejecting photons not within the desired energy range. This helps reduce scattered lower energy, unwanted photons ("noise") that generally would degrade the resolution of the image. When the information has been processed, the signals are transmitted to the display system.

Multihead gamma camera systems

The original gamma camera was a single detector that could be moved in various positions around the patient. Today, gamma camera systems may include up to three detectors (heads). Dual-head gamma camera systems are the most common, allowing for simultaneous anterior and posterior planar imaging, and are ideal for SPECT. Triple-head systems are not as popular as dual-head systems and are generally used for brain and heart studies. Although the triple-head systems are primarily suited for SPECT, they can also provide multiplanar images (see the section on imaging methods presented later in this chapter).

Processing Systems

Processing systems have become an integral part of the nuclear medicine imaging structure. These systems are used to acquire and process data from gamma cameras. They allow data to be collected over a specific time frame or to a specified number of counts; the data can be analyzed to determine functional changes occurring over time (Fig. 29.11A and B). A common example is the renal study, in which the radiopharmaceutical that is administered is cleared by normally functioning kidneys in about 20 minutes. The computer can collect several images of the kidney during this period and analyze them to determine how effectively the kidneys clear the radiopharmaceutical. It does this by creating a time activity curve (see Fig. 29.11C–E). The computer also allows the operator to enhance a particular structure by adjusting the contrast and brightness of the image.

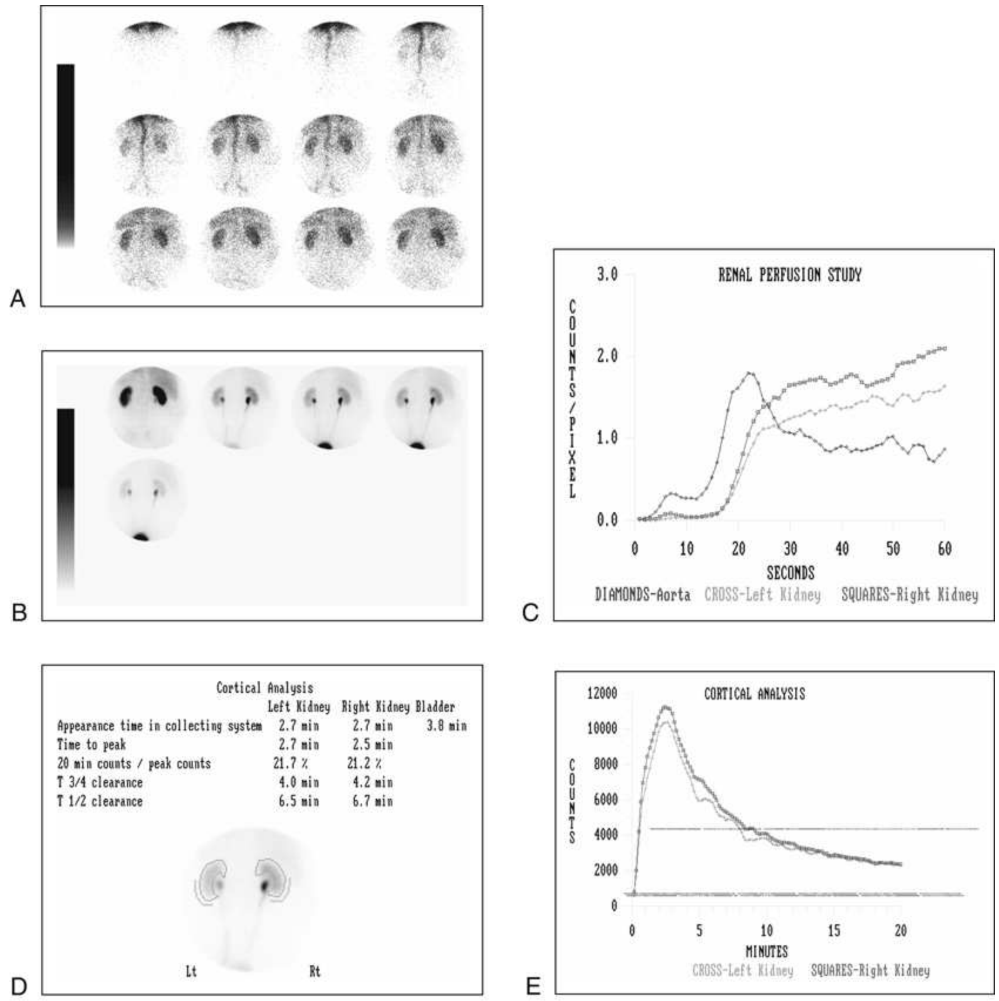


FIG. 29.11 (A) Posterior renal blood flow in an adult patient using 10 mCi of ^{99m}Tc with diethylenetriamine pentaacetic acid (DTPA) imaged at 3 seconds per frame. The image in the *lower right corner* is a blood-pool image taken immediately after the initial flow sequence. Together the images show normal renal blood flow to both kidneys. (B) Normal, sequential dynamic 20-minute ^{99m}Tc with mertiatide (MAG3) images. (C) Renal arterial perfusion curves showing minor renal blood flow asymmetry. (D) Renal cortical analysis curves showing rapid uptake and prompt parenchymal clearance. (E) Quantitative renal cortical analysis indices showing normal values.

(A) The posterior renal blood flow in an adult patient using 10 m C i of 99 m T c with diethylenetriamine pentaacetic acid (D T P A) imaged at 3 seconds per frame. The image in the lower right corner is a blood-pool image taken immediately after the initial flow sequence. Together the images show normal renal blood flow to both kidneys. (B) The normal, sequential dynamic 20-minute 99 m T c with mertiatide (M A G 3) images. (C) Renal arterial perfusion curves showing minor renal blood flow asymmetry. (D) The renal cortical analysis curves shows rapid uptake and prompt parenchymal clearance. (E) The quantitative renal cortical analysis indices shows normal values.

Processing systems are necessary to acquire and process SPECT images (see the next section). SPECT uses a scintillation camera that moves around the patient to obtain images from multiple angles for tomographic image reconstruction. SPECT studies are complex and, similar to MRI studies, require a great deal of computer processing to create images in transaxial, sagittal, and coronal planes. Rotating three-dimensional images can also be generated from SPECT data (Fig. 29.12).

Computer networks are an integral part of the way a department communicates information within and among institutions. In a network, several or many computers are connected so that they all have access to the same files, programs, and printers. Networking allows the movement of image-based and text-based data to any computer or printer in the network. Networking improves the efficiency of a nuclear medicine department. A computer network can serve as a vital component, reducing the time expended on menial tasks while allowing retrieval and transfer of information. Consolidation of all reporting functions in one area eliminates the need for the nuclear medicine physician to travel between departments to read studies. Centralized archiving, printing, and retrieval of most image-based and non-image-based data have increased the efficiency of data analysis, reduced the cost of image hard copy, and permitted more sophisticated analysis of image data than would routinely be possible.

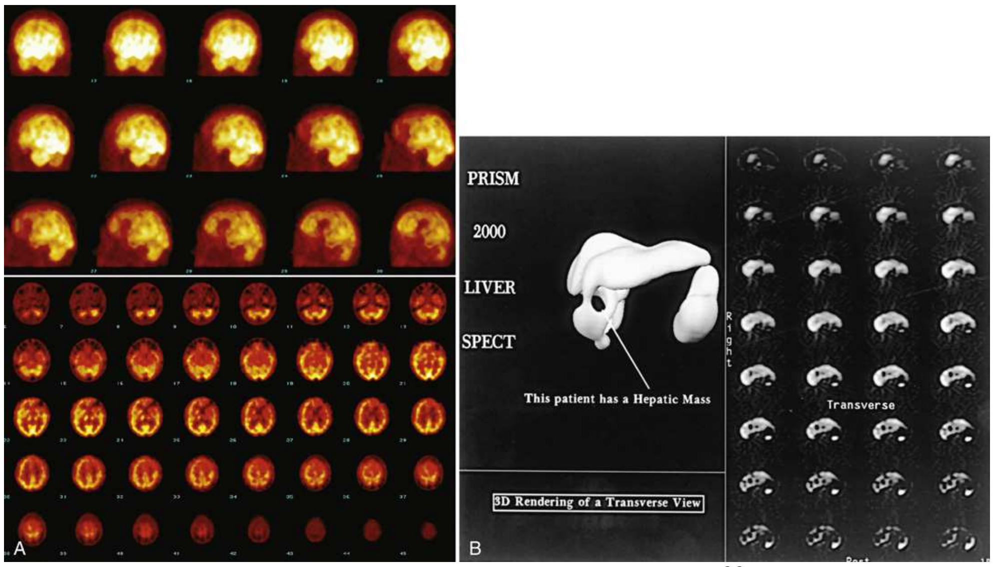


FIG. 29.12 (A) Three-dimensional SPECT brain study using 20 mCi of ^{99m}Tc ethylcysteinate dimer showing a patient with a left frontal lobe brain infarct *(top)*. Baseline and Diamox challenge transaxial, coronal, and sagittal images of the same patient, showing the left frontal lobe brain infarct *(bottom)*. (B) Three-dimensional SPECT liver study using 8 mCi of ^{99m}Tc sulfur colloid. A mass is seen on the three-dimensional image *(left)* and transaxial images *(right)*.

Electronically stored records can decrease the reporting turnaround time, the physical image storage requirements, and the use of personnel for record maintenance and retrieval. Long-term computerized records can also form the basis for statistical analysis to improve testing methods and predict disease courses. Most institutions now use some form of picture archiving and communication systems (PACS) to organize all of the imaging that is done. PACS are the foundation of a digital department, allowing for easy transfer, retrieval, and archiving of all imaging done in the nuclear medicine department.

Quantitative Analysis

Many nuclear medicine procedures require some form of quantitative analysis to provide physicians with numeric or statistical results based on and depicting organ function. Specialized software allows computers to collect, process, and analyze functional information obtained from nuclear medicine imaging systems. Cardiac left ventricular ejection fraction is a common quantitative study (Fig. 29.13). In this dynamic study of the heart's contractions and expansions, the computer accurately determines the ejection fraction, or the percent of blood pumped out of the left ventricle with each contraction.

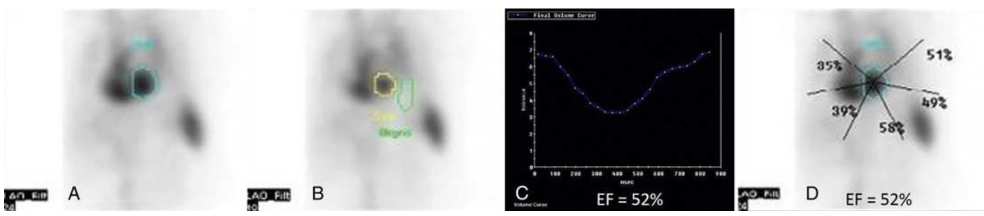


FIG. 29.13 Normal multigated acquisition scan. (A) Left anterior oblique (LAO) image of the left ventricle at end-diastole (relaxed phase) with a region of interest drawn around the left ventricle. (B) Same view showing end-systole (contracted phase). (C) Curve representing the volume change in the left ventricle of the heart before, during, and after contraction. This volume change is referred to as the ejection fraction *(EF)*; normal value is approximately 52%. (D) LAO view with regional ejection fractions displayed.

A) The left anterior oblique (L A O) image of the left ventricle at end-diastole appears in a relaxed phase with a region of interest drawn around the left ventricle. (B) The left anterior oblique (L A O) image of the left ventricle at end-diastole appears in a contracted phase. (C) A curve representing the volume change in the left ventricle of the heart before, during, and after contraction. This volume change is referred to as the ejection fraction (EF) which is 52 percent . (D) L A O view with regional ejection fractions are illustrated.

Imaging Methods

A wide variety of diagnostic imaging examinations are performed in nuclear medicine. These examinations can be described on the basis of the imaging method used: static/planar, whole-body, dynamic, SPECT, and PET.

Static/Planar Imaging

Static imaging is the acquisition of a single two-dimensional image of a particular structure. This image can be thought of as a snapshot of the radiopharmaceutical distribution within the body. Examples of static imaging used in general nuclear medicine include lung scans, limited bone scans, and thyroid imaging. Static images are usually obtained in various orientations around a particular structure to show multiple aspects of the region in question. Anterior, posterior, and oblique images are often obtained.

In static imaging, low radiopharmaceutical activity levels are used to minimize radiation exposure to the patients. Because of these low activity levels, images must be acquired for a preset time or a minimum number of counts or radioactive emissions. This time frame may vary from a few seconds to several minutes to acquire 100,000 to more than 1 million counts.

Whole-Body Imaging

Whole-body imaging uses a specially designed moving detector system to produce an image of the entire body or a large body section. In this type of imaging, the gamma camera collects data as it passes over the body. Earlier detector systems were smaller and required two or three incremental passes to encompass the entire width of the body. Others took multiple static images and "zipped" them together to form one whole-body image.

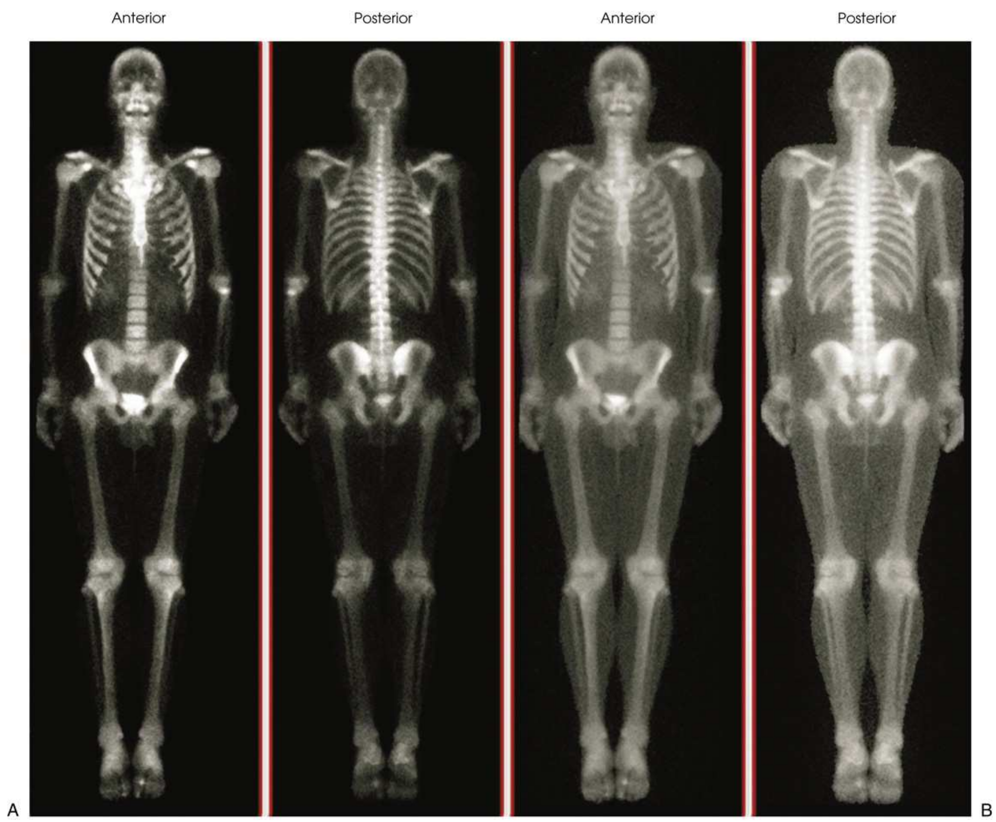


FIG. 29.14 Whole-body scan performed using 25 mCi ^{99m}Tc HDP in a 25-year-old man. The study was normal. (A) Anterior and posterior whole-body view in linear grayscale. (B) Anterior and posterior whole-body view in square-root grayscale to enhance soft tissue. Courtesy General Electric.

Nearly all camera systems used for whole-body imaging incorporate a dual-head design for simultaneous anterior and posterior acquisitions. Whole-body imaging systems are used primarily for whole-body bone, tumor, or infection imaging along with other clinical and research applications (Fig. 29.14).

Dynamic Imaging

Dynamic images display the distribution of a particular radiopharmaceutical over a specific period of time. Very similar to filming a movie, a series of sequential images is collected and aligned together to show function over time. A dynamic or "flow" study of a particular structure is generally used to evaluate blood perfusion to the tissue. Images may be acquired and displayed in time sequences from one-tenth of a second to longer than 10 minutes per image. Dynamic imaging is commonly used for three-phase bone scans, hepatobiliary studies, and renal exams (Fig. 29.15).

Spect Imaging

With SPECT, typically, two gamma detectors are used to produce tomographic images (Fig. 29.16). Tomographic systems are designed to allow the detector heads to rotate 360 degrees around a patient's body to collect "projection" image data. The image data is restructured by a computer using reconstruction algorithms that populate all acquired projections to display the radiopharmaceutical distribution of the object into several formats, including transaxial, sagittal, coronal, planar, and three-dimensional representations.

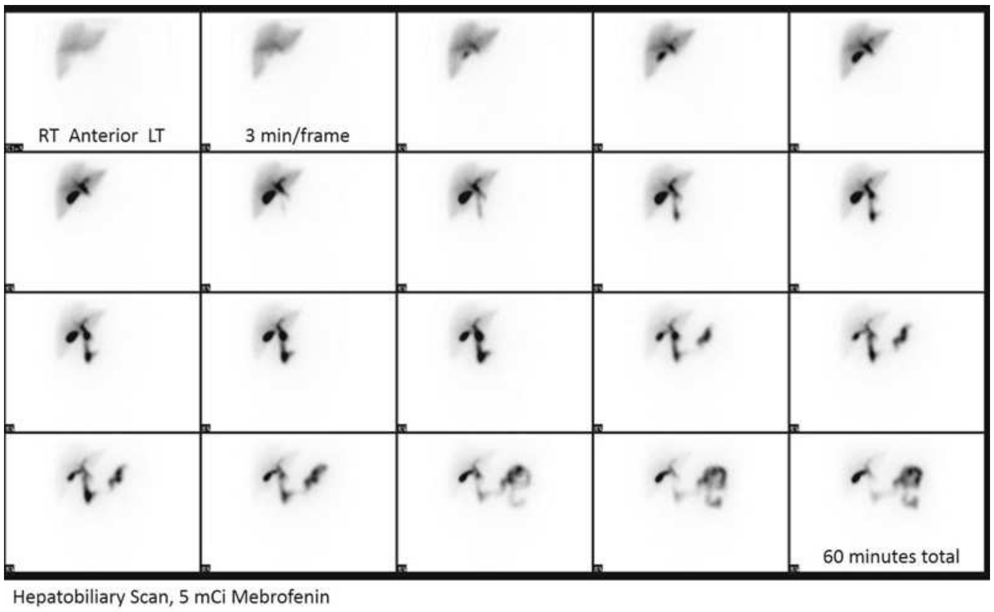


FIG. 29.15 Example of a dynamic hepatobiliary scan using 5 mCi of ^{99m}Tc mebrofenin. Imaging was acquired for 60 minutes and displayed over 20 frames (3 minutes/frame). Normal visualization of the liver, gallbladder, and small bowel is seen within the allotted time.

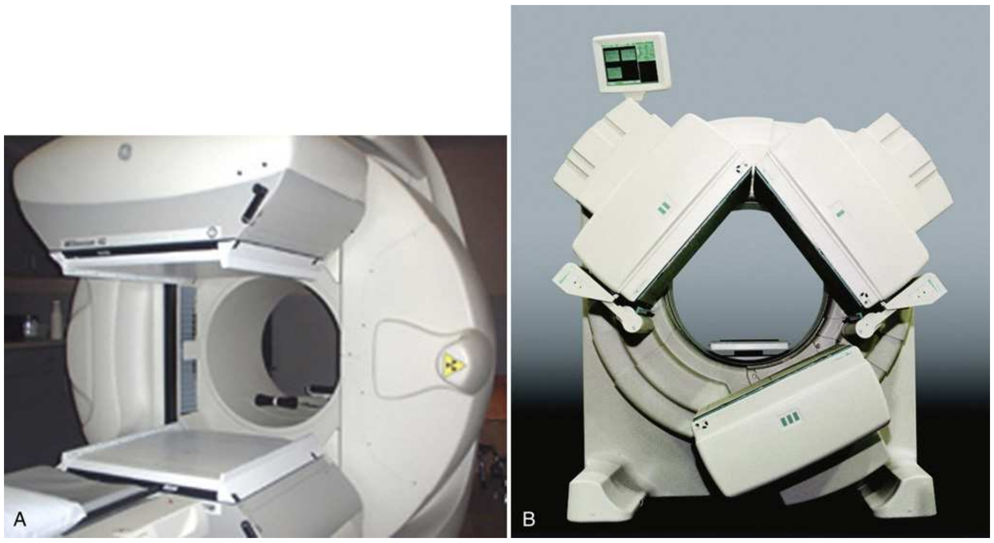


FIG. 29.16 SPECT camera systems. (A) Dual-headed SPECT/CT system. (B) Triple-headed system. B, Courtesy Marconi Medical Systems.

The reconstruction of SPECT data produces image projections similar to those obtained by CT or MRI. This reconstruction technique is used to create thin slices through a particular organ from different angles or planes to help delineate small lesions within tissues. These images can be created for virtually any structure or organ that is acquired using SPECT. Improved clinical results with SPECT are due to improved target-to-background ratios. Planar images record and show all radioactive emissions from the patient within the region of interest (ROI) as well as above and below the ROI, causing degradation of the image. In contrast, SPECT eliminates unnecessary information.

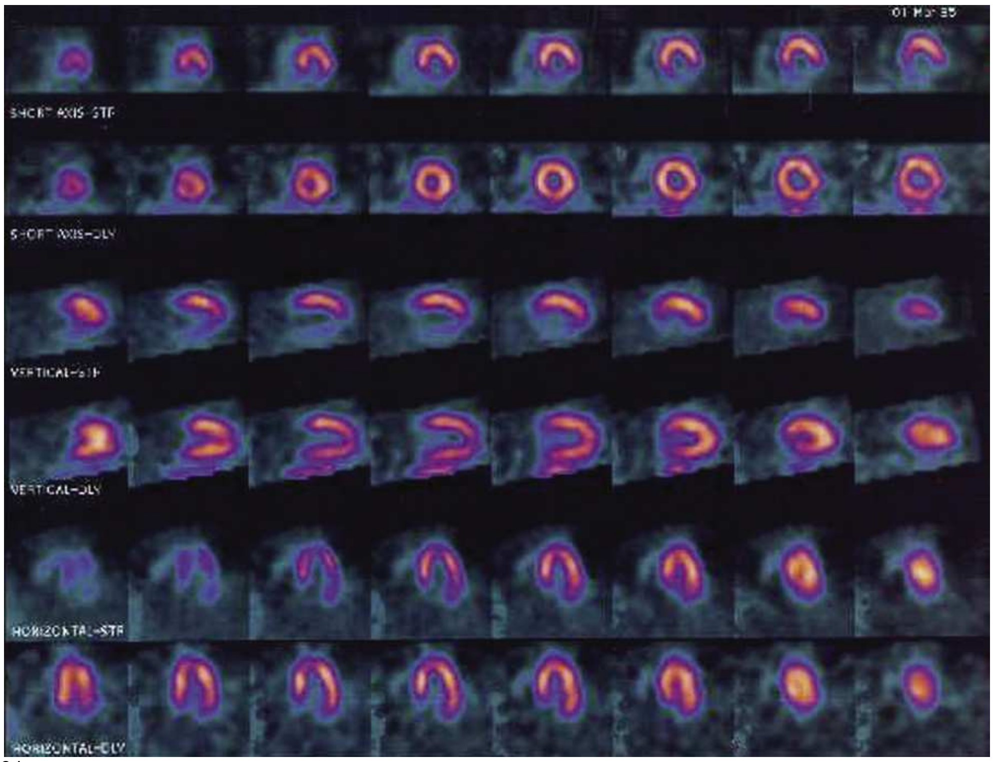


FIG. 29.17 ^{201}Tl myocardial perfusion study comparing stress and redistribution (resting) images in various planes of the heart (short axis and long axis). Perfusion defect is identified in stress images but not seen in redistribution (rest) images. This finding is indicative of ischemia.

The most common uses of SPECT include cardiac perfusion, brain, liver (see Fig. 29.12B), tumor, and bone studies. An example of a SPECT study is the myocardial perfusion thallium (^{201}Tl) study, which is used to identify perfusion defects in the left ventricular wall. The ^{201}Tl is injected intravenously while the patient is being physically stressed on a treadmill or is being infused with a vasodilator. The radiopharmaceutical distributes in the heart muscle in the same fashion as blood flowing to the tissue. An initial set of images is acquired immediately after the stress test. A second set is obtained several hours later when the patient is rested (when the ^{201}Tl has redistributed to viable tissue) to determine whether any blood perfusion defects that were seen on the initial images have resolved. By comparing the two image sets, the physician may be able to tell whether the patient has damaged heart tissue resulting from a myocardial infarction or ischemia (Fig. 29.17).

Combined Spect And Ct Imaging

By merging or “fusing” the functional imaging of SPECT with the anatomic landmarks of CT, more powerful diagnostic information is obtainable (Fig. 29.18). This combination has a significant impact on diagnosing and staging malignant disease and on identifying and localizing metastases. This new technology can also be used for AC. According to manufacturers, statistics show that adding CT (for AC and anatomic definition) changes the patient course of treatment 25% to 30% of the time when compared to medical management based on interpreting the functional image alone. SPECT/CT is discussed further later in this chapter.

Clinical Nuclear Medicine

The term in vivo means “within the living body.” Because all diagnostic nuclear medicine imaging procedures are based on the distribution of radiopharmaceuticals within the body, they are classified as in vivo examinations.

Patient preparation for nuclear medicine procedures is minimal, with most tests requiring no special preparation. Patients usually remain in their own clothing. All metal objects outside or inside the clothing must be removed because they may attenuate anatomic or pathologic conditions on nuclear medicine imaging. The waiting time(s) between dose administration and imaging varies with each study. After completion of a routine procedure, patients may resume all normal activities.

Technical summaries of commonly performed nuclear medicine procedures follow. After each procedure summary is a list, by organ or system, of many common studies that may be done in an average nuclear medicine department.

Bone Scintigraphy

Bone scintigraphy is generally a survey procedure to evaluate patients with malignancies, diffuse musculoskeletal symptoms, abnormal laboratory results, osteomyelitis, and hereditary or metabolic disorders. Tracer techniques have been used for many years to study the exchange between bone and blood. Radionuclides have played an important role in understanding normal bone metabolism and the metabolic effects of pathologic involvement of bone. Radiopharmaceuticals used for bone imaging can localize in bone and in soft tissue structures. Skeletal areas of increased uptake are commonly a result of tumor, infection, or fracture.

Bone scan

Principle

It is unclear how ^{99m}Tc-labeled diphosphonates are incorporated into bone at the molecular level; however, regional blood flow, osteoblastic activity, and extraction efficiency seem to be the major factors that influence the uptake. In areas in which osteoblastic activity is increased, active hydroxyapatite crystals with large surface areas seem to be the most suitable sites for the uptake of the diphosphonate portion of the radiopharmaceutical.

Radiopharmaceutical

Adult dose (intravenous injection):

- 20 mCi (740 MBq) of ^{99m}Tc hydroxymethylene diphosphonate (HDP) or
- 20 mCi (740 MBq) of ^{99m}Tc methylene diphosphonate (MDP)

Pediatric dose (weight-based intravenous injection) (see Fig. 29.7):

- 0.25 mCi/kg (9.3 MBq/kg) of ^{99m}Tc MDP

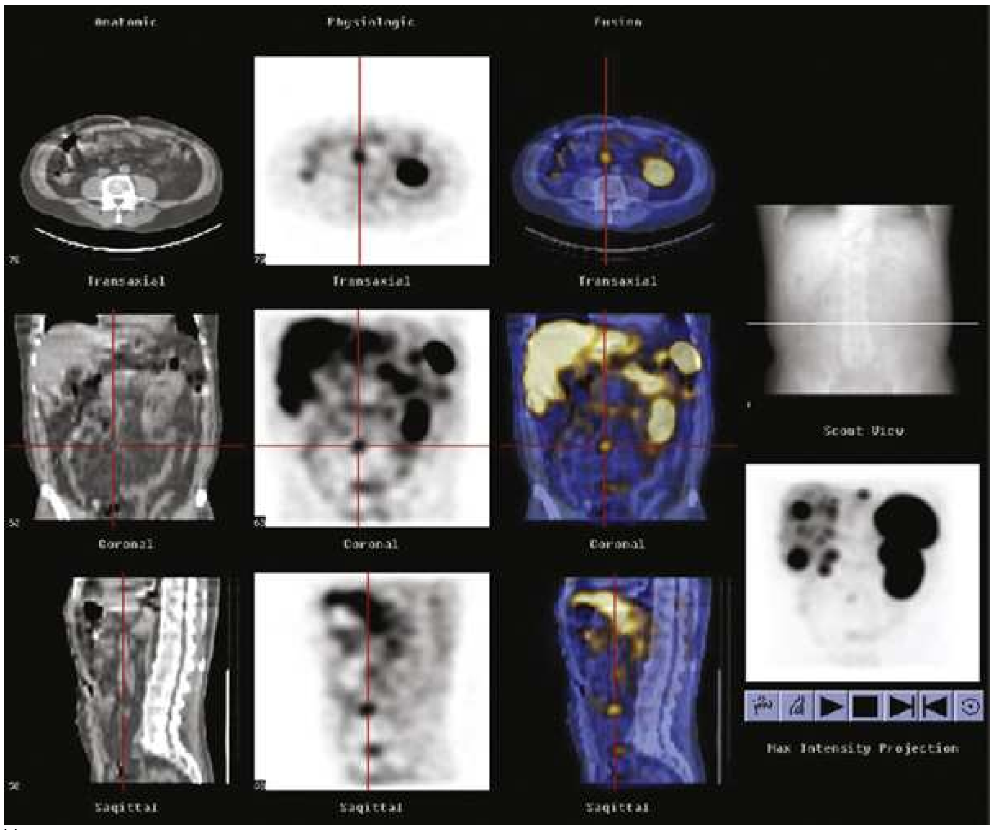


FIG. 29.18 ^{111}In-Octreotide SPECT/CT fusion images showing numerous foci of increased uptake within the liver. This is consistent with the patient's known hepatic metastases. Very small focus of increased uptake is also seen in the inferior abdomen, near midline, anterior to the lumbar spine, and is consistent with nodal metastasis. These findings are indicative of somatostatin-avid hepatic and probable nodal metastases.

Scanning

A routine survey (whole-body, static views, or SPECT) begins about 3 hours after radiopharmaceutical injection and takes 30 to 60 minutes. A flow study would begin immediately after the injection, and extremity imaging may be needed 4 to 5 hours later. The number of camera images acquired depends on the indication for the examination.

Bone (skeletal) studies

Skeletal studies include bone scans, three-phase bone scans, and bone marrow scans.

Nuclear Cardiology

Nuclear cardiology has experienced rapid growth in recent years and currently constitutes a significant portion of daily nuclear medicine procedures. These noninvasive studies assess cardiac performance, evaluate myocardial perfusion, and measure viability and metabolism. Advances in camera technology have facilitated the development of a quantitative cardiac evaluation unequaled by any other noninvasive or invasive methods. Stress tests can be performed with the patient walking on a treadmill or by infusing a pharmacologic stress agent. Once the stress test has begun, the patient's heart rate, electrocardiogram (ECG), blood pressure, and symptoms are continuously monitored and recorded. Some patients cannot exercise because of peripheral vascular disease, neurologic problems, or musculoskeletal abnormalities. In these cases, a pharmacologic intervention can be used in place of the exercise stress test to alter the blood flow to the heart in a way that simulates exercise, allowing the detection of myocardial ischemia.

Radionuclide angiography

Principle

Gated radionuclide angiography (RNA) can be used to measure left ventricular ejection fraction and evaluate left ventricular regional wall motion. RNA requires that the blood be labeled with an appropriate tracer such as ^{99m}Tc. The technique is based on imaging using a multigated acquisition (MUGA) format. During a gated acquisition, the cardiac cycle is divided into 16 to 20 frames. The R wave of each cycle resets the gate so that each count is added to each frame until there are adequate count statistics for analysis. RNA requires simultaneous acquisition of the patient's ECG and images of the left ventricle. The *ejection fraction* and wall motion analysis are measured at rest (see Fig. 29.13).

Radiopharmaceutical

Adult dose (intravenous injection):

- 25 to 30 mCi (925 to 1110 MBq) of ^{99m}Tc-labeled red blood cells

Pediatric dose (weight-based intravenous injection) (see Fig. 29.7):

- 0.32 mCi/kg (11.8 MBq/kg) of ^{99m}Tc-labeled red blood cells

Scanning

Imaging can begin immediately after the injection and takes about 1 hour. For a rest MUGA, imaging of the heart should be obtained in the anterior, left lateral, and left anterior oblique positions. For an ejection fraction–only MUGA, only the left anterior oblique is necessary.

Technetium-99m sestamibi and technetium-99m tetrofosmin MPI

Principle

^{99m}Tc sestamibi and ^{99m}Tc tetrofosmin are radiopharmaceuticals that both have favorable biologic properties for myocardial perfusion imaging (MPI). They are used to assess myocardial salvage resulting from therapeutic intervention in acute infarction; to determine the myocardial blood flow during periods of spontaneous chest pain; and to diagnose coronary artery disease in obese patients. Both ^{99m}Tc sestamibi and ^{99m}Tc tetrofosmin localize in the heart wall based on regional blood flow. Thus, areas of the heart that suffer from reduced flow due to coronary artery disease will have decreased or no activity (photopenia) on the images. Injecting and imaging patients under rest (baseline) and stress (treadmill or pharmacologic) conditions helps to illustrate the severity of their situation (normal/ischemic/infarct). Gating (refer to MUGA) the exam can be performed at stress only, or both rest and stress, to obtain an ejection fraction and evaluate wall motion.

Radiopharmaceutical

Adult dose (intravenous injection):

- At peak stress: 20 to 30 mCi (740 to 1110 MBq) for 2-day MPI and 30 to 36 mCi (1110 to 1332 MBq) for 1-day MPI
- At rest: 8 to 12 mCi (296 to 444 MBq) for a 1-day MPI and 20 to 30 mCi (740 to 1110 MBq) for a 2-day MPI

Scanning

SPECT imaging at 180 degrees (45 degrees right anterior oblique to 45 degrees left posterior oblique) is normally performed 30 to 60 minutes after the injection of the radiotracer for both stress and rest studies. When needed, delayed images can be obtained up to 4 to 6 hours after injection based on the tracer used. A 2-day protocol provides optimal image quality, but the 1-day protocol is more convenient for patients, technologists, and physicians.

Thallium-201 MPI and viability studies

Principle

^{201}Tl is sometimes used in MPI studies and has a high sensitivity (about 90%) and specificity (about 75%) for the diagnosis of coronary artery disease, but currently, sestamibi and tetrofosmin are used more often due to their better imaging properties. ^{201}Tl also has been useful for assessing myocardial viability in patients with known coronary artery disease and for evaluating patients after revascularization.

^{201}Tl is an analog of potassium and has a high rate of extraction by the myocardium over a wide range of metabolic and physiologic conditions. It is distributed in the myocardium in proportion to regional blood flow and myocardial cell viability. Regions of the heart that are infarcted or hypoperfused at the time of injection appear as areas of decreased activity (photopenia).

Radiopharmaceutical

Adult MPI dose (intravenous injection):

- At peak stress: 3 mCi (111 MBq) of ^{201}Tl thallous chloride
- A rest: 1 mCi (37 MBq) of ^{201}Tl thallous chloride (generally 3 to 4 hours after stress)

Adult viability dose (intravenous injection):

- One dose given at rest: 4 mCi (148 MBq) of ^{201}Tl thallous chloride

NOTE: In obese patients, ^{99m}Tc sestamibi (adult peak stress dose) can be used in place of ^{201}Tl so that a higher dose may be administered for clearer imaging results.

Scanning

Imaging for a ^{201}Tl MPI study includes a 180-degree SPECT study (45 degrees right anterior oblique to 45 degrees left posterior oblique) approximately 10 minutes after the peak stress injection has occurred. Due to ^{201}Tl's high redistribution rate, the patient must be scanned very close to their injection time. Rest 180-degree SPECT imaging usually takes place 4 hours after stress imaging and 15 to 30 minutes after the rest injection.

For a viability study, a 180-degree SPECT imaging usually takes place 15 minutes post injection and 4 to 6 hours post injection. The 4 to 6 hours delay allows the ^{201}Tl to redistribute to regions of the heart that do not have direct blood flow but are viable.

Cardiovascular studies

Cardiovascular studies include cardiac shunt study, MUGA (dobutamine, exercise, and rest), MPI (^{99m}Tc sestamibi, ^{99m}Tc tetrofosmin, ^{201}Tl thallous chloride), viability imaging (^{99m}Tc sestamibi and ^{201}Tl thallous chloride), and ^{99m}Tc pyrophosphate (PYP) myocardial infarct scan.

Central Nervous System Imaging

The central nervous system consists of the brain and spinal cord. For patients with diseases of the central or peripheral nervous systems, nuclear medicine techniques can be used to assess the effectiveness of surgery or radiation therapy, document the extent of involvement of the brain by tumors, and determine the progression or regression of lesions in response to different forms of treatment. Brain perfusion imaging is useful in the evaluation of patients with stroke, transient ischemia, and other neurologic disorders, such as Alzheimer disease (AD), epilepsy, and Parkinson disease. Radionuclide cisternography is particularly useful in facilitating the diagnosis of cerebrospinal fluid leakage after trauma or surgery and normal-pressure hydrocephalus. More recent studies indicate that documented lack of cerebral blood flow should be the criterion of choice to confirm brain death when clinical criteria are equivocal; a complete neurologic examination cannot be performed; or patients are younger than 1 year.

Brain SPECT study

Principle

Some imaging agents are capable of penetrating the intact *blood-brain barrier.* After a radiopharmaceutical crosses the blood-brain barrier, it becomes trapped inside the brain. The regional uptake and retention of the tracer are related to the regional perfusion.

Radiopharmaceutical

Adult dose (intravenous injection):

- 20 mCi (740 MBq) of ^{99m}Tc ethylcysteinate dimer (ECD) or
- 20 mCi (740 MBq) of ^{99m}Tc hexamethylpropyleneamine oxime (HMPAO)

Pediatric dose (weight-based intravenous injection) (see Fig 29.7)

- 0.3 mCi/kg (11.1 MBq/kg), minimum of 5 mCi (185 MBq)

Scanning

Before the tracer is injected, the patient is placed in a quiet, darkened area and instructed to close their eyes. These measures are helpful in reducing uptake of the tracer in the visual cortex (occipital lobe). Imaging begins 30 to 90 minutes after ^{99m}Tc ECD injection or ^{99m}Tc HMPAO injection. Tomographic images of the brain are obtained.

Dopamine transporter study

Principle

A reduction of dopaminergic neurons in the striatal region of the brain is a characteristic of Parkinson disease, parkinsonian syndromes, multiple system atrophy, and progressive supranuclear palsy. ^{123}I ioflupane has a high binding affinity for presynaptic dopamine transporters in the striatal region of the brain.

Radiopharmaceutical

Adult dose (intravenous injection):

- A slow infusion of 3 to 5 mCi (111 to 185 MBq) of ^{123}I ioflupane

Scanning

Prior to the administration of ^{123}I ioflupane, a thyroid blocking agent such as Lugol solution should be given to the patient. This will prevent the iodine from being absorbed by the thyroid, thus protecting it from any unnecessary exposure. Imaging begins 3 to 6 hours after injection. Tomographic images of the brain are obtained.

Central nervous system studies

Central nervous system studies include brain perfusion imaging–SPECT study, brain imaging–acetazolamide challenge study, central nervous system shunt patency, cerebrospinal fluid imaging–cisternography/ventriculography, and ^{99m}Tc HMPAO scan for determination of brain death.

Endocrine System Imaging

The endocrine system organs, located throughout the body, secrete hormones into the bloodstream. Hormones have profound effects on overall body function and metabolism. The endocrine system consists of the thyroid, parathyroid, pituitary, adrenal glands, the islet cells of the pancreas, and the gonads. Nuclear medicine procedures have played a significant part in the current understanding of the function of the endocrine glands and their role in health and disease. These procedures are useful for monitoring the treatment of endocrine disorders, especially in the thyroid gland.

Thyroid scan

Principle

Thyroid imaging is performed to evaluate the size, shape, nodularity, and functional status of the thyroid gland. Imaging is used to determine the relative function in different regions within the thyroid, to screen for thyroid cancer, and to differentiate hyperthyroidism, nodular goiter, solitary thyroid nodule, and thyroiditis. Scanning can also determine the presence and site of thyroid tissue in unusual areas of the body, such as the tongue and anterior chest (ectopic tissue).

^{99m}Tc pertechnetate or ^{123}I can be used to image the thyroid gland. ^{99m}Tc pertechnetate is trapped by the thyroid gland, but in contrast to ^{123}I, is not *organified*. ^{123}I is organified into the gland and trapped until it is metabolized into thyroid hormones. These agents offer the advantages of a low radiation dose to the patient and well-resolved images.

Radiopharmaceutical

Adult dose:

- 5 mCi (185 MBq) of ^{99m}Tc pertechnetate (intravenous injection)
- 0.2 to 0.3 mCi of ^{123}I (administered orally, pill)

Pediatric dose (see Fig. 29.7):

- 0.03 mCi/kg (1.1 MBq/kg) of ^{99m}Tc pertechnetate (weight-based intravenous injection), minimum of 2.5 mCi (93 MBq)
- 0.0075 mCi/kg (0.28 MBq/kg) of ^{123}I (weight based, administered orally, pill), minimum of 0.027 mCi (1 MBq)

NOTE: Uptake may be affected by thyroid medication and by foods or drugs, including some iodine-containing contrast agents.

Scanning

Imaging should start 20 minutes after the injection of ^{99m}Tc pertechnetate, or 24 hours after the administration of ^{123}I. A gamma camera with a pinhole collimator is used to obtain anterior, left anterior oblique, and right anterior oblique statics of the thyroid. The pinhole collimator is a thick, conical collimator that allows for magnification of the thyroid (see Fig. 29.10).

Iodine-123 thyroid uptake measurement

Principle

Radioiodine is concentrated by the thyroid gland in a manner that reflects the ability of the gland to handle stable dietary iodine. ^{123}I uptake is used to estimate the function of the thyroid gland by measuring its avidity for administered radioiodine. The higher the uptake of ^{123}I, the more active the thyroid; conversely, the lower the uptake, the less functional the gland. Uptake conventionally is expressed as the percentage of the dose in the thyroid gland at a given time after administration. Measurement of ^{123}I uptake is valuable in distinguishing between thyroiditis (significantly reduced uptake), Graves disease, and toxic nodular goiter (Plummer disease), which have an increased uptake. It is also used to determine the appropriateness of a therapeutic dose of ^{131}I in patients with Graves disease.

Radiopharmaceutical

The adult and pediatric doses are the same as listed earlier in the Thyroid Scan section. A standard dose is counted with the thyroid probe the morning of the procedure and is used as the 100% uptake value. The patient's total count is compared with the standard count to obtain the patient percent uptake.

Measurements are obtained using an uptake probe consisting of a 2 × 2 inch (5 × 5 cm) sodium iodide/PMT assembly fitted with a flat-field lead collimator (Fig. 29.19). Uptake readings are generally acquired at 6 hours, at 24 hours, or both.

Total-body iodine-123/iodine-131 scan

Principle

A total-body ^{123}I/^{131}I (TBI) scan is recommended for locating residual thyroid tissue or recurrent thyroid cancer cells in patients with thyroid carcinoma. Most follicular or papillary thyroid cancers concentrate radioiodine; other types of thyroid cancer do not. A TBI scan is usually performed 1 to 3 months after a thyroidectomy to check for residual normal thyroid tissue and the metastatic spread of the cancer before ^{131}I ablation therapy. After the residual thyroid tissue has been ablated (destroyed), another $^{123}I/^{131}I$ TBI scan may be performed to check for residual disease.

Radiopharmaceutical

Adult dose (administered orally):

- 2 to 5 mCi (74 to 185 MBq) of ^{123}I

Scanning

Total-body imaging begins 24 to 72 hours after dose administration (depending on the radiopharmaceutical used). Images are obtained of the anterior and posterior whole body. SPECT imaging can also be performed to localize any specific areas of interest better.

FIG. 29.19 Uptake probe used for thyroid uptake measurements over the extended neck area.

Endocrine studies

Endocrine studies include the adrenal scan (^{131}I or ^{123}I-labeled MIBG), ectopic thyroid scan (^{131}I or ^{123}I), thyroid scan (^{123}I or ^{99m}Tc pertechnetate), thyroid uptake measurement (^{131}I or ^{123}I), thyroid uptake/scan (^{123}I), total body iodine scan (^{131}I or ^{123}I), parathyroid scan and ^{111}In pentetreotide scan (Fig. 29.20).

Imaging Of The Gastrointestinal System

The gastrointestinal system, or alimentary canal, consists of the mouth, oropharynx, esophagus, stomach, small bowel, colon, and several accessory organs (salivary glands, pancreas, liver, and gallbladder). The liver is the largest internal organ of the body. The portal venous system brings blood from the stomach, bowel, spleen, and pancreas to the liver.

Liver and spleen scan

Principle

Liver and spleen imaging is used to evaluate the liver for functional disease (e.g., cirrhosis, hepatitis, metastatic disease) and to search for residual splenic tissue after splenectomy or traumatic event. Imaging techniques, such as ultrasound, CT, and MRI, provide excellent information about the anatomy of the liver, but nuclear medicine studies can assess the *functional* status of this organ. Liver and spleen scintigraphy is also useful for detecting hepatic lesions and evaluating hepatic morphology, perfusion, and function. It is also used to determine whether certain lesions found with other methods may be benign (e.g., focal nodular hyperplasia) or obviating the need for biopsy. Uptake of a radiopharmaceutical in the liver, spleen, and bone marrow depends on blood flow and the functional capacity of the phagocytic cells. In normal patients, 80% to 90% of the radiopharmaceutical is localized in the liver, 5% to 10% is localized in the spleen, and the rest is localized in the bone marrow.

Radiopharmaceutical

Adult dose (intravenous injection):

- 6 mCi (222 MBq) of ^{99m}Tc sulfur colloid

Scanning

Imaging sometimes begins with a flow study based on the indication, but usually planar (anterior, posterior, right and left anterior oblique, right and left lateral, right posterior oblique, and a marker view) are obtained, followed by SPECT if necessary.

Gastrointestinal studies

Gastrointestinal studies include esophageal scintigraphy, gastroesophageal reflux study, gastric emptying study, hepatic artery perfusion scan, hepatobiliary scan, hepatobiliary scan with gallbladder ejection fraction, liver and spleen scan, liver hemangioma study, Meckel diverticulum study, and salivary gland study.

Genitourinary Nuclear Medicine

Genitourinary nuclear medicine studies are recognized as reliable, noninvasive procedures for evaluating the anatomy and function of the renal system (kidneys, ureters, bladder, and urethra). These studies can be accomplished with minimal risk of allergic reactions, unpleasant side effects, or excessive radiation exposure to the organs.

Dynamic renal scan

Principle

Renal imaging is used to assess renal perfusion and function, particularly in renal failure and renovascular hypertension and after renal transplantation. ^{99m}Tc mertiatide (MAG3) is secreted primarily by the proximal renal tubules and is not retained in the parenchyma of normal kidneys.

Radiopharmaceutical

Adult dose (intravenous injection):

- 10 mCi (370 MBq) of ^{99m}Tc MAG3

Pediatric dose (weight-based intravenous injection) (see Fig. 29.7):

- Without flow study: 0.10 mCi/kg (1.85 MBq/kg), minimum of 1.0 mCi (37 MBq)
- With flow study: 0.15 mCi/kg (5.55 MBq/kg)

Scanning

Dynamic imaging is initiated immediately after radiopharmaceutical injection. Because radiographic contrast media may interfere with kidney function, renal scanning is usually delayed for 24 hours after contrast studies. Images are often taken over the posterior lower back, centered at the level of the 12th rib. Transplanted kidneys are imaged in the anterior pelvis. Patients need to be well hydrated before all renal studies.

Genitourinary studies

Genitourinary studies include dynamic renal scan (baseline or no pharmaceutical intervention, with furosemide, or with captopril), ^{99m}Tc dimercaptosuccinic acid (DMSA) renal scan, residual urine determination, testicular scan, and voiding cystography.

Imaging For Infection

Imaging for infection is another useful nuclear medicine diagnostic tool. Inflammation, infection, and abscess may be found anywhere within the body. ^{67}Ga scans and ^{111}In-labeled white blood cell scans are useful for diagnosis and localization of infection and inflammation.

Infection studies

Infection studies include ^{67}Ga gallium scan, ^{111}In white blood cell scan, ^{99m}Tc HMPAO, and phase bone scans in conjunction with bone marrow exams following joint replacement surgeries.

Respiratory Imaging

Respiratory imaging commonly involves the comparison of pulmonary perfusion (using limited, transient capillary blockade) and pulmonary ventilation (using an inhaled radioactive gas or aerosol). Lung imaging is most commonly performed to evaluate acute and chronic pulmonary emboli in patients unable to undergo a CT angiography (CTA). It is also used for lung transplant evaluation.

Xenon-133 lung ventilation scan

Principle

Lung ventilation scans are used in combination with lung perfusion scans. The gas used for a ventilation study must be absorbed significantly by the lungs and diffuse easily. ^{133}Xe has adequate imaging properties, and the body usually absorbs <15% of the gas.

Radiopharmaceutical

Adult dose (inhalation):

- 15 to 30 mCi (555 to 1110 MBq) of ^{133}Xe gas

Scanning

Imaging begins immediately after inhalation of the ^{133}Xe gas within a closed rebreathing system to which oxygen is added, and carbon dioxide is withdrawn. For optimal imaging, the ventilation study must precede the ^{99m}Tc perfusion scan. Anterior and posterior images are obtained for the first breath, equilibrium, and *washout*. If possible, left and right posterior oblique images should be obtained between the first breath and equilibrium.

Technetium-99m MAA lung perfusion scan

Principle

^{99m}Tc MAA is a collection of small radioactive particles (~400,000 to 600,000 in a standard dose) that become trapped in the arterioles of the lungs based on blood flow. If a region (lobe or wedge) of the lung is blocked via emboli, the area will not be perfused by the radiotracer creating a photopenic area on the images. The lungs contain millions of arterioles; thus there are no side effects due to the blockade.

Radiopharmaceutical

Adult dose (intravenous injection):

- 5 mCi (185 MBq) of ^{99m}Tc MAA

Pediatric dose (weight-based intravenous injection) (see Fig. 29.7):

- If ^{133}Xe was used for the ventilation: 0.03 mCi/kg (1.11 MBq/kg), minimum of 0.4 mCi (14.8 MBq)
- If ^{99m}Tc was used for the ventilation: 0.07 mCi/kg (2.59 MBq/kg)

Scanning

Imaging starts approximately 5 minutes after radiopharmaceutical injection. Eight images are obtained: anterior, posterior, right and left lateral, right and left anterior oblique, and right and left posterior oblique. All patients should have a chest radiograph within 24 hours of the lung scan. The chest radiograph is required for accurate interpretation of the lung scans so as to determine the probability of pulmonary embolism.

Respiratory studies

Respiratory studies include the ^{133}Xe lung ventilation scan, ^{99m}Tc MAA lung perfusion scan, and ^{99m}Tc diethylenetriamine pentaacetic acid (DTPA) lung aerosol scan.

Sentinel Node Imaging

Many tumors metastasize via lymphatic channels. Defining the anatomy of lymph nodes that drain from a primary tumor site helps guide surgeons resecting the nodes during surgery. Sentinel node imaging does just this; it maps the routes of lymphatic drainage and permits more effective surgical or radiation treatments. Radionuclide lympho-scintigraphy has been useful in patients in whom the channels are relatively inaccessible. This method is indicated for patients with melanoma and breast cancer.

Principle

Colloidal particles injected intradermally or subcutaneously adjacent to a tumor site show a drainage pattern similar to that of the tumor. Colloidal particles in the 10- to 50-nm range seem to be the most effective for this application. The colloidal particles drain into the sentinel lymph node where they are trapped by phagocytic activity; this aids in the identification of the lymph nodes most likely to be sites of metastatic deposits from the tumor.

Radiopharmaceutical

Adult dose (intradermal/subcutaneous injection):

- 100 µCi (3.7 MBq) of ^{99m}Tc filtered sulfur colloid in a volume of 0.1 mL per injection site (up to 4 injection sites)

Scanning

Patients with malignant melanoma should be positioned supine or prone on the imaging table based on tumor location, and patients with breast cancer should be positioned supine with their arms extended over their head. Images are acquired immediately after injection, and then every few minutes for the first 15 minutes followed by every 5 minutes for 30 minutes. Additional lateral and oblique views are required after visualization of the sentinel node.

Therapeutic Nuclear Medicine

The potential that radionuclides have for detecting and treating cancer has been recognized for a long time. The most common nuclear medicine therapies use radioiodine (^{131}I) to treat Graves disease. High-dose ^{131}I therapy (≥30 mCi) can be used in patients with residual thyroid cancer or thyroid metastases. ^{131}I is also labeled with monoclonal antibodies (^{131}I-MoAb) to target specific cancers such as non-Hodgkin lymphoma. ^{90}Yttrium (^{90}Y-MoAb) can also be labeled in a similar manner to treat the same cancer. Skeletal metastases occur in more than 50% of patients with breast, lung, or prostate cancer in the end stages of the disease. ^{89}Sr (strontium-89) or ^{153}Sm (samarium-153) ethylene diamine tetramethylene phosphate (EDTMP) is often useful for managing patients with bone pain from metastases when other treatments have failed. ^{90}Y microspheres are a new treatment in nuclear medicine. This therapy involves the embolization of radioactive ^{90}Y microspheres straight into the liver's arterial supply, directly delivering them into primary and secondary hepatic tumors. New radiopharmaceuticals are being developed every day to target inoperable/treatable cancers.

Special Imaging Procedures

Special imaging procedures include dacryoscintigraphy, the LeVeen shunt patency test, and lymphoscintigraphy of the limbs.

Tumor Imaging

Octreoscan

Principle

Somatostatin is a neuroregulatory peptide known to localize on many cells of neuroendocrine origin. Cell membrane receptors with a high affinity for somatostatin have been shown to be present in most neuroendocrine tumors, including carcinoids, islet cell carcinomas, and gonadotropin hormone-producing pituitary adenomas.^{111} In pentetreotide (OctreoScan) is a radiolabeled analog of the neuroendocrine peptide somatostatin. This allows it to localize in somatostatin receptor-rich tumors and aid in identifying questionable masses.

Radiopharmaceutical

Adult dose (intravenous injection):

- 6 mCi (222 MBq) of ^{111}In pentetreotide

Scanning

At 4 to 6 hours after injection, anterior and posterior whole-body images should be acquired. At 24 hours, whole-body images should be obtained once more along with anterior and posterior spot views of the chest and abdomen. SPECT imaging is most helpful in the localization of intraabdominal tumors. SPECT/CT can assist in lesion localization. Additional imaging at 48 and 72 hours is at the discretion of the radiologist interpreting the exam. Images of an octreotide scan can be seen in Fig. 29.18.

Tumor studies

Tumor studies include ^{67}Ga tumor scan, ^{99m}Tc sestamibi breast scan, ^{111}In capromab pendetide (ProstaScint) scan, ^{99m}Tc nofetumomab merpentan (Verluma), and ^{111}In OctreoScan.

Principles and Facilities in Positron Emission Tomography

PET is a noninvasive nuclear imaging technique that involves the administration of a positron-emitting radioactive tracer followed by subsequent imaging of its physiological distribution. PET radiotracers use extremely small molar amounts of the radiopharmaceutical per dose, which means equilibrium conditions within the body are not altered. Currently, PET is used to image multiple organs in the body (heart, brain, lungs, and prostate).

Three important factors distinguish PET from all radiologic procedures and from other nuclear imaging procedures. First, the results of the data acquisition and analysis techniques yield an image related to a particular physiologic parameter such as blood flow or metabolism. The ensuing image is aptly called a *functional* or *parametric image*. Second, the images are created by the simultaneous detection of a pair of *annihilation photons* that result from *positron* decay (Fig. 29.21). The third factor that distinguishes PET is the chemical and biologic form of the radiopharmaceutical. The radiotracer is specifically chosen for its similarity to naturally occurring biochemical constituents of the human body. For example, if the radiopharmaceutical is a form of sugar, it behaves much like the natural sugar used by the body. The kinetics or the movement of the radiotracer (such as sugar) within the body is followed by using the PET scanner to acquire multiple images that measure the distribution of the *radioactivity concentration* as a function of time. From this measurement, the local tissue metabolism may be deduced by converting a temporal sequence of images into a single parametric image. PET is a multidisciplinary technique that involves four major processes: radionuclide production, radiopharmaceutical production, data acquisition (PET scanner or tomograph), and image reconstruction and processing. This section of the chapter is focused on these major categories within in PET.

Positrons

Positrons (β^+) are the resultant of a radiation decay process (positron decay) in which an unstable *proton-rich* nucleus is attempting to reach its ground state. As the number of protons increases within a nucleus, so does the net positive charge and its instability. Based on *Coulomb forces* inside the nucleus, protons continuously try to push away from one another. To help stabilize these atoms, the nucleus spontaneously converts a proton into a neutron. This then lowers the net positive charge of the nucleus by one, and the neutron acts as a buffer amongst the remaining protons. To account for the loss of the positive charge and energy, a positron is emitted from the nucleus. Positrons are identical to electrons with the exception that they possess a positive charge instead of a negative one. The characteristics of positrons are listed in Table 29.3.

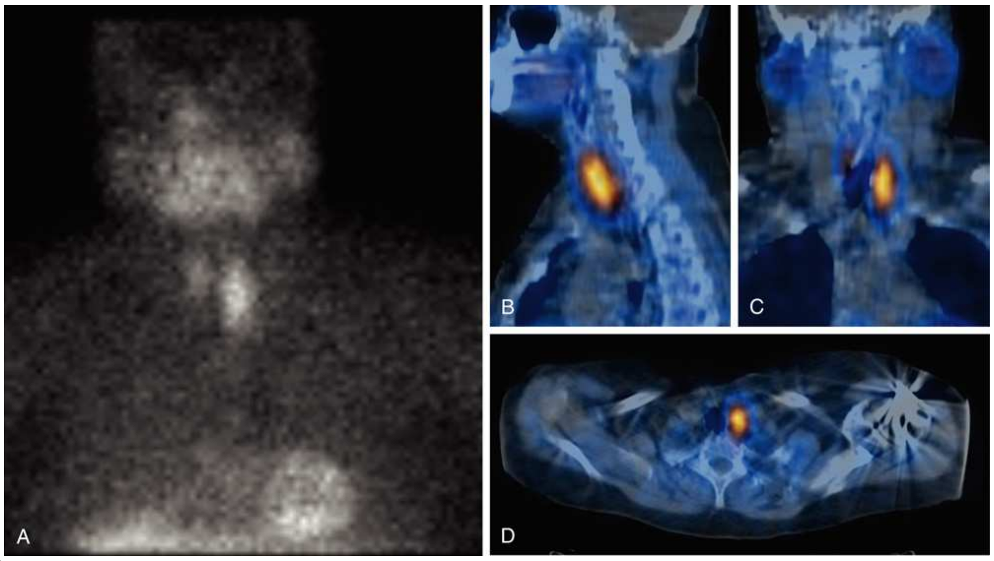


FIG 29.20 ^{99m}Tc Parathyroid SPECT/CT fused imaging. Increased uptake/activity in the left lower lobe. Results are indicative of an adenoma. (A) A 60-minute static delay of the neck and chest (tracer activity only). (B) Sagittal plane (SPECT/CT fused imaging). (C) Coronal plane (SPECT/CT fused imaging). (D) Axial plane (SPECT/CT fused imaging).

(A) shows a grey and black region with white areas. It appears grainy. (B) shows a blue colored structure with a orange area on the left. (C) shows a blue colored structure with a smaller orange region. (D) shows a blue colored structure with a orange area in the middle.

TABLE 29.3

Positron characteristics

Definition	Positively charged electron
Origin	Proton-rich nuclei
Production	Accelerators and cyclotrons
Nuclide decay	$p = n + \beta^+$ neutrino
Positron decay	Annihilation to two 0.511-MeV photons
Number	About 240 known
Range	Proportional to kinetic energy of β^+
Routine PET nuclides	^{11}C, ^{13}N, ^{15}O, ^{18}F, ^{82}Rb

For the positron decay process to occur, the nucleus must possess at least an excess of energy greater than 1.022 MeV (equivalent to the mass of two electrons). Positrons are emitted from the nucleus with high velocity and kinetic energy. As mentioned in the Basic Nuclear Physics section of this chapter, each radioisotope releases its own defined amount of energy per decay and decay process (like a fingerprint). This means different radioisotopes that decay by positron emission emit positrons with different energies. Based on their energy, positrons from different elements can travel farther from the nucleus than others (Fig. 29.22A).

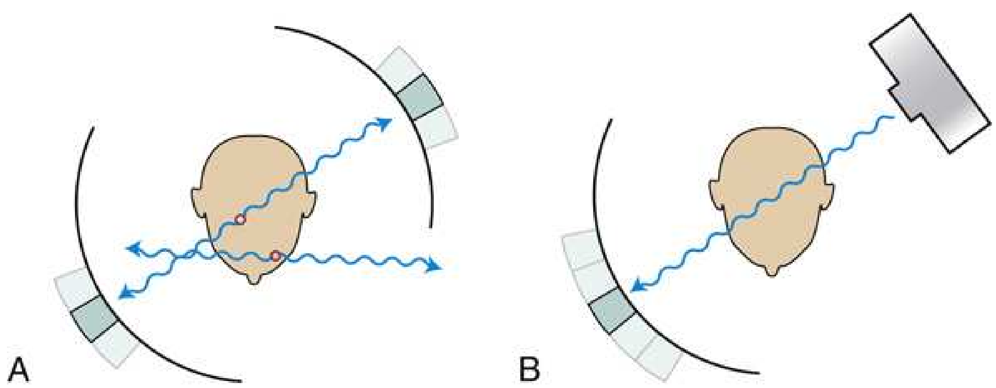


FIG. 29.21 (A) PET relies on the simultaneous detection of a pair of annihilation radiations emitted from the body. (B) In contrast, CT depends on the detection of x-rays transmitted through the body.

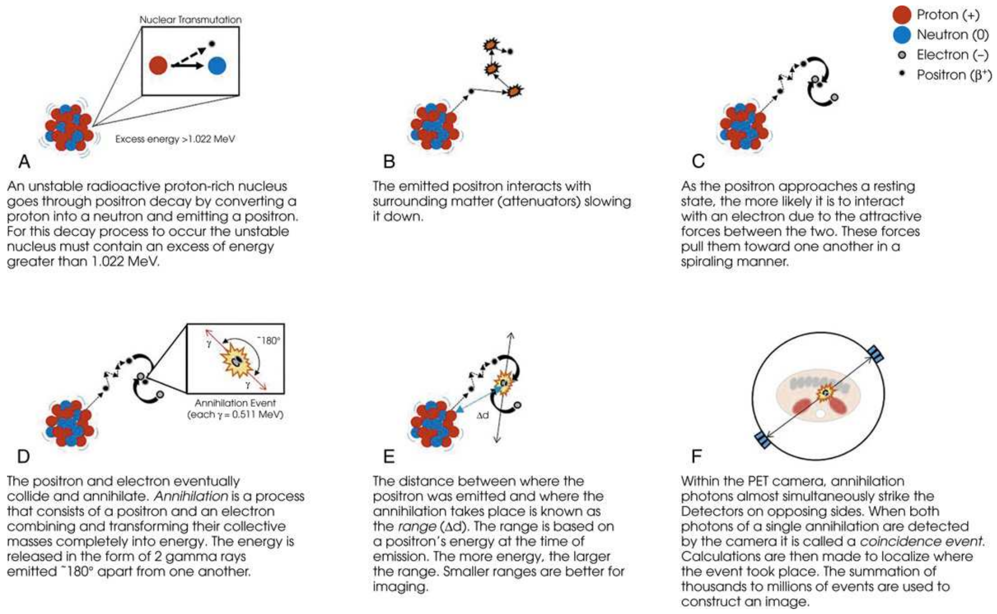


FIG. 29.22 (A) An unstable radioactive proton-rich nucleus goes through positron decay by converting a proton into a neutron and emitting a positron. For this decay process to occur, the unstable nucleus must contain an excess of energy greater than 1.022 MeV. (B) The emitted positron interacts with surrounding matter (attenuators) slowing it down. (C) As the positron approaches a resting state, the more likely it is to interact with an electron due to the attractive forces between the two. These forces pull them toward one another in a spiraling manner. (D) The positron and electron eventually collide and annihilate. *Annihilation* is a process that consists of a positron and an electron combining and transforming their collective masses completely into energy. The energy is released in the form of two gamma rays (511 keV) emitted ~180 degrees apart from one another. (E) The distance between where the positron was emitted and where the annihilation takes place is known as the *range* (Δ*d*). The range is based on a positron's energy at the time of emission. The more energy, the larger the range. Smaller ranges are better for imaging. (F) Within the PET camera, annihilation photons almost simultaneously strike the detectors on opposing sides. When both photons of a single annihilation are detected by the camera, it is called a *coincidence event.* Calculations are then made to localize where the event took place. The summation of thousands to millions of events is used to construct an image.

(A) An unstable radioactive proton-rich nucleus goes through positron decay by converting a proton into a neutron and emitting a positron. For this decay process to occur the unstable nucleus must contain an excess of energy greater than 1.022 mega electron volt. (B) The emitted positron interacts with surrounding matter (attenuators) slowing it down. (C) The positron approaches a resting state and interacts with an electron due to the attractive forces between the two. These forces pull them toward one another in a spiraling manner. (D) The positron and electron eventually collide and annihilate. Annihilation is a process that consists of a positron and an electron combining and transforming their collective masses completely into energy. The energy is released in the form of 2 gamma rays emitted 180 degrees apart from one another. (E) The distance between where the positron was emitted and where the annihilation takes place is known as the range (d). The range is based on a positron's energy at the time of emission. (F) annihilation photons almost simultaneously strike the detectors on opposing sides. When both photons of a single annihilation are detected by the camera it is called a coincidence event.

Once the positron has been emitted, it begins to rapidly slow due to interactions with surrounding matter (attenuators) (see Fig. 29.22B). As it decreases in speed, the positron becomes more likely to interact with a nearby electron (Coulomb forces, opposite charges attract). When the attraction between the two particles is strong enough to pull them away from their original path, they begin to spiral toward one another (like water circling a drain) (see Fig. 29.22C). Eventually, the particles collide and totally *annihilate* or disintegrate. During the annihilation process, the combined positron-electron mass (1.022 amu) is completely transformed into two equal-energy photons of 0.511 MeV (annihilation photons/total energy 1.022 MeV), which are emitted approximately 180 degrees (±0.3 degrees) from one another (see Fig. 29.22D). The average distance a positron travels after being ejected from the nucleus to where the annihilation takes place is known as the positron's *range* (see Fig. 29.22E). Specific isotope properties can be reviewed in Table 29.4. The resulting annihilation photons behave like gamma and x-rays: they have sufficient energy to traverse body tissues with only modest attenuation, and they can be detected externally (see Fig. 29.22F).

TABLE 29.4

Nuclide (decay product)	Physical half-life	Decay mode	Maximal and average positron energy (keV)	Maximum and mean range in water (mm)	Production reaction
Carbon-11 (Boron-11)	20.3min	99.8% positron 0.2% electron capture	960, 320	4.1, 1.1	$^{14}N(p,alpha)^{11}C$[a]
Nitrogen-13 (Carbon-13)	10min	100% positron	1198, 432	5.1, 1.5	$^{16}O(p,alpha)^{13}N$ $^{13}C(p,n)^{13}N$
Oxygen-15 (Nitrogen-15)	124s	99.9% positron	1732, 696	7.3, 2.5	$^{15}N(p,n)^{15}O$ $^{14}N(d,n)^{15}O$
Fluorine-18 (Oxygen-18)	110min	97% positron 3% electron capture	634, 202	2.4, 0.6	$^{18}O(p,n)^{18}F$ $^{20}Ne(d,alpha)^{18}F$ $^{16}O(^{3}He,alpha)^{18}F$
Rubidium-82	1.27min (75s)	96% positron 4% electron capture	3356, 1385	14.1, 5.9	^{82}Sr generator (T1/2 25.3 days)

[a] This symbolism means that a proton is accelerated into an atom of nitrogen-14, causing ejection of an alpha particle from the nucleus to produce an atom of carbon-11.

From Mettler FA, Guiberteau MJ: *Mettler's essentials of nuclear medicine imaging*, ed 6. Philadelphia, 2012, Elsevier.

The positron emitting radioisotopes currently being used in PET are carbon-11 (^{11}C), nitrogen-13 (^{13}N), oxygen-15 (^{15}O), rubidium-82 (^{82}Rb), and fluorine-18 (^{18}F). ^{18}F is the most commonly used radioisotope because it can be used as a hydrogen substitute in many compounds. This substitution of ^{18}F for hydrogen is successfully accomplished because of its small size and strong bond with carbon. Copper and gallium agents are currently being researched.

Radionuclide Production

Radionuclides used in PET exams are produced using a *nuclear particle accelerator* or cyclotron to bombard appropriate nonradioactive *target* atoms with accelerated charged particles. High energies are necessary to overcome the electrostatic and nuclear forces of the target nuclei so that a nuclear reaction can occur. An example is the production of ^{15}O. *Deuterons* (d), or heavy hydrogen ions, are accelerated to approximately 7 MeV. The target material is stable nitrogen gas (N_2). The resultant nuclear reaction yields a neutron and a ^{15}O atom, which can be written in the following form: $^{14}N(d,n)^{15}O$ (^{14}N is the target material, the deuteron (d) is the bombarding charged particle, the neutron (n) is emitted from the nucleus, and ^{15}O is the product). The ^{15}O atom quickly associates with a stable ^{16}O atom that has been intentionally added to the target gas to produce a radioactive ^{15}O-^{16}O molecule in the form of O_2 (oxygen is a diatomic element).

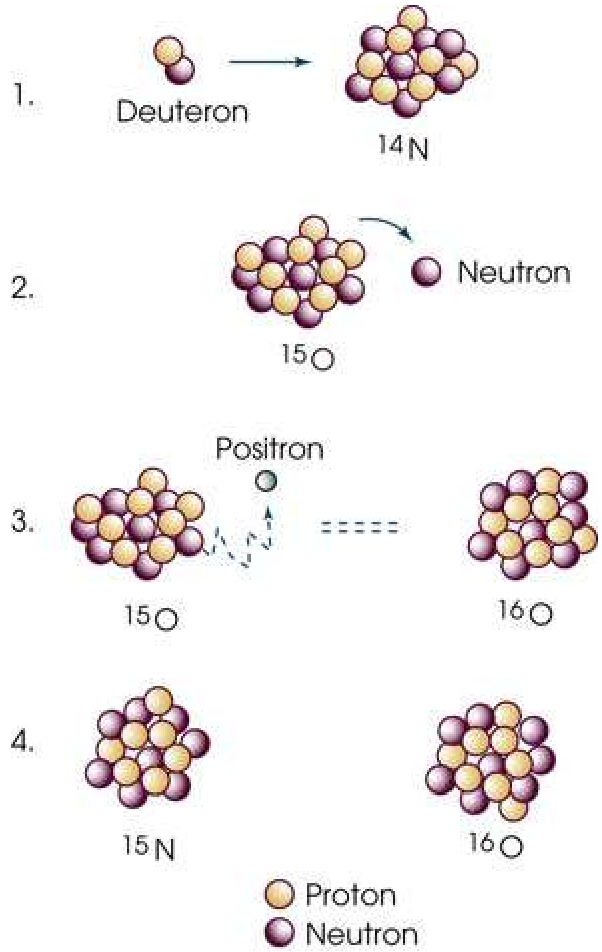


FIG. 29.23 Typical radionuclide production sequence. The $^{14}N(d,n)^{15}O$ reaction is used for making ^{15}O-^{16}O molecules. *1,* A deuteron ion is accelerated to high energy (7 MeV) by a cyclotron and impinges on a stable ^{14}N nucleus. *2,* As a result of the nuclear reaction, a neutron is emitted, leaving a radioactive nucleus of ^{15}O. *3,* ^{15}O atom quickly associates with ^{16}O atom to form O_2 molecule. Later, unstable ^{15}O atom emits a positron. *4,* As a result of positron decay (i.e., positron exits nucleus), ^{15}O atom is transformed into stable ^{15}N atom, and O_2 molecule breaks apart.

1, A deuteron ion is accelerated to high energy and impinges on a stable 14 N nucleus. 2, As a result of the nuclear reaction, a neutron is emitted, leaving a radioactive nucleus of 15 O. 3, 15 O atom quickly associates with 16O atom to form O2 molecule. Later, unstable 15O atom emits a positron. 4, As a result of positron decay, 15 O atom is transformed into stable 15 N atom, and O 2 molecule breaks apart.

When the unstable or radioactive ^{15}O atom decays via positron emission, the ^{15}O atom becomes a stable ^{15}N atom and forces the O_2 molecule to break apart This process is shown in Fig. 29.23, and the decay schemes for the four routinely produced PET radionuclides are depicted in Fig. 29.24. The common reactions used for the production of positron-emitting forms of carbon, nitrogen, oxygen, and fluorine are given in Table 29.4.

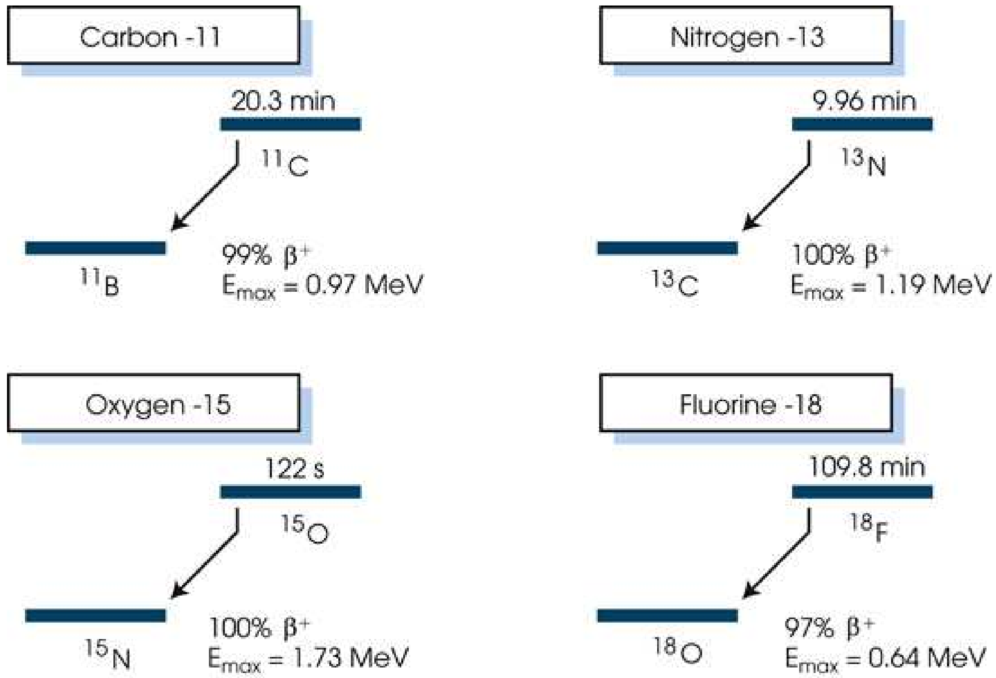


FIG. 29.24 Decay schemes for ^{11}C, ^{13}N, ^{15}O, and ^{18}F. Each positron emitter decays to a stable nuclide by ejecting a positron from the nucleus. E_{max} represents the maximum energy of the emitted positron. Electron capture is a competitive process with positron decay; positron decay is not always 100%.

Decay scheme for carbon 11 takes 20.3 minutes to decay from 11 sub C to 11 sub B. The maximum energy of emitted positron is 0.97 megaelectron volt. Decay scheme for nitrogen 13 takes 9.96 minutes to decay from 13 sub N to 13 sub C. The maximum energy of emitted positron is 1.19 megaelectron volt. Decay scheme for oxygen 15 takes 122 seconds to decay from 15 sub O to 15 sub N. The maximum energy of emitted positron is 1.73 megaelectron volt. Decay scheme for fluorine 18 takes 109.8 minutes to decay from 18 sub F to 18 sub O. The maximum energy of emitted positron is 0.64 megaelectron volt.

Because of the very short half-lives of the routinely used positron-emitting radionuclides of oxygen, nitrogen, rubidium, and carbon, nearby access to a nuclear particle accelerator, cyclotron, or generator is necessary to produce sufficient quantities for diagnostic testing. The most common device to achieve nuclide production within reasonable space (250 ft^2 [223 m^2]) and energy (150 kW) constraints is a compact medical cyclotron (Fig. 29.25).

FIG. 29.25 Compact cyclotron (2.2 m high × 1.5 m wide × 1.5 m deep) used for routine production of PET isotopes. Cyclotron can be located in a concrete vault, or it can be self-shielded. Particles are accelerated in vertical orbits and impinge on targets located near the top center of the machine. This is an example of a negative-ion cyclotron. Courtesy GE Medical Systems, Milwaukee, WI.

Radiopharmaceutical Production

Living organisms are composed primarily of compounds that contain the elements hydrogen, carbon, nitrogen, and oxygen. In PET, radiotracers are made by synthesizing compounds with radioactive isotopes of these elements. Chemically, the radioactive isotope is indistinguishable from its equivalent stable isotope.

Radiopharmaceuticals are synthesized from radionuclides derived from the target material. These agents may be simple, such as the ^{15}O-^{16}O molecules described earlier, or they may be much more complex. Regardless of the chemical complexity of the radioactive molecule, all radiopharmaceuticals must be synthesized rapidly. This entails specialized techniques not only to create the labeled substance but also to verify the purity (chemical, radiochemical, and radionuclide) of the radiotracer.

One of the simplest radiopharmaceuticals used in PET studies is ^{15}O-water ([^{15}O]-H_2O), which is produced continuously from the $^{14}N(d,n)^{15}O$ nuclear reaction or in batches from the $^{15}N(p,n)^{15}O$ nuclear reaction. As previously discussed, the radioactive oxygen quickly combines with a stable ^{16}O atom, which has been added to the stable N_2 target gas, to form an oxygen molecule (O_2). The ^{15}O-^{16}O molecule is reduced over a platinum catalyst with small amounts of stable H_2 and N_2 gas. Radioactive water vapor ([^{15}O]-H_2O) is produced and collected in sterile saline for injection. It is used primarily for the determination of local cerebral blood flow (LCBF). PET LCBF images from one subject using two different techniques are shown in Fig. 29.26. Blood flow to tumor, heart, kidney, or other tissues also can be measured using [^{15}O]-H_2O.

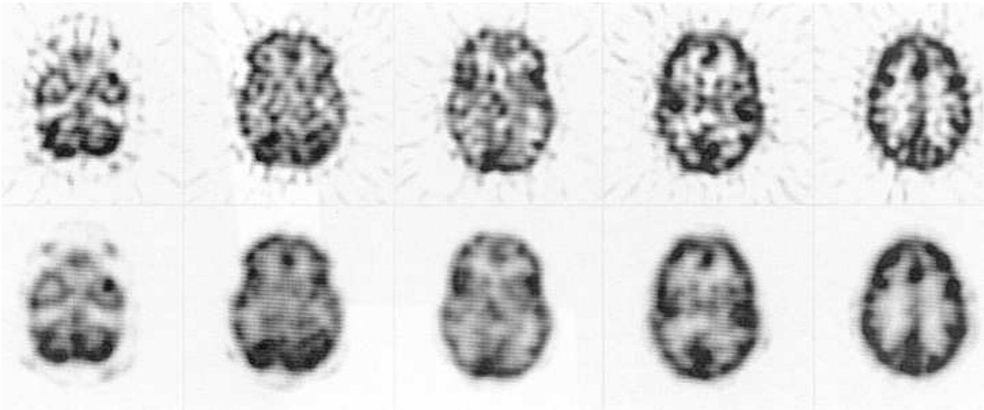


FIG. 29.26 PET local cerebral blood flow images. Images in the *top row* were created using a standard filtered back-projection reconstruction technique. An iterative reconstructive method was used to create images in the *bottom row* from the same raw data that were used for upper images. In all images, *dark areas* correspond to high brain blood flow. There is about an 8-mm separation between each brain slice within a row.

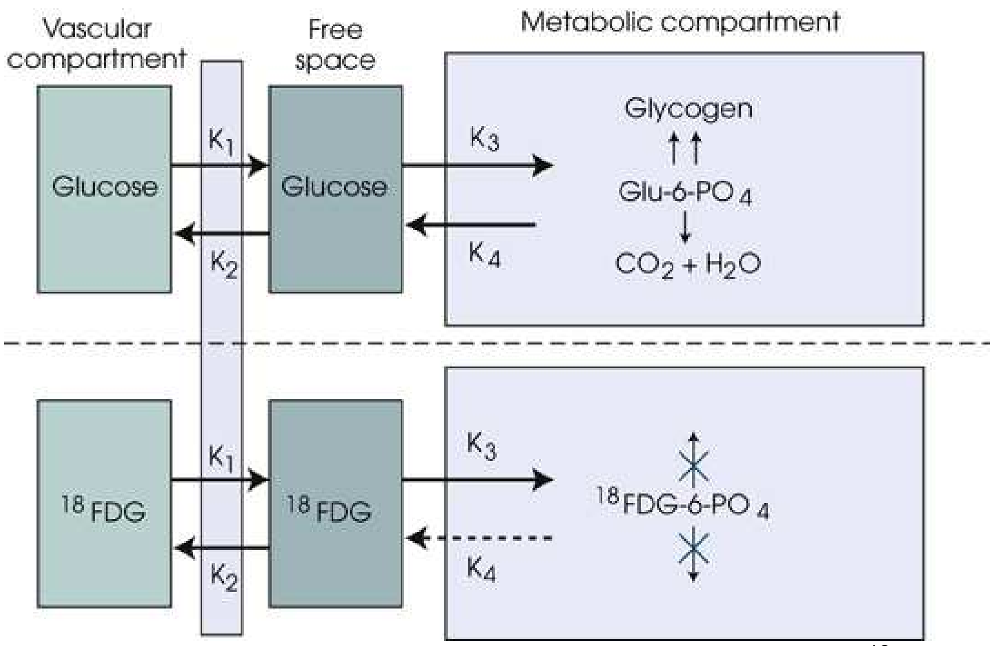


FIG. 29.27 Glucose compartmental model *(above dashed line)* compared with the ^{18}F-FDG model *(below dashed line)*. ^{18}F-FDG does not go to complete storage (glycogen) or metabolism ($CO_2 + H_2O$) as does glucose. The constants (*K*) refer to reaction rates for moving substances from one compartment to another. *Dashed arrow* refers to extremely small *K* value that can usually be neglected.

The most common and widely used PET radiopharmaceutical for clinical PET imaging is a little more complex than labeled water and employs ^{18}F-labeled fluoride ions (F−) to form a sugar analog called [^{18}F]-2-fluoro-2-deoxy-D-glucose (^{18}F-FDG). This agent is used to determine the local metabolic rate of glucose use in tumor, brain, heart, or other tissues that use glucose at an increased rate. The glucose obtained from food is metabolized by the body's cells via the first stage of cellular respiration (glycolysis) and continues to be broken down, creating large quantities of adenosine triphosphate (ATP). However, in contrast to glucose, ^{18}F-FDG cannot be completely metabolized. Once ^{18}F-FDG is phosphorylated into fluorodeoxyglucose-6-phosphate ([^{18}F]-FDG-6-PO_4), the cell can no longer process it. The cell then retains the newly formed [^{18}F]-FDG-6-PO_4 for a few hours before breaking it down and filtering it out. This period of retention allows for imaging. These pathways for glucose and ^{18}F-FDG are shown schematically in Fig. 29.27.

The total time for FDG production, which includes target irradiation (1 hour to 90 minutes), radiochemical synthesis (30 minutes to 1 hour), and purity certification (15 minutes), is approximately 2 to 3 hours (depending on the exact synthesis method used). Because of the short half-life of most positron-emitting radioisotopes, radiopharmaceutical production must be closely tied to the clinical patient schedule. Injected doses of ^{18}F-FDG range from 5 to 20 mCi; a standard dose is 15 to 20 mCi. FDG is dissolved in a few milliliters of isotonic saline and is administered intravenously.

Camera design

Scintillators used in PET cameras can be constructed from various materials. Each material has a different set of characteristics that may improve or degrade the quality of the system. The optimal scintillator would have a short decay time, high light output, high-energy resolution, and high stopping power. Characteristics of commercial materials available are listed in Table 29.5. The newest scintillator, lutetium orthosilicate (Lu_2SiO_5:Ce), has a higher light output (approximately four times that of bismuth germanate [BGO]) and faster photofluorescent decay (approximately 7.5 times that of BGO). Scintillator dimensions are also being reduced to improve resolution. At the present time, the resolution within the image plane for PET scanners is between 3 mm and 5 mm full width at half maximum. This means an image of a point source of radioactivity appears to be 3 to 5 mm wide at half the maximum intensity of the source image.

The basic component of the PET scanner is the block. A block is composed of a scintillation crystal coupled with 4 PMTs. The crystal is cut into a matrix (6 × 6, 7 × 8, or 8 × 8) of small rectangular boxes (3 to 6 mm long, 3 to 6 mm wide) with varying depths (10 to 30 mm deep) (Fig. 29.28). These blocks are then organized into a row to form detector modules. Next, the modules are aligned side by side to construct a ring (Fig. 29.29), and to increase the imaging field *(z)*, several rings are combined. Typical new scanners have 800 to 1,000 detectors per ring.

The average bore width (*x*, *y*) of these scanners is approximately 70 cm, with newer scanners being slightly larger in diameter. The radial field of view (FOV) or the imaging dimension parallel to the detector rings for these scanners is approximately 10 inches (24 cm) and 22 inches (55 cm) (Fig. 29.30). The *z* axis, or dimension perpendicular to the detector rings, is 6 to 20 inches (15 to 50 cm). An actual PET/CT scanner can be seen in Fig. 29.31.

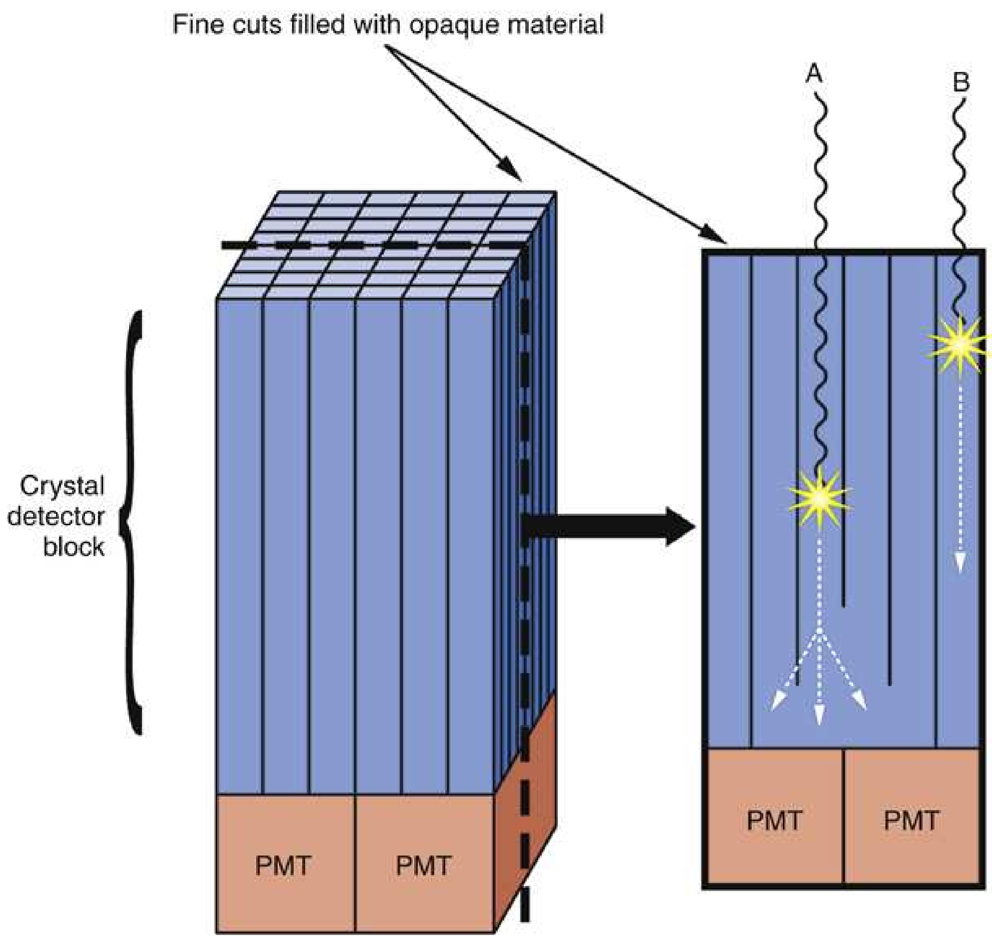


FIG. 29.28 PET scintillation block detector. Many crystal detectors are made from a single block of material and have cuts made to different depths and filled with opaque material. There are often 8 × 8 detector elements made, and the different depths of cuts allow localization with only four photomultiplier tubes *(PMTs)*. *A,* If a photon interacts with a central detector element, the shallow cut allows the light from the scintillation to be localized by several PMTs. *B,* A photon interacting with a detector element near the edge of the block may have light that is seen by one PMT only. From Mettler FA, Guiberteau MJ. *Mettler's essentials of nuclear medicine imaging,* ed 6, Philadelphia: Elsevier; 2012.

A P E T scintillation block detector is illustrated. If a photon interacts with a central detector element, the shallow cut allows the light from the scintillation to be localized by several P M T s. B, A photon interacting with a detector element near the edge of the block may have light that is seen by one P M T only.

TABLE 29.5

Property	NaI	BGO $Bi_4Ge_3O_{12}$	GSO $Gd_2SiO_5(Ce)$	LSO $Lu_2SiO_5(Ce)$	LYSO $Lu_{2(1-x)}Y_{2x}SiO_5(Ce)$
Z (atomic number) stopping power	50	74	58	66	65
Density (g/cm^3)	3.7	7.1	6.7	7.4	7.1
Light yield	100	15	26	75	80
Decay constant (ns)	230	300	65	40	41
Energy resolution @ 511keV (%)	6.6	10.2	8.5	10	14
Attenuation length (mm) for 511 keV photons	28.8	10.5	14.3	11.6	12
Attenuation coefficient (cm^{-1}) @ 511keV	0.34	0.94	0.67	0.87	0.83

BGO, Bismuth germanium oxide; *GSO*, gadolinium oxyorthosilicate; *LSO*, lutetium oxyorthosilicate; *LYSO*, lutetium yttrium orthosilicate; *NAI*, sodium iodide.

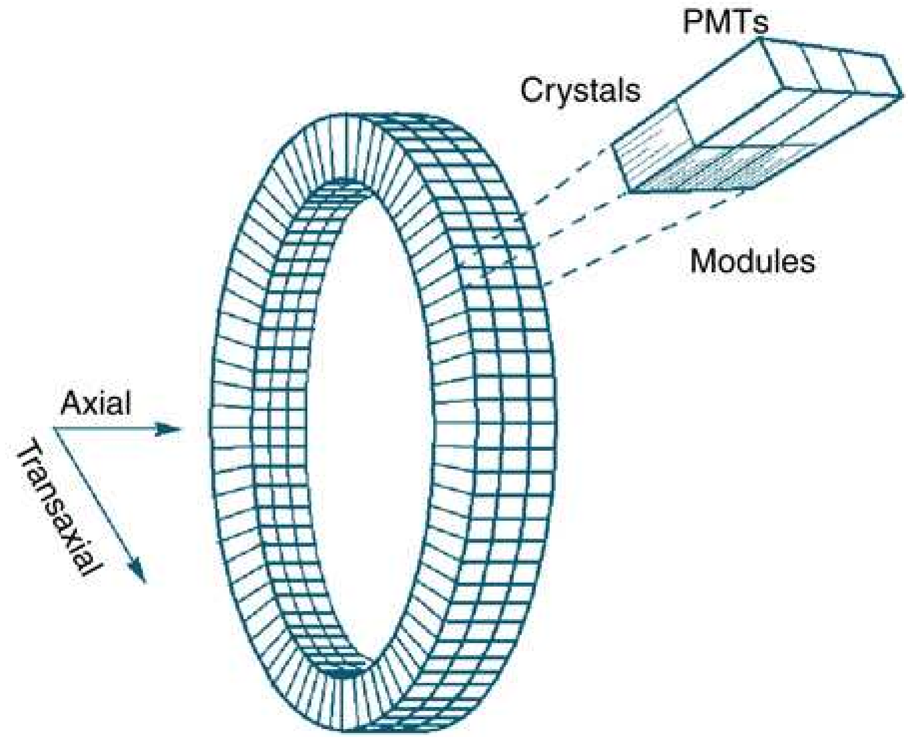


FIG. 29.29 Detector blocks, or modules, are used to construct a ring of detectors around the patient. Hundreds of blocks are used to create 18 to 40 consecutive rings of detectors that for a cylindrical field of view approximately 5 cm long and that can acquire many slices of coincidence data at one time. *PMTs,* Photomultiplier tubes. From Waterstram-Rich K, Gilmore D. *Nuclear medicine and PET/CT: technology and techniques,* ed 8, Philadelphia: Elsevier; 2017.

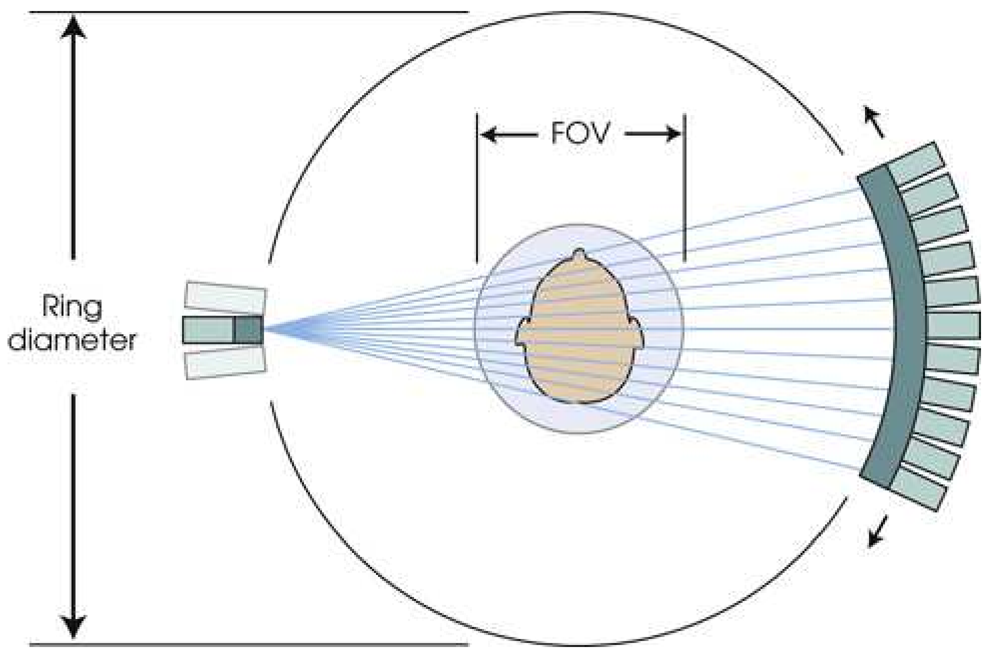


FIG. 29.30 Detector arrangement in neurologic PET ring (head-only scanner). Rays from opposed detector pairs (*lines* between detectors) depict possible coincidence events. The useful field of view *(FOV)* is delineated by the *central circle*.

FIG. 29.31 Typical whole-body PET/CT scanner. The bed is capable of moving in and out of the scanner to measure the distribution of PET radiopharmaceuticals throughout the body, and it adjusts to a very low position for easy patient access. Sophisticated computer workstations are required to view and analyze data.

The sensitivity of a PET camera has contributed to not only the scintillator being used but whether or not the camera is using *septa*. PET collimation is the addition of thin lead or tungsten attenuators, placed between the detector elements. The collimation is designed to block annihilation photons not directly in line with the detector. This reduces the sensitivity greatly, requires higher radiopharmaceutical doses to be administered, and requires longer imaging times, but increases the camera's resolution. PET cameras with septa installed are known as *2-Dimensional* or *2D* PET Scanners. With improvements in software reconstruction techniques, current PET scanners have eliminated septa between detector components. These cameras are referred to as *3-Dimensional (3D)* PET scanners. 3D systems allow for first, second, third, fourth, and upward adjacent planes (rings) to be used to produce images all at one time (Fig. 29.32). With the inclusion of the additional cross-plane information, the PET scanner's *sensitivity* is greatly increased. Thus, injected doses of radiopharmaceutical are significantly reduced (50% to 90% less radioactivity given) to yield PET images with a quality equivalent to that of images obtained from the original dose levels used in 2D PET scanners.

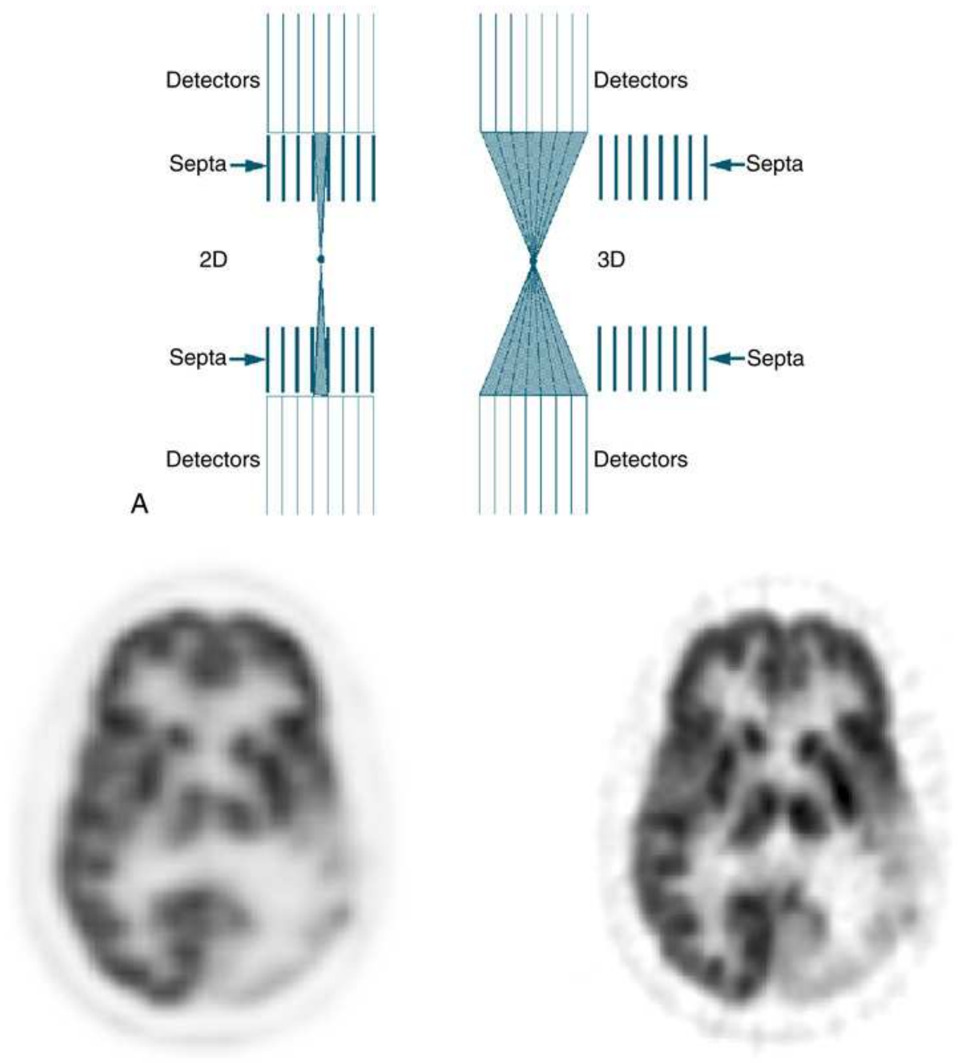


FIG. 29.32 (A) Two-dimensional acquisition with septa in position has scanner sensitivity limited by septa. Three-dimensional mode with the septa retracted from the gantry significantly increases the sensitivity. (B) Brain images demonstrate a two-dimensional image *(left)* and a higher-quality three-dimensional image *(right)*. From Waterstram-Rich K, Gilmore D. *Nuclear medicine and PET/CT: technology and techniques,* ed 8, Philadelphia: Elsevier; 2017.

(A) The two-dimensional acquisition with septa in position has scanner sensitivity limited by septa. The three-dimensional mode below with the septa retracted from the gantry significantly increases the sensitivity. (B) The brain images demonstrate a two-dimensional image on the left and a higher-quality three-dimensional image on the right. The blacks are darker in the brain on the right.

Data And Image Acquisition

The ring design described above is engineered to capture annihilation photons after they are produced. When two identical or isoenergetic photons are emitted at almost exactly 180 degrees from one another, the nearly simultaneous detection of both photons can define a straight line that passes through the body. The detection of the two annihilation photons is called a *coincidence event*, and the theoretical line that was created is known as the *line-of-response* (LOR). For a coincidence event to occur and be deemed real, the photons must reach the detectors within a specific time frame or the *coincidence time window* (6 to 12 ns). If one photon is detected and no other photon is observed during that time window, the original event is discarded. This is defined as electronic collimation. If both photons strike opposing detectors, it is referred to as a *true* coincidence event, a LOR is generated, and it is used to identify the location of the annihilation. Because each photon travels at the speed of light, coincidence electronics can use simple math to deduce where the event took place based on the time it took each photon to reach the detectors. Multiple true events are summed to formulate an image.

Coincidence events fall into one of three categories: true events, scattered events, or random events. A true event is when the annihilation photon pair, unaffected by any attenuation or scatter, strikes the detectors within the resolving time and is registered as a single count. Scattered events are those in which one of the photons from the annihilation is deflected but not slowed enough to fall outside of the coincidence time frame. This creates a false LOR and increases background noise in the image. A random event is two annihilations taking place in two separate locations, and a single photon from each pair strikes opposing detectors within the coincidence timing window. Again, a false LOR is created, degrading the images. Refer to Fig. 29.33 to get a better understanding of these events.

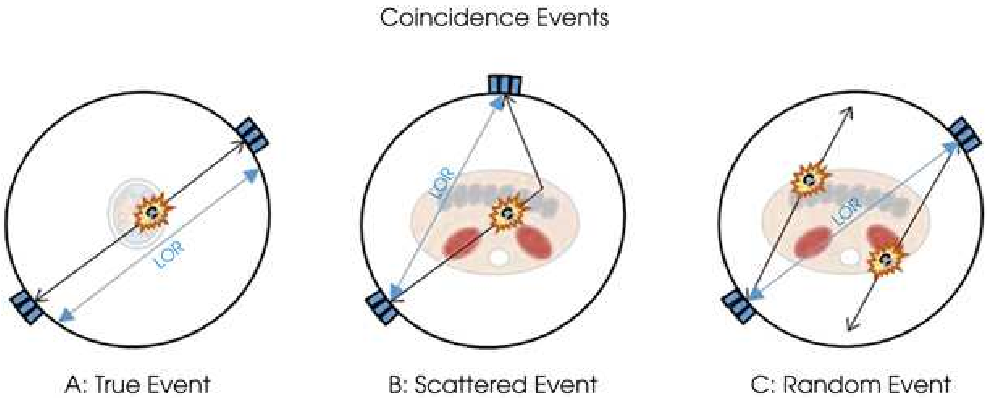


FIG. 29.33 (A) A *true event* is when annihilation photons from a single annihilation event are detected ~180 degrees apart within the coincidence timing window. This creates correct LOR, increasing the target to background ratio. (B) A *scattered event* occurs due to attenuation deflecting the photon. This results in an incorrect LOR and degrades the image. (C) A *random event* is the resultant of two separate annihilation events striking detectors on opposite sides of the gantry within the same coincidence timing window. This also creates a false LOR and decreases the target to background ratio. *Remember*, all coincidence events are detected and are potentially applied to the final image.

(A) The annihilation photons from a single annihilation eventare detected within the coincidence timing window. This creates correct L O R. (B) shows a single photon from each pair strikes opposing detectors within the coincidence timing window. (C) shows two separate annihilation events striking detectors on opposite sides of the gantry within the same coincidence timing window.

PET scanners must operate with a high sensitivity, and as a result, scanners must also be able to handle very high count rates with minimum *deadtime* losses. Coincidence events are collected not only for detector pairs within each ring (direct-plane information) but also between adjacent rings (cross-plane information), as shown in Fig. 29.34. However, not all photons emitted from the patient can be detected. The emission process is *isotropic*, which means that the annihilation photons are emitted with equal probability in all directions so that only a small fraction of the total number of photons emitted from the patient actually strikes two opposing detectors (Fig. 29.35). In most cases, almost 99% of annihilation events are missed or discarded by the camera.

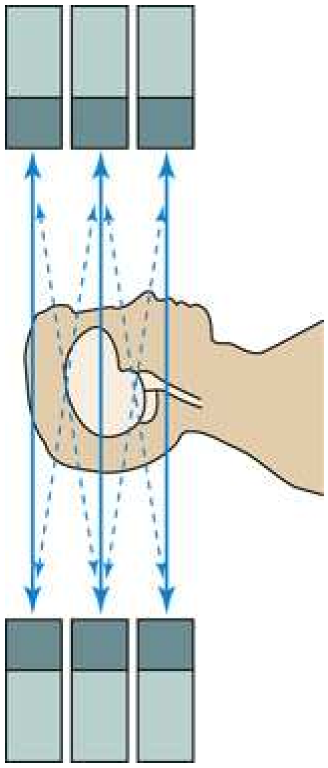


FIG. 29.34 Side-view schematic of a small portion of a multi-ring PET scanner. *Darker green squares* indicate the scintillator-matrix, which is attached to multiple photomultiplier tubes. *Solid lines* indicate the direct planes, and *dashed lines* depict the cross planes. Improvements in PET scanner instrumentation not only permit cross-plane information between adjacent rings to be acquired, but it also allows for expansion to the second, third, fourth, and fifth neighboring rings. This significantly enhances overall scanner sensitivity.

The side-view schematic of a small portion of a multi-ring P E T scanner. A patient is lying supine between them. The darker green squares close to the patient indicate the scintillator-matrix, which is attached to multiple photomultiplier tubes.

Imaging

The *z*-axis, or the imaging dimension parallel to the detector rings for these scanners, is approximately 6 to 20 inches (15 to 50 cm). When imaging a patient, the length of the *z*-axis is referred to as the bed. Depending on the imaging being performed, one to several beds may be required. To obtain enough counts to form a diagnostic PET image, the patient must remain in one bed position for a set period of time (~2 to 4 minutes). Once adequate counts have been gathered, the scanner table moves the patient in/out to scan the next section of their body. Because the resolution and sensitivity of PET cameras become increasingly poor as it approaches the edges of the FOV, motion increments are designed to overlap by a few centimeters. This allows for sufficient axial sampling achieved for all but the first and last bed position. Fig. 29.36 illustrates bed and patient positioning.

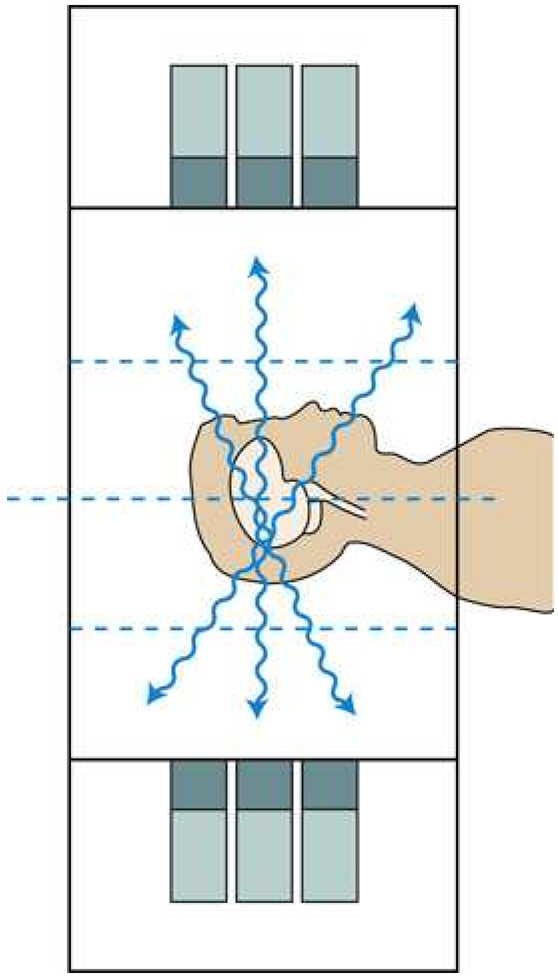


FIG. 29.35 Side view of PET scanner, illustrating possible photon directions. Only 15% of the total number of emitted photons from the patient can be detected in a whole-body tomograph (ring diameter 39 inches [100 cm]). This is increased to 25% for a head tomograph (ring diameter 24 inches [60 cm]). For these estimates, axis coverage was considered to be 6 inches (15 cm). The actual number of detected coincidences would be less than either the 15% or 25% estimate because the detector efficiency is not 100% (typical efficiency 30%).

The side-view schematic of a small portion of a multi-ring P E T scanner. A patient is lying supine between them. The darker green squares close to the patient indicate the scintillator-matrix, which is attached to multiple photomultiplier tubes. The photons emitted from the patient strikes two opposing detectors.

In PET there are three types of scans. The first type is brain and cardiac imaging, which only requires one bed. Imaging times vary due to the attenuation (skull) and radiopharmaceutical doses. Brain scans can take up to 10 minutes, while only 5 minutes is required for most heart scans. The second type is known as "eye-to-thigh" imaging. Eye-to-thigh imaging is just that; images are obtained from a patient's orbitals to their mid-thighs. A scout or low-grade x-ray image (similar to CT) is taken of the patient to identify these anatomical structures so the technologist can adjust the beginning and ending points. The average eye-to-thigh exam is composed of about seven beds, at 3 minutes per bed. The third type of scan is the whole-body scan. A whole-body scan is used in patients with melanoma or cancers that are known to metastasize anywhere in the body. These scans are begun at the top of the head and continued all the way to the tip of the toes. Due to most table constraints, the patients' legs must be scanned separately. Whole-body scans consist of 9 to 12 beds, at 1 to 3 minutes per bed.

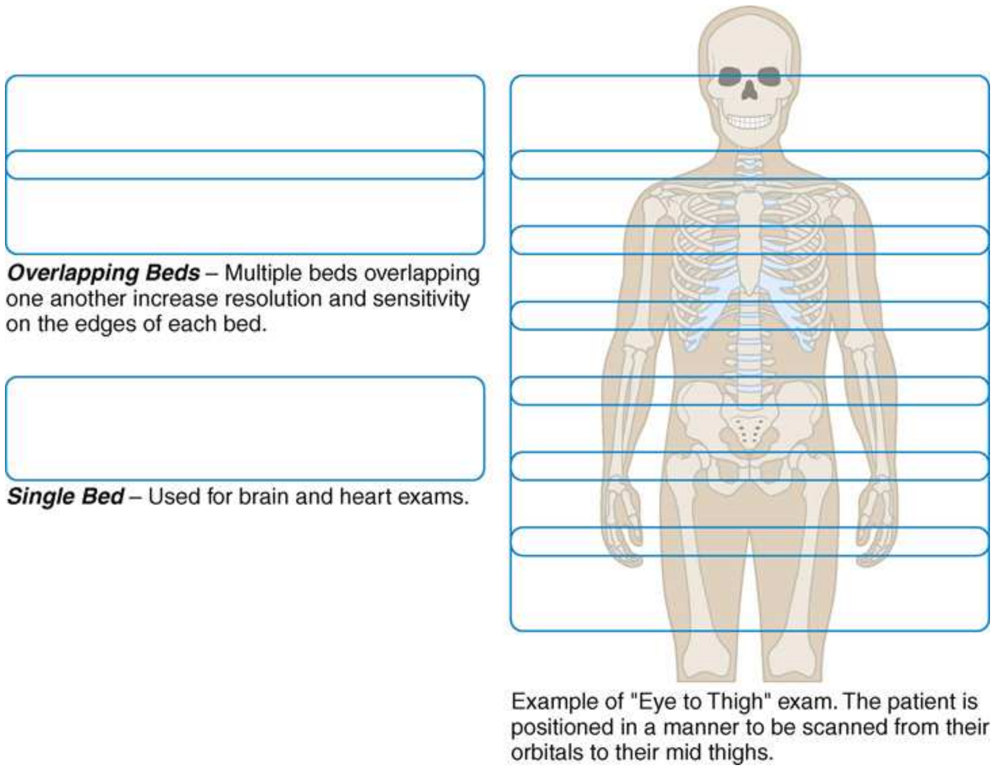


FIG. 29.36 Bed positions during a typical PET scan.

Diagram on the left shows multiple beds overlapping. Diagram below it shows a single rectangular bed. Diagram on the right shows the anterior view of the human body with multiple overlapping beds from the eyes to the thighs.

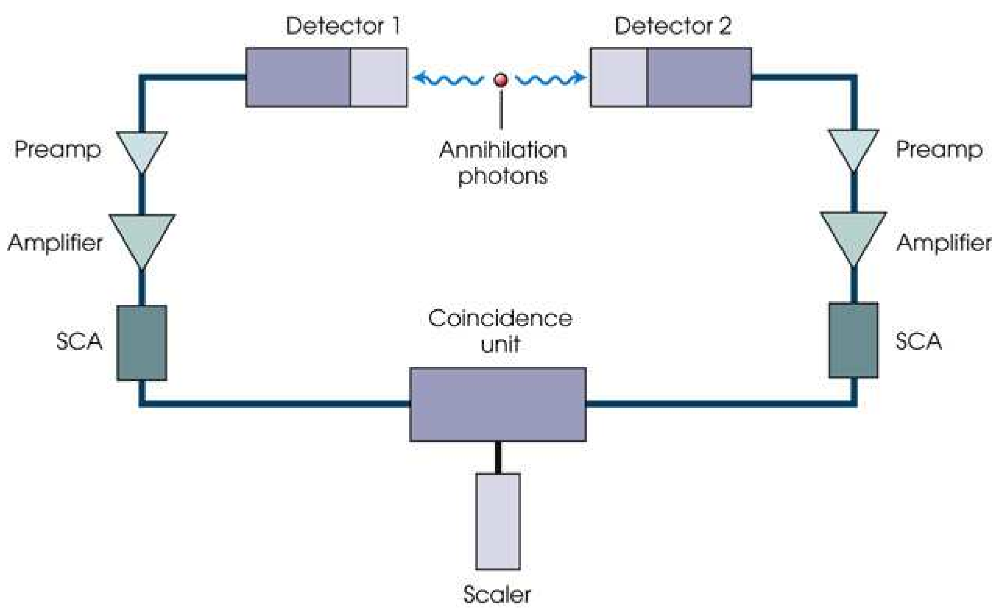


FIG. 29.37 Simplified coincidence electronics for one pair of detectors in a PET tomograph. A single channel analyzer *(SCA)* is used to measure and verify the amplitude of the pulse received by the detector (e.g., 511 keV). Different radioisotopes present the PET unit with different photo-peaks. Photo-peaks that fall outside that of the radioisotope being used are discarded.

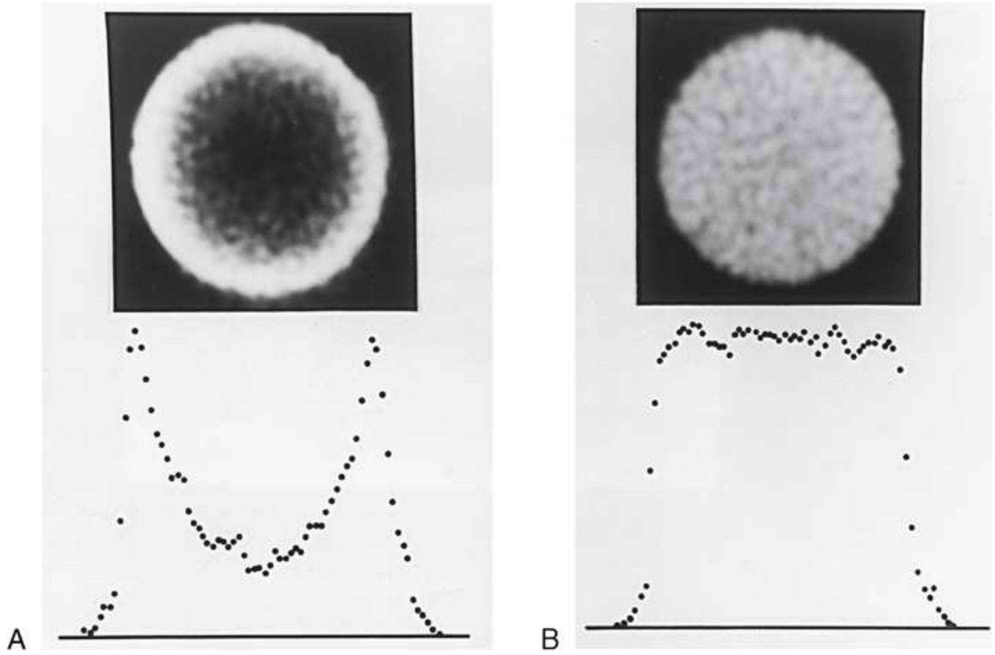


FIG. 29.38 (A) Uncorrected image of a phantom homogeneously filled with water-soluble PET nuclide of ^{68}Ga or ^{18}F. (B) Attenuation-corrected image of same phantom. Cross-sectional cuts through the center of each image are shown in *lower panels*. The attenuation correction for a phantom with a diameter of 8 inches (20 cm) can be 70% in the center of the object.

(A) A box on top shows a circle in the middle. The circle has a black region at the center surrounded by a white region. Below it, is a M shaped scatter graph. (B) A box on top shows a grey circle in the middle. The region outside the circle appears black. Below it is a scatter graph.

FIG. 29.39 Typical PET/CT scanner. Courtesy GE Medical Systems, Milwaukee, WI.

Image Reconstruction And Image Processing

Array processors are used to perform the maximum likelihood (iterative) reconstruction that converts the raw *sinogram* data into PET images. This technique is similar to the technique employed for CT image reconstruction. Faster and less costly desktop computers are replacing array processor technology and greatly simplifying software requirements for image reconstruction. A simplified block diagram for a single coincidence circuit is shown in Fig. 29.37.

Three important corrections need to be made during image reconstruction to ensure an accurate and interpretable scan. First, the disintegration of radionuclides follows Poisson statistics. As discussed earlier, random and scattered events are registered by the PET scanner as coincidence events, which degrade the overall image quality. A simple approximation allows for the subtraction of the random events after image acquisition and is based on the individual count rates for each detector and the coincidence resolving time (8 to 12 ns) of the tomograph electronics.

Second, photons traversing biologic tissues also undergo absorption and scatter. As shown in Fig. 29.38, an AC is applied to account for photons that should have been detected but were not. AC also identifies events that were registered outside the body and subtracts them from the final images. In the past, the correction was typically based on a transmission scan acquired under computer control using a radioactive rod or pin source of ^{68}Ge (germanium; 271-day half-life) that circumscribed the portion of the patient's body within the PET scanner. At the present time, PET/CT scanners use the CT data to correct for attenuation more accurately (Fig. 29.39).

Lastly, count rates from the detectors also need to be corrected for deadtime losses. At high count rates, detector electronics cannot handle every incoming event; some events are lost because the electronics are busy processing prior events. Measuring the tomograph response to known input count rates allows empiric formulations for the losses to be determined and applied to the reconstructed image data. Valid corrections for deadtime losses can approach 100%.

For PET procedures, data acquisition is not limited to images of tomographic count rates. The creation of *quantitative* parametric images for the measurement of glucose metabolism is used to identify the locations of potential metastases. Cancers known to have high metabolic activity tend to absorb ^{18}F-FDG at a higher rate. By identifying the absorption rates of normal tissues to those of potentially abnormal ones, the physician can gain a better understanding of a patient's condition. This begins with the assessment of the radioactive concentration (mCi/mL) within a specific volume or voxel (cubic pixel) of tissue. This information is then applied to calculate the *standardized uptake value* (SUV). The SUV is a semiquantitative index used to identify tissues likely of cancer. On average, when the SUV is found to be >2.5, the tissue is suggestive of malignancy. SUVs of the brain, heart, kidneys, and liver are already elevated due to their normal high level of glucose metabolism.

Clinical PET

PET is unique in its ability to measure in vivo physiology because its results are quantitative, easily repeatable, and validated against the results of accurate but much more invasive techniques. However, it is relatively costly and best used for answering complex questions that involve locating and quantitatively assessing tissue function (Figs. 29.40 and 29.41). Anatomic imaging, such as CT, is often limited in its ability to determine whether found masses are of malignant or benign etiology. Because PET is a functional modality, it can often be used to determine malignancy, even in very small nodes or masses.

Patient preparation for PET studies can be detailed and is imperative for optimal imaging. In most cases, the area that is to be examined must be free of metallic objects to avoid creating artifacts on the reconstructed images. This is especially important when using a PET/CT scanner because metallic objects may cause false-positive results in the final images due to attenuation overcorrection in that region. The waiting time between dose administration and imaging varies with each study, as does the total imaging time. After completion, patients may resume all normal activities. Technical summaries of commonly performed PET procedures follow.

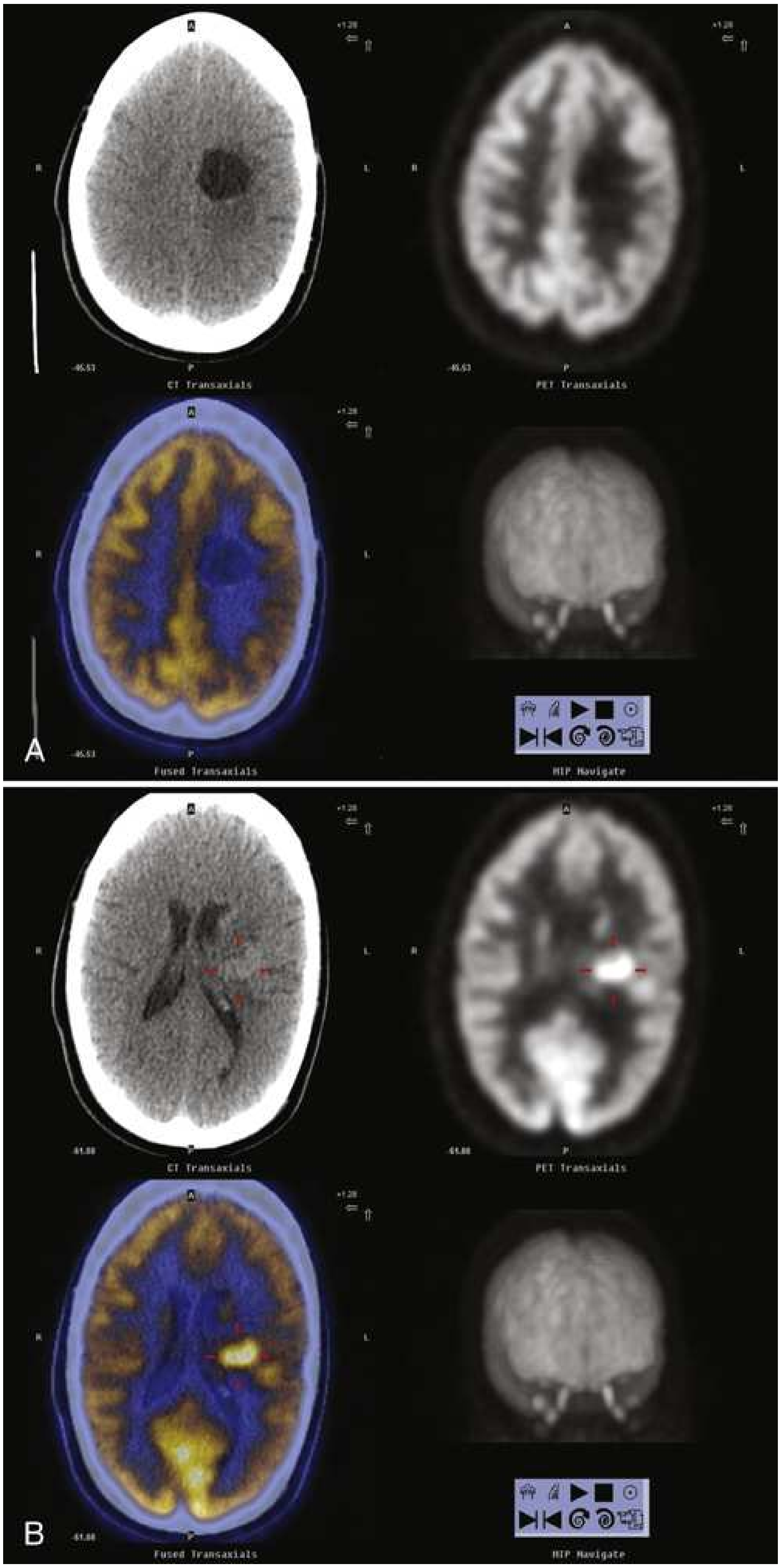


FIG. 29.40 (A) PET FDG brain imaging with CT fusion shows left subcortical resection site consistent with prior tumor resection. (B) At inferior and lateral margins of resection site, in the adjacent white matter, a hypermetabolic mass is identified. This case represents recurrent high-grade malignancy

located in the left periventricular white matter at the frontoparietal junction adjacent to previous resection site.

(A) shows a brain with a black circle in a grey region, The outer covering of the brain appears white. A brain below has a blue colored outer covering. The inner region appears yellow and dark blue. (B) shows a brain with a black circle in a grey region, The outer covering of the brain appears white. A brain below has a blue colored outer covering. The inner region appears yellow and dark blue.

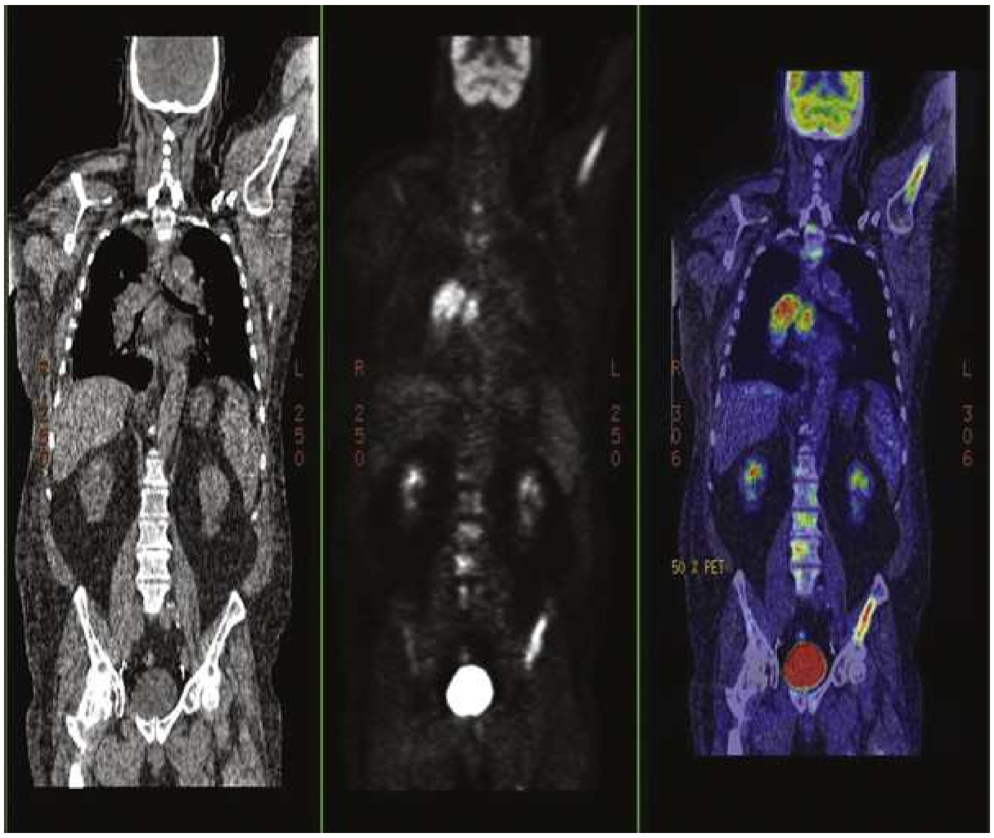


FIG. 29.41 PET FDG image with CT fusion shows large hypermetabolic right lung mass. Many PET FDG studies are done for lung cancer because of its high glucose metabolism.

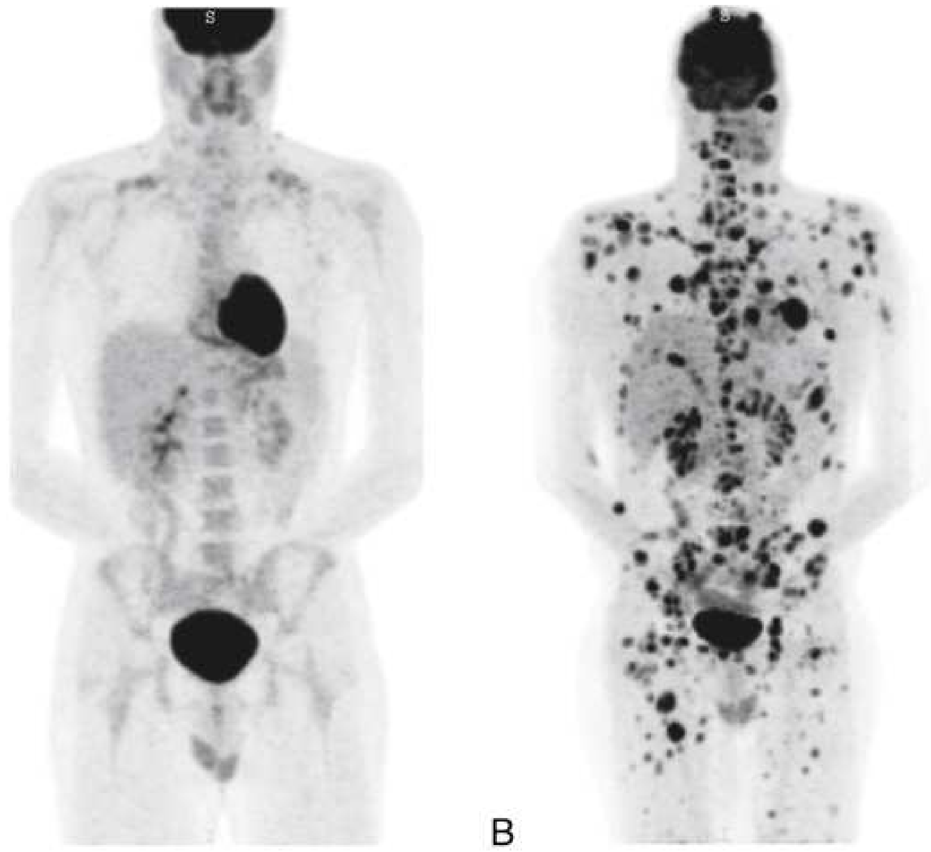


FIG. 29.42 (A) PET image to evaluate a patient with a history of melanoma on the scalp. Scan shows no definite evidence for recurrence. (B) Image 6 months later shows profound and widely disseminated hypermetabolic metastases throughout the body.

(A) shows the anterior view of the human body with black circular regions on the head, heart and below the abdomen. (B) shows the anterior view of the human body with multiple black regions scattered all over the body.

Pet Oncology Imaging

Clinically, 70% to 80% of PET scans are done to diagnose, stage, or restage cancer (Fig. 29.42). ^{18}F-FDG is the radiopharmaceutical of choice. PET plays an important role in differentiating benign from malignant processes and is used for image-guided biopsies. PET is an important modality for detecting cancer recurrence in patients who have undergone surgery, chemotherapy, or radiation treatments. It is also very effective in monitoring therapeutic interventions by rapidly yet noninvasively assessing the metabolic response of the tissues to drugs.

With new reimbursement policies in effect, most malignant tumors are being imaged with ^{18}F-FDG in PET. The most common cancers imaged include lung, colorectal, head and neck, lymphoma, thyroid, esophageal, ovarian, and melanoma.

^{18}F-Fdg Oncologic Study

Principle

Even though ^{18}F-FDG is currently the prevailing radiopharmaceutical in tumor PET imaging, it was initially developed as a tracer to study glucose metabolism in the brain. In the late 1980s, successful reports of ^{18}F-FDG tumor imaging began to surface. It became apparent that certain tumors had a much greater uptake of ^{18}F-FDG than surrounding tissues. Tumor cells tend to have a much greater affinity for glucose than cells of surrounding tissues because of their higher glucose metabolism. This distinction is paramount in understanding how ^{18}F-FDG PET is able to detect metastatic disease.

Although there are many considerations to take into account when performing ^{18}F-FDG PET, the most important is in the regulation of the patient's blood glucose. Generally, a blood glucose level of <180 mg/dL is required for optimal imaging and can be achieved with a 4-hour fast. Patients with high glucose levels generally have poor ^{18}F-FDG uptake because of the already overabundant presence of glucose in their blood. In cases in which the glucose level is <150 mg/dL, it is still important to have the patient fasting for approximately 4 hours before the injection of ^{18}F-FDG because postprandially the insulin response is still strong enough to push the ^{18}F-FDG into more soft tissue than is normally seen in a fasting patient. The result is an image that appears to have a low target-to-background ratio. There are several other protocols that various institutions follow to increase ^{18}F-FDG uptake by the tumor, including having the patient eat low-carbohydrate meals the day before and the day of the scan.

^{18}F-FDG studies require a 60- to 90-minute uptake period after injection for the incorporation of the radiopharmaceutical into the body. Some protocols suggest that imaging tumors after 90 minutes of ^{18}F-FDG incorporation may lead to significantly better signal-to-noise values in the tumor compared with surrounding tissues. During the uptake phase of the protocol, it is important that the patient be still and relaxed. Any motion, especially in the area of interest, would cause the muscles in that area to accumulate FDG and make interpretation of the images difficult. No reading, talking on the phone, or other activity is allowed. The patient also must be kept warm. If the patient develops a shiver, muscle uptake also can be increased.

Radiopharmaceutical

Adult dose (intravenous injection):

- 0.214 mCi/kg (7.9 MBq/kg) of ^{18}F-FDG, minimum 10 mCi (370 MBq), maximum 20 mCi (740 MBq)

Pediatric dose (weight-based intravenous injection) (see Fig. 29.7):

- 0.10 to 0.14 mCi/kg (3.7 to 5.2 MBq/kg) of ^{18}F-FDG, minimum of 0.7 mCi (27 MBq)

Scanning

Most oncologic PET exams are eye-to-thigh studies with the exception of melanoma and thyroid cancer (whole-body imaging). Depending on the dose injected and PET scanner sensitivity, approximately 3 minutes per bed position are required for the emission scan to measure the distribution of ^{18}F-FDG glucose metabolism in tissue. When using a CT scan for AC, the total time for the scan is about 25 minutes.

Pet Neurologic Imaging

Metabolic neurologic study

Principle

Because the brain uses about 25% of the body's total metabolic energy, it provides an excellent gateway for functional imaging of glucose metabolism using ^{18}F-FDG, and this is why most clinical PET brain imaging is currently done with ^{18}F-FDG. PET brain scanning is done to differentiate necrotic tissue from recurrent disease, to facilitate a diagnosis of cognitive status, and to monitor cerebrovascular disease. Another use that is proving to be beneficial is using PET imaging in patients with temporal lobe epilepsy. The identification and location of brain tumors are difficult to assess with ^{18}F-FDG, because of the high metabolic uptake of ^{18}F-FDG in the brain.

When using a PET/CT system, the anatomic information provided by the CT scan can be especially helpful in determining the effects of therapy. The guiding principle in ^{18}F-FDG PET brain imaging is that the healthy brain has high glucose metabolism and high blood flow to the cerebral cortex, which demonstrates the concentration of ^{18}F-FDG within the brain. PET is also routinely used in monitoring the response to therapy and the progression of cognitive disease. With the progression of cognitive decline, glucose metabolism in the brain declines. ^{18}F-FDG assesses temporal lobe epilepsy by evaluating the brain blood flow.

Radiopharmaceutical

Adult dose (intravenous injection):

- 5 to 10 mCi (185 to 370 MBq) of ^{18}F-FDG

Pediatric dose (weight-based intravenous injection) (see Fig. 29.7):

- 0.10 mCi/kg (3.7 MBq/kg) of ^{18}F-FDG, minimum 0.37 mCi (14 MBq)

Scanning

Before and after injection with ^{18}F-FDG, the patient should follow the same procedure as though undergoing an ^{18}F-FDG whole-body scan. The main difference is the importance of having no visual or auditory stimulation if possible. The visual cortex has a high rate of glucose metabolism during stimulation, which can make the images more difficult to interpret. Generally, the patient is injected with ^{18}F-FDG in a darkened room and is given instructions to remain still and to try to stay awake for a 30-minute uptake period. At the end of this period, the scan is performed in three-dimensional mode, with bed time of 8 to 10 minutes. The transmission is generally done for 5 minutes, unless an elliptic or contoured AC is done. When done on a PET/CT scanner, the CT scan is used to determine positioning of the brain and for the attenuation map. The time savings of using the CT scan for the AC can be very helpful, especially in pediatric patients, or claustrophobic patients who may have difficulty staying still for any length of time.

Amyloid neurologic study

Principle

β-Amyloid protein is a protein that forms in patients with AD along with other cognitive disorders. Thioflavin binds to beta-amyloid histologically and fluoresces. Amyloid radiotracers are thioflavin derivatives. Patients with AD tend to have a build-up of beta-amyloid proteins between nerve cells that form plaques. Amyloid radiotracers target these plaques and identify their presence. Patients with AD will have increased uptake of ^{18}F-florbetapir as it targets beta-amyloid plaque.

Radiopharmaceutical

Adult dose (intravenous injection):

- 10 mCi (370 MBq) of ^{18}F-florbetapir (total volume of 10 mL or less)

Scanning

Because ^{18}F-florbetapir does not rely on glucose metabolism for distribution, blood glucose does not need to be assessed. A 10-minute, dynamic acquisition should be acquired after a 30- to 50-minute uptake period with the patient laying supine and head positioned in a head holder to help eliminate patient movement. The FOV should include the entire brain.

Other brain studies

Other brain imaging is now being done for Parkinson disease with ^{18}F-fluorodopa, which traces dopamine synthesis in the brain. There are also a few ^{15}O radiotracers in use, such as $H_2\,^{15}O$, which are employed to assess cerebral blood flow quantitatively.

Pet Cardiology Imaging

PET is a highly valuable diagnostic tool in the determination of myocardial viability and coronary flow reserve. Because of its higher temporal and spatial resolution and its built-in AC, PET is able to offer higher diagnostic accuracy than conventional nuclear medicine techniques. Because PET tracers emit higher energy gamma rays (511 keV) compared with conventional nuclear tracers (^{201}Tl at 80 keV and ^{99m}Tc sestamibi at 140 keV), PET is able to measure tracer uptake in the body more accurately. Currently, the clinical application of PET imaging in cardiology can be divided into two main categories: the detection of myocardial viability and the assessment of coronary flow reserve.

Cardiac viability

Principle

PET imaging for cardiac viability is an invaluable tool in the assessment of viable tissue in the left ventricle. The use of ^{18}F-FDG as an indicator of glucose metabolism allows the clinician to assess the likelihood of successful coronary revascularization. Patients with moderate to severe left ventricular dysfunction, yet high myocardial viability are the most likely to benefit from revascularization. Patients who are found to have minimally viable tissue would not benefit from revascularization and may undergo the procedure needlessly if no noninvasive testing is done. Normal protocols stipulate that patients undergo a resting cardiac perfusion scan before cardiac ^{18}F-FDG PET. Traditional patterns of myocardial viability include decreased resting blood perfusion in the presence of enhanced metabolic uptake.

Radiopharmaceutical

Adult dose (intravenous injection):

- Viability imaging:
- 10 mCi of ^{18}F-FDG
- Perfusion (rest imaging)
    - 20 mCi (740 MBq) of ^{13}N-ammonia
    - 30 to 60 mCi (1110 to 2220 MBq) of ^{82}Rb

Scanning

The patient preparation for PET cardiac viability scans is very important in obtaining accurate images. On the day of the scan, all patients are to fast and refrain from caffeine and nicotine intake. Upon arrival, patients have two intravenous lines placed, one in each arm. One line is for the radiopharmaceutical injection; the other is for the insulin and dextrose infusion. A rest perfusion scan with ^{13}N-ammonia or ^{82}Rb is usually performed first. After completion of the scan, the patient is given a combination of dextrose and insulin intravenously to increase the levels of glucose in the bloodstream. This converts the heart from using fatty acids as its primary source of energy to glucose. When the patient's blood glucose level reaches an optimal level, ^{18}F-FDG is injected. Approximately 30 minutes after injection, the patient is moved onto the scanner and positioned for the transmission scan. A transmission scan of 10 to 15 minutes ensues with a 5- to 10-minute emission scan to follow. When the scan is completed, patients are fed a light lunch, and their blood glucose levels are monitored until they reach normal levels.

Coronary flow reserve

Principle

PET is now commonly used to facilitate diagnosis of coronary artery disease and to assess coronary flow reserve. It is especially helpful in differentiating between stress-induced coronary ischemia and necrosis. These studies are most often done using ^{13}N-ammonia, but the advantages of other radioisotopes, such as ^{82}Rb and ^{15}O, are making their use more common. The advantage of ^{82}Rb is that it is generator-produced and acts as a potassium analog, similar to ^{201}Tl, but it is expensive and requires a large patient load to make it cost effective. The benefit of ^{15}O is that it is freely diffusible into the myocardium and is independent of metabolism, making it an excellent choice for quantitative studies. However, it does present other problems because its short half-life and short imaging time can lead to grainy images, making it a poor choice for qualitative studies. The use of ^{13}N-ammonia is most common because of its relatively short half-life (10 minutes) and because it is trapped by the myocardium by means of the glutamine synthesis reaction.

Radiopharmaceutical

Adult dose (intravenous injection):

- 10 to 20 mCi (370 to 740 MBq) of ^{13}N-ammonia
- 30 to 60 mCi (1110 to 2220 MBq) of ^{82}Rb

NOTE: Rest and stress doses are the same.

Scanning

Patients are asked to eat a light meal approximately 2 hours before the test and to avoid caffeine and nicotine products for 24 hours before the test. This is because caffeine may affect the pharmacologic stress agent used for PET coronary flow reserve studies. The test consists of two portions: rest imaging and stress imaging. The rest imaging is initiated by using the transmission scan to locate and position the heart in the center of the FOV. If the imaging is being done on a PET/CT system, this is done using the CT scan as a scout. When the heart is centered, a transmission scan of 10 to 15 minutes, based on patient girth, is performed for attenuation purposes. On completion of the transmission scan, ^{13}N-ammonia may be injected. The emission scan generally takes 10 to 15 minutes, and may be done as a gated acquisition if desired. After approximately 50 minutes (five ^{13}N half-lives), the stress study may begin. The stress agent is infused over the appropriate time and ^{13}N-ammonia is injected based on the department protocol. Emission imaging should begin immediately. On completion of the examination, the patient may be discharged and allowed to resume normal activity.

Future of Nuclear Medicine

Radioimmunotherapy

Several radioimmunotherapy protocols have come into clinical use in recent years. Monoclonal antibodies specifically designed to localize on the surface of different types of cancer cells can now be tagged with a radioisotope and then imaged. If the monoclonal antibody successfully localizes on the tumor site, the radioisotope may be replaced with a beta-emitting therapeutic radioisotope such as ^{131}I or ^{90}Y. Current studies are looking to treat refractory low-grade transformed B-cell non-Hodgkin lymphoma with ^{90}Y-ibritumomab tiuxetan (Zevalin) or ^{131}I-tositumomab (Bexxar). Other cancers in which specific gene expression is present are also targets using this type of treatment. These studies provide convincing evidence that more diseases may be treatable in the future using radioimmunotherapy.

Hybrid Imaging

Considerable research into the fusion of functional (SPECT and PET) and anatomic (CT and MRI) imaging has led to the introduction of dual-modality, or hybrid, imaging systems. This is one of the most exciting developments in the field of nuclear medicine. The combined PET/CT camera shown in Fig. 29.39 couples the functional imaging capabilities of PET with the superb anatomic imaging of CT. Images from each modality are coregistered during the acquisition process and in near-simultaneity. Because the images can be overlaid one on another, the position of suspected tumors can be recognized more easily. Suspicious metabolically active areas can now be identified anatomically from the CT information. These features have improved the reliability of SPECT and PET interpretation. Metabolic and anatomic evaluation after therapy can now be accomplished in one imaging session. For all these reasons, SPECT/CT and PET/CT are becoming among the most useful diagnostic procedures for staging disease and evaluating the treatment of cancer. All of the advantages of the integration between PET and MRI have not yet been identified. Continued research utilizing PET/MRI in the areas of oncology, neurology, and cardiology will lead radiologic imaging into a new era. With the hybridization of PET/CT and PET/MRI, molecular imaging has made tremendous advancements toward improving diagnostic care for all patients.

PET PET technology is advancing on many fronts. ^{18}F-FDG is routinely being produced in distribution centers throughout the United States and Europe. One or more cyclotrons at each distribution site are continuously producing ^{18}F-fluoride for incorporation into ^{18}F-FDG. Unit doses are shipped via common commercial carriers, which also include chartered air and special ground couriers from a network of registered pharmacy distribution centers to individual PET centers that do not have cyclotrons. Clinical PET imaging no longer requires the high financial commitment to own and operate a nuclear accelerator to produce PET radiopharmaceuticals at a local site.

New radiopharmaceuticals are also being developed. As PET radiopharmaceutical distribution centers expand and are able to handle the daily demands of providing ^{18}F-FDG to the existing and new PET centers, production of more ^{18}F-labeled radiopharmaceuticals specifically for tumor imaging is likely to become available. FDA approval would be required before clinical imaging, but several PET radiopharmaceutical manufacturers are sponsoring drug clinical trials to accelerate the deployment of new and viable clinical PET imaging agents. Radiolabeled choline, thymidine, fluorodopa, estrogen receptors, and numerous other biomolecules are likely candidates for new PET clinical tracers.

Mobile PET units are a reality, as shown in Figs. 29.43 and 29.44. PET scanner technology has matured to the point that the original frailty of the electronics and detector systems has been eliminated. Robust mobile units travel to community hospitals that need PET imaging but not at the level that necessitates a dedicated in-house PET scanner. By spending 1 or 2 days/week at several different hospitals in smaller communities or rural settings, the mobile PET camera best serves the needs of their oncology patients. The ^{18}F-FDG distribution centers are necessary in this scenario because the mobile PET camera unit needs a supply of radiotracer to carry out PET imaging studies. Until nationwide ^{18}F-FDG distribution centers became a reality, as they now are, the use of mobile PET was extremely limited.

Best Practices

Every patient and/or procedure presents its own set of challenges and obstacles to completion of an exam. In nuclear medicine, best practices include performing the "8 Rights" on every patient. These rights include the following.

1. ***Right patient preparation:*** Nuclear medicine is founded on appropriate patient preparation due to the physiological limitations each exam can potentially bring. Things like NPO status and underlying medications are essential to making sure correct radiopharmaceutical localization occurs. For example, something as simple as a multivitamin can drastically change a patient's thyroid uptake percentage due to the potential amounts of iodine in the vitamin. This would decrease the patient's radioactive iodine uptake making it appear as if the patient has a hypo-functioning thyroid. Proper and consistent patient preparation will lead to quality imaging and accurate data collection.

FIG. 29.43 Mobile PET coach showing operator on staff stairs and elevator platform in the elevated position. Elevator used to transport patients from ground level to floor level of the PET scanner unit. Courtesy Shared PET Imaging, LLC.

FIG. 29.44 Interior of mobile coach showing PET workstation *(foreground)* and PET scanner *(background)*. Courtesy Shared PET Imaging, LLC.

2. ***Right patient education:*** Patient education is one of the best weapons a nuclear medicine technologist can have. These exams are long and boring for most patients. Patients tend to become uncomfortable, fidgety, and anxious while in the scanner. By educating the patient on what to expect during the exam, informing the patient of what they can and can't do during the exam, and providing answers to their questions, a technologist can calm a patient before anything has even been started. This leads to less patient motion and anxiety, which ultimately leads to better imaging.
3. ***Right radiopharmaceutical:*** Identifying the correct radiopharmaceutical for each and every exam is essential in the success of the study. The wrong selection will lead to incorrect physiological distribution.
4. ***Right dose:*** Radiopharmaceutical dose ranges are set to not only enhance image quality but also reduce radiation to the patient. Administering a dose that is too low causes low counts within the images, which increase scan times. This leads to patient motion and image distortion. Too high of a dose can lead to not only imaging problems but also potentially over exposing patients to unnecessary radiation.
5. ***Right patient positioning:*** Imaging is only as good as the positioning of the patient. Although most imaging in nuclear medicine is taken in the prone position, there are little details that have to be considered such as arm and leg positioning for a procedure. Due to the limitations of the gamma camera, arms and feet can be clipped during initial whole-body imaging. In other exams, limbs can attenuate and create artifacts. Technologists need to be aware of potential issues and know how to maximize imaging in these situations.
6. ***Right timing:*** Once a radiopharmaceutical is administered, it is vital to obtain imaging at the right time. Some studies require immediate imaging following injections, and others can require delays out to 5 to 10 days. Timing is also used to set up appropriate uptake times, which increases image quality. For example, in parathyroid imaging, the radiopharmaceutical is localized by both the thyroid and parathyroid. The thyroid processes the radiotracer faster than the parathyroid. This means, if the technologist performs images too early, the images would include both organs without separation, and if too late, the tracer may have washed completely out. In both cases, an adenoma may be missed. Maintaining consistency and standardized imaging times within protocols is very important in establishing best practices.

7. ***Right imaging:*** As discussed before, there is not only one kind of imaging in nuclear medicine. A study may require a blood flow, static(s), whole body, or SPECT imaging. Identifying what imaging provides the most information in regard to the exam's indication drives best practices.
8. ***Right documentation:*** A large part of a radiologist's dictation and regulatory agencies includes documentation relevant to each exam. Documentation in some studies is as simple as the radiopharmaceutical, the dose, and the technologist who performed the procedure. Others require dose sheets, public exposure notifications, and even planned diets. Verifying the right documentation is important before completing the exam.

Each of the eight rights is a cornerstone of effective nuclear medicine imaging and patient care. When performed correctly, each come together like a puzzle allowing every exam to be considered a best practice.

Conclusion

Nuclear medicine technology is a multidisciplinary field in which medicine is linked to quantitative sciences including chemistry, radiation biology, physics, and computer technology. Since the early 20th century, nuclear medicine has expanded to include molecular nuclear medicine, in vivo and in vitro chemistry, and physiology. The spectrum of nuclear medicine technology skills and responsibilities varies. The scope of nuclear medicine technology includes patient care, quality control, diagnostic procedures, computer data acquisition and processing, radiopharmaceuticals, radionuclide therapy, and radiation safety. Many clinical procedures are performed in nuclear medicine departments across the United States and throughout the world. Nuclear medicine procedures complement other imaging methods in radiology and pathology departments.

The evolution of PET has provided the nuclear medicine department with complex diagnostic imaging procedures. PET is a useful clinical and research tool, which requires the multidisciplinary support of the physician, physicist, physiologist, chemist, engineer, software programmer, and radiographer. This imaging procedure allows numerous biologic parameters in the working human body to be examined without disturbing normal-equilibrium physiology. PET measures regional function that cannot be determined by any other means, including CT and MRI. Current PET studies of the brain involve the imaging of patients with epilepsy, Huntington disease, stroke, schizophrenia, brain tumors, AD, and other disorders of the central nervous system. PET studies of the heart are providing routine diagnostic information on patients with coronary artery disease by identifying viable myocardium for revascularization. The greatest impact PET has made is the ability to identify highly metabolic tumors. PET scanning is critically involved in the determination of the effects of therapeutic drug regimens on tumors and the differentiation of necrosis from viable tumor. Nearly 80% of all PET imaging today is directed at tumor detection and the evaluation of therapeutic intervention. Overall, human physiology will become better understood as the technology advances, yielding higher resolution instruments, new radiopharmaceuticals, and improved analysis of PET data.

The future of nuclear medicine may lie in its unique ability to identify functional or physiologic abnormalities. With the continued development of new radiopharmaceuticals and imaging technology, nuclear medicine will continue to be a unique and valuable tool for diagnosing and treating disease.

Definition of Terms

alpha particle: Nucleus of a helium atom, consisting of two protons and two neutrons, having a positive charge of 2.
analog: Radiopharmaceutical biochemically equivalent to a naturally occurring compound in the body.
annihilation: Total transformation of matter into energy; occurs after the antimatter positron collides with an electron. Two photons are created; each equals the rest mass of the individual particles.
attenuation coefficient: Number that represents the statistical reduction in photons that exit a material *(N)* from the value that entered the material (N_0). The reduced flux is the result of scatter and absorption, which can be expressed in the following equation: $N = N_0 e^{-\mu\chi}$, where μ is the attenuation coefficient and | is the distance traversed by the photons.
becquerel (Bq): Unit of activity in the International System of Units; equal to 1 disintegration per second (dps): 1 Bq = 1 dps.
beta particle: Electron whose point of origin is the nucleus; electron originating in the nucleus by way of decay of a neutron into a proton and an electron.
blood-brain barrier: Anatomic and physiologic feature of the brain thought to consist of walls of capillaries in the central nervous system and surrounding glial membranes. The barrier separates the parenchyma of the central nervous system from blood. The blood–brain barrier prevents or slows the passage of some drugs and other chemical compounds, radioactive ions, and disease-causing organisms, such as viruses from the blood, into the central nervous system.
coincidence event: The result of two annihilation photons strike opposing detectors in a PET scanner.
coincidence time window: The time in which annihilation photons must strike opposing detectors to be considered coincidence events (6 to 12 nanoseconds).
cold spot: Lack of radiation being received or recorded, not producing any image and resulting in an area of no, or very light, density; may be caused by disease or artifact.
collimator: Shielding device used to limit the angle of entry of radiation; usually made of lead.
Coulomb forces: Forces exerted upon objects with charge. When the charges are the same, the forces repel one another (+, +). If the charges are opposite, the forces attract one another (+, −). Particles without charge (neutrons) are unaffected by these forces.
curie: Standard of measurement for radioactive decay; based on the disintegration of 1 g of radium at 3.731010 disintegrations per second.
cyclotron: Device for accelerating charged particles to high energies using magnetic and oscillating electrostatic fields. As a result, particles move in a spiral path with increasing energy.
daughter: Element that results from the radioactive decay of a parent element.
deadtime: Time when the system electronics are already processing information from one photon interaction with a detector and cannot accept new events to be processed from other detectors.
decay: Radioactive disintegration of the nucleus of an unstable nuclide.

detector: Device that is a combination of a scintillator and photomultiplier tube used to detect x-rays and gamma rays.
deuteron: Ionized nucleus of heavy hydrogen (deuterium), which contains one proton and one neutron.
dose: Measure of the amount of energy deposited in a known mass of tissue from ionizing radiation. Absorbed dose is described in units of rads; 1 rad is equal to 10^{-2} J/kg or 100 ergs/g.
ejection fraction (cardiac): Percent of the total volume of blood of the left ventricle ejected per contraction.
electron capture: Radioactive decay process in which a nucleus with an excess of protons brings an electron into the nucleus, converting a proton into a neutron. The resulting atom is often unstable and gives off a gamma ray to achieve stability.
external radiation detector: Instrument used to determine the presence of radioactivity from the exterior.
^{18}F-FDG: Radioactive analog of naturally available glucose. It follows the same biochemical pathways as glucose; however, in contrast to glucose, it is not totally metabolized to carbon dioxide and water.
fission: Splitting of a nucleus into two or more parts with the subsequent release of enormous amounts of energy.
functional image: See parametric image.
gamma camera: Device that uses the emission of light from a crystal struck by gamma rays to produce an image of the distribution of radioactive material in a body organ.
gamma ray: High-energy, short-wavelength electromagnetic radiation emanating from the nucleus of some nuclides.
generator system: A piece of equipment used in radiopharmacies to quantitatively separate technetium-99m from its parent radionuclide molybdenum-99.
ground state: State of lowest energy of a system.
half-life (T½): Term used to describe the time elapsed until some physical quantity has decreased to half of its original value.
homeostasis: State of equilibrium of the body's internal environment.
hot lab: Location in a nuclear medicine department or radiopharmacy where radioisotopes are stored before use or compounding.
image coregistration: Computer technique that permits realignment of images that have been acquired from different modalities and have different orientations and magnifications. With realignment, images possess the same orientation and size. Images can then be overlaid, one on the other, to show similarities and differences between the images.
in vitro: Outside a living organism.
in vivo: Within a living organism.
isotope: Nuclide of the same element with the same number of protons but a different number of neutrons.
isotropic: Referring to uniform emission of radiation or particles in three dimensions.
kinetics: Movement of materials into, out of, and through biologic spaces. A mathematic expression is often used to describe and quantify how substances traverse membranes or participate in biochemical reactions.
light pipe: Tube-like structure attached to the scintillation crystal to convey the emitted light to the photomultiplier tube.
line of response (LOR): Theoretical line created by the detection of a coincidence event on opposing sides of the PET camera (see Fig. 29.33).
magnetic resonance imaging (MRI): Technique of nuclear magnetic resonance (NMR) as it is applied to medical imaging. Magnetic resonance is abbreviated MR.
metastable: Describes the excited state of a nucleus that returns to its ground state by emission of a gamma ray; has a measurable lifetime.
nuclear particle accelerator: Device to produce radioactive material by accelerating ions (e.g., electrons, protons, deuterons) to high energies and pro jecting them toward stable materials. Accelerators include linac, cyclotron, synchrotron, Van de Graaff accelerator, and betatron.
nuclear reactor: Device that under controlled conditions is used for supporting a self-sustained nuclear reaction.
nuclide: General term applicable to all atomic forms of an element.
organified: The ability of the thyroid to absorb and incorporate iodine into thyroid hormone.
parametric image: Image that relates anatomic position (the x and y position on an image) to a physiologic parameter such as blood flow (image intensity or color). It may also be referred to as a functional image.
parent: Radionuclide that decays to a specific daughter nuclide either directly or as a member of a radioactive series.
particle accelerator: Device that provides the energy necessary to enable a nuclear reaction.
pharmaceutical: Relating to a medicinal drug.
photomultiplier tube (PMT): Electronic tube that converts light photons to electrical pulses.
photopenia: See cold spot.
pixel (picture element): Smallest indivisible part of an image matrix for display on a computer screen. Typical images may be 128 × 128, 256 × 256, or 512 × 512 pixels.
positron: Positively charged particle emitted from neutron-deficient radioactive nuclei.
positron emission tomography (PET): Imaging technique that creates transaxial images of organ physiology from the simultaneous detection of positron annihilation photons.
pulse height analyzer: Instrument that accepts input from a detector and categorizes the pulses on the basis of signal strength.
pyrogen-free: Free of a fever-producing agent of bacterial origin.
quantitative: Type of PET study in which the final images are not simply distributions of radioactivity but rather correspond to units of capillary blood flow, glucose metabolism, or receptor density. Studies between individuals and repeat studies in the same individual permit comparison of pixel values on an absolute scale.
radiation: Emission of energy; rays of waves.
radioactive: Exhibiting the property of spontaneously emitting alpha, beta, and gamma rays by disintegration of the nucleus.
radioactivity: Spontaneous disintegration of an unstable atomic nucleus resulting in the emission of ionizing radiation.
radioisotope: Synonym for radioactive isotope. Any isotope that is unstable undergoes decay with the emission of characteristic radiation.
radionuclide: Unstable nucleus that transmutes via nuclear decay.
radiopharmaceutical: Refers to a radioactive drug used for diagnosis or therapy.
radiotracer: Synonym for radiopharmaceutical.

random event: When two annihilations take place in two separate locations, and a single photon from each pair strikes opposing detectors within the coincidence timing window, a false LOR is created, degrading PET images.
ray: Imaginary line drawn between a pair of detectors in the PET scanner or between the x-ray source and detector in a CT scanner.
reconstruction: Mathematic operation that transforms raw data acquired on a PET tomograph (sinogram) into an image with recognizable features.
region of interest (ROI): Area that circumscribes a desired anatomic location on a PET image. Image-processing systems permit drawing of ROI on images. The average parametric value is computed for all pixels within the ROI and returned to the radiographer.
resolution: Smallest separation of two point sources of radioactivity that can be distinguished for PET or SPECT imaging.
scattered event: The result of a photon from an annihilation being deflected but not slowed enough to fall outside of the coincidence time frame.
scintillation camera: See gamma camera.
scintillation detector: Device that relies on the emission of light from a crystal subjected to ionizing radiation. The light is detected by a photomultiplier tube and converted to an electronic signal that can be processed further. An array of scintillation detectors is used in a *gamma camera.*
scintillator: Organic or inorganic material that transforms high-energy photons such as x-rays or gamma rays into visible or nearly visible light (ultraviolet) photons for easy measurement.
sensitivity: Term used when describing the percentage of photons striking the detector versus those being attenuated by collimation.
septa: High-density metal collimators that separate adjacent detectors on a ring tomograph to reduce scattered photons from degrading image information.
single photon emission computed tomography (SPECT): Nuclear medicine scanning procedure that measures conventional single photon gamma emissions (^{99}mTc) with a specially designed rotating gamma camera.
sonogram: Two-dimensional raw data format that depicts coincidence detectors against possible rays between detectors. For each coincidence event, a specific element of the sinogram matrix is incremented by 1. The sum of all events in the sinogram is the total number of events detected by the PET scanner minus any corrections that have been applied to the sinogram data.
target: Device used to contain stable materials and subsequent radioactive materials during bombardment by high-energy nuclei from a cyclotron or other particle accelerator. The term is also applied to the material inside the device, which may be solid, liquid, or gaseous.
tracer: Radioactive isotope used to allow a biologic process to be seen. The tracer is introduced into the body, binds with a specific substance, and is followed by a scanner as it passes through various organs or systems in the body.
transmission scan: Type of PET scan that is equivalent to a low-resolution CT scan. Attenuation is determined by rotating a rod of radioactive 68Ge around the subject. Photons that traverse the subject either impinge on a detector and are registered as valid counts or are attenuated (absorbed or scattered). Ratio of counts with and without the attenuating tissue in place provides the factors to correct PET scans for the loss of counts from attenuation of the 0.511-MeV photons.
true event: The result of an annihilation photon pair, unaffected by any attenuation or scatter, strikes PET detectors within the coincidence time window and is registered as a single count.
washout: End of the radionuclide procedure, during which time the radioactivity is eliminated from the body.

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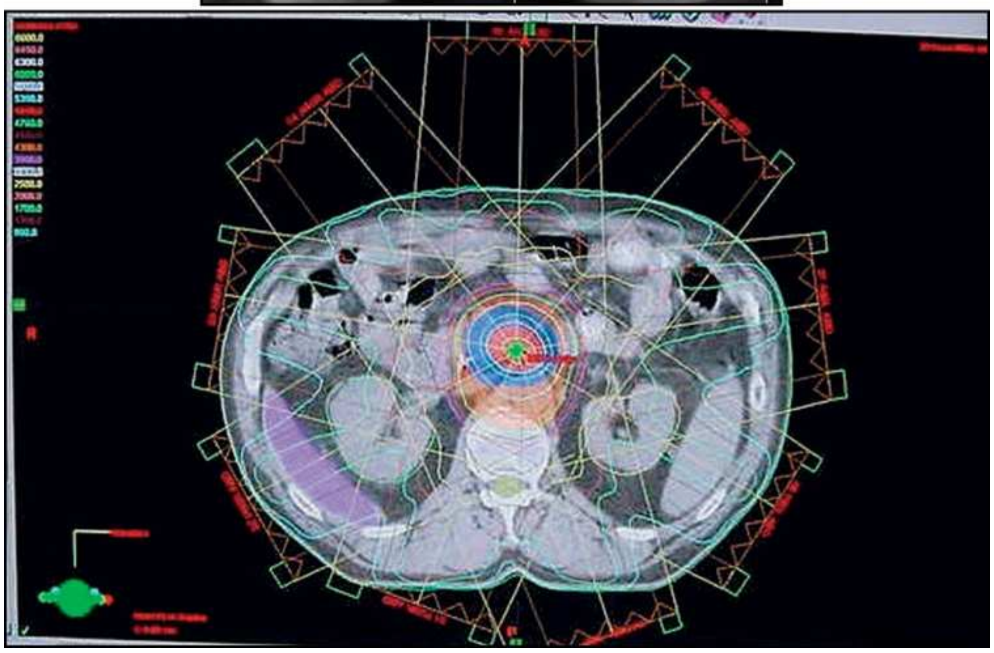
[a] Almost all italicized words on the succeeding pages are defined at the end of this chapter.

30: Radiation Oncology



Machele D. Michels

OUTLINE

Principles of Radiation Oncology

Radiation oncology, [a] or *radiation therapy*, is one of three principal modalities used in the treatment of cancer, with chemotherapy and surgery comprising the other two. In radiation therapy for malignancies, *tumors* or *lesions* are treated with *cancericidal doses* of ionizing radiation as prescribed by a *radiation oncologist*, a physician who specializes in the treatment of malignant disease with radiation. The goals of the treatment are to deliver a cancericidal dose of radiation precisely to the tumor, while limiting as much radiation dose as possible received by normal, noncancerous tissues. These dual tasks make this form of treatment complex and often challenging. Input from all members of the radiation oncology team is crucial in developing the optimal treatment plan or approach for a patient.

Cancer treatment requires a multidisciplinary approach from various departments. First, diagnostic radiologic studies including radiographs, computed tomography (CT) scans, magnetic resonance imaging (MRI), positron emission tomography (PET) scans, and sonograms are obtained to acquire information about the location and anatomic extent of the tumor. Second, a tissue specimen (*biopsy*) is removed surgically. A *pathologist* examines the tissue to determine whether the lesion is cancerous. Once cancer is officially diagnosed, the best treatment approach is determined through consultation with various *oncology* specialists (e.g., surgical *oncologist*, radiation oncologist, medical oncologist).

Although radiation oncology may be used as the only method of treatment for malignant disease, a more common approach is in conjunction with surgery, chemotherapy, or both. Some patients with cancer may be treated only with surgery or chemotherapy; however, approximately 50% of all diagnosed cancer patients can benefit from radiation therapy. The choice of treatment can depend on many patient variables, such as the patient's overall physical and emotional condition, the histologic type of the disease, and the extent and anatomic position of the tumor. If a tumor is small, and its margins are well defined, a surgical approach alone may be prescribed. If the disease is *systemic*, a chemotherapeutic approach may be chosen. Most tumors exhibit degrees of size, invasion, and spread, however, and require variations in the treatment approach that is likely to include radiation treatments administered as an adjunct to or in conjunction with surgery or chemotherapy.

Radiation is generally used after surgery when a patient is deemed to be at high risk for tumor recurrence in the *surgical bed.* The risk of recurrence is considered to be increased in the following situations:

- When the surgical margin between normal tissue and cancerous tissue is minimal (<2 cm)
- When the margin is positive for cancer (i.e., when cancerous tissue is not completely removed)
- When the tumor is incompletely resected because of its large size, its relationship with normal vital structures, or both
- When the cancer has spread to adjacent lymph nodes

Radiation can be used as the definitive (primary) cancer treatment or as an adjuvant treatment (i.e., in combination with another form of therapy). It can also be used for *palliation.*

Radiation treatments most often are delivered on a daily basis, Monday through Friday, for 2 to 8 weeks. The length of time and the total dose of radiation delivered depend on the type of cancer being treated and the purpose of treatment (*cure* or palliation). Prescribed dosages of radiation can range from 800 centigray (cGy) for palliation to 8000 cGy for curative intent (total doses). The delivery of a small amount of radiation per day (180 to 200 cGy) for a certain number of treatments, instead of one large dose, is termed *fractionation.* Because these smaller doses of radiation are more easily tolerated by normal tissue, fractionation can help minimize the acute toxic effect a patient experiences during treatment and the possible long-term side effects of treatment.

The precision and accuracy necessary to administer high doses of radiation to tumors while not harming normal tissue require the combined effort of all members of the radiation oncology team. Members of this team include radiation oncologists, physicists, dosimetrists, radiation therapists, and oncology nurses.

The radiation oncologist prescribes the quantity of radiation and determines the anatomic region or regions to be treated. The *medical physicist* is responsible for calibration and maintenance of the radiation-producing equipment. The physicist also advises the physician about dosage calculations and complex treatment techniques. The *medical dosimetrist* devises a plan for delivering the treatments in a manner to meet best the physician's goals of irradiating the tumor while protecting normal vital structures. The *radiation therapist* is responsible for obtaining radiographs or CT scans that localize the area to be treated, administering the treatments, keeping accurate records of the dose delivered each day, and monitoring the patient's physical and emotional well-being. Educating patients about potential radiation side effects and assisting patients with the management of these side effects are often the responsibilities of the oncology nurse.

The duties and responsibilities of the radiation therapist are more thoroughly described later in this chapter. In addition, more information is provided about the circumstances in which radiation is used to treat cancer. The steps necessary to prepare a patient for treatment are also described. These steps include (1) simulation, (2) development of the optimal treatment plan in dosimetry, and (3) treatment delivery. Current techniques and future trends are also discussed.

Historical Development

Ionizing radiation was originally used to obtain a radiographic image of internal anatomy for diagnostic purposes. The resultant image depended on many variables, including the energy of the beam, the processing techniques, the material on which the image was recorded, and, most importantly, the amount of energy absorbed by the various organs of the body. The transfer of energy from the beam of radiation to the biologic system and the observation of the effects of this interaction became the foundation of radiation oncology.

Two of the most obvious and sometimes immediate biologic effects observed during the early diagnostic procedures were epilation (loss of hair) and erythema (reddening of the skin). Epilation and erythema resulted primarily from the great amount of energy absorbed by the skin during radiographic procedures. These short-term, radiation-induced effects afforded radiographic practitioners an opportunity to expand the use of radiation to treat conditions ranging from relatively benign maladies such as hypertrichosis (excessive hair), acne, and boils to grotesque and malignant diseases such as lupus vulgaris and skin cancer.

Ionizing radiation was first applied for the treatment of a more in-depth lesion on January 29, 1896, when Emil Grubbé is reported to have irradiated a woman with carcinoma of the left breast. This event occurred only 3 months after the discovery of x-rays by Wilhelm Röntgen (Table 30.1). Although Grubbé neither expected nor observed any dramatic results from the irradiation, the event is significant simply because it occurred.

In January 1902, in New Haven, Connecticut, Clarence Skinner performed the first reported curative treatment using ionizing radiation. Skinner treated a woman who had a diagnosed malignant fibrosarcoma. Over the next 2 years and 3 months, the woman received 136 applications of the x-rays. In April 1909, 7 years after the initial application of the radiation, the woman was free of disease and considered "cured."

As data were collected, the interest in radiation therapy increased. More sophisticated equipment, a greater understanding of the effects of ionizing radiation, an appreciation for time-dose relationships, and numerous other related medical breakthroughs gave impetus to the interest in radiation therapy that led to the evolution of a distinct medical specialty—radiation oncology.

TABLE 30.1

Significant developments in radiation therapy

Date	Person	Event
1895	Röntgen	Discovery of x-rays
1896	Grubbé	First use of ionizing radiation in treatment of cancer
	Becquerel	Discovery of radioactive emissions by uranium compounds
1898	M. and P. Curie	Discovery of radium
1902	Skinner	First documented case of cancer "cure" using ionizing radiation
1906	Bergonié and Tribondeau	Postulation of first law of radiosensitivity
1932	Lawrence	Invention of cyclotron
1934	Joliot and Joliot-Curie	Production of artificial radioactivity
1939	Lawrence and Stone	Treatment of cancer patient with neutron beam from cyclotron
1940	Kerst	Construction of betatron
1951		Installation of first cobalt-60 teletherapy units
1952		Installation of first linear accelerator (Hammersmith Hospital, London)

Cancer

Cancer is a disease process that involves an unregulated, uncontrolled replication of cells; put more simply, the cells do not know when to stop dividing. These abnormal cells grow without regard to normal tissue. They invade adjacent tissues, destroy normal tissue, and create a mass of tumor cells. Cancerous cells can spread further by invading the lymph or blood vessels that drain the area. When tumor cells invade the lymphatic or vascular system, they are transported by that system until they become caught or lodged within a lymph node or an organ such as the liver or lungs where secondary tumors form. The spread of cancer from the original site to different, remote parts of the body is termed *metastasis*. When cancer has spread to a distant site via blood-borne metastasis, the patient is considered incurable. Early detection and diagnosis are the keys to curing cancer.

In 2020, the estimated number of new cancer cases of any site in the United States is over 1,800,000, and the estimated number of persons who will die from cancer is over 600,000. Data based on cases reported between 2013 and 2017 indicated the rate of new cancer cases of any site was 442.4 per 100,000 men and women, and the age group of cancer diagnosed was most frequently found among persons 65 to 74 years. The most common cancers that occur in the United States are lung, prostate, breast, and colorectal cancer. Prostate cancer is the most common malignancy in men, and breast cancer is the most common malignancy in women. The second and third most common cancers in men and women are lung and colorectal cancer (Table 30.2). Overall, cancer incidence rates are higher among men than women. A higher number of new cases are found among African American men and white women, while fewer new cases are among Asian/Pacific Islanders of both genders. In 2017, heart disease was the first leading cause of death, followed by cancer for the non-Hispanic white, non-Hispanic blacks, and non-Hispanic American Indian or Alaska Native populations. However, cancer surpassed heart disease as the first leading cause of death for the non-Hispanic Asian or Pacific Islander and Hispanic populations.

Risk Factors

External factors

Many factors can contribute to a person's potential for the development of a *malignancy*. These factors can be external exposure to chemicals, viruses, or radiation within the environment or internal factors such as hormones, genetic mutations, and disorders of the immune system. Cancer is commonly the result of exposure to a *carcinogen*, which is a substance or material that causes cells to undergo malignant transformation and become cancerous. Some known carcinogenic agents are listed in Table 30.3. Cigarettes and other tobacco products are the principal cause of cancers of the lung, esophagus, oral cavity and pharynx, and bladder. Cigarette smokers are 25 times more likely to develop lung cancer than nonsmokers. Occupational exposure to chemicals such as chromium, nickel, or arsenic can also cause lung cancer. A person who smokes and works with chemical carcinogens is at even greater risk for developing lung cancer than is a nonsmoker. In other words, risk factors can have an additive effect, acting together to initiate or promote the development of cancer. Other risk factors that have been identified are obesity, physical inactivity, and poor nutrition.

TABLE 30.2

Top five most common cancers in men and women

Men	Women
1. Prostate	1. Breast
2. Lung and bronchus	2. Lung and bronchus
3. Colon and rectum	3. Colon and rectum
4. Bladder	4. Uterus (endometrium)
5. Melanoma	5. Thyroid

The human papilloma virus (HPV) is associated with the development of cancer of the uterine cervix, oropharynx, and anus. Infection with the hepatitis B virus (HBV) and hepatitis C virus (HCV) increase one's risk for the development of hepatocellular carcinoma of the liver. Vaccines do exist to prevent infection with HPV or HBV.

Another carcinogen is *ionizing radiation.* It was responsible for the development of osteogenic sarcoma in radium-dial painters in the 1920s and 1930s, and it caused the development of skin cancers in pioneer radiologists. Early radiation therapy equipment used in the treatment of cancer often induced a second malignancy in the bone. The low-energy x-rays produced by this equipment were within the photoelectric range of interactions with matter, resulting in a 3:1 preferential absorption in bone compared with soft tissue. Some patients with breast cancer who were irradiated developed an osteosarcoma of their ribs after a 15- to 20-year latency period. With advances in diagnostic and therapeutic equipment and improved knowledge of radiation physics, radiobiology, and radiation safety practices, radiation-induced malignancies have become relatively uncommon, although the potential for their development still exists. In keeping with standard radiation safety guidelines, any dose of radiation, no matter how small, significantly increases the chance of a genetic mutation.

TABLE 30.3

Carcinogenic agents and the cancers they cause

Carcinogen	Resultant cancer
Cigarette smoking	Cancers of lung, esophagus, bladder, and oral cavity/pharynx
Arsenic, chromium, nickel, hydrocarbons	Lung cancer
Ultraviolet light	Melanoma and nonmelanomatous skin cancers
Benzene	Leukemia
Ionizing radiation	Sarcomas of bone and soft tissue, skin cancer, and leukemia

Internal factors

Internal factors are causative factors over which persons have no control. Genetic mutations on individual genes and *chromosomes* have been identified as predisposing factors for the development of cancer. Mutations can be sporadic or hereditary, as in colon cancer. Chromosomal defects have also been identified in other cancers, such as leukemia, Wilms tumor, retinoblastoma, and breast cancer. Because of their familial pattern of occurrence, breast, ovarian, and colorectal cancer are three major areas currently under study to obtain earlier diagnosis, which increases the cure rate. Patients with a family history of breast or ovarian cancer can be tested to see whether they have inherited the altered *BRCA-1* and *BRCA-2* genes. Patients with these altered genes are at a significantly higher risk of developing breast and ovarian cancer. Women identified as carriers of the altered genes can benefit from more intensive and early screening programs in which breast cancer may be diagnosed at a much earlier and more curable stage. These patients also have the option of *prophylactic surgery* to remove the breasts or ovaries. Some women still develop cancer, however, in the remaining tissue after surgery.

Familial adenomatous polyposis

Familial adenomatous polyposis is a hereditary condition in which the lining of the colon becomes studded with hundreds to thousands of polyps by late adolescence. A mutation in a gene identified as the adenomatous polyposis coli *(APC)* gene is considered the cause of this abnormal growth of polyps. Virtually all people with this condition eventually develop colon cancer. These individuals develop cancer at a much earlier age than the normal population. Treatment involves removal of the entire colon and rectum.

Hereditary nonpolyposis colorectal cancer syndrome

Hereditary nonpolyposis colorectal cancer syndrome develops in the proximal colon in the absence of polyps or with fewer than five polyps. It has a familial distribution, occurring in three first-degree relatives in two generations, with at least one person being diagnosed before age 50. Hereditary nonpolyposis colorectal cancer syndrome, also known as Lynch syndrome, has also been associated with the development of cancers of the breast, endometrium, pancreas, and biliary tract.

Familial cancer research

Current research to identify the genes responsible for cancer can assist in detecting cancers at a much earlier stage in high-risk patients. Many institutions have familial cancer programs to provide genetic testing and counseling for persons with strong family histories of cancer. Experts assist in educating individuals about their potential risk for developing cancer and the importance of screening and early detection. Genetic testing remains the patient's option, and many patients prefer not to be tested.

Tissue Origins of Cancer

Cancers may arise in any human tissue. Tumors are usually categorized under six general headings according to their tissue of origin (Table 30.4). Of cancers, 90% arise from *epithelial tissue* and are classified as *carcinomas*. Epithelial tissue lines the free internal and external surfaces of the body. Carcinomas are subdivided further into squamous cell carcinomas and adenocarcinomas based on the type of epithelium from which they arise. A squamous cell carcinoma arises from the surface (squamous) epithelium of a structure. Examples of surface epithelium include the oral cavity, pharynx, bronchus, skin, and cervix. An adenocarcinoma is a cancer that develops in glandular epithelium, such as in the prostate, colon and rectum, lung, breast, or endometrium.

To facilitate the exchange of patient information from one physician to another, the International Union Against Cancer and the American Joint Committee for Cancer (AJCC) Staging and End Results Reporting designed a system for classifying tumors based on anatomic and histologic considerations. The AJCC TNM classification (Table 30.5) describes a tumor according to the size of the primary lesion or tumor (*T*), the involvement of the regional lymph nodes (*N*), and the occurrence of metastasis (*M*).

TABLE 30.4

TABLE 30.5

Application of TNM classification system

Classification	Description of tumor
Stage 0—$T_0N_0M_0$	Occult lesion; no evidence clinically
Stage I—$T_1N_0M_0$	Small lesion confined to organ of origin with no evidence of vascular and lymphatic spread or metastasis
Stage II—$T_2N_1M_0$	Tumor of <5 cm invading surrounding tissue and first-station lymph nodes but no evidence of metastasis
Stage III—$T_3N_2M_0$	Extensive lesion >5 cm with fixation to deeper structure and lymph invasion but no evidence of metastasis
Stage IV—$T_4N_3M_1$	More extensive lesion than above with invasion of bone or other adjacent structures or with distant metastasis (M_1)

Note: This is a generalization. Variations of the staging system exist for each tumor site.

Theory

The biologic effectiveness of ionizing radiation in living tissue depends partially on the amount of energy that is deposited within the tissue and partially on the condition of the biologic system. The terms used to describe this relationship are *linear energy transfer* (LET) and *relative biologic effectiveness* (RBE).

LET values are expressed in thousands of electron volts deposited per micron of tissue (keV/μm) and vary depending on the type of radiation being considered. Because of their mass and possible charge, particles tend to interact more readily with the material through which they are passing and have a greater LET value. A 5-MeV alpha particle has an LET value of 100 keV/mm in tissue; nonparticulate radiations such as 250-kilovolt (peak) (kVp) x-rays and 1.2-MeV gamma rays have much lower LET values: 2.0 and 0.2 keV/mm.

RBE values are determined by calculating the ratio of the dose from a standard beam of radiation to the dose required of the radiation beam in question to produce a similar biologic effect. The standard beam of radiation is 250-kVp x-rays, and the ratio is set up as follows:

$$\text{RBE} = \frac{\text{Standard beam dose to obtain effect}}{\text{Similar effect using beam in question}}$$

As the LET increases, so does the RBE. RBE and LET values are listed in Table 30.6.

The effectiveness of ionizing radiation on a biologic system depends not only on the amount of radiation deposited but also on the state of the biologic system. One of the first laws of radiation biology, postulated by Bergonié and Tribondeau, stated in essence that the *radiosensitivity* of a tissue depends on the number of *undifferentiated* cells in the tissue, the degree of mitotic activity of the tissue, and the length of time that cells of the tissue remain in active proliferation. Although exceptions exist, the preceding is true in most tissues. The primary target of ionizing radiation is the DNA molecule, and the human cell is most radiosensitive during mitosis. Current research tends to indicate that all cells are equally radiosensitive; however, the manifestation of the radiation injury occurs at different time frames (i.e., acute versus late effects).

Because tissue cells are composed primarily of water, most of the *ionization* occurs with water molecules. These events are called *indirect effects* and result in the formation of free radicals such as OH, H, and HO_2. These highly reactive free radicals may recombine with no resultant biologic effect, or they may combine with other atoms and molecules to produce biochemical changes that may be deleterious to the cell. The possibility also exists that the radiation may interact with an organic molecule or atom, which may result in the inactivation of the cell; this reaction is called the *direct effect*. Because ionizing radiation is nonspecific (i.e., it interacts with normal cells as readily as with tumor cells), cellular damage occurs in normal and abnormal tissue. The deleterious effects are greater in the tumor cells; however, because a greater percentage of these cells are undergoing mitosis, tumor cells also tend to be more poorly *differentiated*. In addition, normal cells have a greater capability for repairing sublethal damage than tumor cells. Greater cell damage occurs to tumor cells than to normal cells for any given increment of dose. The effects of the interactions in either normal or tumor cells may be expressed by the following descriptions:

- Loss of reproductive ability
- Metabolic changes
- Cell transformation

- Acceleration of the aging process
- Cell mutation

TABLE 30.6

Relative biologic effectiveness and linear energy transfer values for certain forms of radiation

Radiation	RBE	LET
250-kV x-rays	1	2.0
^{60}Co gamma rays	0.85	0.2
14-MeV neutrons	12	75
5-MeV alpha particles	20	100

LET, Linear energy transfer; *RBE,* relative biologic effectiveness.

The greater the number of interactions that occur, the greater the possibility of cell death.

The preceding information leads to a categorization of tumors according to their radiosensitivity:

1. Very radiosensitive
   - Gonadal germ cell tumors (seminoma of testis, dysgerminoma of ovary)
   - Lymphoproliferative tumors (Hodgkin and non-Hodgkin lymphomas)
   - Embryonal tumors (Wilms tumor of the kidney)
2. Moderately radiosensitive
   - Epithelial tumors (squamous and basal cell carcinomas of skin)
   - Glandular tumors (adenocarcinoma of prostate)
3. Relatively radioresistant
   - Mesenchymal tumors (sarcomas of bone and connective tissue)
   - Nerve tumors (glioma)

As cellular function and the effects of radiation on the cell are increasingly understood, the use of drugs, or simply oxygen, to enhance the effectiveness of radiation treatments continuously prove advantageous.

Technical Aspects

External-Beam Therapy And Brachytherapy

Two major categories for the application of radiation for cancer treatment are external-beam therapy and brachytherapy. For *external-beam treatment*, the patient lies underneath a machine that emits radiation or generates a beam of x-rays. Most cancer patients are treated in this fashion. Some patients may also be treated with *brachytherapy*, a technique in which the radioactive material is placed within the patient.

The theory behind brachytherapy is to deliver low-intensity radiation over an extended period to a relatively small volume of tissue. The low-intensity isotopes are placed directly into a tissue or cavity, depositing radiation only a short distance, covering the tumor area but sparing surrounding normal tissue. This technique allows a higher total dose of radiation to be delivered to the tumor than is achievable with external-beam radiation alone. Brachytherapy may be accomplished in any of the following ways:

1. Mold technique—placement of a *radioactive* source or sources on or in close proximity to the lesion
2. Intracavitary implant technique—placement of a radioactive source or sources in a body cavity (i.e., uterine canal and vagina)
3. Interstitial implant technique—placement of a radioactive source or sources directly into the tumor site and adjacent tissue (i.e., sarcoma in a muscle)

Most brachytherapy applications tend to be temporary in that the sources are left in the patient until a designated tumor dose has been attained. Two different brachytherapy systems exist. They are *low-dose-rate* (LDR) and *high-dose-rate* (HDR). LDR brachytherapy has been the standard system for many years. A low-activity isotope is used to deliver a dose of radiation at a slow rate of 40 to 500 cGy per hour. This therapy requires that a patient be hospitalized for 3 to 4 days until the desired dose is delivered.

HDR systems are the current standard method of brachytherapy. This system uses a high-activity isotope capable of delivering greater than 1200 cGy per hour. The HDR system allows the prescribed dose to be delivered over minutes, which means this treatment can occur on an outpatient basis. Gynecologic tumors are one of the most common sites to be treated with HDR brachytherapy. HDR systems use a high-activity iridium-192 source.

Permanent implant therapy may also be accomplished. This is the most common type of LDR brachytherapy in practice today. An example of a permanent implant nuclide is iodine-125 and palladium-103 seeds. Permanent implant nuclides have relatively short *half-lives* of days and are indefinitely left in the patient. The amount and distribution of the radionuclide implanted in this manner depend on the total dose that the radiation oncologist is trying to deliver. Early-stage prostate cancer is commonly treated with this technique alone. In some cases of brachytherapy implantation, the implant is applied as part of the patient's overall treatment plan and may be preceded by or followed by additional external-beam radiation therapy.

Equipment

Most radiation oncology departments use linear accelerators (linacs) as their main treatment unit. Following are treatment units that may be found in a radiation oncology department:

- 120-kVp superficial x-ray unit for treating lesions on or near the surface of the patient
- 250-kVp orthovoltage x-ray unit for moderately superficial tissues
- ^{60}Co (cobalt-60) *gamma ray* source with an average energy of 1.25-MeV; Gamma Knife Unit
- 6-MV to 35-MV *linear accelerator* to serve as a source of high-energy (megavoltage) electrons and x-rays
- TomoTherapy
- CyberKnife
- Proton Therapy

The dose depositions of these units are compared in Fig. 30.1.

The penetrability, or energy, of an x-ray or gamma-ray totally depends on its wavelength: The shorter the wavelength, the more penetrating the photon; conversely, the longer the wavelength, the less penetrating the photon. A low-energy beam (≤120 kVp) of radiation tends to deposit all or most of its energy on or near the surface of the patient and is suitable for treating lesions on or near the skin surface. In addition, with the low-energy beam, a greater amount of absorption or dose deposition occurs in bone than in soft tissue.

A high-energy beam of radiation (≥1 MeV) tends to deposit its energy throughout the entire volume of tissue irradiated, with a greater amount of dose deposition occurring at or near the entry port than at the exit port. In this energy range, the dose is deposited about equally in soft tissue and bone. The high-energy (megavoltage) beam is most suitable for tumors deep beneath the body surface.

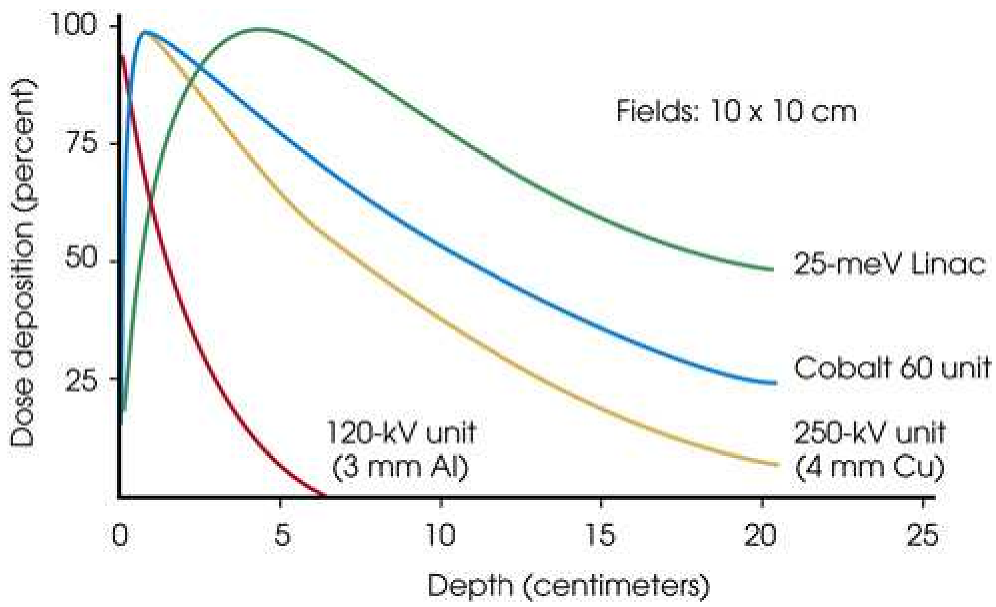


FIG. 30.1 Plot of percent of dose deposition in relation to depth in centimeters of tissue for various energies of photon beams.

The graph has dose deposition percent plotted on the vertical axis from 0 to 100 with and interval of 25 and depth in centimeter plotted on horizontal axis from 0 to 25 with an interval of 5. Three curves labeled as 25 mega electron volt linac, cobalt 60 unit, and 250 Kilovolt unit rises to a peak around 95 and then gradually falls. The curve labeled 120 kilovolt unit is a concave up falling curve. Note: All data is approximate.

The *skin-sparing* effect, a phenomenon that occurs as the energy of a beam of radiation is increased, is valuable from a therapeutic standpoint. In the superficial and orthovoltage energy range, the maximum dose occurs on the surface of the patient, and the deposition of the dose decreases as the beam traverses the patient. As the energy of the beam increases into the megavoltage range, the maximum dose absorbed by the patient occurs at some point below the skin surface. The skin-sparing effect is important clinically because the skin is a radiosensitive organ. Excessive dose deposition to the skin can damage the skin, requiring treatments to be stopped and compromising treatment to the underlying tumor. The greater the energy of the beam, the more deeply the maximum dose is deposited (Fig. 30.2).

Cobalt-60 units

The cobalt-60 (^{60}Co) unit was the first skin-sparing machine. It replaced the orthovoltage unit in the early 1950s because of its greater ability to treat tumors located deeper within tissues. ^{60}Co is an artificially produced *isotope* formed in a nuclear *reactor* by the bombardment of stable cobalt-59 with neutrons. ^{60}Co emits two gamma-ray beams with an energy of 1.17 and 1.33 MeV. The unit was known as a “workhorse” because it was extremely reliable, was mechanically simple, and had little downtime. It was the first radiation therapy unit to rotate 360 degrees around a patient. A machine that rotates around a fixed point, or axis, and maintains the same distance from the source of radiation is called an *isocentric machine*. All modern therapeutic units are isocentric machines. This type of machine allows the patient to remain in one position, lessening the chance for patient movement during treatment. Isocentric capabilities also assist in directing the beam precisely at the tumor while sparing normal structures.

Because ^{60}Co is a radioisotope, it constantly emits radiation as it *decays* in an effort to return to a stable state. It has a half-life of 5.26 years (i.e., its activity is reduced by 50% at the end of 5.26 years). Because the source decays at a rate of 1% per month, the radiation treatment time must be adjusted, resulting in longer treatment times as the source decays.

The use of ^{60}Co units has declined significantly since the 1980s, and ^{60}Co is rarely used for conventional external-beam radiation therapy today. This decline has been basically attributed to the introduction of the more sophisticated linac, which has greater skin-sparing capabilities and more sharply defined radiation *fields*. The radiation beam, or field, from a ^{60}Co unit also has large penumbra, which results in fuzzy field edges, another undesirable feature. ^{60}Co is still used in radiation oncology as part of a special procedure called stereotactic radiosurgery (SRS). The treatment unit is called the Gamma Knife. The Gamma Knife consists of 192 to 201 ^{60}Co sources arranged in a hemispherical array with all sources converging at a single point (Fig. 30.3). The point where the beams converge forms a treatment area of 4 to 18 mm in diameter.

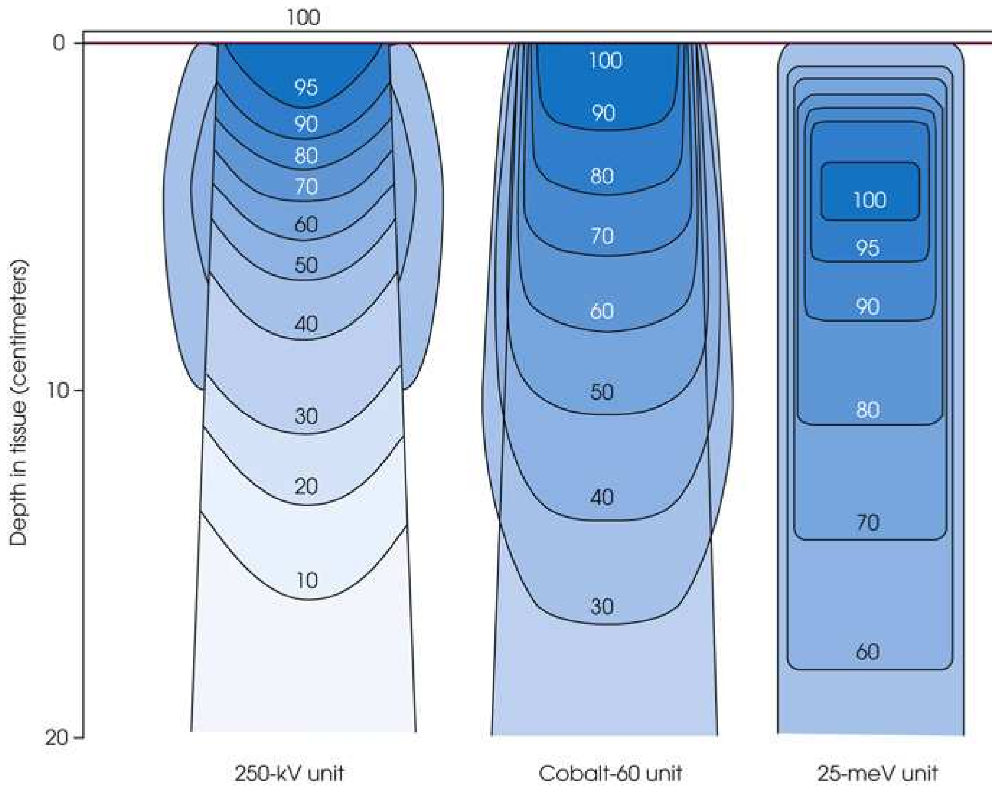


FIG. 30.2 Three isodose curves showing comparison of percent of dose deposition from three x-ray units of different energies. As the energy of the beam increases, the percentage of dose deposited on the surface of the patient decreases.

A graph has units scaled on the horizontal axis and depth in tissue (centimeters) scaled on the vertical axis. The vales in the vertical axis range from 0 to 20 with an interval of 10. The first isodose curve has the following values 10, 20, 30, 40, 50, 60, 70, 80, 90, 95, 100. The second isodose curve has the following values 30, 40, 50, 60, 70, 80, 90, 100. The third isodose curve has the following values 60, 70, 80, 90, 95, 100. The greater the energy of the beam, the more deeply the maximum dose is deposited.

The Gamma Knife is primarily used to treat small benign or malignant lesions located deep within the brain, employing an external rigidly fixed stereotactic head frame. The Gamma Knife does not involve surgery. It is called radiosurgery because the radiation is delivered in such a precise, focused manner that the lesion is ablated as if removed surgically. Adjacent normal tissues receive minimal radiation and are unharmed. The stereotactic head frame provides a coordinate system that allows the lesion to be three-dimensionally localized on MRI, CT scan, or angiography so that the radiation can be planned and targeted directly to the involved area. The Gamma Knife delivers a large dose of radiation in a single treatment to one or more areas in the brain. The types of conditions treated with the Gamma Knife include benign conditions such as acoustic neuromas, pituitary adenomas, arteriovenous malformations, and trigeminal neuralgia. Malignant lesions treated with the Gamma Knife include gliomas, meningiomas, chordoma, and solitary brain metastasis.

Gamma Knife radiosurgery has many advantages over conventional neurosurgery. First, the patient does not have to undergo an invasive surgical procedure. The procedure can be done as an outpatient or may require an overnight stay in the hospital. The Gamma Knife procedure requires no major recuperation period. The cost of Gamma Knife radiosurgery is much less than the cost of neurosurgery. The Gamma Knife is considered a very effective treatment for small intracranial lesions. One disadvantage of the Gamma Knife is that it can be used only for intracranial lesions. Another disadvantage is that the effects of radiation on the lesion are not immediate but occur over a period of weeks.

Linear accelerators

Linacs are the most commonly used machines for cancer treatment. The first linac was developed in 1952 and first used clinically in the United States in 1956. A linac is capable of producing high-energy beams of photons (x-rays) or electrons in the range of 4 to 35 million volts. These megavoltage photon beams allow a better distribution of dose to deep-seated tumors with better sparing of normal tissues than their earlier counterparts—the orthovoltage or ^{60}Co units.

The photon beam is produced by accelerating a stream of electrons toward a target. When the electrons hit the target, a beam of x-rays is produced. By removing the target, the linac can also produce a beam of electrons of varying energies.

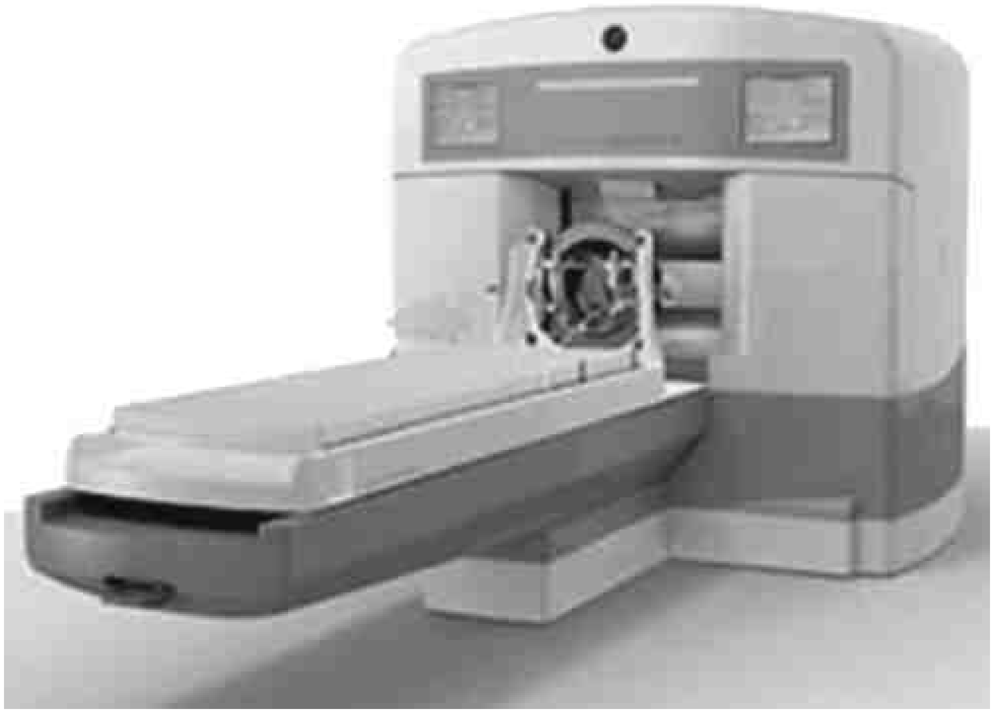


FIG. 30.3 Gamma Knife unit without a patient on the treatment table. From Washington CM, Leaver DT, eds. *Principles and practice of radiation therapy*, 3rd ed. St Louis: Mosby; 2010.

Typically, a linear accelerator is equipped with two photon energies consisting of one low-energy (6-MeV) and one high-energy (18-MeV) photon beam plus a range of electron energies (Fig. 30.4). The dual photon energy machine gives the radiation oncologist more options in prescribing radiation treatments. As the energy of the beam increases, so does its penetrating power. A lower energy beam is used to treat tumors in thinner parts of the body, whereas high-energy beams are prescribed for tumors in thicker parts of the body. A brain tumor or a tumor in a limb would most likely be treated with a 6-MeV beam; conversely, a pelvic malignancy would be better treated with an 18-MeV beam.

Electrons are advantageous over photons in that they are a more superficial form of treatment. Electrons are energy dependent, which means that they deposit their energy within a given depth of tissue and go no deeper, depending on the energy selected. An 18-MeV beam has a total penetration depth of 3.5 inches (9 cm). Any structure located deeper than 3.5 inches (9 cm) would not be appreciably affected. This is important when the radiation oncologist is trying to treat a tumor that overlies a critical structure.

FIG. 30.4 Radiation therapists shown aligning the patient and shielding block in preparation for treatment using a modern linac. X-ray beams of 6 to 25 million V may be produced to treat tumors in the body.

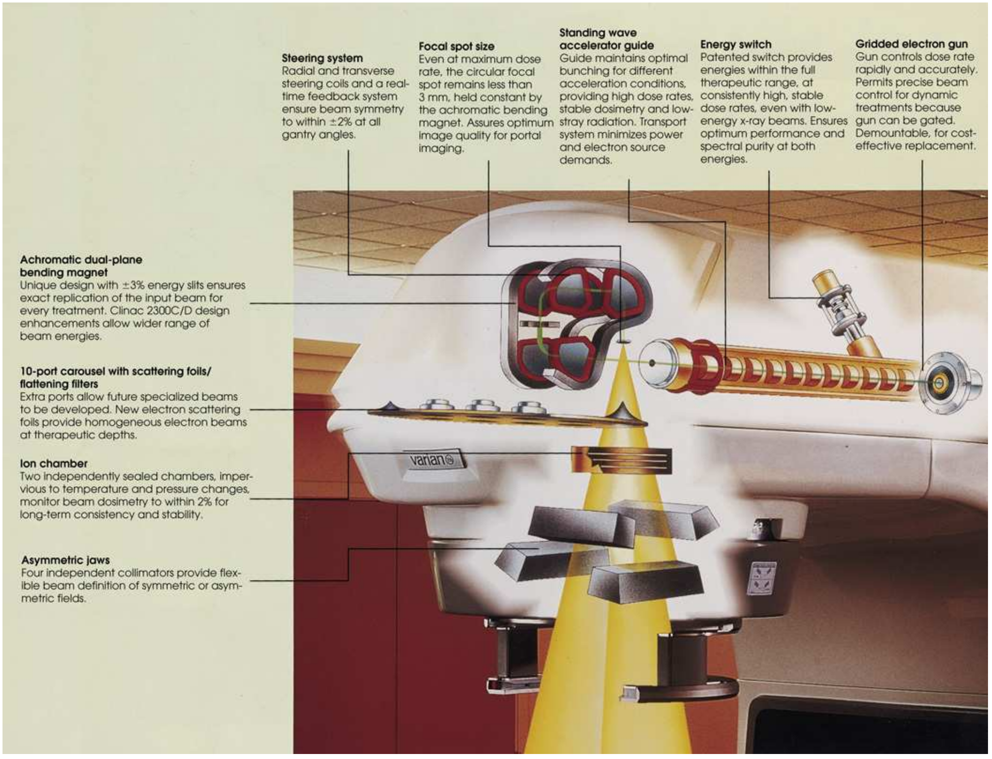


FIG. 30.5 Asymmetric jaws. Note the four independent collimators. Courtesy Varian Associates, Palo Alto, CA.

Diagram shows an x-ray machine. The parts labeled are as follows. 1. Steering system: radial and transverse steering coils and a real-time feedback system ensure beam symmetry to within 2 percent at all gantry angles. 2. Focal spot size: even at maximum dose rate, the circular focal spot remains less than 3 millimeter, held constant by the achromatic bending magnet. Assures optimum image quality for portal imaging. 3. Standing wave accelerator guide: guide maintains optimal bunching for different acceleration conditions, providing high dose rates, stable dosimetry and lowstray radiation. Transport system minimizes power and electron source demands. 4. Energy switch: patented switch provides energies within the full therapeutic range, at consistently high, stable dose rates, even with low energy x-ray beams. Ensures optimum performance and spectral purity at both energies. 5. Gridded electron gun: gun controls dose rate rapidly and accurately. Permits precise beam control for dynamic treatments because gun can be gated. Demountable, for cost-effective replacement. 6. Achromatic dual-plane bending magnet: unique design with 3 percent energy slits ensures exact replication of the input beam for every treatment. Clinac 2300 C over D design enhancements allow wider range of beam energies. 7. 10-port carousel with scattering foils or flattening filters: extra ports allow future specialized beams to be developed. New electron scattering foils provide homogeneous electron beams at therapeutic depths. 8. Ion chamber: two independently sealed chambers, impervious to temperature and pressure changes, monitor beam dosimetry to within 2 percent for long-term consistency and stability. 9. Asymmetric jaws: four independent collimators provide flexible beam definition of symmetric or asymmetric fields.

As with a diagnostic x-ray machine, the irradiated field of a linac is defined by a light field projected onto the patient's skin. This corresponding square or rectangle equals the length and width setting of the x-ray *collimators.* A modern linac is equipped with *asymmetric* (*independent*) *jaws;* this allows each of the four collimator blades that define length or width to move independently (Fig. 30.5). The jaw that defines the superior extent of the field may be 2.75 inches (7 cm) from the central axis, whereas the inferior region may be at 4 inches (10 cm). The total length would equal 6.75 inches (17 cm), but it is not divided equally because it is in a diagnostic x-ray collimator. The radiation oncologist is able to design a field that optimally covers the area of interest while sparing normal tissue. Independent collimation can also assist in reducing the total weight of lead shielding blocks generally constructed to protect normal tissues.

Multileaf collimation

Multileaf collimation (MLC) is the newest and most complex beam-defining system. Within the head of the linac, 45 to 80 individual collimator blades, about

$^3/_8$

to

$^3/_4$

inch (1 to 2 cm) wide, are located and can be adjusted to shape the radiation field to conform to the target volume (Fig. 30.6). The design of the field is digitized from a radiograph into a computer software program, which is transferred to the treatment room. The MLC machine receives a code that tells it how to position the individual leaves for the treatment field. Before MLC, custom-made lead blocks, or *cerrobend* blocks, were constructed to shape radiation fields and shield normal tissues from the beam of radiation. Heavy cerrobend blocks were placed within the head of the linac for each treatment field. Linacs equipped with the MLC package receive a custom-designed field at the stroke of a computer keyboard. Multileaf collimators are programmed to move across the radiation field during a treatment to alter the intensity of the radiation beam. Altering the beam intensity across the radiation field allows a lower dose to be delivered to normal structures and tissues and ensures the tumor or target receives the prescribed dose. This technique is called *intensity-modulated radiation therapy* (IMRT). IMRT allows the dose of radiation to be more tightly conformed to the target areas and has greatly reduced the dose to normal tissues and structures. IMRT is widely used and has replaced the conventional treatment field approach for most cancers, such as prostate and gynecologic cancers in the pelvis and cancers of the head and neck. IMRT can be used for any anatomical site.

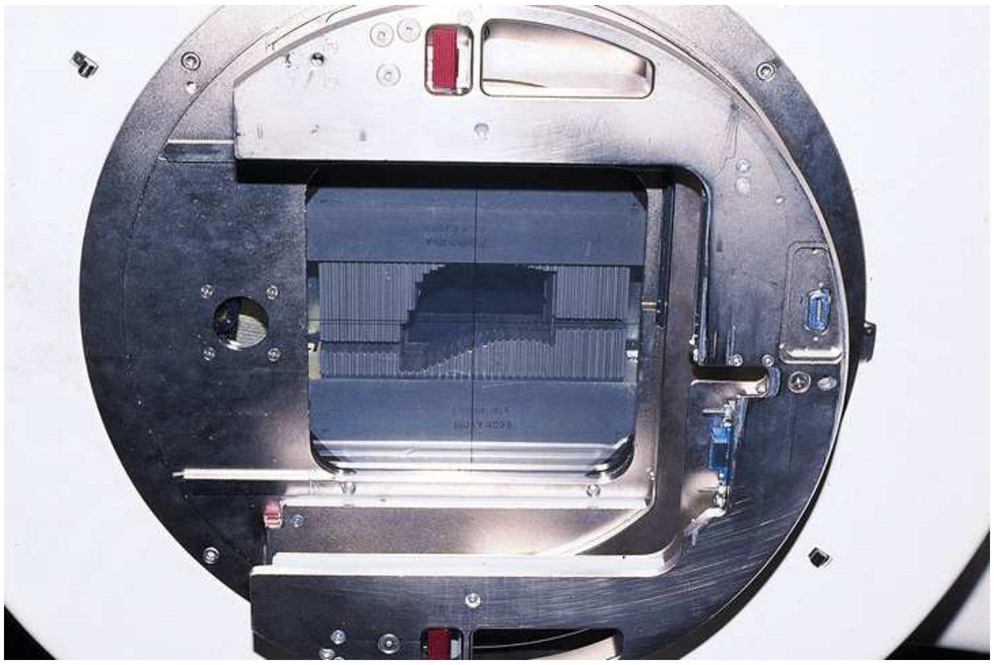


FIG. 30.6 Multileaf collimation system on the treatment head.

Steps in Radiation Oncology

Simulation

The first step of radiation therapy involves determining the volume of tissue that needs to be encompassed within the radiation field. This is done with a *CT simulator*. During simulation, the radiation oncologist uses the patient's CT images or MRI to determine the tumor's precise location and to design a treatment volume, or area. The treatment volume often includes the tumor plus a small margin, the draining lymphatics that are at risk for involvement, and a rim of normal tissue to account for patient movement.

Most centers perform virtual simulations using a CT scanner equipped with radiation oncology software tools (Fig. 30.7). CT simulation is to position the patient in a manner that is stable and reproducible for each of the prescribed radiation treatments, which can range from 1 to 68 treatments (most commonly 25 to 40). Therapists are responsible for constructing immobilization devices to help patients hold their position. It is crucial for a patient to hold still and maintain the same position. If the patient does not maintain the planned position, critical normal tissues may be irradiated, or the tumor may not be irradiated. Immobilization devices greatly assist the radiation therapist in correctly aligning the patient for each treatment, and many patients feel more secure when supported by these devices. Immobilization devices can be constructed for any part of the body but are most important for more mobile parts, such as the head and neck region or the limbs. Many different types of immobilization systems exist. Fig. 30.8 shows a thermoplastic device that secures the head and neck against rotation or flexion-extension. Fig. 30.9 shows a vacuum bag device that may be used to secure upper body or lower extremities.

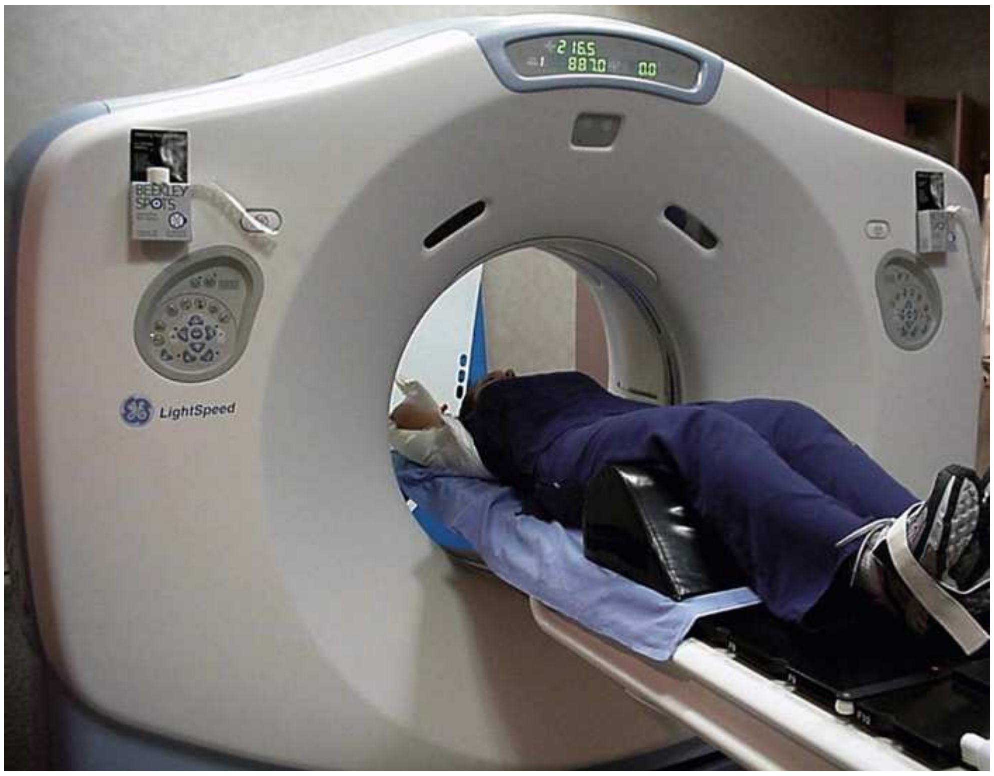


FIG. 30.7 CT simulator.

A patient is in a supine position on the treatment table in side the gantry. A support is placed under the knee to elevate the leg. The foot is strapped together. A digital screen is on top of the gantry.

FIG. 30.8 Aquaplast mask.

Contrast material is often administered before or during a simulation to localize the area that needs to be treated or to identify vital normal structures that are to be shielded. A small amount of meglumine diatrizoate (Gastrografin or Gastroview) for CT simulation is injected into the rectum of a patient with rectal cancer to assist in localizing the rectum on the simulation images. Contrast material in the bladder is used to assist in localizing the prostate gland, which lies directly inferior to the bladder. Rectal contrast material is used to show the relationship of the rectum to the prostate to monitor and minimize the dose the rectum receives (Fig. 30.10).

When a CT simulation is performed, a reference isocenter is marked on the patient, and a pilot or scout scan is obtained. The radiation oncologist uses the scout or pilot image to determine the superior and inferior extent of the area to be scanned. The CT data are transferred to the virtual simulation computer workstation. From this limited scan, the physician reviews the CT images and uses imaging tools to outline the target volume and critical normal structures. The physician establishes the actual treatment isocenter. The computer software determines the change in location from the coordinates associated with the reference marks to the newly established treatment isocenter. The radiation therapist adjusts the couch and uses the laser marking system to apply these shifts to mark the treatment isocenter on the patient. The radiation therapist records all details regarding the patient's position in the treatment chart, and the patient is dismissed.

The physician, physicist, or dosimetrist create treatment fields (length and width) electronically with the CT virtual simulation software (Fig. 30.11). The CT simulation data are transferred to the treatment planning system. In complex cases, the physician communicates preferences for treatment goals to the dosimetrist, who then designs the beam's eye view treatment fields and beam arrangement as part of the three-dimensional planning. A digitally reconstructed radiograph (DRR) for each treatment field is produced. The DRR is analogous to the radiograph taken in the conventional simulator (Fig. 30.12).

Precise measurements and details about the field dimensions, machine position, and patient positioning are recorded in the treatment chart. In some centers, the treatment parameters, such as field length, width, couch, and gantry positions, are electronically captured and transferred to the treatment unit. Recording of this information is crucial so that the radiation therapist performing the treatment can precisely reproduce the exact information.

FIG. 30.9 Vacuum bag immobilization device.

FIG. 30.10 CT simulation digitally reconstructed radiograph of standard PA field. From Washington CM, Leaver DT, eds. *Principles and practice of radiation therapy*, 4th ed. St Louis: Mosby; 2016.

FIG. 30.11 Virtual CT simulation. Note divergent radiation beam lines indicating the path of the beam. Target volume, kidneys, and spinal cord have been outlined on CT axial image and reconstructed sagittal and coronal images. Treatment field outline is seen on DRR and coronal image.

A C T image on the top left shows the chest. The vertebrae appear radiopaque. A C T image on the top right shows the section of the abdomen. A C T image at the bottom left shows the abdomen. A C T image at the bottom right shows the lateral view of the spine. The kidneys, and spinal cord have been outline in red.

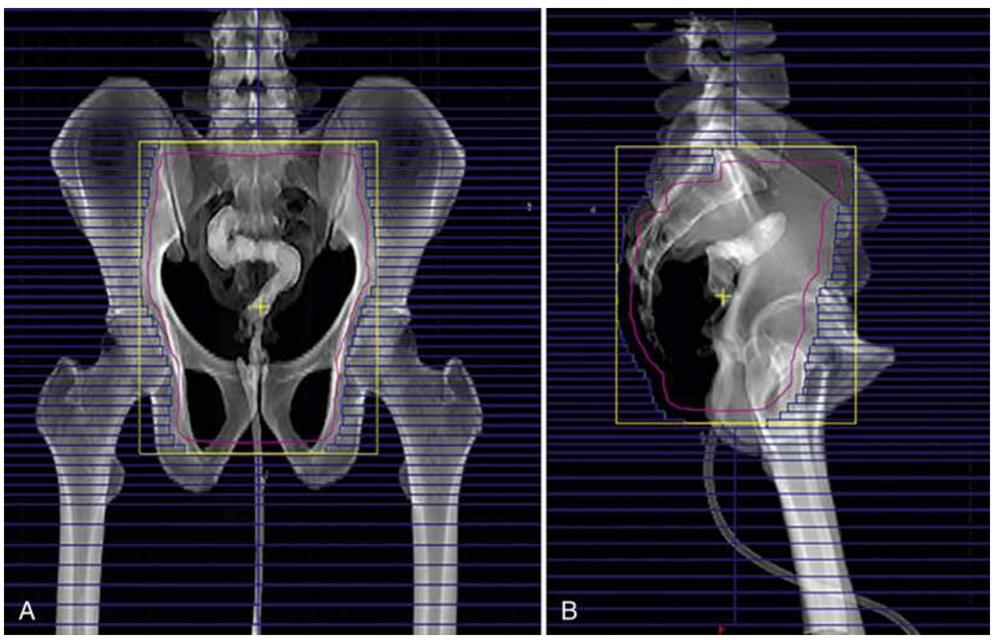


FIG. 30.12 DRR PA (A) and lateral (B) pelvis with rectal contrast. Note outline of treatment field.

A radiographic image on the left shows the pelvis. The bones appear grey. The pelvic area is marked inside a box. A radiographic image on the right shows the lateral view of the pelvis and rectum. They appear white. It is marked inside a box.

Dosimetry

Dosimetry refers to the measurement of radiation dose, and it shows how the radiation is distributed or *attenuated* throughout the patient's body (absorbing medium). The dosimetrist devises a treatment plan that best fulfills the physician's prescription for the desired dose to the *tumor/target volume* while minimizing the amount of radiation to critical normal structures or tissues.

Each organ of the body has a tolerance dose to radiation that limits the amount it can receive and still function normally. If an organ receives an excess of the tolerance dose, the organ can fail, resulting in a fatal complication. The kidneys are among the more radiosensitive structures of the body (Table 30.7). A dose greater than 2500 cGy can result in fatal radiation nephritis. The spinal cord has a higher tolerance dose, but many tumors require even higher doses for treatment to be effective.

Precise localization of dose-limiting structures and their relationship with the target volume is crucial for adequate planning. The dosimetrist must devise a plan that delivers a homogeneous dose to the tumor, while not exceeding the tolerance dose of a specific organ. This task can be quite challenging. The radiation oncologist might prescribe 6000 cGy to treat lung cancer located in the mediastinum directly over the spine but must limit the spinal cord dose to 4500 cGy to prevent irreparable damage, which could result in paralysis. The dosimetrist must devise a plan that enables combined treatment and protection to be accomplished.

TABLE 30.7

Tolerance doses to radiation

Structure	Tolerance dose (cGy)
Testes	500
Ovary	500
Lung (whole lung)	1800
Kidney (whole organ)	2300
Liver (whole organ)	3000
Spinal cord (5 cm^3)	4500

Historically, the first step in dosimetry is to obtain a contour or CT scan of the patient in treatment position. A *contour* is an outline of the external surface of the patient's body at the level of the central axis (center of treatment field). This contour is typically performed in the transverse plane, but other planes may be used. Then the tumor volume and critical dose-limiting internal structures are transferred from the simulation radiographs and drawn onto the contour. CT scans from a CT simulator are almost exclusively used today rather than contours. With CT scanning, the tumor and internal structures and their relationships are directly visible. These images are interfaced with the treatment planning computer system for development of the plan.

PET and MRI with the patient in treatment position are also obtained sometimes to facilitate the planning process. Fusion of MRI or PET images onto the CT simulation data set allows a more precise delineation of the tumor volume than what would be seen on CT alone. To obtain an even distribution of radiation to the target volume, radiation is delivered from various angles focused on the area of interest. Three-dimensional treatment planning allows for the design of a beam that exactly conforms to the shape of the tumor at any plane within the body. The treatment planning system can digitally reconstruct the anatomy, which allows the dosimetrist to manipulate the image to view the tumor from any angle or plane. Important critical anatomic structures such as the kidneys and spinal cord are also more readily identified. Such a system allows the dosimetrist to plan and design beams that are coplanar and noncoplanar, tightly conforming to the target or tumor volume. This is known as *three-dimensional conformal radiotherapy* (CRT). The beam's eye view obtained by three-dimensional beams allows higher doses of radiation to be administered more safely by treating the cancer through multiple fields (more than four) on different planes, which reduces the amount of dose that normal tissues receive (Fig. 30.13).

The standard approach for a tumor located in the pelvis, such as rectal cancer, is the use of three fields—posteroanterior (PA), right lateral, and left lateral. Using the treatment parameters established in the simulator, the dosimetrist enters this information into the treatment planning system, designs beam's eye view conformal fields, and obtains an isodose distribution, which shows how the radiation is being deposited. An *isodose line/curve* is a summation of areas of equal radiation dosage and may be stated as percentages of the total prescribed dose or as actual radiation dosages in *gray* (Gy) units.

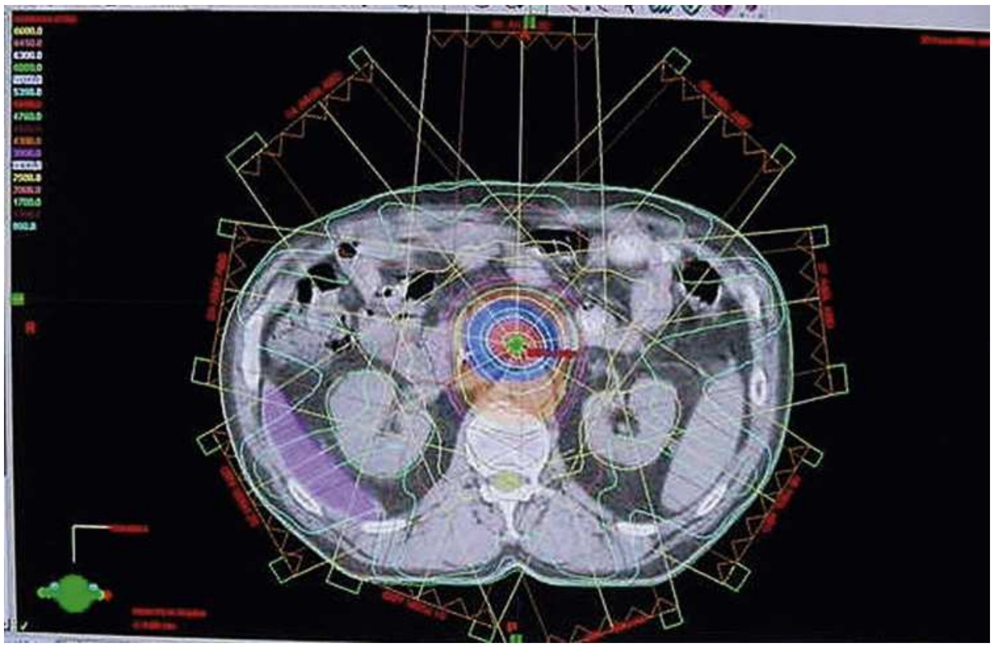


FIG. 30.13 Dosimetry plan showing nine different radiation fields used to treat pancreatic tumor.

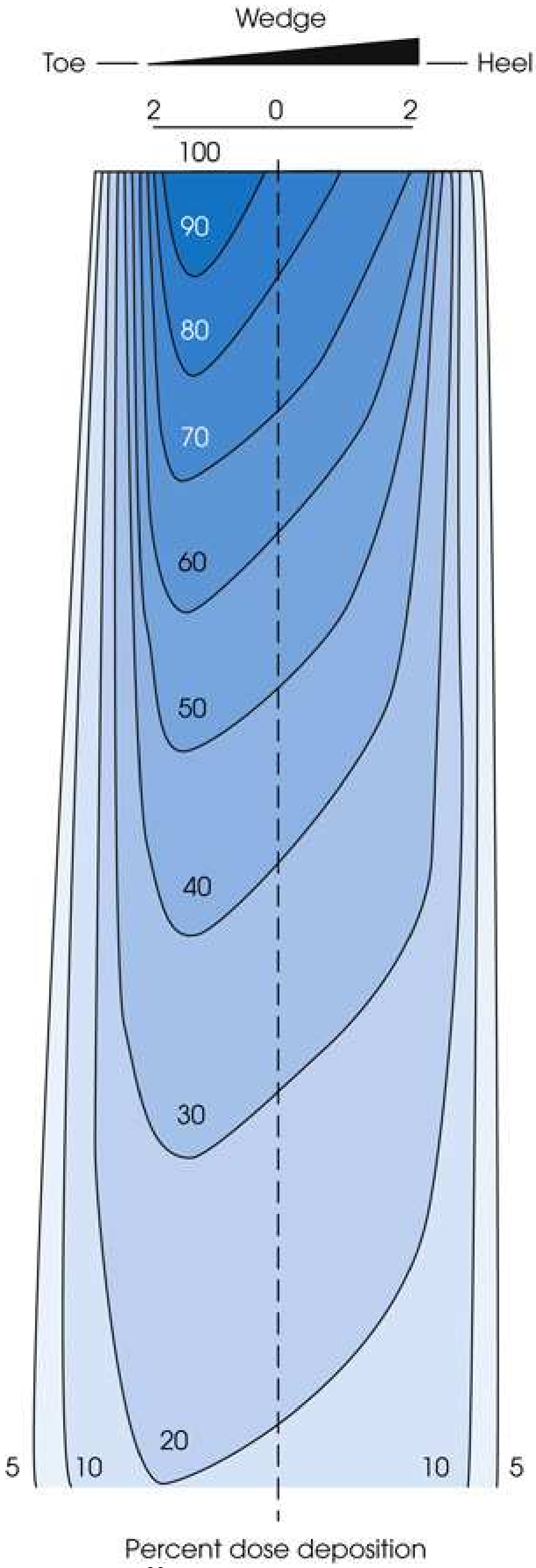


FIG. 30.14 Isodose curve obtained from ^{60}Co unit, with wedge placed between the source and absorbing material.

A wedge is placed on top between the toe and the head. A horizontal line with values 2, 0, 2 is on top of a isodose curve. A dotted lines divides the isodose curve into two halves. The values in the isodose curve on the left are 5, 10, 20, 30, 40, 50, 60, 70, 80. 90, 100.

The dosimetrist optimizes the plan by eliminating any areas of dose inhomogeneity (e.g., hot spots). A *hot spot* is an area of excessive radiation dose. One method to adjust for hot spots is to add a *wedge filter*. This wedge-shaped device is made of lead and is placed within the radiation beam to absorb the radiation preferentially, altering the shape of the isodose curve (Fig. 30.14). Another method of reducing hot spots is to change the weighting of the radiation beams by delivering a greater dose of radiation from a particular field (i.e., the anterior field than from the posterior field.

Another major task of the dosimetrist is to monitor the dose that critical structures are receiving and to keep the dose within the established guidelines dictated by the physician. To avoid treating the spinal cord in the aforementioned example, the dosimetrist may angle the entry points of the radiation beams to include the target volume while not irradiating the spinal cord. The resultant fields might be right anterior oblique and left posterior oblique (RAO/LPO) fields. The dosimetrist evaluates the dose distribution after each modifier is added and looks at different combinations of wedges, beam weighting, and beam entry points until an acceptable plan is produced. This technique is called *forward planning*. The final plan directs the radiation therapist, who treats the patient, how to proceed. For the example presented previously (i.e., lung cancer in the mediastinum directly over the spine), the plan might consist of the following specifications:

1. Deliver 25 treatments anteroposterior (AP) and PA fields, RAO and LPO, 30 degrees off vertical.
2. Reduce field size to 12 cm long; deliver five more treatments AP, PA, RAO, and LPO, 30 degrees off vertical.

When the plan is complete, treatment of the patient can begin.

Another type of three-dimensional treatment planning is IMRT. The planning process begins as previously described—the physician identifies target volume and critical structures. Treatment fields are designed and arranged so that the target receives the prescribed dose, and the dose to critical structures is limited. The optimization of the dose distribution is not done, however, by trying different combinations of wedges or dose weighting as in conventional forward planning. IMRT uses a method called *inverse planning*. The prescribed dose to the target and the dose limit assigned to each critical structure are entered into the inverse planning system. A sophisticated mathematic algorithm creates a dose distribution that conforms to the target area while sparing critical normal structures. This is achieved by modifying the intensity of radiation within the treatment field and moving the individual leaves of the multileaf collimator across the radiation field during a treatment from open to closed position, modulating the intensity of a beam to obtain the desired dose. The plan is computed by dividing the treatment field beam into hundreds of beamlets. Each beamlet can have an intensity level that measures from 0% to 100%. The intensity of a beamlet is changed by maintaining the multileaf collimator open at a certain position for a specific amount of time and then closing it.

The IMRT planning process is time intensive and requires a comprehensive physics quality assurance check of multileaf collimator movement and dose verification before treatment is administered for the first time. IMRT has proven to be better at minimizing the dose to normal structures than conventional three-dimensional CRT and has allowed higher doses to be delivered to the target or tumor volume. IMRT was initially used for prostate cancer and cancers of the head and neck region. In prostate cancer treatment, IMRT optimized the dose to the prostate, while substantially minimizing the dose to the rectum and bladder. When treating cancer in the head and neck region (e.g., nasopharynx), IMRT significantly reduced the dose to the parotid gland and spinal cord. IMRT is also used in the treatment of brain tumors, gastrointestinal, gynecologic, lung, breast, and soft tissue sarcomas.

The advantages of IMRT are well known—a method to deliver a highly conformal dose of radiation to the tumor while reducing the dose received by normal tissues. One disadvantage of IMRT is the total time it takes to deliver the daily session of radiation therapy. A patient with head and neck cancer might be on the table for 30 minutes each day to deliver radiation from 10 to 18 different radiation fields. The patient might move between or during the time the radiation beam is on. A new method of delivering IMRT treatment called volumetric modulated arc therapy (VMAT) has been developed. This method involves the linac rotating around the patient while the radiation beam is on and while the MLC leaves are dynamically moving for the IMRT delivery. With VMAT, the dose to the target and normal tissues is customized by altering the speed of the rotation, altering the dose rate of the linac, and simultaneously moving the MLC leaves. VMAT results in the delivery of the same highly conformal dose to the target while sparing normal tissues but in about half the time of a traditional IMRT stationary field technique. VMAT is also being used for prostate, lung, gynecologic, gastrointestinal, breast, and brain cancers. VMAT is widely utilized and is a very common form of treatment delivery and has replaced standard IMRT in many cases.

Treatment

On completion of the planning stage, including simulation and dosimetry, patient treatment can begin. The radiation therapist positions the patient and aligns the skin marks according to what was recorded in the treatment chart at the time of simulation. Accuracy and attention to detail are crucial for precise administration of the radiation to the patient. The radiation therapist is responsible for interpreting the radiation oncologist's prescription and calculating the correct monitor units to achieve a desired dose of radiation for each treatment field. This responsibility also involves recording the daily administration of the radiation and the cumulative dose to date.

Precision in positioning the machine, proper selection of treatment field and MLC, accurate placement of cerrobend blocks or wedges, and implementation of any change in a patient's treatment plan are crucial for ensuring optimal treatment. Failure to do any of these may result in an overdose to normal tissue, causing long-term side effects, or underexposure of the tumor, reducing the patient's chance for cure. Most radiation oncology departments use an electronic radiation oncology medical record and computer verification system that ensures a patient's treatment parameters are correct before treatment may begin. The complexity of three-dimensional CRT, IMRT, and VMAT treatments with the numerous positions of the treatment couch, gantry, or collimator necessitates the use of a verification system. The computer verification system compares the machine settings with the information in the patient's electronic radiation chart. If there is a mismatch between any of the parameters in the electronic chart and what is being set up for treatment, the radiation therapist would be unable to initiate treatment. When a mismatch occurs, a computer prompt appears, highlighting the areas of disagreement. The radiation therapist must double-check parameters and patient setup, making corrections before treatment may occur. The verification and record system also records and adds the cumulative radiation doses.

Almost all linacs are now equipped with electronic portal imaging devices (EPIDs) and a kilovolt (kV) imager. These retractable imaging devices produce digital images that are displayed immediately on a computer screen adjacent to the linac computer console. The EPID imager uses the 6-MV beam of the linac to obtain an image. Most radiation oncology departments have linacs equipped with a kV x-ray tube and flat panel image detector in addition to EPID. The kV imager, called an onboard imager (OBI), provides a better diagnostic quality image with improved skeletal to soft tissue contrast compared with the megavoltage EPID imagers. These images can be viewed before treatment, and adjustments can be made to the table or patient position before delivering radiation, ensuring accurate and precise treatment. Most systems have computer software that compares the CT simulation image with the EPID or kV image using a registration algorithm. The computer automatically calculates the necessary adjustments (e.g., shift in couch position) to be made. The radiation therapist makes the adjustments and begins treatment.

When this treatment is used in cases of prostate cancer, gold seed markers are injected into the prostate gland before simulation. After the CT simulation is performed, the patient's treatment plan is completed, and treatment begins. The radiation therapist positions the patient, aligns the treatment machine, and takes an anterior and lateral or oblique kV image. The images are analyzed, and the computer generates any necessary shifts. These adjustments in couch or collimator position are made before initiating treatment. This process is done daily. Many treatment systems or situations also require the radiation therapist to analyze the kV images, compare skeletal anatomy to CT simulation DRR, and make adjustments to the couch position before treating the patient (Fig. 30.15).

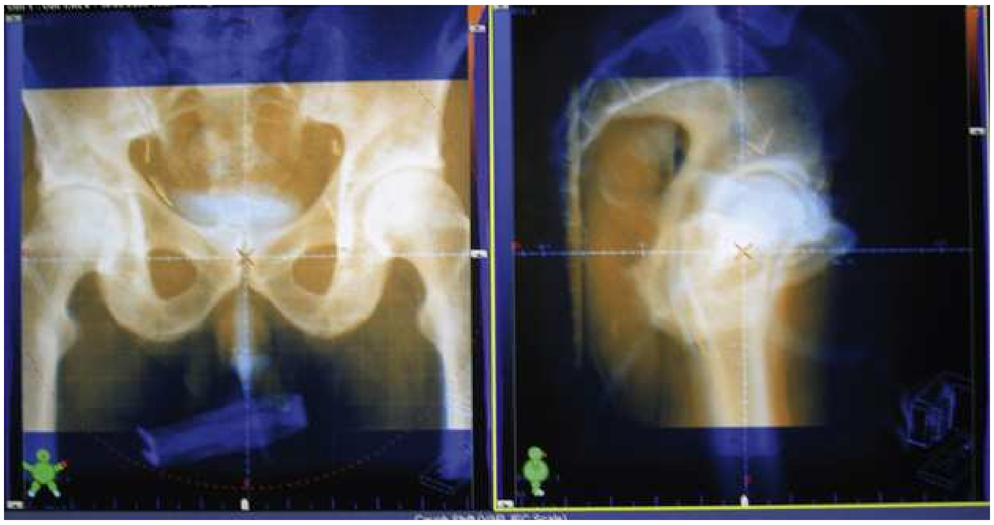


FIG. 30.15 OBI kV image overlaid on CT DRR; therapists shift couch to match skeletal anatomy.

A radiographic image on the left shows the pelvis. The bones appear yellow. A radiographic image on the right shows the lateral view of the femur joint. The bones appear yellow and the joint region appears radiopaque.

If the patient has been positioned correctly, why do these changes or errors in the treatment field position occur? Patient movement during treatment has always been a major constraint in providing accurate and precise delivery of radiation treatments. Improvements in immobilization devices have been made; however, they do not prevent internal organ movement. The prostate may move and be in a different position within the treatment field from day to day or even during treatment because of the filling of the rectum or bladder. Tumor or organ movement can also occur because of normal respiration. This movement can result in a geographic miss of the tumor or irradiation of critical normal structures.

Because movement of internal structures does occur, many technologic innovations are being developed to address this issue. Obtaining daily kV or EPID images before treatment is one method. The process of using images such as EPID, kV, to verify the treatment field position daily before treatment is known as *image-guided radiation therapy* (IGRT). Other methods of IGRT involve the use of a CT scan, an infrared camera system, or a sophisticated tracking system that uses two x-ray tubes mounted 90 degrees apart. In addition, there are two newly developed treatment units, TomoTherapy and the CyberKnife, which combine IGRT and innovative treatment delivery. These various IGRT methods are discussed subsequently.

The use of a CT scan before treatment as a means of IGRT is very common. A CT scan is obtained with the patient in treatment position immediately before treatment to verify target, isocenter, and patient position. This method is accomplished in one of two ways. One approach is to equip the linac with a kV x-ray tube and panel detector that obtains a cone-beam CT image when the accelerator gantry rotates a complete 360 degrees. The kV x-ray tube also provides a means of obtaining diagnostic quality images for treatment and patient position verification as previously discussed (Fig. 30.16). Another technique is using the linac's megavoltage beam and EPID imager to acquire a cone-beam CT image. The cone-beam CT image is obtained in the same fashion by rotating the linac 360 degrees. The kV cone-beam CT image provides better contrast and soft tissue delineation than megavoltage CT and has proved advantageous to evaluate rectum or bladder filling consistency for prostate patients. The megavoltage CT images are of a high enough quality to compare target position and related bony anatomy to determine if any adjustments in patient or couch position are necessary before treatment. Another method of CT image guidance is having a CT scanner located in the actual treatment room opposite the linac, near the foot end of the treatment couch. The scanner can be moved into position to obtain a CT scan with the patient positioned for treatment. The most common method is the use of the linac to obtain a cone-beam CT image.

The infrared camera is a complex system that detects respiratory motion during simulation and treatment. This is a technique called *respiratory gating*. A reflective marker box is placed on the external surface of the patient's abdomen during simulation. The infrared camera detects the marker box, and a special computer software program connected to the infrared camera monitors the marker box movement (Fig. 30.17). The movement of the reflective marker is correlated with the patient's diaphragm position during the CT simulation. The respiratory cycle is evaluated relative to the treatment target volume and diaphragm movement. A specific portion of the respiratory cycle that has the least amount of motion is selected as the gated interval. This information is saved as a tolerance or standard to use during treatment. When the patient is treated, the reflective marker box is placed on the same place on the abdomen, and an infrared camera is used to monitor the movement of the box. Pretreatment portal images (AP and lateral) to verify patient position, isocenter location, and gating interval are obtained with the EPID or kV imager. When approved, the radiation therapist initiates treatment. The respiratory gating computer monitors the marker box movement and automatically turns off the radiation beam if the marker moves out of the acceptable gated interval. Treatment automatically begins again when the marker box returns to the acceptable position. Respiratory gating has been done in various ways. One method is to have patients breathe freely, whereas another method is to have patients exhale and hold their breath.

FIG. 30.16 Linac equipped with kV x-ray tube and flat panel detector. EPID is extended underneath the patient.

A patient is in a supine position on the radiographic table with both his arms resting on his chest. The legs are elevated by placed a support under the knee. An x-ray tube is placed next to the table.

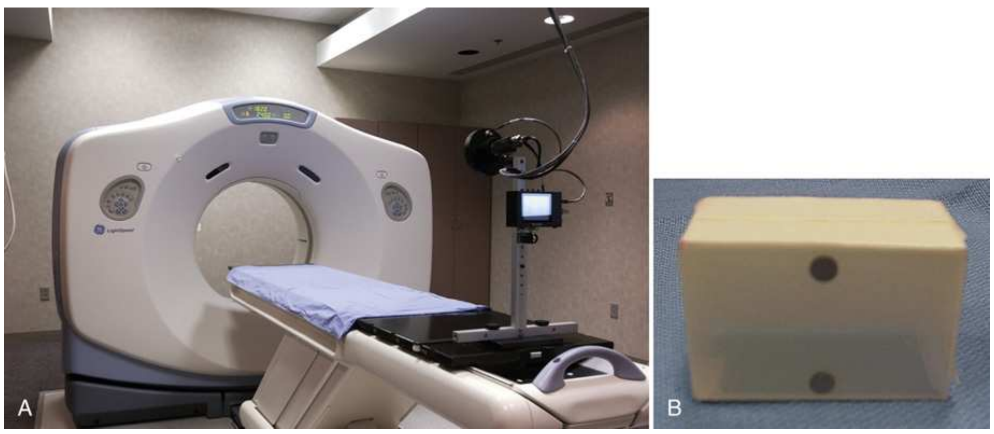


FIG. 30.17 (A) Infrared camera system attached to CT simulator. (B) Reflective marker box.

The ExacTrac by Brainlab AG (Heimstetten, Germany) is a system that uses two kV x-ray tubes mounted in the floor 90 degrees apart that project a beam at 45-degree angles to the patient through the linac isocenter. The flat panel detectors are located in the ceiling. This sophisticated system is able to analyze the stereoscopic images and compare bony anatomy or implanted fiducial markers with the digital radiographs from simulation. The computer system calculates shifts in six dimensions rather than using the typical three-dimensional imaging. When the radiation therapist has acknowledged the recommended shifts, the information is sent to the robotic couch, and the adjustments are made automatically from outside the treatment room. The ExacTrac system may be used to take images anytime during treatment for real-time tracking of target motion during treatment as in respiratory gating. ExacTrac is commonly used for the treatment of head and neck cancers, prostate cancer, lung cancer, and small centrally located brain tumors and for stereotactic radiation therapy (SRT).

SRT is similar to SRS in that the area being treated is small and surrounded by critical structures. The difference is that SRS is a large dose delivered in one treatment and is typically used for intracranial lesions. SRT is a conventional dose delivered in a fractionated manner using very focused small beams while the patient is rigidly immobilized. This technique is typically for intracranial lesions. SRT has been expanded to include tumors within the body. The treatment involves delivering larger doses of radiation per treatment than conventional treatment with a smaller number of total treatments. A patient may receive only one to five total treatments, but the dose may be similar to that of conventional treatment. This new technique is called stereotactic body radiation therapy (SBRT). SBRT is being used for small lesions in the lung, liver, pancreas, other bone metastasis, spine patients who cannot undergo surgery, and more recently, prostate patients.

FIG. 30.18 TomoTherapy Hi-Art imaging and treatment system, which uses a megavoltage source for CT and for treatment. Courtesy TomoTherapy Incorporated. From Washington CM, Leaver DT, eds. *Principles and practice of radiation therapy*, 3rd ed. St Louis: Mosby; 2010.

TomoTherapy

TomoTherapy is a treatment unit developed at the University of Wisconsin in 2001 and first treated patients clinically in 2004, providing precise and conformal radiation treatment. The system delivers radiation slice by slice ("tomo"), combining the principles of helical CT scanning with a 6-MV linac and is one of the first devices capable of providing daily image guidance. The TomoTherapy unit contains a CT scanner geometry with a detector system originally utilizing KV imaging; however, current models only use MV imaging. The 6-MV gantry rotates in a continuous full circle while the couch and patient simultaneously move slowly through the aperture of the machine (Fig. 30.18). The TomoTherapy unit is equipped with computer-controlled multileaf collimators that move to modulate the radiation beam intensity. TomoTherapy provides IMRT in a helical pattern delivering highly conformal radiation to the specific prescribed anatomic regions, while sparing normal structures. Before initiating treatment, megavoltage CT of the patient is obtained and is compared against the initial CT image used in treatment planning to verify patient position. Any necessary shifts to match isocenter location are made before treatment is delivered. Tomotherapy is an excellent routine application for sites such as prostate, head and neck, and brain.

CyberKnife

The CyberKnife (Accuray Inc., Sunnyvale, CA) is an SRS system that uses continuous image guidance for delivering radiation treatments with sub-millimeter precision. The treatments are delivered in a single fraction or in two to five fractions termed hypofractionated radiotherapy. The CyberKnife is a 6-MV linac housed within a robotic arm containing six different joints, or axes, that allow thousands of beam angle options from essentially any direction around the patient (Fig. 30.19), providing excellent tumor coverage with steep dose fall-off outside of the target. The beams are collimated to range in diameter from 5 to 60 mm, allowing dose to conform tightly to the target while sparing normal surrounding tissue, thereby achieving higher doses safely.

FIG. 30.19 Accelerator on a robotic arm. Two ceiling-mounted x-ray tubes are clearly shown. From Washington CM, Leaver DT, eds. *Principles and practice of radiation therapy*, 3rd ed. St Louis: Mosby; 2010.

The image guidance system consists of two diagnostic x-ray tubes mounted in the ceiling at 45-degree angles, offset 90 degrees from one another with two opposing amorphous silicon detectors located in the floor. The imaging system continually takes a set of images at each treatment angle and analyzes the images during treatment to track target and patient motion. The robotic arm is automatically adjusted to correct for any motion it detects, resulting in treatment times that range from 30 to 90 minutes. CyberKnife was the first system to use real-time tracking of target motion during treatment and is used to treat cancers of the lung, pancreas, brain, head and neck, spine, and prostate.

Proton Therapy

The first use of a proton beam was in 1954 at the University of California in Berkeley; however, owing to the complexity, cost, and size of a cyclotron or synchrotron facility, protons were not widely implemented at that time but are increasingly common today with over 30 proton centers in the United States. Characteristic properties of the proton beam create dosimetrical advantages that allow treatment for challenging tumors, such as higher doses to volumes adjacent to critical structures and for nonresectable volumes in patients that are not ideal surgical candidates. Protons are especially useful for patients with recurrences or secondary malignancies in which specific organs at risk have been previously irradiated; therefore, the patients have lower radiation thresholds. Therapeutic proton energies range between 70 and 250 MeV, which deposit minimal scatter and little energy as the beam first traverses tissue as it enters the body (termed entrance dose). In a uniform medium, monoenergetic protons will increasingly lose energy as they slow down before coming to a stop and depositing their dose at the predetermined depth.

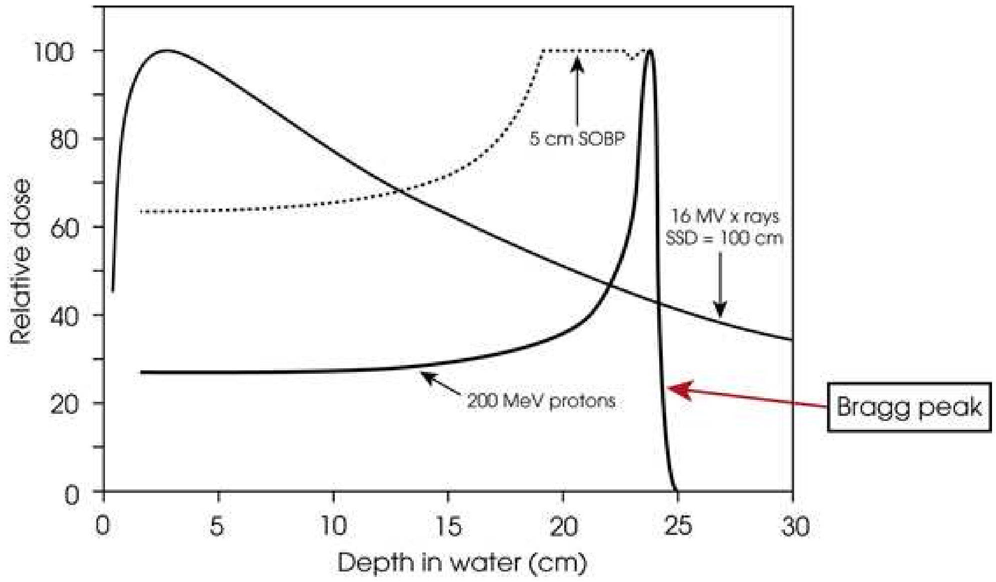


FIG. 30.20 Depth-dose curves for a 200-MeV proton beam: both unmodulated and with a 5-cm spread-out Bragg peak *(SOBP)*, compared with a 16-MV x-ray beam (for 10 × 10 cm^2 fields). The curves are normalized in each case to 100 at maximum dose. Adapted from Jones DTL. Present status and future trends of heavy particle radiotherapy. In: Baron E, Lieuvin M, eds. *Cyclotrons and their applications 1998*. Bristol: Institute of Physics Publishing; 1999:13–20.

A graph has relative dose plotted on the vertical axis plotted from 0 to 100 with an interval of 20 and depth in water in centimeters is plotted on horizontal axis from 0 to 30 with an interval of 5. A curve labeled 200 mega electron volt rises to a peak and falls steeply which is labeled as Bragg peak. Another curve labeled 16 M V x rays S S D equals 100 centimeter rises steeply and falls gradually. A dashed curve labeled 5 centimeter S O B P is a concave up increasing curve. Note: All data is approximate.

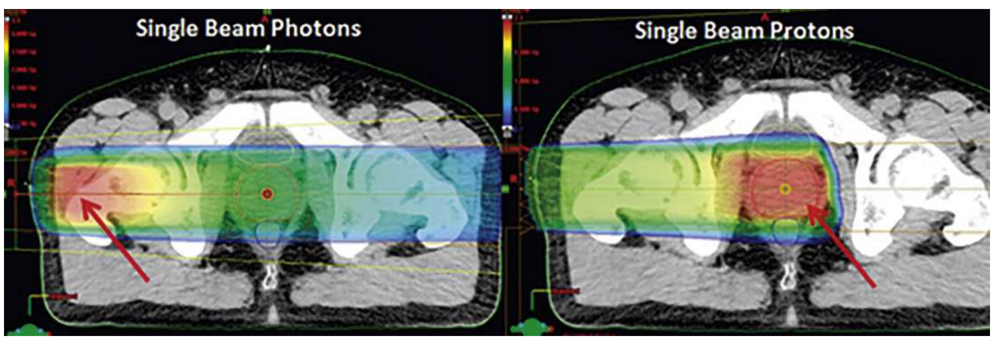


FIG. 30.21 Single beam photon compared to single beam of protons. Note no exit dose and sparing of normal tissues with proton beam. From Washington CM, Leaver DT, eds. *Principles and practice of radiation therapy*, 4th ed. St Louis: Mosby; 2016.

Two radiographic image titled single beam protons shows a multicolored beam entering and exiting the first image. The red colored region is marked by a red arrow. There is no exit beam in the second image. The red colored region in the middle is marked by a red arrow.

This burst of energy deposited at a specific depth is termed the *Bragg peak* (Fig. 30.20). The depth at which this peak dose deposition occurs can be adjusted by changing the energy of the proton beam and adding beam modifiers. The proton beam can be precisely controlled to deliver the Bragg peak dose at a prescribed depth providing the principle advantage of sparing surrounding normal tissues at risk. The rapid fall-off of the beam allows treatment of the tumor volume while sparing critical structures located within millimeters of the target (Fig. 30.21).

Proton therapy units can have various treatment unit designs, and most centers utilize more than one type. The most common types include a fixed horizontal beam, a fixed vertical beam, a 360-degree gantry, or a partial 185-degree gantry. The two main ways to deliver proton therapy treatments are passively scattered particle therapy and pencil beam scanning (PBS). *Passively scattered particle therapy* involves the use of specific devices intended to spread the proton beam out laterally and longitudinally. Two scattering foils of high Z materials are placed in the path of the pencil-thin beam to spread the beam out laterally to a useful treatment field size. A device within the machine called a range modulator wheel *spreads out the Bragg peak* (SBOP) longitudinally to allow the high-energy beam to treat from the distal extent of the tumor to the most proximal aspect of the tumor. To shape the dose distribution laterally to the size of the targeted volume, passively scattered beams are further shaped using blocks of brass apertures (similar to a cerrobend block for photons) thick enough (2 to 8 cm) to absorb the highest energies of the incident protons. To shape the dose distribution to the distal edge of the target volume, a tissue compensator (made of acrylic or wax) is used to degrade the beam energy to further conform and adjust for variation in patient's external shape as well as internal tissue heterogeneity or density differences.

PBS is the most current method of proton beam delivery which does not require custom-made apertures or compensators and allows for more flexibility and control for conformality of the dose distribution to the target. The positively charged proton beamlet is directed by magnets to deliver the beam in an alternating scanning fashion to paint the tumor across the intended treatment volume in layers. Once the protons reach the required energy, they are extracted via the "beamline" to the treatment room and used to treat varying depths in tissue (Fig. 30.22). Typically, the deepest layer is painted first using the highest energy followed by the next layer per energy level, moving upward until the entire tumor is treated. PBS delivers a more conformal dose distribution to the tumor than passively scattered particle therapy and also allows for modulation of the intensity of the proton beam or intensity-modulated proton therapy (IMPT). This is a similar principle to IMRT for photons and the standard delivery in new proton centers. Characteristic differences, as well as main planning considerations between photon and proton characteristics are noteworthy.

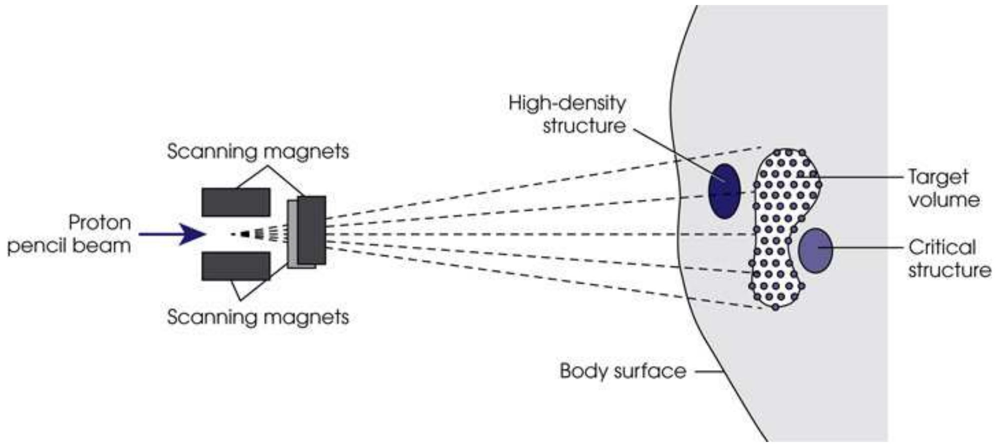


FIG. 30.22 Pencil beam scanning note magnet for directing the beam to spot paint the dose in the target volume. Courtesy MD Anderson Cancer Center website.

A schematic illustration shows the pencil beam scanning note magnet. The positively charged proton pencil beam is directed by three scanning magnets and delivers the beam on the body surface. A blue colored oval region on the surface is marked as high density structure. A white region with black pots is marked as target volume and a blue colored circle next to it is marked as critical structure.

Proton beam therapy is the preferred modality of treatment for pediatric malignancies since there is virtually no exit dose, thus delivering lower dosage to normal tissues and decreasing the risk of secondary malignancies due to radiation. The use of proton therapy has expanded to treat essentially any anatomical site where clinically significant reduction of doses can be achieved, such as craniospinal volumes, prostate, brain, head and neck, breast, lung, gastrointestinal, and gynecologic malignancies.

With new and emerging technological advancements, it is imperative that the radiation therapist does not become complacent or dependent on automated equipment. The therapist must still use critical thinking skills to analyze why couch parameters are being adjusted and evaluate all aspects of the patient's setup before automatically implementing shifts to the table or patient position. The therapist should ask if the computer-generated shifts are excessive or abnormal for this particular patient. If it is an outlier, further questioning should be performed and assessed.

The radiation therapist is also responsible for monitoring the patient's physical and emotional well-being. The radiation therapist is generally the only member of the radiation oncology team who sees the patient on a daily basis. The radiation therapist monitors the patient's progress and assists in the management of any side effects. Acting as a liaison between the patient and the physician, the radiation therapist must know when to withhold treatment and refer the patient to be seen by the physician or oncology nurse for further evaluation. The daily interaction with the patient is generally the most rewarding aspect of the radiation therapist's job. Putting the patient at ease and making a cancer diagnosis and subsequent treatment a less traumatic experience is a satisfying aspect of the career. Patients often express their gratitude to radiation therapists for their care and support.

Best Practices

The following best practices adhere to professional ethics and standards of practice established by national guidelines. All oncology team members should embrace a culture that supports professionalism and ensures patient safety on levels.

1. ***Staffing:*** A minimum of two radiation therapists per linear accelerator is recommended with potentially more depending on a facility's number of new patients and procedures performed annually. As IMRT and complicated treatments are increasingly used as the standard of delivery, the complexity of plan review, image review, and margin of error also increases demands for the radiation therapists. These challenges should be considered for staffing purposes.
2. ***Accuracy:*** Since cancer cells divide rapidly, making them particularly susceptible to radiation, accuracy is crucial to effective treatment since too little radiation to the treatment volume will allow cancer cells to regrow while too much (or missed targets) will harm surrounding organs at risk, harming the patient. Image guidance assists in delivering accurate treatments to the intended target volumes; however, therapists should verify all shifts make sense to ensure accuracy is maintained.
3. ***Attention to detail:*** This is especially important in radiation therapy as even very minor inconsistencies can have major effects such as a shift in the wrong direction, incorrectly recorded treatment doses, or immobilization or treatment devices misplaced or not used. All of these finite details play an important role in delivering the correct dose to the correct volume and can be detrimental for the patient if directions are not followed correctly or missed.

4. ***Speed:*** As accuracy and attention to detail demand being thorough and taking time for critical thinking, speed is also very important for effective treatment. Many patients requiring radiation are under an intense amount of pain, making it difficult to hold a specific position to be treated for very long. If the patient is unable to maintain the correct position verified by the therapists using image guidance, a geometric miss can occur. If treatment cannot be delivered in a reasonable time frame, patient motion, breathing motion, and time between image matching verification increasingly introduce higher risks of missing the target volume.
5. ***Patient care:*** As stated earlier, the radiation therapist is often the only member of the oncology team that interacts with the patient on a daily basis. A change in routine for the patient such as dietary restrictions or any new symptom or side effect the patient may experience can also have an effect on the patients' radiation treatment. Diet or stress can affect weight gain/loss or displacement of internal organs (bowel, stomach, etc.), therefore possibly changing position from the treatment plan intent and dose distribution. Communication between the patient and therapist minimizes unexpected circumstances that could alter these variabilities.
6. ***Receptive/questioning workplace culture:*** Error reporting and prevention are top priorities in radiation therapy. National guidelines specify criteria for reporting purposes, and facilities should use guidelines as well as have processes in place for "near misses" and error prevention. Administration should provide the tools, training, sufficient staff, and time to ensure these processes are completed. All members of the team should feel comfortable questioning any aspect of the patient's treatment at any time without fear of reprimand or consequence. Physicians, physicists, dosimetrists, and therapists should all be open to a questioning and receptive environment as well as encourage this type of workplace culture.
7. ***Professionalism:*** Part of professionalism in radiation therapy is minimizing distractions during patient treatment. Monitoring and focusing on the patient during treatment are the top priorities during beam delivery, and therapists should feel open to remind colleagues if this is not being followed. Therapists report that most distractions include interruptions from oncology nurses, physicians, fellow therapists, and crowded workspaces.
8. *Proper training:* Rapidly changing technological advancements within the field introduce reliance on complex new equipment without previous and thorough training. Proper skills assessments should be performed and evaluated before equipment is put into clinical use and periodically to avoid complacency. Work environments should embrace a lifelong learning approach and process improvement.

Clinical Applications

The amount of radiation prescribed depends on the type of tumor and the extent of the disease. The following are brief summaries of radiation therapy techniques used in the management of common forms of cancer.

Lung Cancer

Treatment of lung cancer varies by type and stage. Radiation therapy is often used in conjunction with surgery and chemotherapy. A dose of 5000 to 6000 cGy of 10-MeV photons is often applied via a combination of AP, PA, and off-cord oblique fields. The primary tumor plus draining lymphatics are generally included in the treatment volumes (Fig. 30.23). More recently, the use of multiple oblique IMRT fields, VMAT, or a hybrid technique that incorporates both static fields and VMAT is used to treat lung cancer. These techniques provide a more conformal dose to the target volume while delivering a lower dose to normal lung and spinal cord than the traditional static AP-PA and oblique fields. SBRT is used for the treatment of medically inoperable patients with stage I non-small-cell lung cancers. One to five treatments with doses in the range of 1000 to 2000 cGy per treatment may be given for a total dose of 5000 to 6000 cGy.

Prostate Cancer

Definitive radiation therapy is a standard treatment for prostate cancer. Surgical removal of the prostate gland is another common approach to the management of this disease. Traditionally, a four-field technique of AP, PA, and right and left lateral ports using a megavoltage beam of 10 MV or more is often used to deliver a dose of 7000 to 7600 cGy to the prostate gland. A series of six to eight oblique fields delivered with IMRT or VMAT to a dose of 7600 cGy is a common method of treatment for prostate cancer. Another method of treating limited, early-stage prostate cancer is a brachytherapy procedure known as prostate seed implant. This procedure involves the permanent implantation of 100 or more seeds of the radioisotope iodine-125 or palladium-103 into the prostate gland. A dose of 145 Gy is delivered with iodine-125, and a dose of 125 Gy is delivered with palladium-103.

HDR brachytherapy is another method for treating early-stage prostate cancer. This procedure is done on an outpatient basis and is a temporary implant. The patient has four HDR brachytherapy treatments. The interstitial needles are inserted early in the morning, then the patient has a morning and afternoon treatment. The patient comes back 2 to 3 weeks later for another two HDR treatments. Prostate cancer is one anatomic site that may be treated with protons.

Head And Neck Cancers

Numerous approaches may be used to treat head and neck cancers depending on the location, size, and extent of the tumor. The most common method of treating head and neck cancer is with VMAT. VMAT allows a significant reduction in the dose to the parotid gland and spinal cord, while allowing a greater dose to be delivered to the target area. VMAT treatments are shorter in duration than the traditional IMRT technique for head and neck cancer. This makes the treatment more tolerable for the patient, who is held in place on the table by a thermoplastic mask. VMAT is the newest IMRT method for delivering radiation to head and neck cancers.

Cervical Cancer

Early diagnosed cervical cancers can be treated with either surgery or radiation therapy. A four-field technique of AP, PA, and right and left lateral ports using a megavoltage unit, preferably 10 MV or greater, delivers 4500 to 5000 cGy in 5 weeks to an area of the primary and regional lymph nodes (Fig. 30.24). IMRT or VMAT are becoming common methods of treating cervical cancer. An intracavitary HDR implant is also included in the standard treatment of cervical cancer.

FIG. 30.23 Digitally reconstructed radiograph for parallel-opposed fields for right lung tumor with extension across the midline. Courtesy Bayhealth Medical Center at Kent General Hospital, Dover, DE.

Hodgkin Lymphoma

The age of the patient and extent of the disease may determine treatment and prognosis for Hodgkin lymphoma. Involved field lymph node irradiation after chemotherapy is more commonly used than extended field therapy that included the lymphatic chain above or below the diaphragm. Treatment consists of chemotherapy followed by 2000 to 3000 cGy delivered through AP-PA fields or IMRT fields using a megavoltage unit. Chemotherapy may also be indicated for more advanced cases.

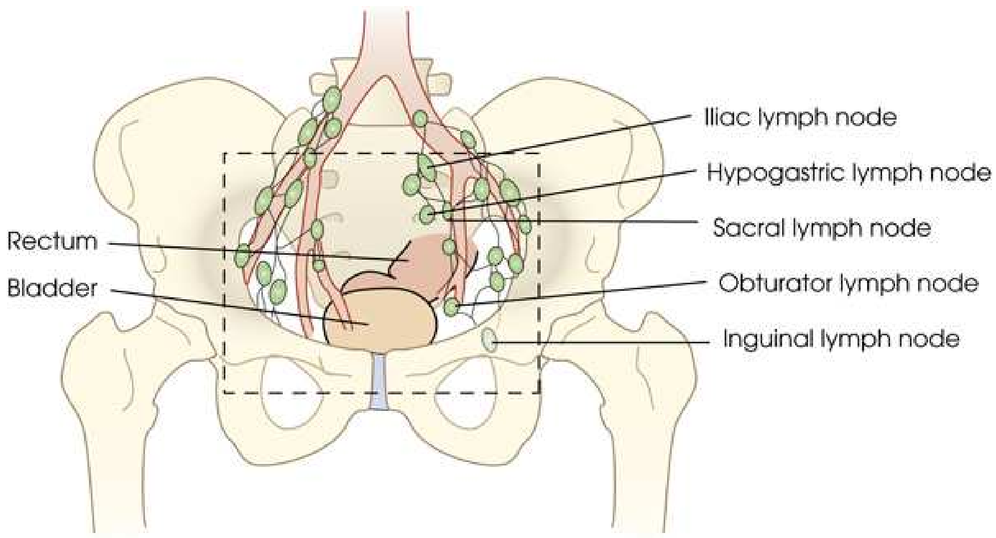


FIG. 30.24 Field used for irradiation of primary tumor and adjacent lymph nodes.

Diagram shows a tumor and the lymph notes in the pelvic region. The parts labeled in the diagram are follows: rectum, bladder, iliac lymph node, sacral lymph node, hypogastric lymph node, obturator lymph node, and inguinal lymph node.

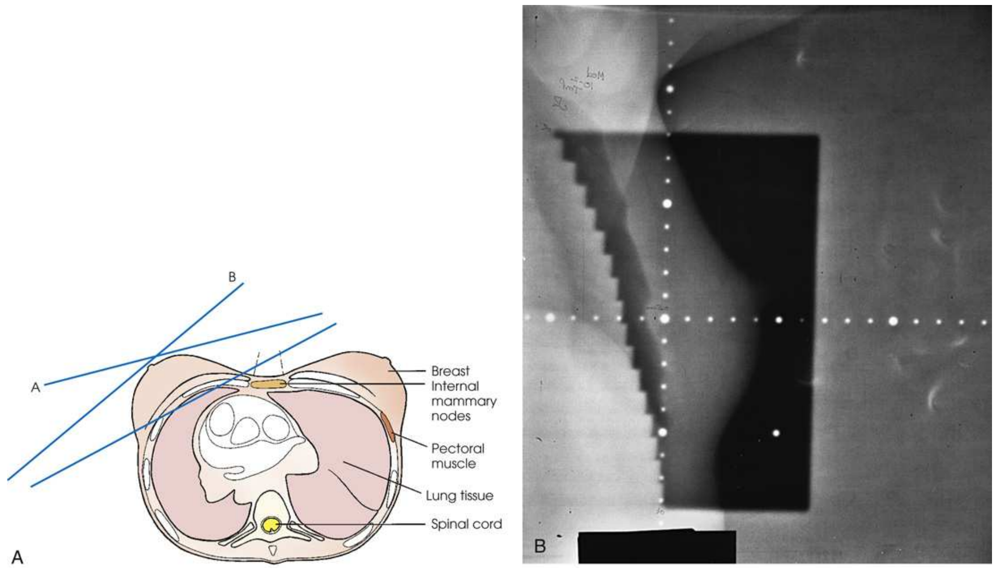


FIG. 30.25 (A) Cross section of thorax showing field arrangements to irradiate the intact breast tangentially while sparing the lung (*lines A* and *B*). (B) Port image of tangential breast field. Note sparing of lung tissue.

Diagram (A) shows a cross section of the thorax. Two lines A and B intersect each other above the breast. diagram. Another line pass below the breast. The parts labeled in the diagram are follows: breast, internal mammary nodes, pectoral muscle, lung tissue, spinal cord. (B) shows a radiographic image of the breast. A region on the left appears radiolucent. It is divided into four quadrants by two dotted vertical and horizontal lines.

Breast Cancer

Using two tangential fields to the chest wall or intact breast, megavoltage radiation delivers 5000 cGy in 5 weeks (Fig. 30.25). An electron boost to the site of initial lumpectomy adds an additional 1000 cGy. Irradiation of the axillary, supraclavicular, and internal mammary nodes to a dose of 5000 cGy is indicated for patients with a large primary tumor or node-positive disease. IMRT may also be used for the treatment of breast cancer. The breast is one location that respiratory gating may be utilized. A patient's breathing is monitored, and patients are instructed to hold their breath to limit internal organ motion while treatment commences. Respiratory gating limits the dose to the heart in patients with left-sided breast cancer.

Accelerated partial-breast irradiation (APBI) is a breast conservation method being studied as an alternative to whole breast irradiation. This treatment option may be offered to a subset of women who are older than 50 years of age with tumors of less than 3 cm located in the outer quadrant of the breast. The patient must have negative surgical margins and no lymph nodes involved. *Accelerated* is the term used because the treatment is delivered in 1 week with twice-a-day treatments using external beam or brachytherapy. The two commonly used brachytherapy applicators are MammoSite and strut adjusted volume implant applicator (SAVI). Both applicators are placed in the lumpectomy site. The MammoSite applicator is a balloon catheter that is placed in the lumpectomy cavity. The SAVI has individual catheters in the shape of an eggbeater and is placed in the cavity created by the lumpectomy. The applicator used is hooked up to the HDR unit for treatment delivery. A total dose of 3400 cGy is delivered in the 1-week period. Chemotherapy, hormonal therapy, or both are also commonly used to treat breast cancer.

Laryngeal Cancer

Cancer of the larynx is best treated with megavoltage radiation. Tumors that are confined to the true vocal cord, with normal cord mobility, have a 90% 5-year cure rate; in addition, the voice remains useful. The method of treatment is usually accomplished by using small 2 × 2-inch (5 × 5-cm) opposing lateral wedged fields and delivering a dose of 6300 to 6500 cGy over a 6-week period.

Skin Cancer

Carcinomas of the skin are usually squamous cell or basal cell lesions that may be treated with superficial radiation or surgery. Cure rates tend to be 80% to 90%, and basal cell lesions less than

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inch (1 cm) in diameter have a cure rate of almost 100%. The method of treatment is usually a single-field approach with attention given to shielding the uninvolved skin and delivering 4000 to 5000 cGy in a 3- to 4-week period.

Medulloblastoma

Children with medulloblastoma are usually referred to the radiation oncology department after a biopsy and shunt procedure. The tumor is radiosensitive, and patients who have had treatment of the entire cerebrospinal axis have a 5-year cure rate of greater than 60%. The therapeutic approach tends to be complicated because the entire brain is irradiated with 3600 cGy, the spinal cord receives a dose of 2340 to 3600 cGy, and the cerebellum receives an additional dose of radiation to bring the total up to 5500 cGy (Fig. 30.26). This irradiation is usually accomplished with parallel opposed fields to the cranial vault and an extended single field to the spinal cord. The boost dose of 2000 cGy to the posterior fossa may be given with IMRT to provide better dose optimization to the target and a lower dose to critical structures. A megavoltage unit is used with extreme care given to the areas of abutting fields. Medulloblastoma is one area that has been treated with proton therapy.

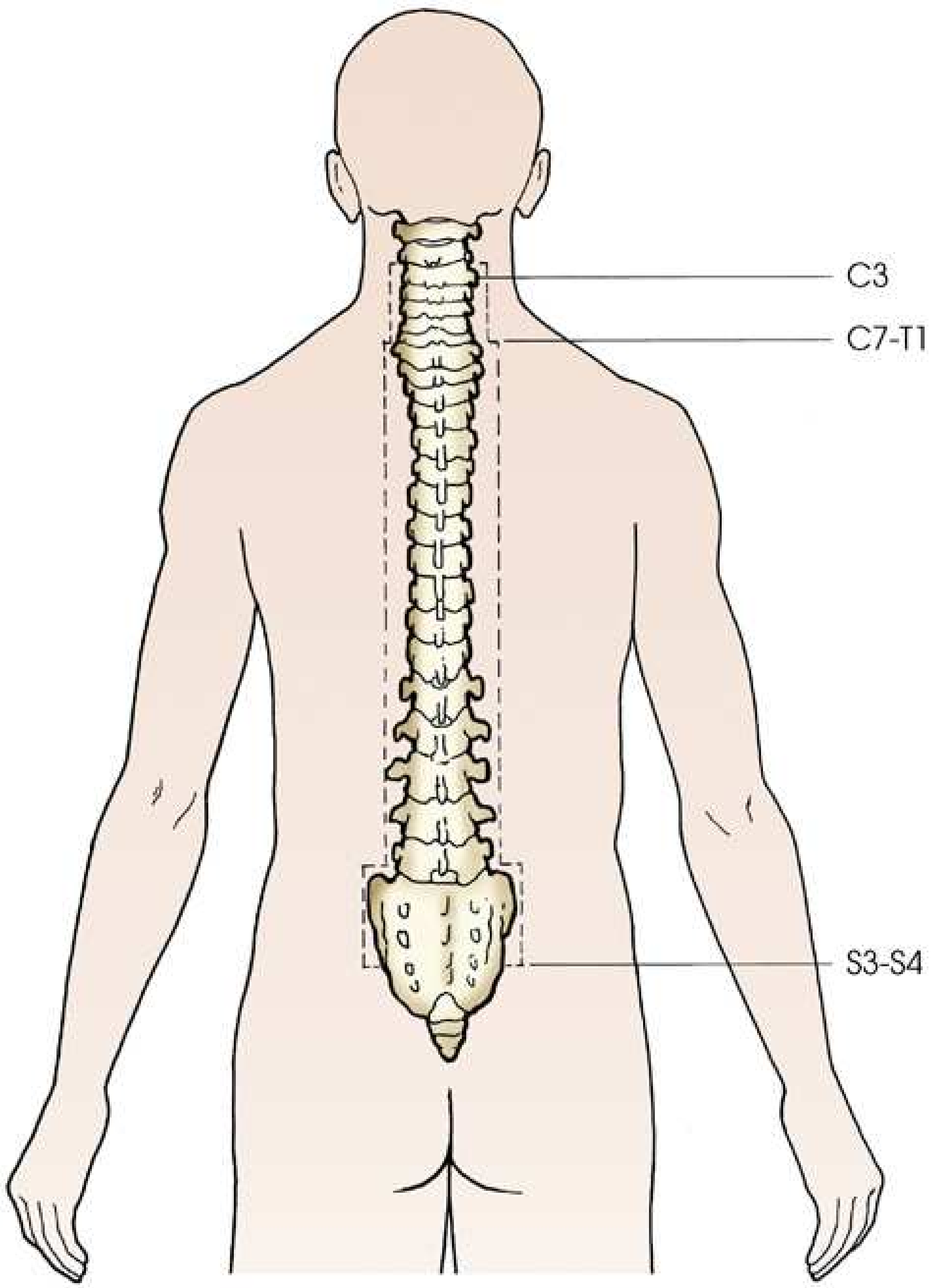

FIG. 30.26 Spinal treatment portal for medulloblastoma.

Future Trends

Radiation therapy has entered the electronic age with increased technologic advancement in the areas of dosimetry, simulation, and treatment. Most institutions use computer-interfaced accelerators with treatment verification software packages to ensure accurate treatment. Paperless treatment charting and filmless departments are the standard design of a facility. VMAT and IMRT are standard treatment techniques used in most facilities to treat various tumor types. Developments will continue to occur in the use of IGRT. Refinements in the application of linac cone-beam CT and other modalities, such as PET, to verify target, isocenter, and patient position before treatment will occur more routinely. Advancements and implementation of respiratory gating will permit better delineation of three-dimensional conformal target volumes, lessen the chance of a geographic miss of the target volume, and further minimize the dose to normal structures. The use of gating may permit higher doses to be prescribed and result in greater control and cure rates. The use of SBRT may expand for use in the treatment of other cancer sites within the body.

Conclusion

From a questionable beginning, radiation therapy has emerged as one of the primary modalities used in the treatment of malignant disease. Radiation therapy departments are currently examining and treating approximately 75% of all patients with a new diagnosis of cancer. Radiation oncologists and radiation therapists are integral members of the health care team that discusses and selects the appropriate treatment regimens for all cancer patients.

As the factors that initiate cellular change, growth, and spread become better understood, the radiation treatments for cancer are expected to become even more effective. The irradiation techniques presently used may change dramatically based on this new information. In addition, new, more sophisticated radiation-producing equipment is currently under design and may lead to the reevaluation of presently accepted therapeutic techniques and dose levels. Finally, new chemotherapeutic agents are being produced that, when used by themselves or with other drugs, may enhance tumor sensitivity when used in conjunction with irradiation.

Definition of Terms

absorbed dose: Amount of ionizing radiation absorbed per unit of mass of irradiated material.
accelerator (particle): Device that accelerates charged subatomic particles to great energies. These particles or rays may be used for direct medical irradiation and basic physical research. Medical units include linear accelerators, betatrons, and cyclotrons.
asymmetric jaws: Four independent x-ray collimators that are used to define the radiation treatment field.
attenuation: Removal of energy from a beam of ionizing radiation when it traverses matter, accomplished by disposition of energy in matter and by deflection of energy out of the beam.
betatron: Electron accelerator that uses magnetic induction to accelerate electrons in circular path; also capable of producing photons.
biopsy: Removal of a small piece of tissue for examination under the microscope.
brachytherapy: Placement of radioactive nuclide or nuclides in or on a neoplasm to deliver a cancericidal dose.
cancer: Term commonly applied to malignant disease; abnormal growth of cells; *neoplasm* (new growth) or *-oma* (tumor).
cancericidal dose: Dose of radiation that results in the death of cancer cells.
carcinogen: Any cancer-producing substance or material, such as nicotine, radiation, or ingested uranium.
carcinoma: Cancer that arises from epithelial tissue—either glandular or squamous epithelium.
cerrobend block: Beam-shaping device made of a lead alloy that attenuates the x-ray beam, preventing exposure of normal tissue.
chromosome: Unit of genetic information that guides cytoplasmic activities of the cell and transmits hereditary information.
cobalt-60: Radioisotope with half-life of 5.26 years, average gamma ray energy of 1.25 MeV (range 1.17 to 1.33 MeV), and ability to spare skin with buildup depth in tissue of 0.5 cm.
collimator: Diaphragm or system of diaphragms made of radiation-absorbing material that defines dimension and direction of beam.
conformal radiation: Treatment designed to deliver radiation to the exact target volume as seen on any plane (e.g., transverse, sagittal, vertex views); requires a three-dimensional treatment planning system.
contour: Reproduction of an external body shape, typically in the transverse plane at the level of the central axis of the beam; facilitates planning of radiation treatment. Other planes of interest may also be obtained.
cure: Usually a 5-year period after completion of treatment during which time the patient exhibits no evidence of disease.
decay or disintegration: Transformation of radioactive nucleus, resulting in emission of radiation.
differentiation: Acquisition of cellular function and structure that differ from that of the original cell type.
direct effect: Radiation that interacts with an organic molecule such as DNA, RNA, or a protein molecule. This interaction may inactivate the cell.
dosimetry: Measurement of radiation dose in an absorbing medium.
epithelial tissue: Cells that line the surfaces of serous and mucous membranes, including the skin.
etiology: Study of causes of diseases.
external-beam treatment: Delivery of radiation to a patient from a unit such as a linear accelerator in which the radiation enters the patient from the external surface of the body.
field: Geometric area defined by collimator or radiotherapy unit at skin surface.
fractionation: Division of total planned dose into numerous smaller doses to be given over a longer period. Consideration must be given to biologic effectiveness of smaller doses.
gamma ray: Electromagnetic radiation that originates from radioactive nucleus and causes ionization in matter; identical in properties to x-ray.
gray (Gy): International unit for the quantity of radiation received by the patient; previously rad; 1 cGy = 1 rad.
grenz rays: X-rays generated at 20 kVp or less.
half-life: Time (specific for each radioactive substance) required for radioactive material to decay to half its initial activity; types are biologic and physical.
half-value layer: Thickness of attenuating material inserted in beam to reduce beam intensity to half of the original intensity.
high-dose-rate brachytherapy: Use of a high-activity radionuclide placed with in the body for the treatment of cancer. Delivers more than 1200 cGy per hour.
image-guided radiation therapy (IGRT): Use of images to verify treatment isocenter, target, and patient positioning before initiating radiation treatment.
independent jaws: X-ray collimator with four individual blades that can be moved independently of one another (see *asymmetric jaws*).
indirect effect: Interaction of radiation with water molecules within the cell; results in the formation of free radicals OH, H, and HO_2, which can damage the cell.
intensity-modulated radiation therapy (IMRT): Modification of beam intensity to deliver nonuniform exposure across radiation field.
ionization: Process in which one or more electrons are added to or removed from atoms, creating ions; can be caused by high temperatures, electrical discharges, or nuclear radiations.
ionizing radiation: Energy emitted and transferred through matter that results in the removal of orbital electrons (e.g., x-rays or gamma rays).
isocentric: Refers to rotation around a fixed point.
isodose line curve: Curve or line drawn to connect points of identical amounts of radiation in a given field.
isotope: Atoms that have the same atomic number but different mass numbers.
lesion: Morbid change in tissue; mass of abnormal cells.
linear accelerator (linac): Device for accelerating charged particles, such as electrons, to produce high-energy electron or photon beams.
linear energy transfer (LET): Rate at which energy is deposited as it travels through matter.
low-dose-rate brachytherapy: Use of a low-activity radionuclide placed within the body for treatment of cancer. Dose is slowly delivered, 40 to 500 cGy per hour, to a small volume of tissue over a period of days.
malignancy: Cancerous tumor or lesion.

medical dosimetrist: Person responsible for calculation of proper radiation treatment dose who assists the radiation oncologist in designing individual treatment plans.
medical physicist: Specialist in the study of the laws of ionizing radiation and their interactions with matter.
metastasis: Transmission of cells or groups of cells from primary tumor to sites elsewhere in body.
multileaf collimator (MLC): Individual collimator rods within the treatment head of the linear accelerator that can slide inward to shape radiation field.
oncologist: Physician specializing in the study of tumors.
oncology: Study of tumors.
palliation: To relieve symptoms; not for cure.
passively scattered particle therapy: Involves the use of special devices to spread the proton beam out laterally and distally.
pathologist: Specialist in the study of the microscopic nature of disease.
pencil beam scanning: Method of proton beam delivery. The positively charged thin proton beamlet is directed by two magnets to deliver the beam in an alternating scanning fashion to paint the tumor with dose.
prophylactic surgery: Preventive surgical treatment.
radiation oncologist: Physician who specializes in the use of ionizing radiation in treatment of disease.
radiation oncology: Medical specialty involving the treatment of cancerous lesions using ionizing radiation.
radiation therapist: Person trained to assist and take directions from the radiation oncologist in the use of ionizing radiation for treatment of disease.
radiation therapy: Older term used to define the medical specialty involving treatment with ionizing radiation.
radioactive: Pertaining to atoms of elements that undergo spontaneous transformation, resulting in emission of radiation.
radiocurable: Susceptibility of neoplastic cells to cure (destruction) by ionizing radiation.
radiosensitivity: Responsiveness of cells to radiation.
radium (Ra): Radionuclide (atomic number 88, atomic weight 226, half-life 1622 years) used clinically for radiation therapy. In conjunction with its subsequent transformations, radium emits alpha and beta particles and gamma rays. In encapsulated form, it is used for various intracavitary radiation therapy applications (e.g., for cervical cancer).
reactor: Cubicle in which isotopes are artificially produced.
relative biologic effectiveness (RBE): Compares radiation beams with different LETs and their ability to produce a specific biologic response. Dose in gray from 250 kVp beam of x-rays/dose from another type of radiation to produce the same effect.
simulator: Diagnostic x-ray machine that has the same geometric and physical characteristics as a radiation therapy treatment unit.
skin sparing: In megavoltage beam therapy, reduced skin injury per centigray (cGy) exposure because electron equilibrium occurs below skin; occurs

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to 2 inches (0.6 to 5 cm) deep, depending on energy.
spread out Bragg peak: Individual Bragg peaks are spread across the various depths of the tumor, providing a more useful beam.
stereotactic radiation therapy: Use of small, focused radiation beams to treat small extracranial or intracranial lesions; delivered with conventional fractionation or in two to five treatments instead of a single treatment as in stereotactic radiosurgery. Rigid immobilization of involving patient is required.
stereotactic radiosurgery: Use of multiple, narrow, highly focused radiation beams to deliver a large dose in a single treatment to a small intracranial lesion. The patient is immobilized with a fixed stereotactic head frame.
surgical bed: Area of excision and adjacent tissues manipulated during surgery.
systemic: Throughout the human body.
teletherapy: Radiation therapy technique for which the source of radiation is at some distance from the patient.
treatment field: Anatomic area outlined for treatment (e.g., AP or RL pelvis).
tumor/target volume: Portion of anatomy that includes tumor and adjacent areas of invasion.
undifferentiation: Lack of resemblance of cells to cells of origin.
wedge filter: Wedge-shaped beam attenuating device used to absorb beam preferentially to alter the shape of the isodose curve.

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[a] Almost all italicized words on the succeeding pages are defined at the end of the chapter.

Addendum A

Summary of Abbreviations, Volume One

AAA	abdominal aortic aneurysm
AC	acromioclavicular
AEC	automatic exposure control
AP	anteroposterior
ARRT	American Registry of Radiologic Technologists
ASIS	anterior superior iliac spine
ASRT	American Society of Radiologic Technologists
CAMRT	Canadian Association of Medical Radiation Technologists
CDC	Centers for Disease Control and Prevention
cm	centimeter
CMC	carpometacarpal
CR [a]	central ray
CR [a]	computed radiography
CT	computed tomography
DIP	distal interphalangeal (hand and foot)
DR	direct digital radiography
EAM	external acoustic meatus
ERCP	endoscopic retrograde cholangiopancreatography
HNP	herniated nucleus pulposus
IOML	infraorbitomeatal line
IP [b]	image plate
IP [b]	interphalangeal (hand and foot)
IR	image receptor
kVp	kilovolt peak
L	left
LAO	left anterior oblique
LLQ	left lower quadrant
LPO	left posterior oblique
LUQ	left upper quadrant
mA	milliamperage
mAs	milliampere second
MC	metacarpal
MCP	metacarpophalangeal
MMD	mean marrow dose
MRI	magnetic resonance imaging
MSP	midsagittal plane
MTP	metatarsophalangeal
NCRP	National Council on Radiation Protection
NPO	nil per os (nothing by mouth)
OID	object-to-image receptor (IR) distance
OML	orbitomeatal line

OR	operating room
PA	posteroanterior
PIP	proximal interphalangeal (hand and foot)
PTC	percutaneous transhepatic cholangiography
R	right
RA	radiologist assistant
RAO	right anterior oblique
RLQ	right lower quadrant
RPA	radiology practitioner assistant
RPO	right posterior oblique
RUQ	right upper quadrant
SC	sternoclavicular
SI	sacroiliac
SID	source–to–image receptor (IR) distance
SMV	submentovertical
SSD	source–to–skin distance
TEA	top ear attachment
TMT	tarsometatarsal
US	ultrasound
VSM	verticosubmental

[a] Note: CR has two different meanings.

[b] Note: IP has two different meanings.

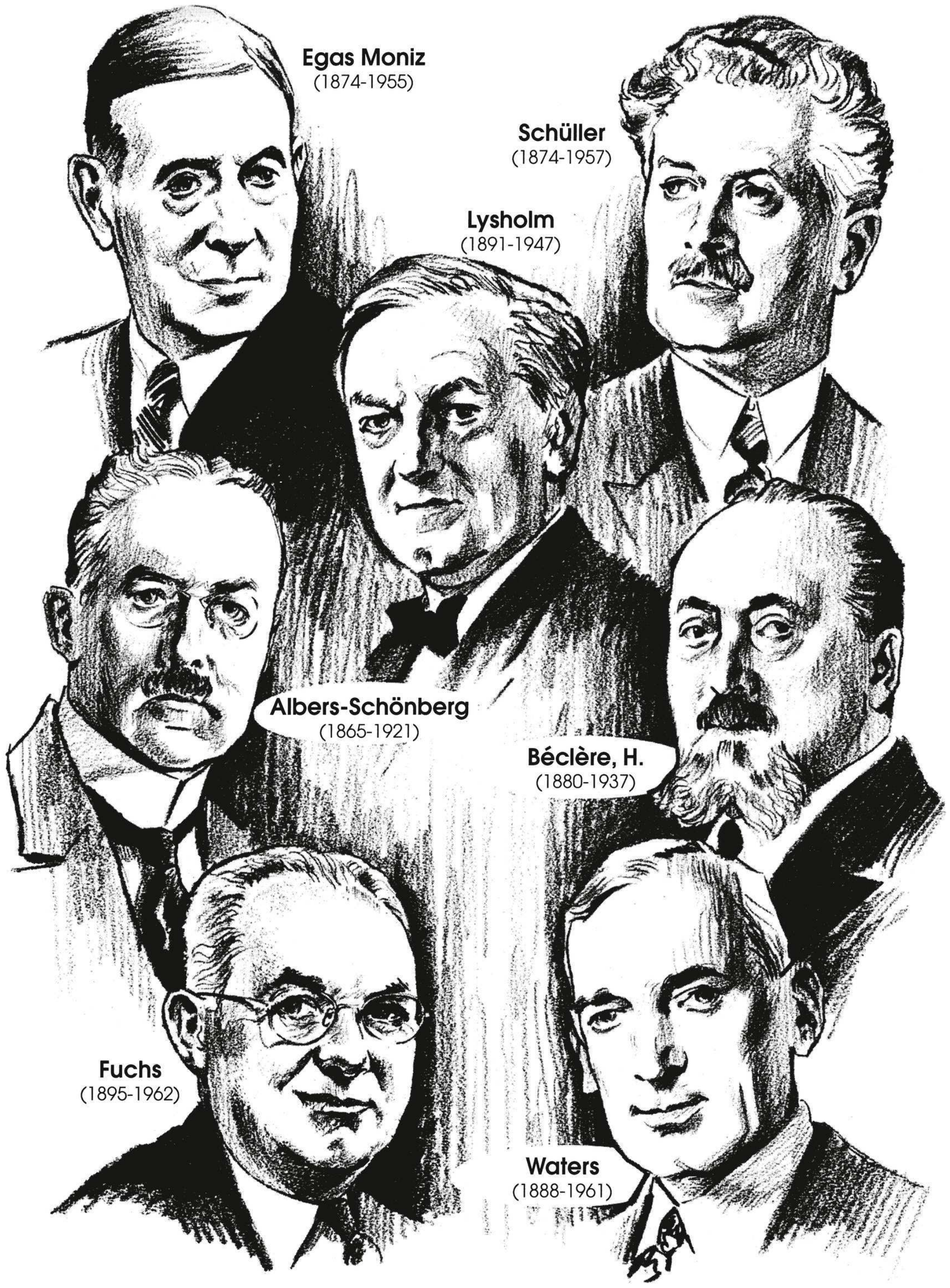
Addendum B

Summary of Abbreviations, Volume Two

ACR	American College of Radiology
AML	acanthiomeatal line
AP	anteroposterior
ASRT	American Society of Radiologic Technologists
BE	barium enema
BPH	benign prostatic hyperplasia
BUN	blood urea nitrogen
CDC	Centers for Disease Control and Prevention
CNS	central nervous system
CPR	cardiopulmonary resuscitation
CR	central ray
CSF	cerebrospinal fluid
CT	computed tomography
CTC	CT colonography
CVA	cerebrovascular accident
EAM	external acoustic meatus
ED	emergency department
ERCP	endoscopic retrograde cholangiopancreatography
EU	excretory urogram
GFR	glomerular filtration rate
GML	glabellomeatal line
GSW	gunshot wound
HSG	hysterosalpingography
IAM	internal acoustic meatus
IOML	infraorbitomeatal line
IPL	interpupillary line
IR	image receptor
IUD	intrauterine device
IV	intravenous
IVP	intravenous pyelogram
IVU	intravenous urography
KUB	kidneys, ureters, and bladder
LES	lower esophageal sphincter
MBSS	modified barium swallow study
MCP	midcoronal plane
MML	mentomeatal line
MPR	multiplanar reconstruction
MRI	magnetic resonance imaging
MSP	midsagittal plane
MVTA	motor vehicle traffic accident
NPO	nil per os (nothing by mouth)
OID	object–to–image receptor (IR) distance
OML	orbitomeatal line

PA	posteroanterior
PTC	percutaneous transhepatic cholangiography
RUQ	right upper quadrant
SID	source–to–image receptor (IR) distance
SMV	submentovertical
TEA	top of ear attachment
TMJ	temporomandibular joint
UES	upper esophageal sphincter
UGI	upper gastrointestinal
UPJ	ureteropelvic junction
UVJ	ureterovesical junction
VC	virtual colonoscopy
VCUG	voiding cystourethrogram
VFSS	videofluoroscopic swallow study

IBC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Waters
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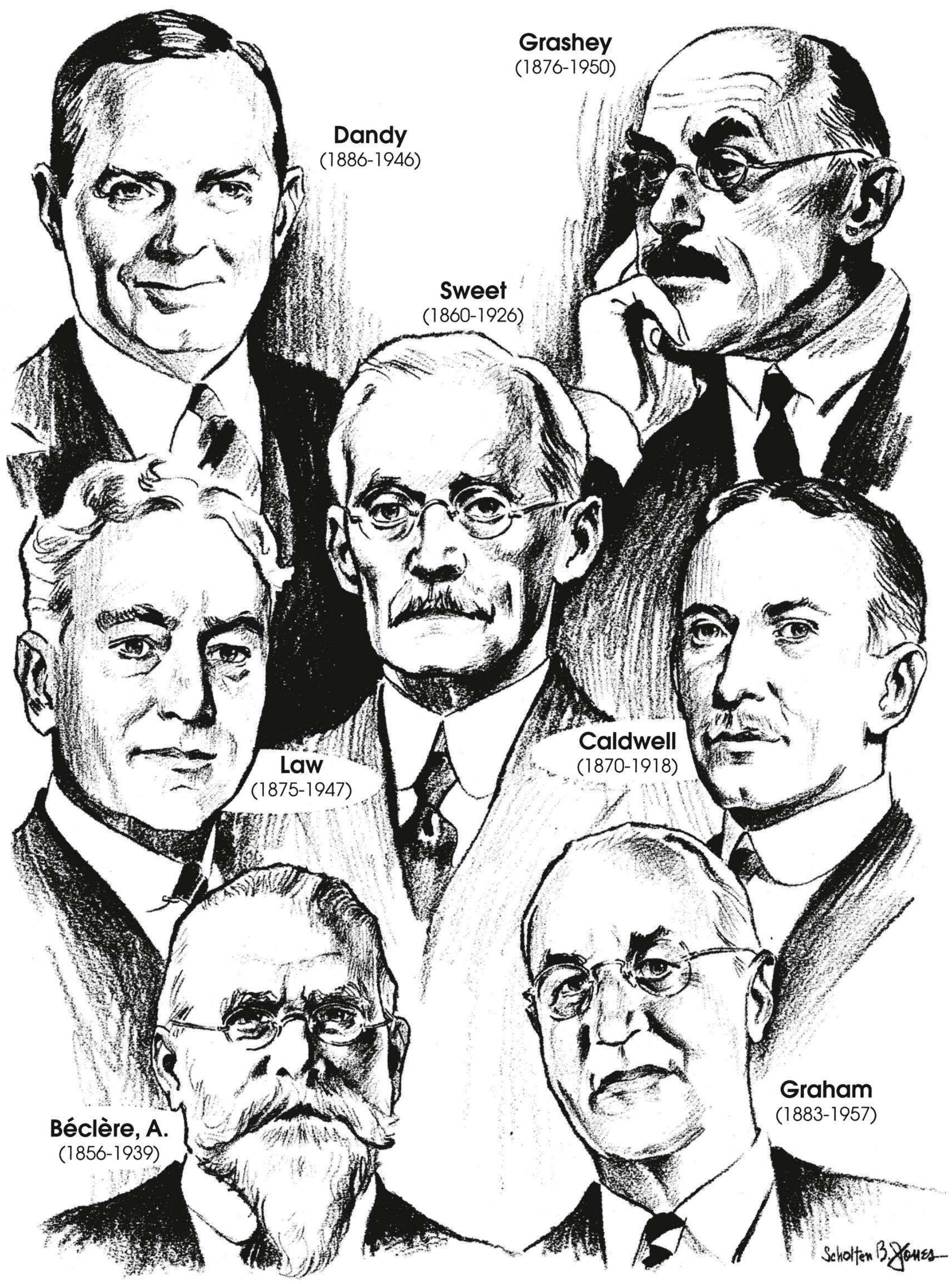
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Dandy
(1886-1946)
Sweet
(1860-1926)
Caldwell
(1870-1918)
Law
(1875-1947)
Graham
(1883-1957)
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Scholten B. Jones

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Knee

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M

Male

Neck

O

P

S

Shoulder joint

Splenic artery

T

X