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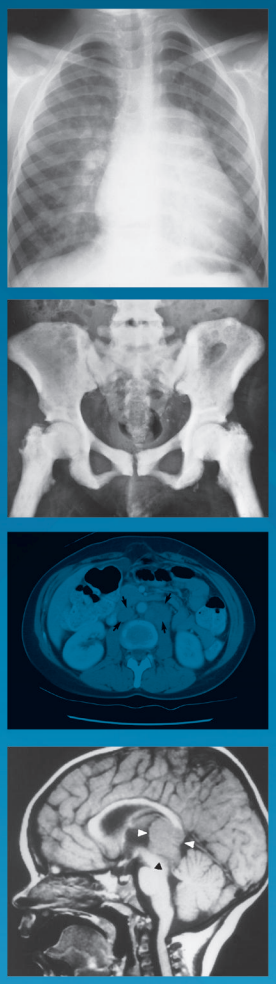

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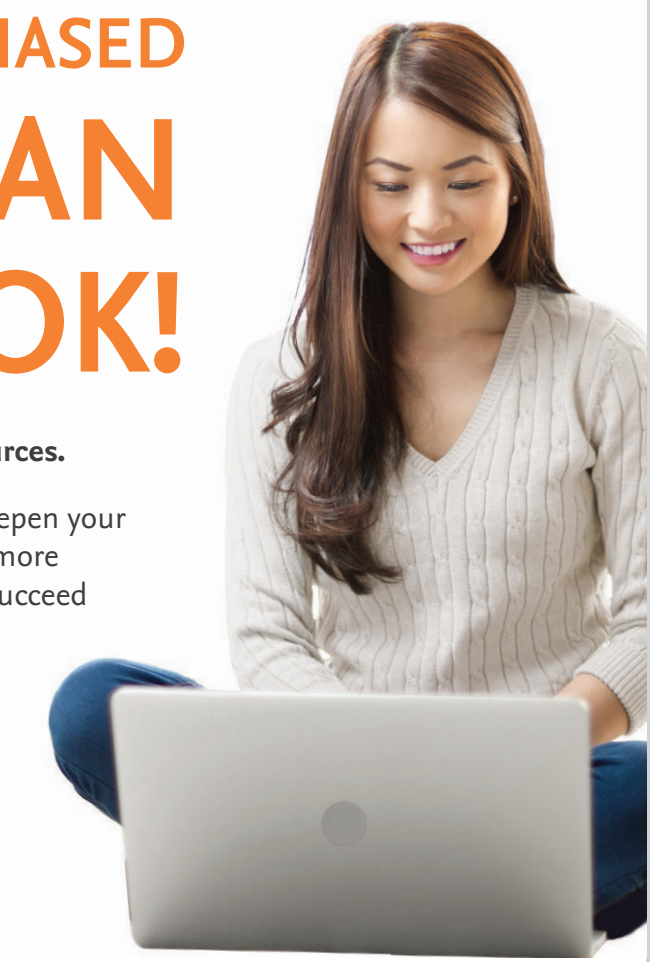

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# Comprehensive Radiographic
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# Comprehensive Radiographic PATHOLOGY

SEVENTH EDITION

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*Comprehensive Radiographic Pathology* is dedicated to all the students and medical imaging professionals who wish to improve their diagnostic images by better understanding the underlying pathologies.

Thank you to all who helped in making this endeavor successful.
Special credit to the contributors of this edition who assisted in updating the content and images.

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# PREFACE

Understanding the basic principles of pathology is an essential part of the radiologic technologist's education. Knowing how disease processes effect anatomical tissue changes and recognizing the radiographic appearance of specific diseases aids the technologist in selecting proper modalities and determining the need for repeat radiographs in different situations. This kind of knowledge enables the radiologic technologist to become a more competent professional and a contributing member of the diagnostic team.

## ORGANIZATION

Fully illustrated and well organized, *Comprehensive Radiographic Pathology* meets the needs of today's student and practicing image personnel. The book opens with a chapter on disease processes that introduces the pathologic terms used throughout the text. Chapter 2 describes the advantages and limitations of eight widely used modalities: mammography, ultrasound, computed tomography (CT), magnetic resonance imaging (MRI), nuclear medicine, single-photon emission computed tomography (SPECT), positron emission tomography (PET), and fusion imaging. Summary tables describe imaging terminology used in each of the modalities.

Each of the remaining chapters is a systematic approach to the diseases involving a specific organ system. These chapters begin with an overview of physiology. For each of the most common pathologic conditions associated with the system, there is a brief description of the disease and its clinical manifestations, followed by imaging findings and treatment. Summary tables follow each major discussion, reiterating the location, imaging appearance, and treatment of the diseases just presented.

## DISTINCTIVE FEATURES

- Comprehensive coverage provides the most thorough explanations of any radiographic pathology text of those pathologies that can be diagnosed with medical imaging.
- Navigating the chapters is easy with the standardized heading scheme and chapter outlines for the systems chapters.
- *Radiographer Notes* in every chapter instruct students on how to deal effectively with varying patient needs and provide perspective on why learning pathology is important for radiography practice.
- A systems approach makes it easy to locate information and to study one area at a time, assimilating details in a logical sequence. It provides the best framework for building understanding of pathology.
- Summary tables list the imaging appearance and treatment of each disease and have been updated to include pathologic conditions included in the text.
- Coverage of the alternative imaging modalities that supplement radiographic imaging for diagnosis of some pathology conditions orients readers to other modalities that may be needed to ensure proper diagnosis of certain pathologies.
- Treatment sections provide useful background treatment and prognosis.
- The student workbook provides extra opportunities for review, self-assessment, and case studies to enhance clinical practice.

## NEW TO THIS EDITION

- Expanded terms related to disease process and imaging features
- Updates and additions of the following: anatomy images, SPECT, PET/CT, and their correlation with general radiography
- Color images, where appropriate, of MR, nuclear medicine, and PET/CT

## PEDAGOGICAL FEATURES

- Each chapter opens with an outline and a key terms list to aid the student in navigating the content.
- *Radiographer Notes* offer helpful suggestions for producing optimal radiographs of the organ system featured in each chapter. Information especially relevant to radiologic technologists is included, such as positioning and exposure factor adjustments for patients with specific conditions and special patient handling requirements. If multiple imaging modalities can be used, the most appropriate initial procedure is indicated, as well as the sequence in which various imaging studies should be performed.
- The body system chapters are organized as follows: physiology, identification of anatomic structures on anatomy figures and radiographs, pathologic conditions, radiographic appearance, and treatment.
- Each section of related pathologies is summarized in a table at the end of the section. The table names the disorder and then lists the location, radiographic appearance, and treatment for easy review and enhanced retention.
- Finally, each chapter ends with a series of review questions to help readers assess their comprehension of the material. An answer key is found at the back of the book, along with several appendices, an extensive glossary, and a list of major prefixes, roots, and suffixes to help readers determine the meaning of unfamiliar words.

## ANCILLARIES

### For the Instructor

- Instructor Resources on Evolve include a test bank with approximately 500 questions, PowerPoint slides, and an image collection with approximately 900 images.

## For the Student

- The Evolve site offers 10 student review questions per chapter and access to the image collection for further review.
- The workbook contains a variety of exercises for each of the 12 chapters in the book. Examples include matching terms with their definitions; labeling diagrams; fill-in-the-blank, short-answer, and multiple-choice questions; pathology case studies; and a post-test. Completing the workbook activities will ensure understanding of disease processes, their radiographic appearance, and their likely treatment. The answers for the exercises are located in the back of the workbook.
- By understanding the disease processes, their image appearance, and their treatment, the technologist will be prepared to contribute to the diagnostic team.

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1

# Introduction to Pathology

## OBJECTIVES

*After reading this chapter, the reader will be able to:*

- Classify the more common diseases in terms of their attenuation of x-rays
- Explain the changes in technical factors required for obtaining optimal quality radiographic images in patients with various underlying pathologic conditions
- Define and describe all boldface terms in this chapter
- Differentiate inflammation, edema, infarction, hemorrhage, and neoplasia
- Characterize the various alterations of cell growth
- Describe the various immune reactions of the body
- Describe acquired immunodeficiency syndrome (AIDS) and the precautions necessary when taking a radiograph of patients with AIDS or any patient with whom contact with any body fluid is possible (standard precautions)

## OUTLINE


**Disease**, 2
- Inflammation, 2
- Edema, 4
- Ischemia and Infarction, 5
- Hemorrhage, 5
- Alterations of Cell Growth, 6
- Neoplasia, 7

**Hereditary Diseases**, 9
**Disorders of Immunity**, 10
**Infectious Disease Exposure**, 11
**Acquired Immunodeficiency Syndrome**, 11
- Imaging Appearance, 12
- Treatment, 12


## KEY TERMS

**abscess**
**acquired immunodeficiency syndrome (AIDS)**
**active immunity**
**anaphylactic**
**anaplastic**
**antibodies**
**antigens**
**asymptomatic**
**atrophy**
**autosomes**
**bacteremia**
**benign**
**cancers**
**carcinomas**
**community acquired**
**diagnosis**
**dominant**
**dysplasia**
**edema**
**epidemiology**
**etiology**
**grading**
**granulation tissue**
**hematogenous spread**
**hematoma**
**hemorrhage**
**hereditary diseases**
**hyperplasia**
**iatrogenic**
**idiopathic**
**immune**
**infarct**
**inflammation**
**ischemia**
**lymphatic spread**
**malignant**
**metastasize**
**morbidity**
**mortality**
**mutations**
**neoplasia**
**nosocomial**
**oncology**
**permeable**
**personal protective equipment**
**prognosis**
**pyogenic**
**recessive**
**sarcomas**
**signs**
**staging**
**standard precautions**
**symptoms**
**syndrome**
**toxoid**
**transmission-based precautions**
**undifferentiated**
**vaccine**

## DISEASE

*Pathology* is the study of diseases that can cause abnormalities in the structure or function of various organ systems. In essence, a *disease* is the pattern of the body's response to some form of injury that causes a deviation from or variation of normal conditions. Diseases may be hereditary or may result from a broad spectrum of traumatic, infectious, vascular, or metabolic processes manifesting as a set of characteristics known as **signs** and **symptoms**. Signs represent the measurable or objective manifestations of the disease process. The experiences the patient feels and describes are the symptoms, those (subjective) manifestations that are not measurable or observable. A patient showing no evidence of diseases is considered **asymptomatic**. Symptoms may reflect alterations of cell growth, as in neoplasia (tumors), or may even be caused by physicians and their treatment (**iatrogenic**). Imaging modalities are used to assist in making a **diagnosis**, the precise disease process affecting the patient. To best treat a disease process, it is important to discover its underlying cause, known as the **etiology**. If the underlying cause is unknown, the disease is termed **idiopathic**. Once the specific diagnosis and etiology are confirmed, the physician offers a **prognosis**, which describes the expected patient outcome. A condition characterized by a group of signs, symptoms, and disease processes may be categorized as a **syndrome**.

Incidences of the development of infections at the acute care facility are called **nosocomial**, whereas infections that develop outside the healthcare facility are known as **community acquired**.

This chapter discusses several basic reactions of the body that characterize the underlying mechanisms for the radiographic manifestations of most pathologic conditions. These processes are inflammation, edema, ischemia and infarction, hemorrhage, and alterations of cell growth leading to the development of neoplasms (tumors). In addition, this chapter deals with hereditary diseases and immune reactions, such as acquired immunodeficiency syndrome (AIDS).

### SUMMARY OF TERMS FOR DISEASE

| Term | Definition |
|---|---|
| Signs | Measurable or objective manifestations |
| Symptoms | Feelings that the patient describes—subjective manifestations |
| Asymptomatic | Without subjective or objective manifestations |
| Diagnosis | Identification of disease process |
| Etiology | Study of the cause of the disease process |
| Idiopathic | Underlying cause is unknown |
| Prognosis | Probable patient outcome |
| Syndrome | Linked combination of signs and symptoms |
| Iatrogenic | Disease caused by physician or treatment |
| Nosocomial infections | Infections contracted in the acute care facility |
| Community-acquired infections | Infections contracted in a public setting outside of the acute care facility |

### RADIOGRAPHER NOTES

Radiography of patients with underlying pathologic conditions can present problems for even the most experienced radiographers. Adjustments in patient position may be necessary to prevent excessive pain caused by the body's response to trauma or certain disease processes. A change in routine projections may be indicated to visualize subtle alterations in the normal imaging appearance. Many disease processes also alter the density of the structures being radiographed and therefore require changes in technique. For example, extensive edema may require an increased technique, whereas severe atrophy may require a decreased technique. Unless the radiographer has access to previous images with recorded exposure factors, a standard technique chart should be used to determine the initial exposures. Any necessary adjustments can then be made on subsequent images.

Box 1.1 lists the relative attenuation of x-rays that can be expected in advanced stages of various disease processes. In chest radiography, 110 to 125 kilovolts peak (kVp) is optimal; therefore milliampere-second (mAs) factors should be adjusted to control density. In skeletal radiography, when bone *quality* changes are expected, the best exposure factor to change is the kVp (beam quality change for structural change). When bone *quantity* changes, the mAs is the exposure factor to change to control density (beam quantity increases to ensure that enough radiation reaches the image receptor without changing the contrast). For example, in osteoporosis there is a decrease in bone quantity and quality; however, a decrease in kilovolts produces a higher-quality image. The normal kilovolt peak easily penetrates the diseased bone, producing a low-contrast image with loss of visibility of detail. As imaging progresses into the digital imaging arena, the same theories apply; however, the processing algorithm will control brightness (density) and contrast. The exposure index (number) will represent the overexposure or underexposure of the image.

Certain diseases suppress the normal immune response. Immunocompromised patients (e.g., those with advanced leukemia) may require special care to prevent their acquiring a disease from the radiographer. Personal protective equipment (PPE) aids in preventing the spread of microorganisms to the patient and to the healthcare worker. The patient may have to be placed in protective isolation (or "reverse" isolation), and the radiographer may be required to put on a mask, gown, and gloves before approaching the patient. Diseases such as AIDS and hepatitis require that the radiographer wear rubber or latex gloves to be protected against exposure to blood and body fluids, which could contaminate any area near the patient. When examining a patient with AIDS who has a productive cough, the radiographer must wear a mask and possibly protective eye goggles if there is a need to be very close to the patient's face. It is important to remember that many patients undergoing radiographic procedures have not been diagnosed, and thus all patients should be treated as though they may have a communicable disease. Therefore, whenever exposure to any type of body secretion or blood may occur, the healthcare worker should wear appropriate PPE.

## Inflammation

Acute **inflammation** is the initial response of body tissues to local injury. The various types of injury include those caused by blunt or penetrating trauma, infectious organisms, and irritating chemical substances. Regardless of the underlying cause, the inflammatory response consists of four overlapping events that occur sequentially (Box 1.2).

The earliest bodily response to local injury is dilation of arterioles, capillaries, and venules, leading to a dramatic increase in blood flow in and around the injury site. This hyperemia produces the heat and redness associated with inflammation. As hyperemia develops, the venules and capillaries become abnormally **permeable**, allowing passage of protein-rich plasma

## BOX 1.1 Relative Attenuation of X-Rays in Advanced Stages of Diseases

### Skeletal System

***Additive (Increased Attenuation)***

Acromegaly
Acute kyphosis
Callus
Charcot joint
Chronic osteomyelitis (healed)
Exostosis
Hydrocephalus
Marble bone
Metastasis (osteosclerotic)
Osteochondroma
Osteoma
Paget disease
Proliferative arthritis
Sclerosis

***Destructive (Decreased Attenuation)***

Active osteomyelitis
Active tuberculosis
Aseptic necrosis
Atrophy (disease or disuse)
Blastomycosis
Carcinoma
Coccidioidomycosis
Degenerative arthritis
Ewing tumor (in children)
Fibrosarcoma
Giant cell tumor
Gout
Hemangioma
Hodgkin disease
Hyperparathyroidism
Leprosy
Metastasis (osteolytic)
Multiple myeloma
Neuroblastoma
New bone (fibrosis)
Osteitis fibrosa cystica
Osteoporosis/osteomalacia
Radiation necrosis
Solitary myeloma

### Respiratory System

***Additive (Increased Attenuation)***

Actinomycosis
Arrested tuberculosis (calcification)
Atelectasis
Bronchiectasis
Edema
Empyema
Encapsulated abscess
Hydropneumothorax
Malignancy
Miliary tuberculosis
Pleural effusion
Pneumoconiosis
- Anthracosis
- Asbestosis
- Calcinosis
- Siderosis
- Silicosis

Pneumonia
Syphilis
Thoracoplasty

***Destructive (Decreased Attenuation)***

Early lung abscess
Emphysema
Pneumothorax

### Circulatory System

***Additive (Increased Attenuation)***

Aortic aneurysm
Ascites
Cirrhosis of the liver
Enlarged heart

### Soft Tissue

***Additive (Increased Attenuation)***

Edema

***Destructive (Decreased Attenuation)***

Emaciation

Even though disease processes increase or decrease the attenuation of the x-rays, it is important to produce a quality image to demonstrate the change in attenuation. Excessive variation of the technical exposure factors may obscure the pathophysiologic changes due to the disease process.
From Thompson TT: *Cahoon's formulating x-ray techniques*, ed 9, Durham, NC, 1979, Duke University Press.

## BOX 1.2 Events That Occur in Inflammatory Response

1. Alterations in blood flow and vascular permeability
2. Migration of circulating white blood cells to the interstitium of the injured tissue
3. Phagocytosis and enzymatic digestion of dead cells and tissue elements
4. Repair of injury by regeneration of normal parenchymal cells or proliferation of granulation tissue and eventual scar formation

across vessel walls into the interstitium. This inflammatory exudate in the tissues results in the swelling associated with inflammation, which produces pressure on sensitive nerve endings and causes pain. The protein-rich exudate of inflammation must be differentiated from a transudate, a low-protein fluid such as that seen in the pulmonary edema that develops in congestive heart failure.

Very early in the inflammatory response, leukocytes (white blood cells, especially neutrophils and macrophages) of the

circulating blood migrate to the area of injury. These white blood cells cross the capillary walls into the injured tissues, where they engulf and enzymatically digest infecting organisms and cellular debris, a process called *phagocytosis*.

The removal of necrotic debris and any injurious agents, such as bacteria, makes possible the repair of the injury that triggered the inflammatory response. In many tissues, such as the lung after pneumococcal pneumonia, regeneration of parenchymal cells permits reconstitution of normal anatomic structure and function. However, some tissues, such as the heart after myocardial infarction, cannot heal by regeneration. A fibrous scar replaces the area of destroyed tissue with **granulation tissue**. Granulation tissue refers to a combination of young developing capillaries and actively proliferating fibroblasts, which produce connective tissue fibers (collagen) that replace the dead tissue. Eventually, the strong connective tissue contracts to produce a fibrous scar. In the abdomen, such fibrous adhesions can narrow loops of intestine and result in an obstruction. The accumulation of excessive amounts of collagen (more common in African Americans) may produce a protruding, tumor-like scar known as a keloid. Unfortunately, surgery to remove a keloid is usually ineffective because the subsequent incision tends to heal in the same way.

Many injuries heal by a combination of regeneration and scar tissue formation. An example is the response of the liver to repeated and persistent alcoholic injury; the result is cirrhosis, in which irregular lobules of regenerated liver cells are criss-crossed and surrounded by bands of scar tissue. Scar tissue formation consists of fibrous connective tissue, which can be divided into primary union (surgical incision) and secondary union (nonsurgical; gunshot wound).

The five clinical signs of acute inflammation are rubor (redness), calor (heat), tumor (swelling), dolor (pain), and loss of function. The localized heat and redness result from increased blood flow in the microcirculation at the site of injury. The swelling occurs because the exudate increases the amount of interstitial fluid, resulting in pressure on nerve endings and thus pain, which results in a loss of function.

Acute inflammation can also lead to systemic manifestations. Fever is especially common in inflammatory conditions associated with the spread of organisms into the bloodstream. The number of circulating white blood cells also increases (leukocytosis).

Some bacterial organisms (e.g., staphylococci and streptococci) produce toxins that damage the tissues and incite an inflammatory response. The presence of **pyogenic** bacteria leads to the production of a thick, yellow fluid called *pus*, which contains dead white blood cells, inflammatory exudate, and bacteria. A suppurative inflammation is one that is associated with pus formation. When a pyogenic infection occurs beneath the skin or in a solid organ, it produces an **abscess**, a localized, usually encapsulated, collection of pus. All pyogens, wherever they become implanted, have the ability to invade blood vessels to produce **bacteremia**, with the potential involvement of other organs and tissues in the body.

A granulomatous inflammation manifests as a distinct pattern seen in relatively few diseases, including tuberculosis, syphilis, and sarcoidosis. A granuloma is a localized area of chronic inflammation, often with central necrosis. It is characterized by the accumulation of macrophages, some of which fuse to form multinucleated giant cells.

## SUMMARY OF TERMS FOR INFLAMMATORY PROCESS

| Term | Definition |
|---|---|
| Inflammation | Initial response of the tissue to local injury |
| Permeable membrane | Allows fluids/cells to pass from one tissue to another tissue or location |
| Granulation tissue | Fibrous scar replaces destroyed tissue |
| Pyogenic bacteria | Thick, yellow fluid called pus (dead white cells) |
| Abscess | Localized, usually encapsulated, collection of fluid |
| Bacteremia | Potential involvement of other organs and tissues in the body by organisms invading the blood vessels |

## Edema

**Edema** is the accumulation of abnormal amounts of fluid in the intercellular tissue spaces or body cavities. Localized edema results from an inflammatory reaction, whereas generalized edema occurs with pronounced swelling of subcutaneous tissues throughout the body (anasarca). Localized edema may result from inflammation, with the escape of protein-rich intravascular fluid into the extravascular tissue. It may also result from a local obstruction to lymphatic drainage; for example, in filariasis, a parasitic worm causes lymphatic obstruction, and the resulting localized edema is termed elephantiasis. Generalized edema occurs most frequently in patients with congestive heart failure, cirrhosis of the liver, and certain forms of renal disease. Because of the effect of gravity, generalized edema is usually most prominent in dependent portions of the body. Thus ambulatory patients tend to accumulate fluid in tissues around the ankles and lower legs, whereas in hospitalized patients who are nonambulatory or sedentary, the edema fluid collects most prominently in the lower back, sacral areas, and lungs.

Extravascular fluid can also accumulate in serous cavities to produce pleural and pericardial effusions and peritoneal ascites. Edema may produce minimal clinical symptoms or be potentially fatal. If localized to the subcutaneous tissues, large amounts of edema may cause minimal functional impairment. In contrast, pulmonary edema, pericardial effusion, or edematous swelling of the brain may have dire consequences.

## SUMMARY OF TERMS FOR EDEMA

| Term | Definition |
|---|---|
| Edema | Accumulation of abnormal amounts of fluid in the intercellular tissue spaces or body cavities |
| Anasarca | Generalized edema that occurs with pronounced swelling of subcutaneous tissues throughout the body |
| Elephantiasis | Localized lymphatic obstruction resulting in localized edema |

## Ischemia and Infarction

**Ischemia** refers to an interference with the blood supply to an organ or part of an organ, depriving the organ's cells and tissues of oxygen and nutrients. Ischemia may be caused by a narrowing of arterial structures, as in atherosclerosis, or by thrombotic or embolic occlusion (Fig. 1.1). Depending on several factors, occlusion of an artery or vein may have little or no effect on the involved tissue, or it may cause death of the tissue and even of the individual. A major determinant is the availability of an alternative or newly acquired route of blood supply (collateral vessels). Other factors include the rate of development of the occlusion, the vulnerability of the tissue to hypoxia, and the oxygen-carrying capacity of the blood. Slowly developing occlusions are less likely to cause tissue death (necrosis) because they provide an opportunity for the development of alternative pathways of flow. Ganglion cells of the nervous system and myocardial muscle cells undergo irreversible damage if deprived of their blood supply for 3 to 5 minutes. Anemic or cyanotic patients tolerate arterial insufficiency less well than normal individuals do, and thus occlusion of even a small vessel in such a patient may lead to death of tissue.

An **infarct** is a localized area of ischemic necrosis within a tissue or organ produced by occlusion of either its arterial supply or its venous drainage. The two most common clinical forms of infarction are myocardial and pulmonary. Almost all infarcts result from thrombotic or embolic occlusion. Infrequent causes include twisting of an organ (volvulus), compression of the blood supply of a loop of bowel in a hernia sac, or trapping of a viscus under a peritoneal adhesion.

In cases in which ischemia continues to progress, resulting in an infarction, necrosis may occur as a result of lack of blood flow. This progressive situation can lead to a condition called *gangrene*. Severe arterial disease of the lower extremities may result in necrosis of several toes or a large segment of the foot, causing gangrene. A frequent presenting symptom in diabetic patients is ischemia of the foot, which may progress to infarction and result in gangrene.

Infarctions tend to be especially severe because they occur more often in the patients least able to withstand them. Thus infarcts tend to occur in older individuals with advanced atherosclerosis or impaired cardiac function and are more likely to occur after surgery or delivery.

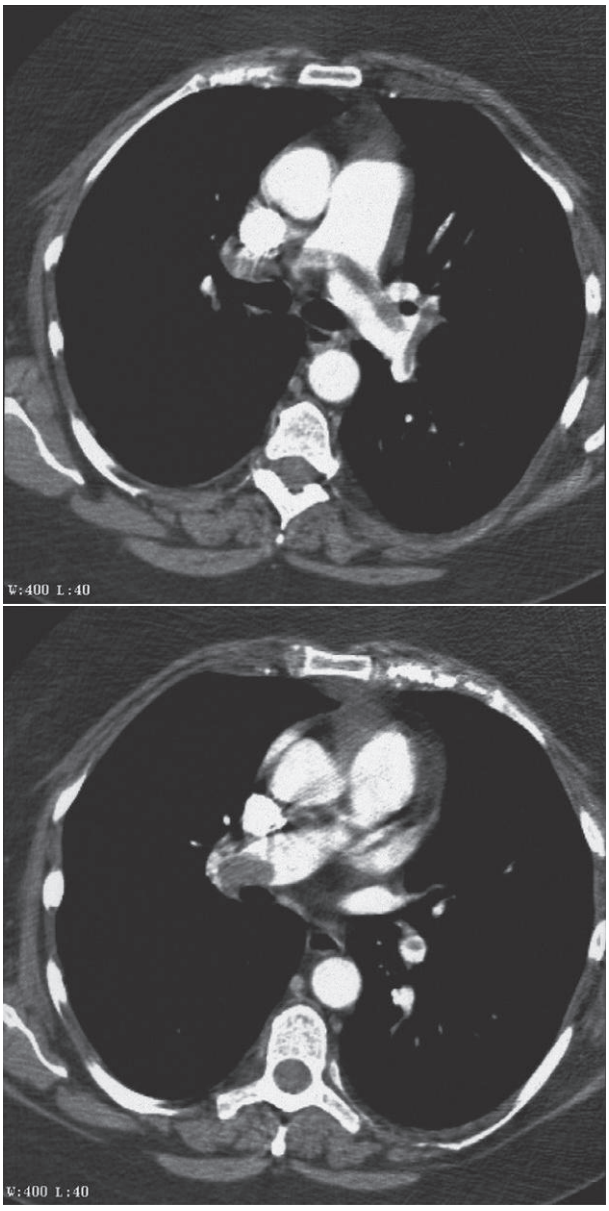


**Fig. 1.1** Computed Tomography Scan of Pulmonary Embolism. (A) Filling defect in both the right and the left pulmonary arteries (saddle type), and (B) a blockage (filling defect) nearly complete on the right.

## Hemorrhage

The term **hemorrhage** implies rupture of a blood vessel. Rupture of a large artery or vein is almost always caused by some form of injury, such as trauma, atherosclerosis, or inflammatory or neoplastic erosion of the vessel wall. Hemorrhage may be external, or the blood may be trapped within body tissues, resulting in an accumulation termed a **hematoma** (Fig. 1.2). The accumulation of blood in a body cavity results in hemothorax, hemopericardium, hemoperitoneum, or hemarthrosis (blood in a joint). Minimal hemorrhages into the skin, mucous membranes, or serosal surfaces are called *petechiae*; slightly larger hemorrhages are termed *purpura*. A large (>1 to 2 cm) subcutaneous hematoma, or bruise, is called an *ecchymosis*.

The significance of hemorrhage depends on the volume of blood loss, the rate of loss, and the site of the hemorrhage. Sudden losses of up to 20% of the blood volume or slow losses of even larger amounts may have little clinical significance. The site of the hemorrhage is critical. For example, an amount of bleeding that would have little clinical significance in the subcutaneous tissues may cause death when located in a vital portion of the brain. Large amounts of external bleeding lead to the chronic loss of iron from the body and anemia. In contrast, internal hemorrhages into body cavities, joints, or tissues permit the iron to be recaptured for the synthesis of hemoglobin and the development of normal red blood cells.

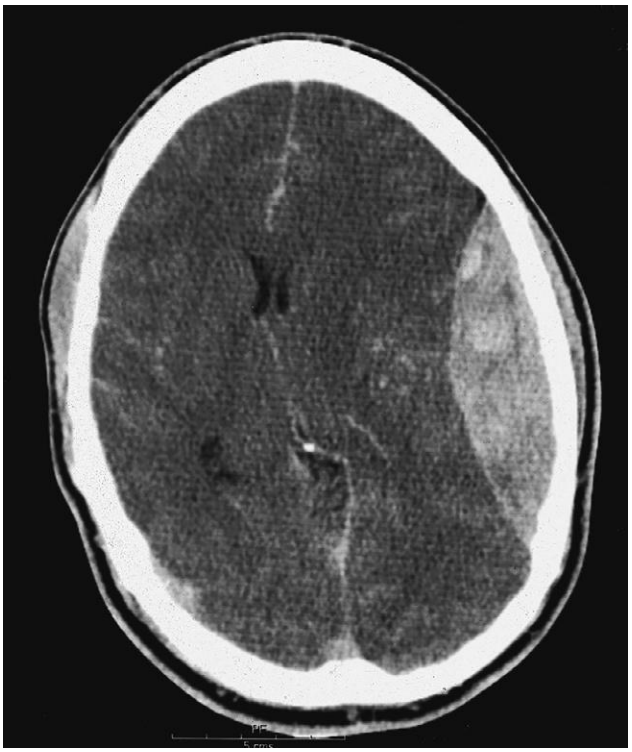

**Fig. 1.2 Subdural Hematoma.** Concave appearance of increased attenuation on the left causing midline shift of the ventricles.

## SUMMARY OF TERMS FOR BLOOD VESSELS

| Term | Definition |
|---|---|
| Ischemia | Interference of blood supply to an organ; deprives cells and tissues of oxygen and nutrients |
| Infarct | Localized area of ischemic necrosis; produced by occlusion of either arterial supply or venous drainage |
| Hemorrhage | Implies rupture of a blood vessel |
| Hematoma | Accumulation of blood trapped within body tissues |

## SUMMARY OF TERMS FOR ALTERATIONS OF CELL GROWTH

| Term | Definition |
|---|---|
| Atrophy | Reduction in the size or number of cells in an organ or tissue, with a corresponding decrease in function |
| Hypertrophy | Increase in the size of the cells of a tissue or organ in response to a demand for increased function |
| Hyperplasia | Increase in the number of cells in a tissue or organ |
| Dysplasia | Loss of uniformity of individual cells and their architectural orientation |
| Neoplasia | Ungoverned abnormal proliferation of cells |
| Oncology | Study of neoplasms (tumors) |
| Benign | Growth that closely resembles the cells of origin in structure and function |
| Malignant | Neoplastic growth that invades and destroys adjacent structures |
| Metastasize | Malignant neoplasms that travel to distant sites |
| Carcinoma | Malignant neoplasm of epithelial cell origin |
| Anaplastic | Undifferentiated cell growth—without form (bizarre) |
| Sarcoma | Highly malignant tumor originating from connective tissue |
| Lymphatic spread | Major route by which carcinoma metastasizes |
| Hematogenous spread | Malignant tumors that have invaded the circulatory system and travel as neoplastic emboli |
| Grading | Assessment of aggressiveness or degree of malignancy |
| Staging | 1. Extensiveness of tumor at the primary site<br>2. Presence or absence of metastases to lymph nodes and distant organs |
| Epidemiology | Study of determinants of disease events in given populations |
| Morbidity | Rate that an illness or abnormality occurs |
| Mortality | Reflects the number of deaths by disease per population |

## Alterations of Cell Growth

Changes in the number and size of cells, their differentiation, and their arrangement may develop in response to physiologic stimuli. **Atrophy** refers to a reduction in the size or number of cells in an organ or tissue, with a corresponding decrease in function. It must be distinguished from hypoplasia and aplasia, in which failure of normal development accounts for small size.

An example is the disuse atrophy that occurs with immobilization of a limb by a plaster cast. The muscle mass of the encased limb reduces dramatically. Because the cast also removes the stress and strain from the enclosed bone that normally stimulates new bone formation, normal bone resorption continues unchecked and the loss of calcified bone can be detected on radiographs. In this situation, there is rapid recovery from the atrophic appearance when the cast is removed and normal function is resumed.

Pathologic, irreversible atrophy may be caused by loss of innervation, by hormonal stimulation, or by decreased blood supply. For example, stenosis of a renal artery may cause atrophy of the kidney with shrinkage of individual nephrons and loss of interstitial tissue.

Hypertrophy refers to an increase in the size of the cells of a tissue or organ in response to a demand for increased function. This must be distinguished from **hyperplasia**, an increase in the number of cells in a tissue or organ (Fig. 1.3). Hypertrophy occurs most often in cells that cannot multiply, especially those in myocardial and peripheral striated muscle. Myocardial hypertrophy is necessary to maintain cardiac output despite increased peripheral resistance in patients with arterial hypertension or aortic valve disease. After the loss of a normal kidney, hypertrophy of the other kidney occurs in an attempt to continue adequate renal function.

Examples of hyperplasia include: (1) proliferation of granulation tissue in the repair of injury and (2) the increased cellularity of bone marrow in patients with hemolytic anemia or after hemorrhage. Hyperplasia of the adrenal cortex is a response to increased adrenocorticotropic hormone (ACTH) secretion; hyperplasia of the thyroid gland occurs with increased thyrotropic hormone secretion by the pituitary gland.

**Dysplasia** is a loss in the uniformity of individual cells and their architectural orientation; it is typically associated with

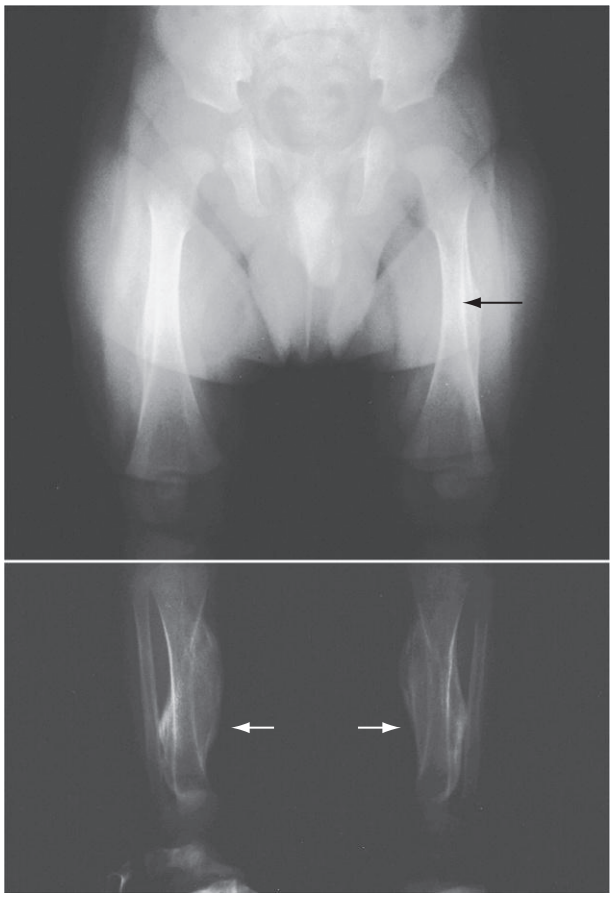


**Fig. 1.3** Infantile Cortical Hyperostosis (Caffey Disease). Affected bones demonstrate cortical thickening with new periosteal bone formation bilaterally on the femurs (A) and tibias (B) *(arrows)*.

prolonged chronic irritation or inflammation. Removal of the irritant may result in a return to normal, but often the tissue change persists, and it may evolve into a totally abnormal growth pattern. Thus dysplasia is generally considered at least potentially premalignant—a borderline lesion that may heal or progress to cancer.

## Neoplasia

**Neoplasia**, from the Latin word for "new growth," refers to an abnormal proliferation of cells that are no longer controlled by the factors that govern the growth of normal cells. Neoplastic cells act as parasites, competing with normal cells and tissues for their metabolic needs. Thus tumor cells may flourish and the patient becomes weak and emaciated, a condition termed *cachexia*.

Neoplasms are commonly referred to as tumors; indeed, the study of neoplasms is called **oncology**, derived from the Greek word *oncos*, meaning "tumor." Although the word *tumor* originally referred to any swelling, which could also be produced by edema or hemorrhage in tissue, the word now refers almost exclusively to a neoplasm.

Neoplasms are divided into benign and malignant categories on the basis of their potential clinical behavior. **Benign** tumors closely resemble their cells of origin in structure and function. They remain localized, without spreading to other sites, and thus can usually be surgically removed with resultant survival of the patient.

Nevertheless, some benign tumors can have severe consequences because of their position or hormonal secretion. For example, a benign pituitary tumor can cause pressure atrophy and destruction of the surrounding gland, and a benign tumor of the islets of Langerhans in the pancreas can produce excessive amounts of insulin, resulting in possibly fatal low levels of blood glucose. Other potentially dangerous benign tumors include those arising in the brain or spinal cord, which may influence central nervous system function. Tumors of the trachea or esophagus may occlude the air supply or make it impossible to swallow.

**Malignant** neoplasms invade and destroy adjacent structures and spread to distant sites (**metastasize**), causing death. Malignancies tend to be poorly differentiated so that it may be impossible to determine the organ from which they originate. Malignant tumors are collectively referred to as **cancers**. This term is derived from the Latin word for "crab," possibly because the finger-like projections that extend into underlying tissue resemble crablike claws.

All tumors, both benign and malignant, have two basic components: (1) the parenchyma (organ tissue), made up of proliferating neoplastic cells, and (2) the supporting stroma (supporting tissue), made up of connective tissue, blood vessels, and possibly lymphatic vessels. The parenchyma of the neoplasm largely determines its biologic behavior and is the component that determines how the tumor is named.

Most benign tumors consist of parenchymal cells that closely resemble the tissue of origin. Their names come from adding the suffix *-oma* to the cell type from which the tumor arose. For example, benign tumors of fibrous tissue are termed *fibromas*, whereas benign cartilaginous tumors are *chondromas* (Fig. 1.4). The term *adenoma* is applied to benign epithelial neoplasms that grow in glandlike patterns. Benign tumors that form large cystic masses are called *cystadenomas*. *Lipomas* consist of soft fatty tissue, *myomas* are tumors of muscle, and *angiomas*

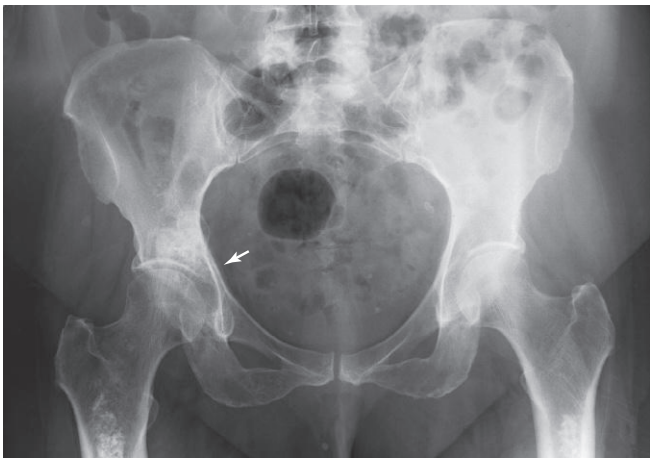

**Fig. 1.4** Enchondroma. A lobulated area with increased bone density in the supra-acetabular region on the right side *(arrow)*.

are tumors composed of blood vessels. An epithelial tumor that grows as a projecting mass on the skin or from an inner mucous membrane (e.g., the gastrointestinal tract) is termed a *papilloma* or a *polyp*.

Malignant neoplasms of epithelial cell origin are called **carcinomas**, from the Greek word *karkinos*, meaning "crab." Carcinomas affect epithelial tissues, skin, and mucous membranes lining body cavities. *Adenocarcinoma* refers to malignancies of glandular tissues, such as the breast, liver, and pancreas, and of the cells lining the gastrointestinal tract. *Squamous cell carcinoma* denotes a cancer in which the tumor cells resemble stratified squamous epithelium, as in the lung, head, and neck regions. At times, the tumor grows in such a bizarre pattern that it is termed **undifferentiated** or **anaplastic** (without form).

**Sarcomas** are highly malignant tumors arising from connective tissues, such as bone, muscle, and cartilage. Although they are less common than carcinomas, sarcomas tend to spread more rapidly.

Substantial evidence exists indicating that most tumors arise from a single cell (monoclonal origin). The rate of growth generally correlates inversely with the level of parenchymal differentiation. Thus well-differentiated tumors tend to grow slowly, whereas bizarre, undifferentiated neoplasms have a rapid growth rate.

Although the cause of cancer is still unknown, many possible causative factors *(carcinogens)* have been implicated. Chemical carcinogens may cause structural alteration of the deoxyribonucleic acid (DNA) molecule (mutation), which may lead to the development of a neoplasm. Examples of chemical carcinogens include air and water pollution, cigarette smoke, asbestos, and a variety of other substances used in industry, food, cosmetics, and plastics. The development of specific types of cancer in certain families suggests a possible genetic predisposition. Excessive exposure to ultraviolet radiation (sunshine) may lead to the development of skin cancer. Survivors of the atom bomb who received huge doses of radiation have demonstrated a high incidence of leukemia. A greater-than-expected rate of leukemia was also seen in persons working with x-radiation before the need for proper protection was appreciated.

The study of experimental animal tumors has offered convincing evidence that DNA and ribonucleic acid (RNA) viruses can induce neoplastic transformation. Viruses that invade normal cells may alter their genetic material, leading to the abnormal cell divisions and rapid growth observed in malignant tumors.

The clinical symptoms of cancer vary with the site of malignancy. A blood-tinged stool, a change in bowel activity (e.g., intermittent constipation and diarrhea), or intestinal obstruction is suggestive of gastrointestinal malignancy. Difficulty in swallowing (dysphagia) or loss of appetite (anorexia), especially if accompanied by rapid weight loss, suggests a neoplasm in the esophagus or stomach. Hematuria may indicate kidney or bladder cancer, whereas difficulties in urination (e.g., urgency, a burning sensation, or an inability to start the stream of urine) in an older man may be a sign of prostate tumor. Hemoptysis (coughing up blood), a persistent cough, or hoarseness may suggest a neoplasm in the respiratory tract. Severe anemia may develop from internal bleeding or from malfunction of the bone marrow caused by growth of a malignant lesion in the skeleton.

It should be stressed that these clinical symptoms may also be caused by benign disease. Nevertheless, because they may signal an underlying malignancy, they should be carefully investigated to exclude the presence of cancer.

Pain is frequently not an early sign of cancer. Unfortunately, pain may be appreciated only when the malignancy has spread too extensively to be curable. Secondary infections are common and an increasing cause of death. Most cancer patients are immunologically compromised, either because of their original disease or as a result of irradiation or chemotherapy. In addition to having typical bacterial and viral infections, immunocompromised patients with malignancy are especially susceptible to unusual opportunistic infections, such as *Pneumocystis jirovecii* (formerly *Pneumocystis carinii*) pneumonia and cytomegalovirus.

Some cancers that are still at a curable stage can be detected by screening procedures. Routine mammography may identify nonpalpable breast cancer; a Papanicolaou (Pap) smear may show otherwise unsuspected cancer of the cervix. Surgical removal of these small tumors without metastatic spread offers an excellent prognosis.

Malignant neoplasms disseminate to distant sites by one of three pathways: (1) seeding within body cavities, (2) lymphatic spread, and (3) hematogenous spread.

*Seeding* (diffuse spread) of cancers occurs when neoplasms invade a natural body cavity. For example, a tumor of the gastrointestinal tract may penetrate the wall of the gut (visceral peritoneum), permitting metastases to enter the peritoneal cavity and implant at distant sites. A similar sequence may occur with lung cancers in the pleural cavity. Neoplasms of the central nervous system (medulloblastoma and ependymoma) may spread from the cerebral ventricles by means of the cerebrospinal fluid to reimplant on the meningeal surfaces within the brain or in the spinal cord.

**Lymphatic spread** is the major metastatic route of carcinomas, especially those of the lung and breast. The pattern of lymph node involvement depends on the site of the primary neoplasm and the natural lymphatic pathways of drainage of that region. Carcinomas of the lung metastasize first to the regional bronchial lymph nodes and then to the tracheobronchial and hilar nodes. Carcinoma of the breast usually arises in the upper outer quadrant and first spreads to the axillary nodes. Medial breast lesions may drain through the chest wall to nodes along the internal mammary artery.

The **hematogenous spread** of cancer is a complex process involving several steps. Tumor cells invade and penetrate blood vessels, traveling as neoplastic emboli in the circulation. These emboli of tumor cells are trapped in small vascular channels of distant organs, where they invade the wall of the arresting vessel and infiltrate and multiply in the adjacent tissue. The localization of hematogenous metastases tends to be determined by the vascular connections and anatomic relationships between the primary neoplasm and the metastatic sites. For example,

carcinomas arising in abdominal organs, such as the gastrointestinal tract, tend to metastasize to the liver because of the flow of portal vein blood to that organ. Cancers arising in midline organs close to the vertebral column (e.g., prostate and thyroid) tend to embolize through the paravertebral venous plexus to seed the vertebral column. Neoplasms in organs drained by the inferior and superior vena cava, such as the kidney, tend to metastasize to the lung. However, several well-defined patterns of metastatic spread cannot be easily explained by vascular-anatomic relationships. Some examples are the tendency for carcinoma of the lung to involve the adrenal glands, simultaneous metastatic deposits in the brain and adrenal glands, and pituitary metastases occurring from breast carcinomas.

The **grading** of a malignant tumor assesses aggressiveness, or degree of malignancy. The grade of a tumor usually indicates its biologic behavior and may allow prediction of its responsiveness to certain therapeutic agents. **Staging** refers to the extensiveness of a tumor at its primary site and the presence or absence of metastases to lymph nodes and distant organs, such as the liver, lungs, and skeleton. The staging of a tumor aids in determining the most appropriate therapy. Well-localized tumors without evidence of metastases may be surgically removed. Fast-growing, undifferentiated tumors, such as those found in patients with Hodgkin disease, may respond best to radiation therapy. Cancer of the prostate responds to hormonal therapy, which consists of either the removal of the sources of male gonadal hormones that stimulate tumor growth or the administration of the female gonadal hormone (estrogen) that inhibits it. Chemotherapy uses one or a combination of cytotoxic substances that kill neoplastic cells, but these drugs may injure many normal cells and result in significant complications.

Upon determination of the type of neoplastic involvement, a study of determinants is compiled for the specific disease in a given population, which is called **epidemiology**. Using epidemiology and the grading of the neoplasms then becomes part of establishing morbidity. **Morbidity** is the rate that an illness or abnormality occurs. Depending on the stage of the tumor, **mortality** is calculated by reviewing the population involved to statistically calculate the expected death rate. These factors will be taken into consideration when the best course of treatment for the patient is being determined.

## HEREDITARY DISEASES

**Hereditary diseases** pass from one generation to the next through the genetic information contained in the nucleus of each cell. They reflect an abnormality in the DNA, which provides the blueprint for protein synthesis in the cell. In many hereditary diseases, an error in a single protein molecule leads to enzyme defects; membrane receptor and transport system defects; alterations in the structure, function, or quantity of nonenzyme proteins; and unusual drug reactions.

The most common hereditary abnormality is an enzyme deficiency. This leads to a metabolic block that results either in a decreased amount of a substance needed for normal function or in an accumulation of a metabolic intermediate that may cause injury. An example of the first mechanism is albinism, the absence of pigmentation resulting from an enzymatic deficiency that prevents the synthesis of the pigment melanin. An example of the second mechanism is phenylketonuria, in which the absence of an enzyme leads to the accumulation of toxic levels of the amino acid phenylalanine.

A defect in the structure of the globin molecule leads to the development of the hemoglobinopathies, such as sickle cell disease and thalassemia. An example of a genetically determined adverse reaction to drugs is glucose 6-phosphate dehydrogenase deficiency, in which an insufficient amount of the enzyme results in a severe hemolytic anemia in patients receiving a common antimalarial drug.

Despite our extensive knowledge of the biochemical basis of many genetic disorders, there are a large number of conditions for which the underlying mechanism is still unknown. This list includes neurofibromatosis, retinoblastoma, and familial colonic polyposis (see Chapter 5). Each human cell contains 46 chromosomes divided into 23 pairs. The chromosomes in turn contain thousands of genes, each of which is responsible for the synthesis of a single protein. Forty-four of the chromosomes are called **autosomes**; the other two are the X and Y chromosomes, which determine the sex of the person. A combination of XY chromosomes results in a male, whereas an XX configuration results in a female.

Each person inherits half of his or her chromosomes from each parent. If the genes inherited from each parent are the same for a particular trait, the person is *homozygous* for that trait. If the genes differ (e.g., one for brown eyes and one for blue eyes), the person is *heterozygous* for that trait. **Dominant** genes always produce an effect regardless of whether the person is homozygous or heterozygous; **recessive** genes manifest themselves only when the person is homozygous for the trait. In determining eye color, brown is dominant, whereas blue is recessive. It must be remembered that although a recessive trait must have been contributed by both parents, the possibility exists that neither parent demonstrates that trait. For example, two parents, each with one gene for brown eyes and one gene for blue eyes, would show the dominant brown coloration, although they could each contribute a blue-eye gene to their offspring, who would manifest the recessive blue-eye trait.

For some traits, the genes are codominant so that both are expressed. An example is the AB blood type, in which the gene for factor A is inherited from one parent and that for factor B is inherited from the other.

**Mutations** are alterations in the DNA structure that may become permanent hereditary changes if they affect the gonadal cells. Mutations may result from radiation, chemicals, or viruses. They may have minimal effect and be virtually undetectable or may be so serious that they are incompatible with life, causing the death of a fetus and spontaneous abortion.

*Autosomal dominant* disorders are transmitted from one generation to the next. These disorders affect females and males, and both can transmit the condition. When an affected person marries an unaffected person, half the children (on average) will have the disease. The clinical manifestations of autosomal dominant disorders can be modified by reduced penetrance and

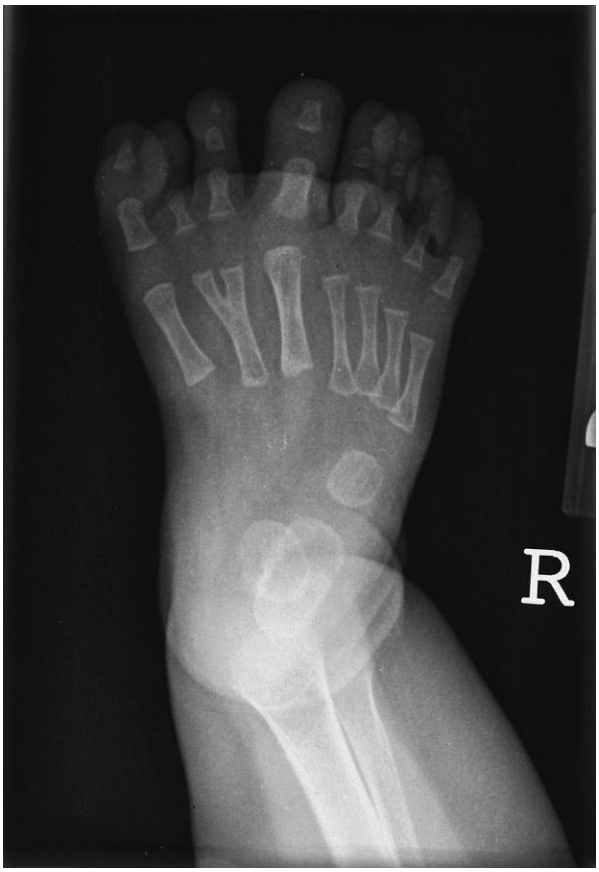


**Fig. 1.5** Polydactyly. Right foot image with seven metatarsals and eight digits.

variable expressivity. *Reduced penetrance* means that not everyone who has the gene will demonstrate the trait; *variable expressivity* refers to the fact that a dominant gene may manifest somewhat differently in different individuals (Fig. 1.5) (e.g., polydactyly may be expressed in the toes or in the fingers as one or more extra digits). Examples of autosomal dominant disorders include achondroplasia (see Chapter 4), neurofibromatosis, Marfan syndrome (see Chapter 12), and familial hypercholesterolemia.

*Autosomal recessive* disorders result only when a person is homozygous for the defective gene. The trait does not usually affect the parents, although siblings may show the disease. On average, siblings have a one-in-four chance of being affected; two out of four will be carriers of the gene, and one will be normal. Recessive genes appear more frequently in a family, and close intermarriage (as between first cousins) increases the risk of the particular disease. Unlike in autosomal dominant diseases, the expression of the defect tends to be uniform in autosomal recessive diseases and the age of onset is frequently early in life. Examples of autosomal recessive disorders are phenylketonuria (see Chapter 12), cystic fibrosis (see Chapter 3), galactosemia, glycogen and lipid storage diseases (see Chapter 12), Tay-Sachs disease, and sickle cell anemia (see Chapter 9).

Sex-linked disorders generally result from defective genes on the X chromosome because the Y chromosome is small and carries very few genes. Most of these conditions are transmitted by heterozygous female carriers virtually only to sons, who have only the single, affected X chromosome. Sons of a heterozygous woman have a one-in-two chance of receiving the mutant gene. An affected man does not transmit the disorder to his sons, but all his daughters carry the genetic trait. In rare cases a female may have the sex-linked disease if she is homozygous for the recessive gene. Virtually all sex-linked disorders are recessive. The most common example of a sex-linked disorder is color blindness. Other conditions are glucose 6-phosphate dehydrogenase deficiency and some types of hemophilia (see Chapter 9) and muscular dystrophy (see Chapter 12).

### SUMMARY OF TERMS FOR HEREDITARY DISEASES

| Term | Definition |
|---|---|
| Hereditary process | Genetic information contained in the nucleus of each cell passed to the next generation |
| Autosomes | 44 chromosomes other than X and Y |
| Dominant gene | Always produces an effect |
| Recessive gene | Manifests when a person is homozygous for the trait |
| Mutation | Alteration in the DNA structures that may become permanent hereditary change |

## DISORDERS OF IMMUNITY

The immune reaction of the body provides a powerful defense against invading organisms by allowing it to recognize foreign substances (**antigens**), such as bacteria, viruses, fungi, and toxins, and to produce **antibodies** to counteract them. The antibody binds together with the antigen to make the antigen harmless. Once antibodies have been produced, a person becomes **immune** to the antigen.

Antibodies, or immunoglobulins, form in lymphoid tissue, primarily in the lymph nodes, thymus gland, and spleen. Although an infant has some immunity at birth, most immunity is acquired either naturally by exposure to a disease or artificially by immunization. There are two types of artificial immunity: active and passive. In **active immunity**, a person forms antibodies to counteract an antigen in the form of a vaccine or a toxoid. A **vaccine** consists of a low dose of dead or deactivated bacteria or viruses. Although these organisms cannot cause disease, they are foreign proteins containing antigens that stimulate the body to produce antibodies against them. A **toxoid** is a chemically altered toxin, the poisonous material produced by a pathogenic organism. As with a vaccine, the toxin cannot cause disease but does trigger the development of antibodies. Examples of active immunity are the vaccines given to prevent smallpox, polio, measles, tetanus, and diphtheria. Active immunity persists for a long time, although a relatively long time is required to build up immunity, and a booster shot frequently gives a stronger effect.

*Passive immunity* refers to the administration of a dose of preformed antibodies from the immune serum of an animal,

usually a horse. This type of immunity acts immediately but lasts for a relatively short time. It is used in situations in which a person is exposed to a serious disease (hepatitis, rabies, and tetanus) but has no immunity against it and thus requires an immediate supply of antibodies to prevent a possibly fatal infection.

Several fundamental mechanisms of immunologic responses to antigens exist. The first type is a rapidly occurring reaction in which antigens are attacked by antibodies previously bound to the surface of mast cells. The mast cells release histamine, which causes a local increase in vascular permeability and smooth muscle contraction. Disorders resulting from localized reactions of this type (which probably have a genetically determined predisposition) include hay fever, asthma, and gastrointestinal allergies. Generalized, or systemic, **anaphylactic** reactions are characterized by hypotension and vascular collapse (shock) with urticaria (hives), bronchiolar spasm, and laryngeal edema. This reaction causes sudden death in patients who are hypersensitive ("allergic") to the sting of bees, wasps, and other insects, and to medications such as penicillin and the iodinated contrast materials used in radiology.

In the second type of immune reaction, called a *cytotoxic reaction*, either the antigen is a component of a cell or it attaches to the wall of red blood cells, white blood cells, platelets, or vascular endothelial cells. The reaction with an antibody leads to cell destruction by lysis or phagocytosis. Examples of a cytotoxic immune reaction include the transfusion reaction occurring after the administration of ABO-incompatible blood, and erythroblastosis fetalis, the hemolytic anemia of the Rh-positive newborn whose Rh-negative mother has produced anti-Rh antibodies.

The third type of immune reaction, a *delayed reaction*, occurs in an individual previously sensitized to an antigen. As an example, the first time a person touches poison ivy, no reaction occurs. However, on the next exposure to poison ivy, antibodies are present to attack the antigen, and the patient develops the typical rash and irritation. A similar process produces a reaction to tuberculosis, leprosy, many fungal diseases, and other infections. This process also represents the principal component of rejection in organ transplants.

## INFECTIOUS DISEASE EXPOSURE

Working in the healthcare environment means that exposure to infectious microorganisms will occur. To minimize exposure, all healthcare workers should follow the Centers for Disease Control and Prevention (CDC) **standard precautions**. Exposure to blood-borne pathogens such as human immunodeficiency virus (HIV) and hepatitis B virus (HBV) can be minimized for all persons involved with the use of the appropriate **personal protective equipment** (PPE). The CDC recommends that all such persons be considered potentially infected and that standard precautions be applied when they are delivering health services to every patient. In cases of highly transmissible pathogens, additional precautions are necessary; **transmission-based precautions** should be used for persons with pathogens transmissible by contact, droplet, or through air (airborne). Each healthcare facility is responsible for administering the precautions; educating, training, and monitoring its employees; and providing a protective environment. Every healthcare worker must take personal responsibility to help contain the infectious process in the work environment by following CDC standards.

### SUMMARY OF TERMS FOR IMMUNITY DISORDERS

| Term | Definition |
|---|---|
| Antigens | Foreign substance that evokes an immune response |
| Antibodies | Immunoglobulins responding to the antigens to make them harmless |
| Immune | Protected against antigens; antibodies binding with antigens to make them harmless |
| Active immunity | Forming antibodies to counteract an antigen by way of vaccine or toxoid |
| Vaccine | Contact with dead or deactivated microorganisms to form antibodies |
| Toxoid | Treated toxin with antigenic power to produce immunity by creating antibodies |
| Anaphylactic reaction | Hypersensitive reaction resulting in a histamine release |
| Standard precautions | Protection used when delivering healthcare services to any person |
| Personal protective equipment | PPE—gowns, gloves, masks, shoe covers, and eye protection used to prevent transmission of potential infectious agents |
| Transmission-based precautions | Additional protective equipment to prevent the spread of highly infectious pathogens through contact, droplet, or airborne transmission |

## ACQUIRED IMMUNODEFICIENCY SYNDROME

**Acquired immunodeficiency syndrome (AIDS)**, which most commonly affects young homosexual men and intravenous drug abusers, is characterized by a profound and sustained impairment of cellular immunity that results in recurrent or sequential opportunistic infections and a particularly aggressive form of Kaposi sarcoma. AIDS has also been reported in a substantial number of hemophiliac patients, in recipients of transfusions, and increasingly in heterosexual partners of affected individuals. AIDS is attributable to infection with retroviruses (RNA viruses) known as HIV. This immune deficiency predominantly involves the lungs, gastrointestinal tract, and central nervous system. Pulmonary infections are extremely common in patients with AIDS and are frequently caused by organisms that only rarely produce disease in individuals with normal immune systems. Approximately 60% of AIDS victims experience one or more attacks of *P. jirovecii* pneumonia, which is characterized by a sudden onset, a rapid progression to diffuse lung involvement, and a considerable delay in resolution. The fungus cannot be cultured, and the disease is usually fatal if untreated. An open-lung biopsy is often necessary to make the diagnosis if a sputum examination reveals no organisms in a patient in whom this disease is suspected.

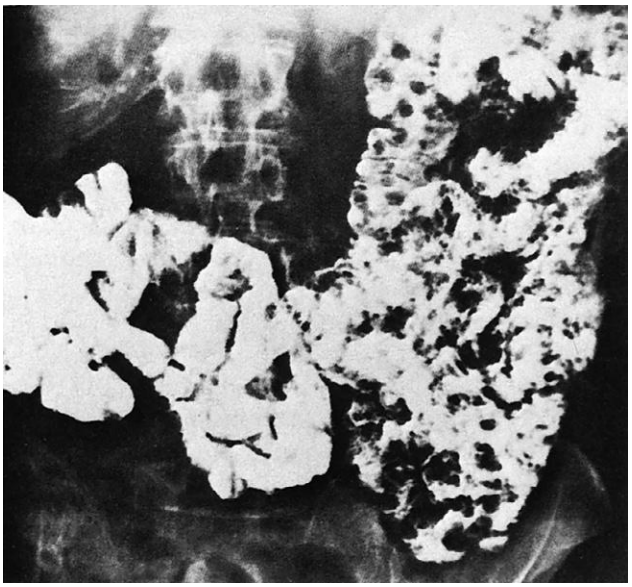

**Fig. 1.6 Kaposi Sarcoma.** Small bowel study shows multiple intramural nodules (predominantly involving the jejunum) that distort the mucosal pattern and produce contour defects and intraluminal lucencies. (From Bryk D et al: Kaposi's sarcoma of the intestinal tract: roentgen manifestations, *Gastrointest Radiol* 3:425, 1978.)

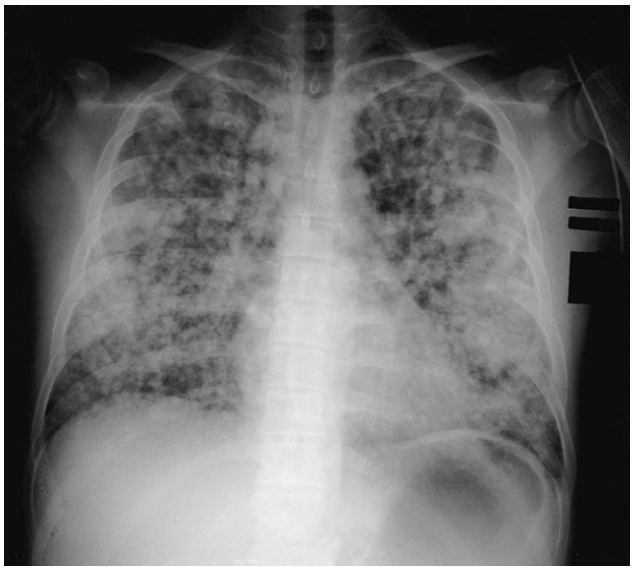

**Fig. 1.7 *Pneumocystis jirovecii* Pneumonia.** Diffuse bilateral air-space consolidation is suggestive of severe bacterial pneumonia or pulmonary edema.

Gastrointestinal manifestations of AIDS include a variety of sexually transmitted diseases involving the rectum and colon, infectious processes (e.g., shigellosis, amebiasis, candidiasis, and giardiasis), and alimentary tract dissemination (spread) of Kaposi sarcoma. Kaposi sarcoma, a systemic disease, characteristically affects the skin and causes an ulcerated hemorrhagic dermatitis. Metastases to the small bowel, which are relatively common, consist of multiple reddish or bluish red nodules that intrude into the lumen of the bowel (Fig. 1.6). Similar lesions can develop throughout the gastrointestinal tract. Central ulceration of the metastases causes gastrointestinal bleeding and a characteristic radiographic appearance of multiple "bull's-eye" lesions simulating metastatic melanoma.

Approximately 40% of all AIDS victims have neurologic symptoms, most commonly progressive dementia. Patients with mass lesions of the brain commonly have focal neurologic symptoms and signs.

## Imaging Appearance

The typical early radiographic finding of *P. jirovecii* pneumonia is a hazy, perihilar, granular infiltrate that spreads to the periphery and appears predominantly interstitial. In later stages the pattern progresses to patchy areas of air-space consolidation with air bronchograms, indicating the alveolar nature of the process (Fig. 1.7). The radiographic appearance may closely resemble that of pulmonary edema or bacterial pneumonia.

Magnetic resonance imaging (MRI) best demonstrates the multiple manifestations of AIDS in the central nervous system, where areas of increased signal intensity can be seen on T2-weighted images. Atypical brain abscesses and meningeal infection often occur, most commonly related to toxoplasmosis, cryptococcosis, cytomegalovirus, and herpesvirus (Fig. 1.8). Increasing evidence indicates that cerebral infections may manifest from the HIV itself. Patients with AIDS also have a high incidence of lymphoma involving the central nervous system.

## Treatment

Although much research has been initiated, no cure for AIDS has been found. Currently, treatment assists in maintaining quality of life and managing symptoms as they manifest. Antiviral drugs help to suppress the HIV infection. A healthy lifestyle free of stress, alcohol, and illegal drugs is recommended. An HIV carrier should avoid infections if possible because they may accelerate the HIV process.

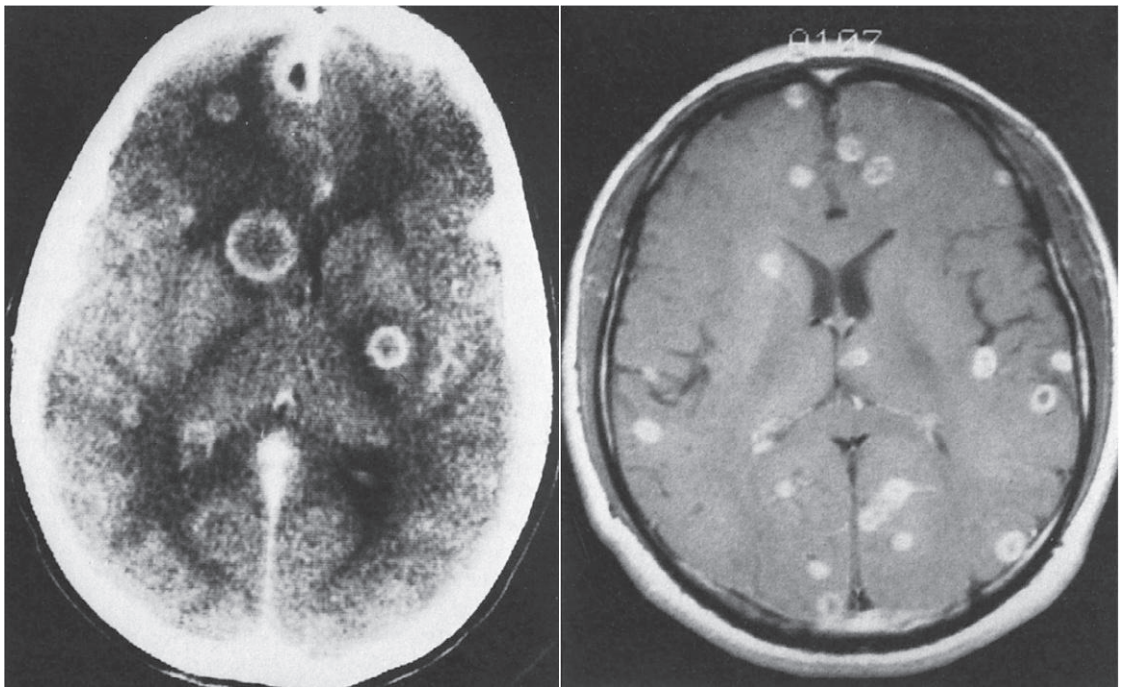


**Fig. 1.8 Neurologic Manifestations of Acquired Immunodeficiency Syndrome.** (A) Computed tomography scan shows multiple ring-enhancing lesions caused by cryptococcal brain abscesses. (B) Magnetic resonance imaging, after intravenous administration of contrast medium, demonstrates multiple enhancing abscesses caused by toxoplasmosis.

## REVIEW QUESTIONS

1. The accumulation of abnormal amounts of fluid in the spaces between cells or in body cavities is termed _____.
2. _____ is the process by which white blood cells surround and digest infectious organisms.
3. A tumor-like scar is referred to as a(n) _____.
4. Inflammation with pus formation is termed _____.
5. An interruption in the blood supply to an organ or body part is referred to as _____.
6. A localized area of ischemic necrosis in an organ or tissue is termed a(n) _____.
7. A swelling caused by bleeding into an enclosed area is termed _____.
8. A decrease in function of an organ or tissue because of a reduction in the size or number of cells is termed _____.
9. The term _____ means new growth.
10. The term for benign epithelial neoplasms that have a gland-like pattern is _____.
11. The study of determinants of disease events in given populations is _____.
12. Statistically, _____ reflects the number of deaths by disease per population.
13. The rate that an illness or abnormality occurs is called _____.
14. Gowns, gloves, masks, shoe covers, and eye protection used to prevent transmission of potential infectious agents are _____.
15. _____ determines the additional protective equipment needed to prevent the spread of highly infectious pathogens through contact, droplet, or airborne transmission.
16. The cause of the disease process is called _____.
17. A(n) _____ is the combination of signs and symptoms used to determine the disease process.
18. When a combination of signs, symptoms, and disease processes are linked, it is known as a(n)_____.
19. _____ is when a patient does not show any evidence of disease.
20. The expected outcome of a disease process is _____.

2

# Specialized Imaging Techniques

## OBJECTIVES

*After reading this chapter, the reader will be able to:*

- Define the imaging features most commonly used by radiologists to indicate pathophysiology changes
- Differentiate screening and diagnostic mammography imaging protocols and how the protocols are used to demonstrate pathology
- Describe the theory of image production with ultrasound and why this modality becomes the optimal choice to demonstrate pathologic conditions
- Describe the theory of image production with computed tomography (CT) and the body structures best demonstrated
- Briefly describe the theory of image production with magnetic resonance imaging (MRI) and the different sequences used to demonstrate specific tissue
- Describe the theory of image production with nuclear medicine, single-photon emission computed tomography (SPECT), and positron emission tomography (PET)
- Identify the fusion imaging techniques required to produce optimal quality images in patients with various underlying pathologic conditions
- Define and describe all boldface terms in this chapter

## OUTLINE

**Diagnostic Imaging Modalities**, 14
Imaging Features, 15
Mammography, 15
Ultrasound, 16
Computed Tomography, 19
Magnetic Resonance Imaging, 21
Nuclear Medicine, 26
Single-Photon Emission Computed Tomography, 28
Positron Emission Tomography, 28
Fusion Imaging, 30

## KEY TERMS

**anechoic**
**annihilation**
**collimator**
**computed tomography (CT)**
**CT number**
**diffusion imaging**
**direct fusion**
**fat suppression**
**functional MRI (fMRI)**
**gamma camera**
**helical**
**hyperechoic**
**hypoechoic**
**imaging features**
**integrated imaging**
**isoechoic**
**magnetic resonance imaging (MRI)**
**mammography**
**nuclear medicine**
**perfusion imaging**
**positron emission tomography (PET)**
**radiofrequency (RF) pulse**
**radiopharmaceutical**
**single-photon emission computed tomography (SPECT)**
**T1-weighted images**
**T2-weighted images**
**ultrasound**
**virtual reality**
**volume-rendered imaging**

## DIAGNOSTIC IMAGING MODALITIES

As the world of technology advances, medical imaging modalities have become more technical. This change requires the radiographer to have a broader and more specific skill set to produce quality images. An example of this trend in diagnostic imaging is the expansion of the department with the development of specific x-ray tubes to produce high-quality mammographic images of the breast.

The first of these new modalities was ultrasound, which was capable of producing images without the use of ionizing radiation, providing a diagnostic tool to view soft tissues, especially in the fetus. In the early to mid-1970s, computed axial tomography (now known as computed tomography [CT]) provided revolutionary new images of the brain that demonstrated the bone structure, white and gray matter, and the fluid-filled ventricles. Eventually, CT eliminated the need for pneumoencephalography and replaced many cerebral angiograms. Scientists integrated the

use of strong magnets and radiofrequencies to provide another mode of producing images without the use of ionizing radiation—nuclear magnetic resonance (now known as magnetic resonance imaging [MRI]). MRI offers clinicians images with high soft tissue resolution and the ability to visualize structural and functional tissue. CT and MRI currently provide diagnosticians with three-dimensional (3D) (axial, sagittal, and coronal) images and offer a way to separate overlapping anatomic structures. With continuing research, nuclear medicine expanded its role by adding movement and a computer that allowed more than anterior and posterior projections, resulting in the development of single-photon emission computed tomography (SPECT). Additional research developments in radiopharmaceuticals led to the creation of a positron-emitting radionuclide, which resulted in the newest modality—positron emission tomography (PET). Now the concept of multiplanar imaging and gamma camera movement (tomography) has provided healthcare with two new perspectives in molecular imaging.

Computerized technology has become prevalent in imaging nowadays. Imaging modalities with special software can now be integrated to create a fused image (superimposition of images from two different modalities). PET/CT is the most prominent hybrid equipment currently available. As computed technology continues to become more complex, the modalities of today's imaging department will also become more complicated. However, these positive changes result in images that are more precise and have greater sensitivity. This offers the radiologist opportunity to make a quicker, more accurate diagnosis for the patient.

## RADIOGRAPHER NOTES

A medical radiographer is one of the patient's healthcare team, providing care, diagnosis, and treatment, especially in the diagnostic imaging department. The role of the radiographer as a team member is to produce the best quality images for diagnosis. Not only radiologists and physicians view the images; technologists using other imaging modalities—such as mammography, ultrasound, computed tomography, magnetic resonance imaging, nuclear medicine, single-photon emission computed tomography, and positron emission tomography—view these images as a basis for producing studies in their respective modalities.

For the healthcare team, communication is especially important. To communicate effectively, the radiographer may need to gather information from the patient (patient history). Once the added information is recorded, the technologist may confer with the radiologist to ensure that the correct examination has been ordered. In some cases, even though the examination is correct, it also would be beneficial if further history were gathered or additional image projections were taken to provide supplementary information. The better radiographers understand their role in imaging, the more adept they will be at producing the correct images for the specific pathophysiologic condition of the patient.

To best demonstrate the pathology, all imaging technologists must do their part to provide added information. The imaging team is responsible for providing the best images to complement one another. The collection of images from all modalities aids the diagnostician in making the most accurate diagnosis.

## Imaging Features

When radiologists interpret images, they use a common terminology called **imaging features**, imaging descriptors that the technologist should become familiar with to better understand the pathophysiologic changes reflected in the diagnostic image. Common features or descriptors include *location, size, density, structure, shape, demarcation, perfusion,* and *integration*. The *location* descriptor indicates the site where the changes in the anatomic features are evident, whereas the *size* descriptor refers to the measurements of those changes on the image. The tissue *density* and *structure* describe the abnormal appearance in comparison with what is expected as normal. *Shape* and *border (demarcation)* describe anatomic structure changes and involvement. *Perfusion* of abnormal tissue relates to its degree of vascularity, which may be of value in distinguishing between cystic and solid-tissue lesions. Depending on the type of pathologic process, the tissue changes may be described as being space-occupying or *integrated* in the anatomic structure. Imaging features and descriptors are essentially a common language used by radiologists in interpreting images and conveying this information to referring physicians reviewing them. Each specific diagnostic modality utilizes a series of imaging descriptors that may have to be modified for it.

## SUMMARY OF IMAGING DESCRIPTORS

| Term | Definition |
|---|---|
| Where | Location, lateralization, relative position to organs and vessels |
| Size | Diameter or width and length (millimeters or centimeters) |
| Density | Relative to surrounding tissue (isodense, hyperdense, or hypodense; radiolucent or radiopaque) |
| Structure | Heterogeneous (septate) or homogeneous (fluids) |
| Shape | Tubular (vessels or muscles)<br>Nodular (tumor or lymph nodes)<br>Reticular (resembling a net)<br>Striate or diffuse (streaked or widely spread) |
| Demarcation | Sharply marginated (more likely benign)<br>Indistinctly marginated (infiltration into surrounding tissue—inflammation or malignancy) |
| Perfusion | Peripheral, homogeneous, or heterogeneous enhancement |
| Integration | Space-occupying effect |

## Mammography

Most modern imaging departments have a separate area where breast imaging procedures are performed. The most common imaging technique for diagnosing breast cancer uses full-field digital mammography (FFDM). Currently, breast tomosynthesis, otherwise known as 3D mammography, is replacing traditional FFDM for some patient imaging, depending upon pathology and breast tissue. Three-dimensional mammography uses conventional tomography techniques (multiple images) with an FFDM imaging receptor to create a clear 3D reconstruction of the breast tissue. The advantages of this imaging system include an increase in diagnostic accuracy through the review of multiple thin slices (1 mm) as compared with traditional full anatomy thickness image and better detailed visualization in patients with dense breast tissue. Some centers still use the conventional screen-film imaging, which uses a specially designed x-ray screen that permits the proper exposure of film by many fewer x-rays than would otherwise be necessary. This procedure produces a

conventional black-and-white image at a very low radiation dose. Full-field digital **mammography** relies on radiation captured by multiple cells that convert the radiation energy to electrical energy to produce a numerical value (i.e., a digitized image). The advantages of digital mammography are faster image acquisition with lower dose (shorter exposure), increased contrast resolution with the ability to manipulate images to visualize specific areas of interest, decreased need to repeat studies, and the ease of sharing images with other professionals. *Screening* mammography consists of two images of each breast, the craniocaudal and mediolateral oblique projections. For a woman with a palpable nodule, the first choice may be a *diagnostic* mammogram, which includes an additional 90-degree mediolateral projection. When screening mammography demonstrates a suspicious area or a definite abnormality, additional images, such as coned-down or magnification projections, can be completed to compliment the study. In some cases, ultrasound supplements mammography images by demonstrating the lesion to be fluid filled (cystic) or solid.

## SUMMARY OF IMAGING FOR MAMMOGRAPHY—ANATOMIC IMAGING

| | |
|---|---|
| Image creation | Ionizing radiation—x-ray attenuation of breast tissue |
| Image receptor | Digital plate or analog system |
| Imaging descriptors | Same as used for general x-ray |

## Ultrasound

**Ultrasound** (also called ultrasonography) is a widely accepted cross-sectional imaging technique because of its low cost, availability, and ability to differentiate cystic (gallbladder), solid (liver), and complex (liver tumor) tissue. A noninvasive imaging modality, ultrasound uses high-frequency sound waves produced by electrical stimulation of a specialized crystal (Fig. 2.1). When the high-frequency sound waves pass through the body, their intensity is reduced by different amounts depending on the acoustic properties of the tissues through which they travel. The crystal mounted in a transducer sends the signal and also acts as a receiver to record echoes reflected back from the body whenever the sound wave strikes an interface between two tissues that have different acoustic properties. The transducer records the tiny changes of the signal's pitch and direction. A water-tissue interface can produce strong reflections (echoes), whereas a solid tissue mass that contains small differences in composition can cause weak reflections. The display of the ultrasound image on an imaging monitor shows both the intensity level of the echoes and the position in the body from which they were scanned. Ultrasound images may be displayed as static gray-scale images or as multiple (video) images that permit movement to be viewed in real time. Color display on a sonogram is used to detect motion (specifically, blood flow). Depending on the equipment used, the interactions of the tissue with the sound wave determine how the tissue or organ is visualized and described.

In general, fluid-filled structures have intense echoes at their borders, no internal echoes, and good transmission of the sound waves. **Anechoic** tissue or structures (which are *echo free,* or lacking a signal) transmit sound waves easily and appear as the dark region on the image; examples are the gallbladder and a distended urinary bladder. Solid structures (e.g., liver and spleen) produce internal echoes of variable intensity. The terms **hyperechoic** and **hypoechoic** are used to make comparisons of echo intensities between adjacent structures. For example, the normal liver can be described as being hyperechoic to the normal renal cortex because the hepatic parenchymal tissue appears as a lighter shade of gray. Conversely, because the normal renal cortex appears as a darker shade of gray than the normal liver parenchyma, it can be described as being hypoechoic to the liver. The term **isoechoic** is used to describe two structures that have the same echogenicity even

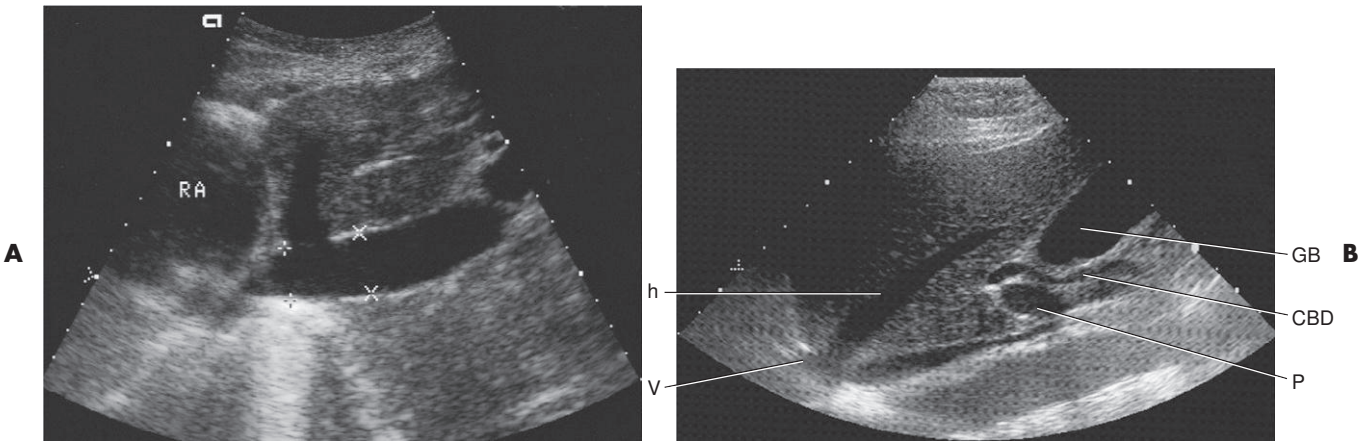


**Fig. 2.1 Ultrasound Images of Normal Abdomens.** (A) Right atrium of the heart *(RA)*, the inferior vena cava (marked for measurement), and the hepatic vein joining the inferior vena cava. (B) Gallbladder *(GB)*, common bile duct *(CBD)*, portal vein *(P)*, hepatic vein *(h)*, and inferior vena cava *(V)*.

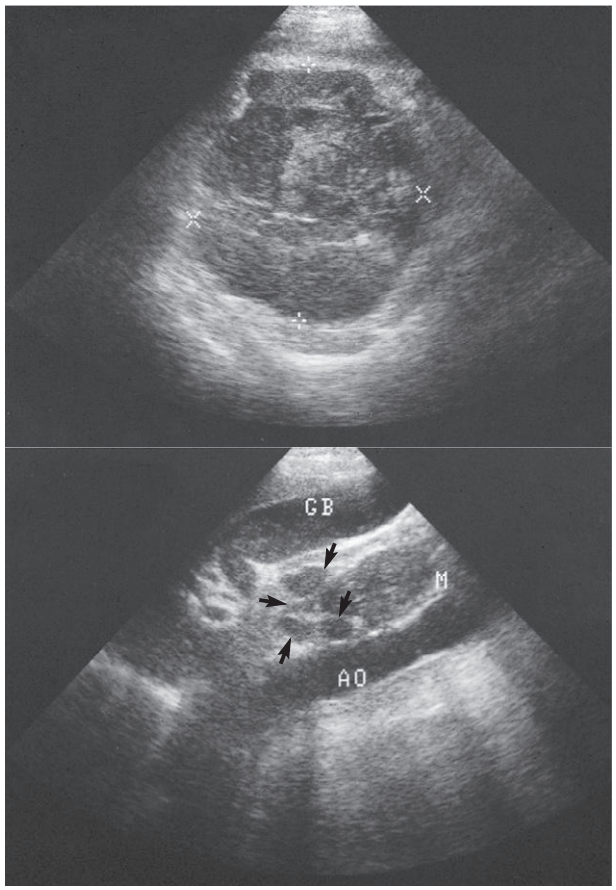


**Fig. 2.2 Ultrasound Images of the Abdomen.** (A) Transverse right kidney demonstrates a hyperechoic area *(white)* within the mass caused by renal cell carcinoma. (B) Gallbladder *(GB)* and aorta *(AO)* are hypoechoic compared with the pancreas. Focal masses *(arrows)* are isoechoic (i.e., similar in density) to the adjacent pancreatic tissue.

though the tissue may not be the same; for example, liver tissue is often isoechoic to the spleen. Complex tissue types have both anechoic and echogenic areas (Fig. 2.2).

The major advantage of ultrasound is its safety. There has been no evidence of any adverse effect on human tissues at the intensity level currently used for diagnostic procedures. Therefore ultrasound is the modality of choice for examinations of children and pregnant women in whom a potential danger exists from the radiation exposure involved with other imaging studies. Ultrasound is by far the best technique for evaluating fetal age and placenta placement, congenital anomalies, and complications of pregnancy (Fig. 2.3). Abdominal ultrasound is used extensively to evaluate the intraperitoneal and retroperitoneal structures, to detect abdominal and pelvic abscesses, and to diagnose obstruction of the biliary and urinary tracts. Pelvic ultrasound images of the prostate gland aid in the detection and accurate staging of neoplasms. Pelvic imaging is performed via a transabdominal (through the abdominal wall), transvaginal (through the vagina), or transrectal (through the rectum) approach.

Vascular or color flow Doppler studies assess the patency of major blood vessels, demonstrating obstructions (stenoses),

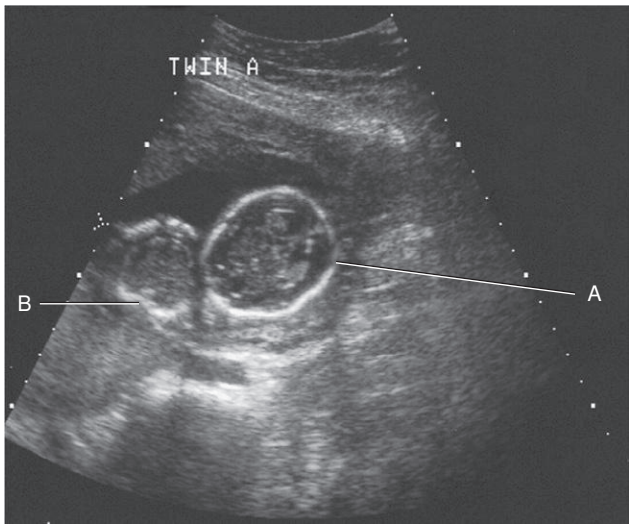


**Fig. 2.3 Sonogram of the Abdomen of a Woman with a Multiple Pregnancy.** Cranial architecture is normal in fetus *A* and abnormal in fetus *B*, a finding that documented demise of fetus *B* (and also fetus C, which is not imaged).

blood clots, plaques, and emboli. The color flow duplex system, in which conventional real-time imaging is integrated with Doppler imaging (to produce quantitative data) and with color, depicts motion and the direction and velocity of blood flow. The color and intensity represent the direction of flow and the velocity, respectively (e.g., in the carotid artery).

Other uses of ultrasound include breast imaging (to differentiate solid from cystic masses) (Fig. 2.4), musculoskeletal imaging (to detect problems with tendons, muscles, and joints, and also soft tissue fluid collections or masses) (Fig. 2.5), and as an imaging guide for invasive procedures (biopsies, aspirations, and drain placement) (Fig. 2.6).

Ultrasound is a quick, inexpensive procedure for evaluating postoperative complications, although it may be difficult to perform in some patients because of overlying dressings, retention

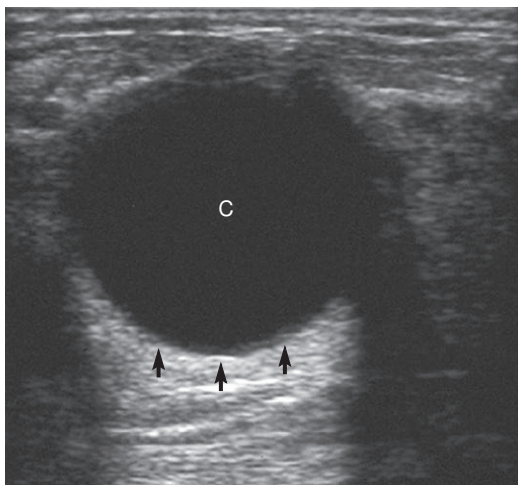


**Fig. 2.4 Ultrasound Image of a Focal Area of Breast Tissue.** The sonogram shows an anechoic mass *(C)* with a well-defined back wall and distal enhancement *(arrows)*.

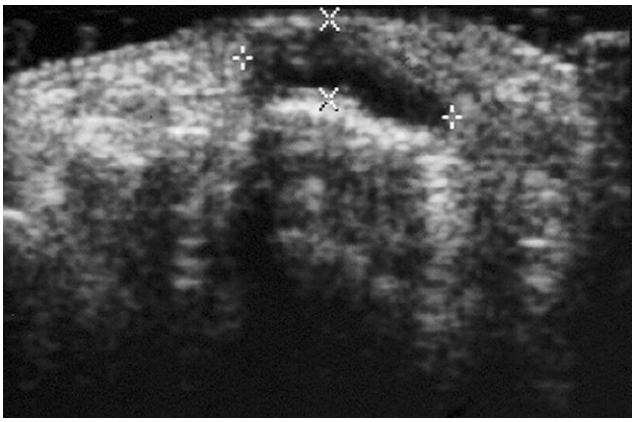

**Fig. 2.5 Ultrasound Image of a Wrist Demonstrating the Musculoskeletal Architecture.** A cystic structure (15 × 5 mm) can be seen near the dorsal aspect of base of the fourth and fifth metacarpals.

sutures, drains, and open wounds, which may prevent the transducer from being in direct contact with the skin. In children with open fontanelles, ultrasound can image the intracranial structures. High-resolution, real-time ultrasound systems can assist surgeons during operative procedures. This technique has been applied to the neurosurgical localization of brain and spine neoplasms, to the evaluation of intraventricular shunt tube placement, to the localization of renal calculi, and to surgical procedures involving the hepatobiliary system and pancreas.

The role of ultrasound imaging has expanded as a result of the availability of multifrequency transducers (2 to 15 MHz) and advances in software (signal-processing) technology. The resultant higher-resolution images are used in musculoskeletal, breast, and small-parts imaging. The latest technologies include harmonic imaging (which involves a broad band of low frequencies and can suppress reflection from surrounding tissue) to reduce image noise and artifact, real-time compound imaging (a combination of multiple lines of sight that increases image clarity and provides more diagnostic information), and contrast agents (microbubble echo-enhancing agents) that increase vasculature definition. Harmonic imaging produces diminished noise images, increasing the resolution in a hypersthenic patient so that patient size does not prevent obtaining diagnostic images. Contrast agents, injectable low-solubility gas bubbles (<5 μm) such as perfluorochemicals (inert dense fluids), increase the differentiation of tissues and enhance visibility of detail in tumors, small and stenotic vessels, heart studies, and ultrasound hysterosonograms.

Ultrasound imaging requires an expanded knowledge of anatomy, physiology, and pathology to locate and demonstrate the specific region of interest. The quality of the scans is operator dependent, and extensive instruction and guidance are required to produce optimal images.

The major limitation of ultrasound is the presence of acoustic barriers, such as air, bone, and barium. For example, air reflects essentially the entire ultrasound beam so that structures beneath cannot be imaged well. This special problem interferes with

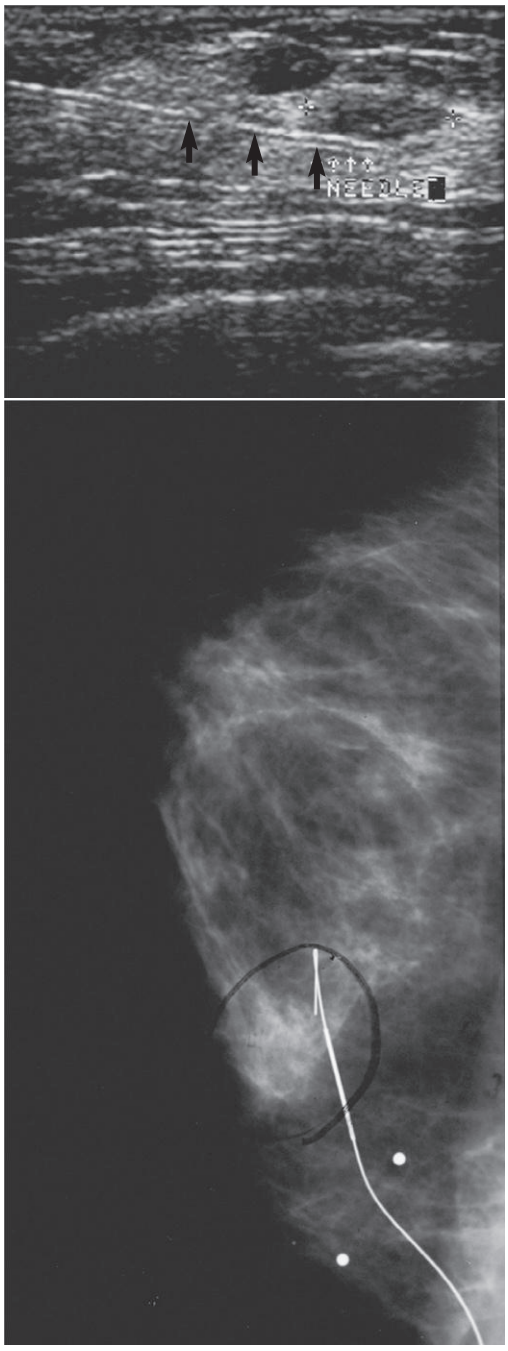

**Fig. 2.6 Ultrasound-Guided Localization.** (A) Ultrasound needle localization for surgical biopsy of the breast. *Black arrows* identify a white line indicating the needle location. (B) Mammography image verifying needle localization.

imaging of the solid abdominal organs (e.g., the pancreas) in a patient with adynamic ileus, and it is the major factor precluding ultrasound examination of the thorax. For an ultrasound examination of the pelvis, the patient usually drinks a large amount of fluid to fill the bladder, thus displacing the air-filled bowel from the region of interest. More information on ultrasound imaging can be found on the following websites: http://www.aium.org, http://www.sdms.org, and www.ardms.org.

## SUMMARY OF IMAGING FOR ULTRASOUND—ANATOMIC IMAGING

| | |
|---|---|
| Image creation | Transducer production of multifrequency sound waves |
| Image receptor | Transducer receiving echoed signal |
| Imaging descriptors | Anechoic (dark region)—echo-free tissue or structure |
| | Hyperechoic (lighter shade) and hypoechoic (darker shade)—comparison of echo intensities for adjacent tissue |
| | Isoechoic (same shade)—two structures that have the same echogenicity |

## Computed Tomography

**Computed tomography (CT)** produces cross-sectional tomographic images by first scanning a slice of tissue from multiple angles with a collimated x-ray beam, then calculating a relative linear attenuation coefficient (representing the amount of radiation absorbed in tissue for the various tissue elements in the section), and finally displaying the computed reconstruction as a gray-scale image on a imaging monitor. Unlike other imaging modalities (except for the more recent MRI), CT permits the radiographic differentiation of a variety of soft tissues from each other (Fig. 2.7). CT is extremely sensitive to slight (1%) differences in tissue densities; for comparison, detection by conventional screen-film radiography requires differences in tissue density of at least 5%. Thus, in the head, CT can differentiate between blood clots, white matter and gray matter, cerebrospinal fluid, cerebral edema, and neoplastic processes.

The **CT number** (Hounsfield number) reflects the attenuation of a specific tissue relative to that of water, which is arbitrarily assigned a CT number of 0 and appears gray on the image. The highest CT number (1000) represents bone, which appears white, and the lowest CT number (−1000) denotes air, which appears black. Fat has a CT number less than 0, whereas soft tissues have CT numbers greater than 0. The use of the computer allows the image to be manipulated by adjustment of the window width (gray scale—contrast scale) and window level (density or brightness). From the radiographer's perspective, the window width determines the number of densities that can be visualized on the monitor. The window level is the midpoint or center of the total number of densities being viewed in a selected window width. Predetermined window widths and window levels are used to demonstrate specific parts of the anatomy (lung, liver, and bone). Technical improvements in CT instrumentation and tube heat unit capacity have greatly reduced the time required to produce multiple slices (1 or 2 seconds), permitting the CT evaluation of virtually any portion of the body. In most instances, some type of preliminary image is obtained (either a radiograph or a CT-generated image—topogram or scout) for localization, the detection of potentially interfering high-density material (metallic clips, barium, and electrodes), and correlation with the CT images. An overlying grid with numeric markers permits close correlation between the subsequent CT scans and the initial scout image (Fig. 2.8).

The intravenous (IV) injection of iodinated contrast material has become an integral part of many CT examinations. Scanning during or immediately after the administration of contrast material permits the differentiation of vascular from nonvascular solid structures. Differences in the degree and the time course of contrast enhancement may permit the detection of neoplastic or infectious processes within normal parenchymal structures. Because of its relatively low CT number, fat can serve as a natural contrast material and can outline parenchymal organs. In patients with malignant lesions, the loss of adjacent fat planes strongly suggests tumor extension. For abdominal studies, especially those of the pancreas and retroperitoneum, dilute oral contrast material (1% to 3% weight per volume barium sulfate or a water-soluble material) is frequently given to demonstrate the lumen of the gastrointestinal tract, and it

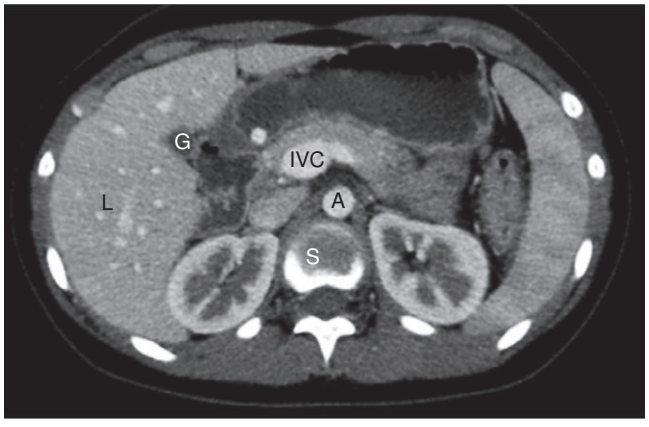


**Fig. 2.7** Normal Contrast-Enhanced Computed Tomography Scan of Lower Abdomen. *A*, Aorta; *G*, gallbladder; *IVC*, inferior vena cava; *L*, liver; *S*, spine.

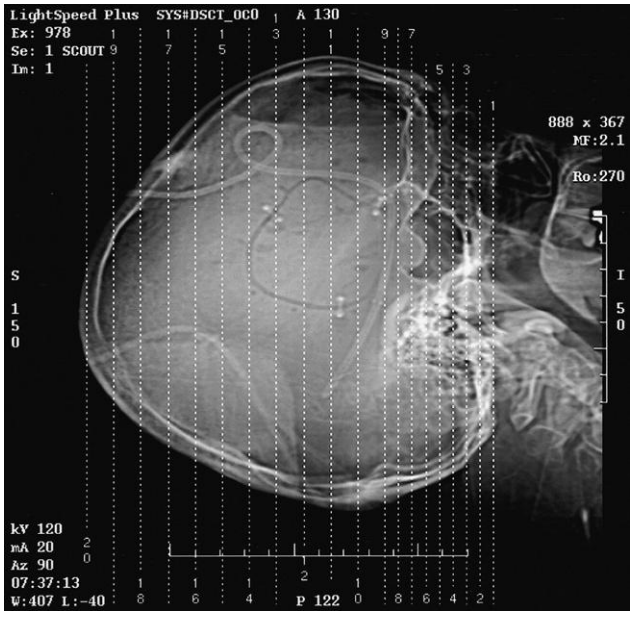


**Fig. 2.8** Computed Tomography Scout Image. Overlying grid represents scan slices.

permits the distinction between loops of bowel and solid abdominal structures.

Conventional CT produces images using a section thickness of 1 to 10 mm. In high-resolution CT, thin sections (1.5- to 2.0-mm slices) are used to produce a very detailed display of lung anatomy. High-resolution CT is far more sensitive and specific than plain chest radiographs (or conventional CT) for the diagnosis of parenchymal lung disease (Fig. 2.9).

CT technology has moved to spiral (**helical**) scanning. In this technique, continual CT scanning is performed as the patient moves through the gantry (unlike the multiple single scans in conventional CT) (Fig. 2.10). This approach permits much faster scanning without respiratory motion and provides volumetric data that can be easily reformatted in coronal and sagittal planes, and in the standard axial plane. Helical scanners with subsecond scanning abilities produce images of the chest (taking less than 20 seconds to complete the scan protocol) that demonstrate the pulmonary arteries without motion and can detect pulmonary emboli. CT imaging protocols for some procedures (e.g., obtaining images of the kidneys and liver) may require three-phase scanning (arterial, capillary, and venous phases and an excretory phase) to demonstrate all anatomic (tissue) structures (Fig. 2.11). The single-scan protocol changed with subsecond scanning because the IV bolus injection appears very dense on the image and may obscure the pathologic features. Subsecond scanning requires delayed scanning and second and third phases to demonstrate a higher sensitivity than single-slice scanning. Subsecond scanning also produces abdominal studies with much less peristaltic motion, resulting in a higher-quality examination. Spiral CT allows reconstruction of images in three dimensions, because the data collected is a volume, and can demonstrate vascular lesions without the need for arteriography (Fig. 2.12). With the thin slices of spiral scanning, the ability to reconstruct at thinner slice than in conventional CT scanning, and the addition of 3D software, the reconstruction can produce virtual colonoscopy and bronchoscopy images.

The sixth-generation scanners perform multiple slices consisting of multidetectors producing 8 to 64 slices per rotation, offering pitch variability (table movement) and variable rotation speed of the tube. It also contains software programing for instantaneous 3D images (Fig. 2.13). Using a coned x-ray beam, the seventh-generation scanners can collect 16 to 320 sections of data in one rotation, and therefore they are known as multisection multidetector (MSMD) scanners or multiple array scanners. With the development of multidetector scanners, CT angiography (CTA) has become more precise and prevalent. The faster scanning times and thinner slices have made cardiac scanning possible well beyond what the electron-beam CT scanner could image. Clinicians and radiologists are quickly accepting the use of CT for vascular imaging; however, the complexity of the imaging protocol creates the need for extensive specialized education for the radiographer to produce the highest-quality images while keeping the patient dose to a minimum. An understanding of vascular anatomy, blood flow rates related to blood pressure, and ejection fraction rates and possible pathophysiologic conditions that can influence protocol is necessary.

Some postprocessing techniques used in CT include maximum intensity projections (MIPs), minimum intensity projections (MinIPs), shaded surface rendering, volume rendering, and virtual reality (VR) images. For CTA, MIPs are used to highlight the brightest pixels and thus enhance the image. The MinIPs, which enhance the lowest intensities (darker structures), are used for virtual colonoscopy. Shaded surface rendering reconstructions take the two-dimensional image and then add depth and shape to make a 3D image. With the use of **volume-rendered imaging** and 3D volume rendering, the vascular system can be viewed from all perspectives (360 degrees) as well as from the surface or internally. **Virtual reality** (VR) reconstructions are used in virtual colonoscopy to demonstrate the area inside of the bowel lumen.

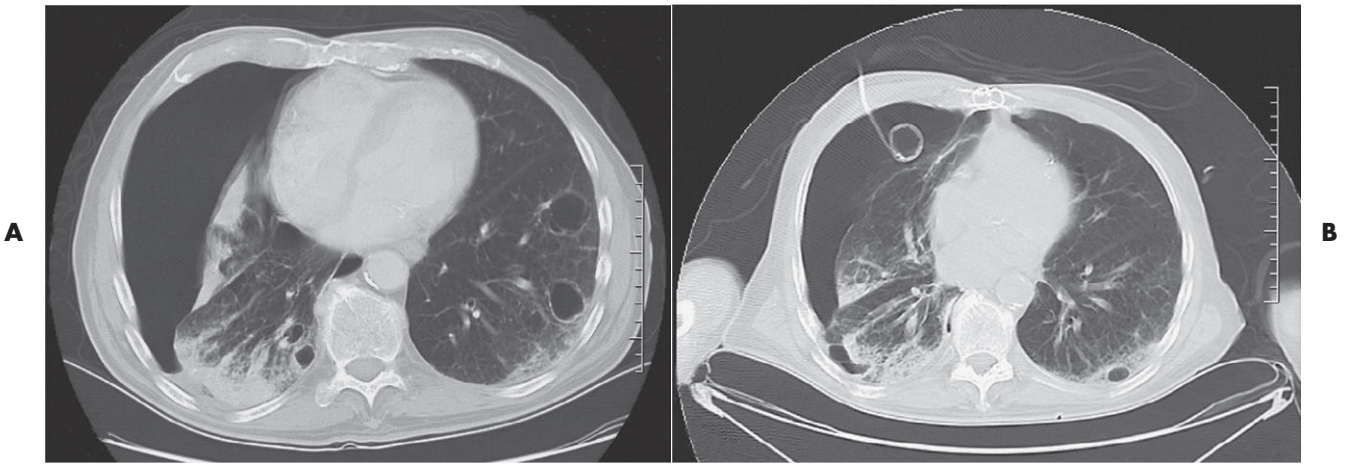


**Fig. 2.9** High-Resolution Computed Tomography Scan of the Lung. (A) A pneumothorax can be seen in the right side of the lung of an emphysematous patient, and blebs (high-density areas) can be seen in the left lung. (B) Visualization of catheter placement in the treatment for the pneumothorax.

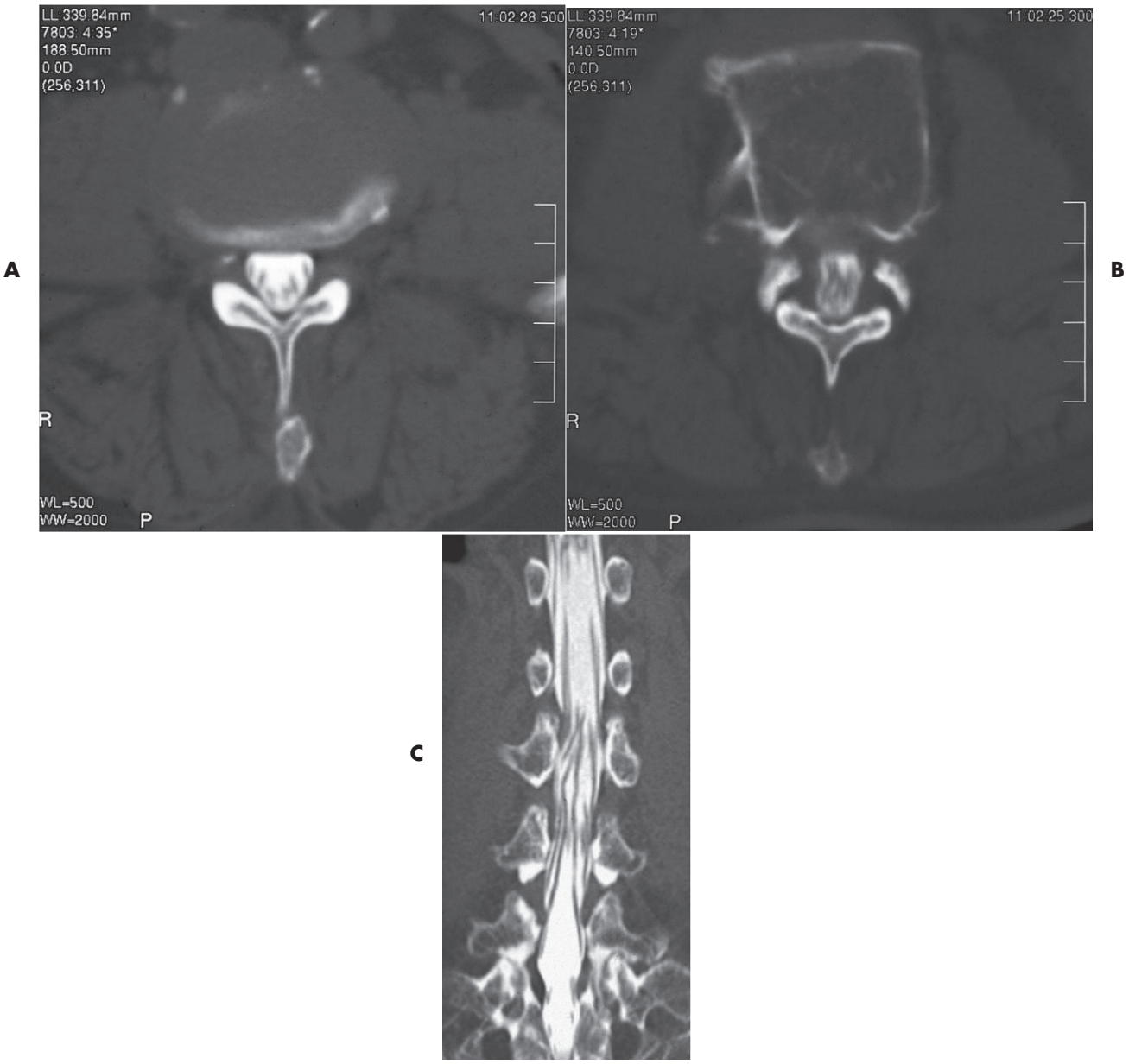


**Fig. 2.10 Computed Tomography (CT) Myelogram.** Nonionic contrast agent (10 mL) was injected into the subarachnoid space. Following the myelogram, CT images using 3-mm slices were taken on a 16-slice scanner. On axial projections, image (A) demonstrates subarachnoid (SA) space enhancement with the vertebral disk anteriorly, and image (B) illustrates the SA shifted to the left. The coronal reconstruction (C) better demonstrates an impingement on the right at the level of L2-L3.

As scanning technology becomes more complex, the technologist must use appropriate exposure settings to minimize patient radiation dose. The newest CT scanners provide dosage calculations that can be recorded as evidence of following ALARA (as low as reasonably achievable) practices.

## Magnetic Resonance Imaging

**Magnetic resonance imaging (MRI)** has become an important clinical tool for a variety of conditions (Fig. 2.14) and the modality of choice for imaging the central nervous system and spine. It is also the first choice for imaging most conditions of the musculoskeletal system, and it is a problem solver in the abdomen and pelvis.

Although the physics of MRI is beyond the scope of this book, the basic technique consists of inducing hydrogen atoms (protons) to alternate between a high-energy state and a low-energy state by absorbing and then releasing, or transferring, energy. This absorption of energy is accomplished by placing the anatomic part to be imaged in a strong static magnetic field and directing a **radiofrequency (RF) pulse** of a specific

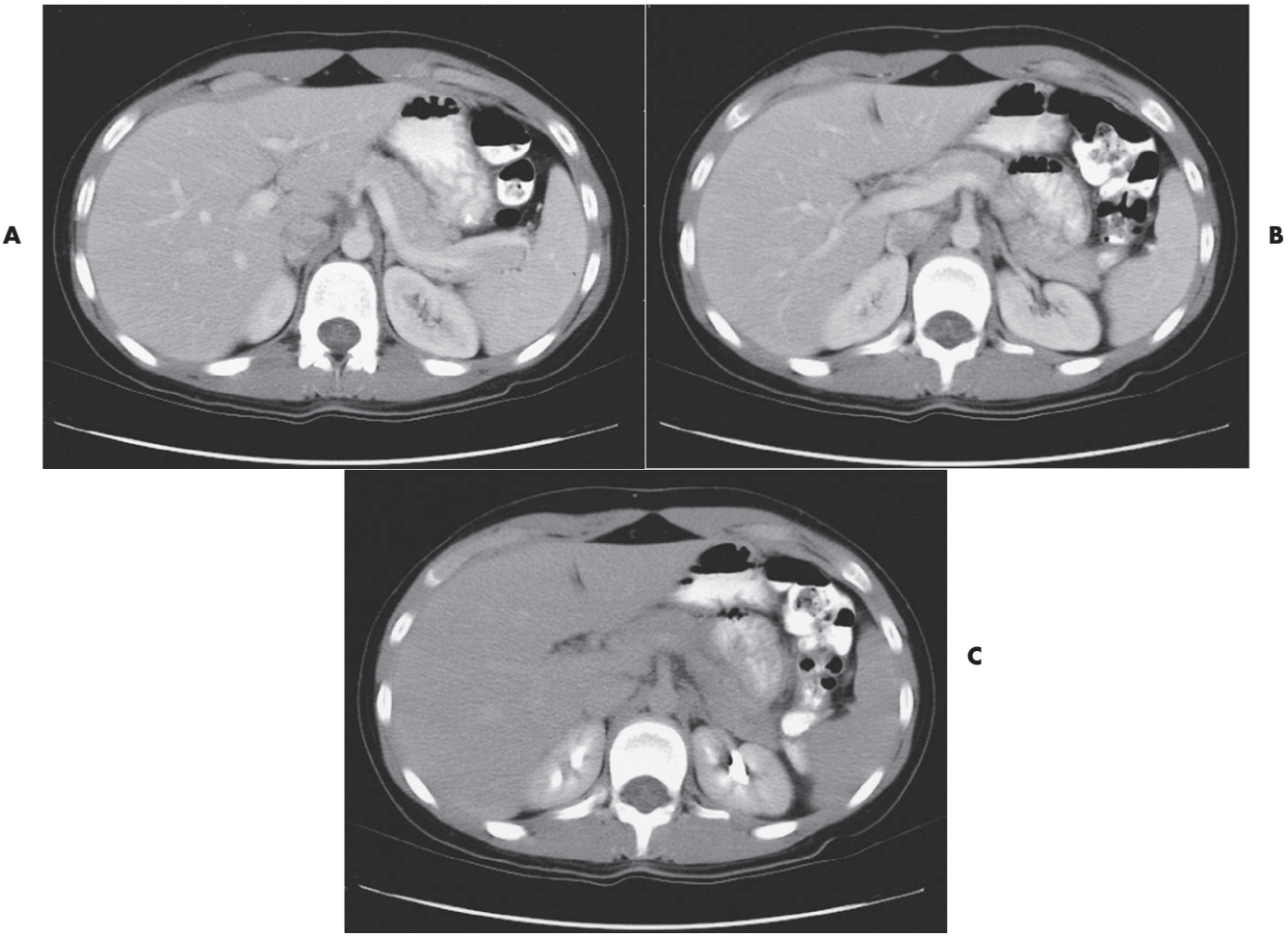


**Fig. 2.11** Three-Phase Computed Tomography Scanning Protocol for an Abdomen. (A) Arterial phase demonstrating the abdominal aorta and kidney nephrogram. (B) Portal venous phase seen in the liver. (C) Excretory phase of the kidneys is visualized.

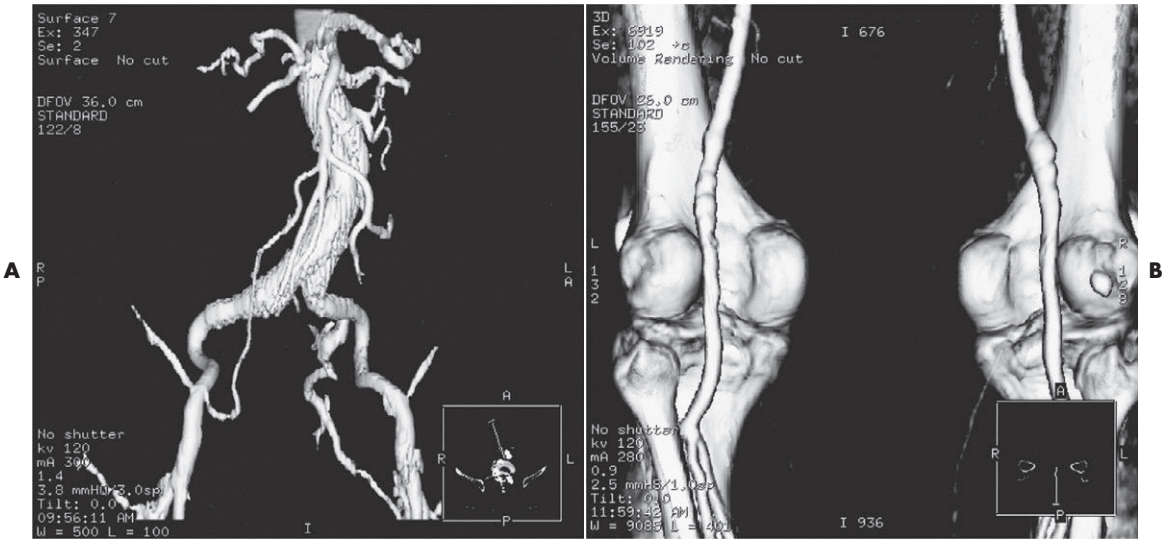


**Fig. 2.12** Computed Tomography Angiography. (A) Special software is used to demonstrate the abdominal aorta, the renal arteries, the superior mesenteric artery, and the iliac arteries. (B) Three-dimensional software in a femoral arterial runoff is used to demonstrate the popliteal arteries.

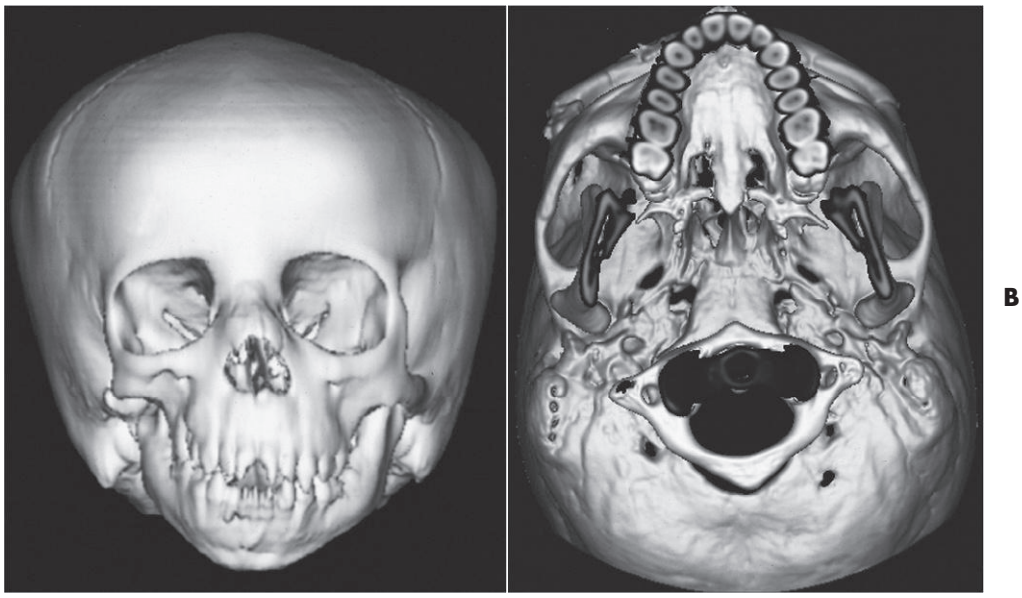


**Fig. 2.13 Three-Dimensional Surface-Rendered Computed Tomography Images.** (A) Skull of 3-year-old girl with closed sutures (craniosynostosis) and shape deformity. (B) Three-dimensional cutaway image illustrating the base of a normal skull. The mandible has been removed from the image.

## SUMMARY OF IMAGING FOR COMPUTED TOMOGRAPHY—ANATOMIC IMAGING

| | |
|---|---|
| Image creation | Collimated x-ray beam attenuation detection |
| Image receptor | Detectors receiving the attenuated signal |
| Imaging descriptors | CT number (Hounsfield number)—reflects the attenuation of a specific tissue relative to water, which equals "0" |
| | Highest CT number is 1000—represents bone (appears white) |
| | Lowest CT number is −1000—represents air (appears black) |
| | Window width—gray scale—contrast scale |
| | Window level—midpoint or center of total number of densities |
| Postprocessing | Maximum intensity projections (MIPs)—enhancing brightest intensities |
| | Minimum intensity projections (MinIPs)—enhancing lowest intensities (colonoscopy) |
| | Shaded surface rendering and volume rendering—3D rendering demonstrating the surface or selected structures |
| | Virtual reality (VR)—demonstrates internal structures for virtual bronchoscopy or colonoscopy |

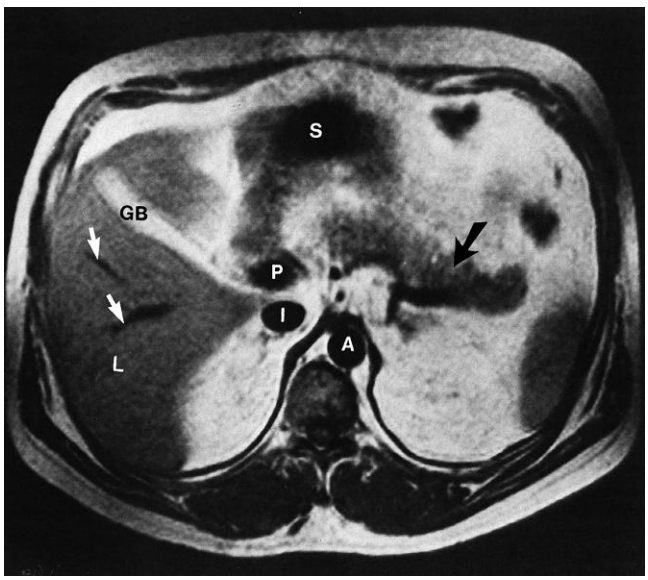


**Fig. 2.14 Magnetic Resonance Imaging of normal upper abdomen.** Transverse image shows liver *(L)* and branches of portal veins *(white arrows)*. Gallbladder *(GB)* has high intensity in this fasting person. Pancreas *(black arrow)* and stomach *(S)* are easily seen. Inferior vena cava *(I)*, aorta *(A)*, and main portal vein *(P)* are seen with signal void because they contain flowing blood.

frequency at the area. As protons absorb energy (called resonance), they move into a high-energy state. After a predetermined time, the RF pulse is turned off and the protons begin to release, or transfer, their absorbed energy as they move back to a low-energy state. This process is called *relaxation* and it occurs over time. Two types of relaxation, T1 and T2, occur simultaneously. A listening device called a receiver coil, placed near the anatomic site, is able to detect the time it takes for both T1 and T2 relaxation types. A complex computer program uses a mathematical operation called a Fourier transform to translate this information from the receiving coil into a computer-generated, gray-scale image.

To generate a magnetic resonance (MR) image, the MRI technologist selects a group of scanning parameters referred to as a *pulse sequence*. A pulse sequence contains a set of RF pulses and their timing, representing a specific echo time (TE)

and a repetition time (TR). By varying the TE and TR, the MRI technologist is able to produce an image that is weighted or demonstrates T1 relaxation, T2 relaxation, or proton density. These images display the differences between normal and abnormal tissues. In general, 1.5-Tesla (1.5T) pulse sequences using a short TR (400 to 700 msec) and a short TE (10 to 30 msec) provide a T1-weighted image. A pulse sequence using a long TR (3500 to 4000 msec) and a long TE (80 to 100 msec) provides a T2-weighted image. A pulse sequence using a short TE (15 to 30 msec) and a long TR (3500 msec) provides a proton-density, or spin-density, image.

Although the degree of signal intensity of various substances on MR scans is complex and depends on multiple factors, some generalizations can be made. On **T1-weighted images**, substances causing high signal intensity (i.e., appears bright) include fat, subacute hemorrhage, melanin, slow-flowing blood, and IV gadolinium contrast material. Water, such as cerebrospinal fluid, has a low signal intensity and appears dark. Soft tissue has an intermediate level of signal intensity (Fig. 2.15A).

On **T2-weighted images**, the opposite is true. Water has a high signal intensity so it appears bright, whereas muscle and other soft tissues (including fat) tend to have lower signal intensity and appear intermediate to dark. Cortical bone, calcium, air, and fast-flowing blood generate no signal, so they appear very dark on most imaging sequences (see Fig. 2.15B and C).

Although MRI is used in conjunction with other modalities, it has some unique advantages. MRI produces images in multiple planes without the use of ionizing radiation and receives no signal from bone so that the underlying tissue can be clearly imaged. The ability to image directly in any plane allows the best visualization of normal and abnormal anatomy. Unlike other imaging modalities that depend on information from one parameter (e.g., CT, which depends on electron density), MRI derives information from multiple biologic parameters, such as proton density (Fig. 2.16A), T1 and T2 relaxation times, flow, diffusion, and perfusion. MRI provides excellent spatial contrast resolution of soft tissue, and although it demonstrates improved sensitivity for detection of abnormal tissue, it can lack specificity. In the head, for example, infarction, edema, tumor, infection, and demyelinating disease all produce similar high signal intensity on T2-weighted images. The introduction of IV contrast materials, some organ specific, and different types of pulse sequences helps to increase specificity.

One disadvantage of MRI is longer scanning times, which can result in image degradation from patient and physiologic motion. This problem is being addressed with new, faster breath-hold techniques. Patient claustrophobia is always a concern due to the small, enclosed space of the MRI scanner. It is also difficult to monitor patients in the MR environment, which requires specialized MRI-compatible equipment. In patients with certain implants, such as brain aneurysm clips, vascular stents, cardiac pacemakers, or other electromechanical devices, MRI may be contraindicated due to the deleterious effects of the magnetic environment.

MR angiography (MRA) produces high-resolution images of the vascular system without the need for IV contrast material (Fig. 2.17A), using time-of-flight and phase-contrast imaging.

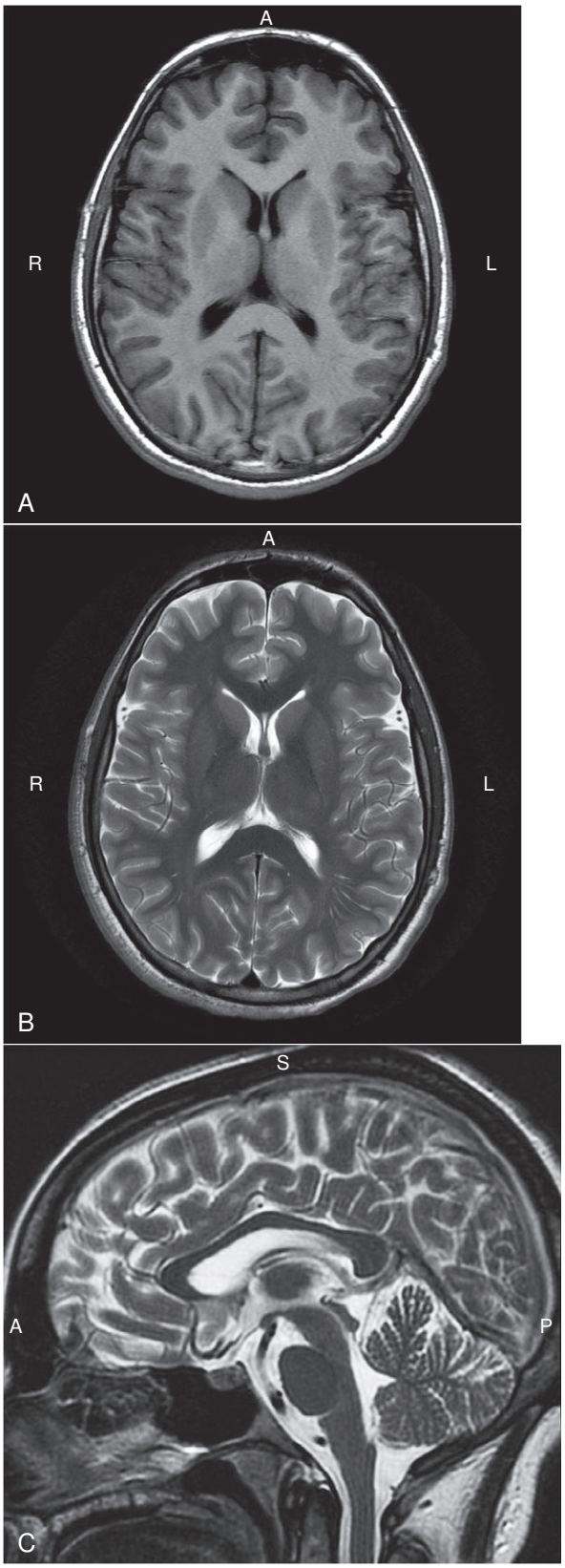


**Fig. 2.15 Magnetic Resonance Imaging of Normal Brain.** (A) T1-weighted image. The ventricles and cerebrospinal fluid areas appear dark, and the white matter and gray matter are shades of gray. (B) T2-weighted image. The cerebrospinal fluid produces a high signal intensity *(white area)* on the image. (C) Sagittal T2-weighted image demonstrates cerebral cortex, ventricles, pons, and cerebellum.

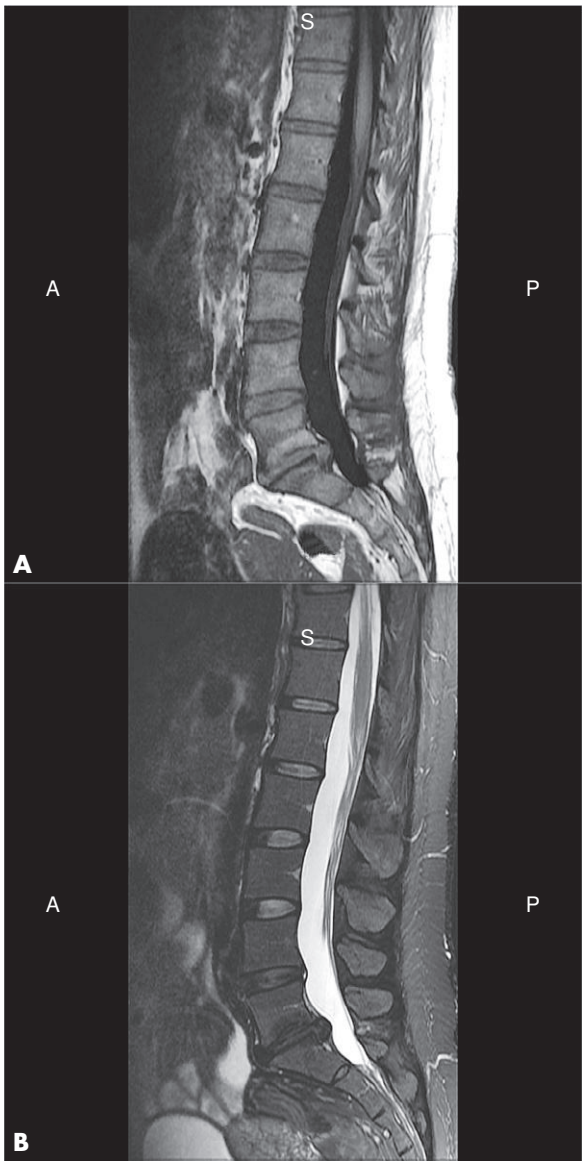


**Fig. 2.16** Magnetic resonance imaging of sagittal lumbar spine with small disk protrusion at L5-S1 and slightly desiccated disk spaces. (A) Proton density fast spin-echo image demonstrating disk protrusion. (B) Fat-suppressed image. Spinal fluid has a high-intensity signal, and spinal nerves have a lower-intensity signal.

Although these techniques acquire images of both arterial and venous systems, they are somewhat slow and lack the ability to cover large areas. The use of a rapidly infused IV contrast agent (gadolinium) and very rapid scanning has resulted in larger areas of coverage and diagnostic images that rival those of invasive catheter angiography (see Fig. 2.17B and C). The development of newer inflow techniques may one day eliminate the need for contrast material. The use of CT and MRA has virtually eliminated conventional contrast angiography for the diagnosis of vascular disease.

The development of MR spectroscopy (MRS) has made it possible to analyze the chemical composition of tissues in vivo. This sophisticated process produces chemical spectra instead of anatomic images. MRS is helping to distinguish benign and malignant lesions in patients in whom breast or prostate carcinoma is suspected. In the brain, MRS is used to discriminate between tumor recurrence and necrotic tissue following radiation therapy, as well to increase specificity in other diseases. Research is also being conducted into other uses of MRS, such as the tracking of adenosine diphosphate/triphosphate (ADP/ATP) in energy metabolism of muscles.

**Diffusion imaging** relies on fast scanning techniques and rapid gradient switching to image the random movement of water (Brownian motion) molecules within the brain or other organs. Using very strong gradients applied in all directions, disruption of this normal random motion by a disease process can be imaged, resulting in a signal change from normal tissue. Diffusion imaging can pinpoint altered diffusion within minutes of the onset of stroke symptoms. It can also be used to help differentiate among liver, breast, and prostate lesions and to detect acute compression fractures.

**Perfusion imaging**, used in conjunction with diffusion imaging, also relies on fast scanning techniques and the rapid infusion of an IV contrast agent (gadolinium) to visualize the transit time of blood through a specific area. Perfusion images of the brain, visceral organs (e.g., the liver), and myocardium demonstrate circulation in viable tissue, which helps to distinguish old from new infarctions or ischemic regions. Mismatches in diffusion and perfusion imaging of the brain during a stroke indicate those parts of the brain that are not salvageable (diffusion) and are at further risk (perfusion). Currently, diffusion and perfusion techniques assist in demonstrating strokes early, increasing the possibility of revascularization with immediate treatment. Perfusion imaging also helps to delineate the vascularization of a tumor mass, which is helpful in presurgical planning. In cardiac imaging, perfusion can indicate ischemic or infarcted tissue. One of the unique advantages of MRI is its ability to acquire images with selective tissue suppression. The tissue most often suppressed in routine imaging is fat. **Fat suppression** or fat separation can be acquired on a T1- or T2-weighted image. With these techniques, fat produces little or no signal (see Fig. 2.16B). On routine T1-weighted images, both fat- and contrast-enhanced lesions appear bright. This technique effectively suppresses the bright signal from fat, allowing the enhancing lesion to be seen. Fat-suppression images are most often used for imaging the skull base and the soft tissues of the neck, the abdomen, and the pelvis. When bone marrow is being imaged, fat suppression accentuates marrow edema, such as is found in stress fractures and bone bruises.

**Functional MRI (fMRI)** is a process that maps specific regions of the brain that correspond to specific functions, such as motor, sensory, memory, vision, and language. The patient is asked to perform a precise function (paradigm), such as finger tapping (motor) or listening to music (sensory). The part of the brain being used demonstrates an increase in blood flow. Using gradient echo pulse sequences, the differing magnetic properties of oxyhemoglobin and deoxyhemoglobin can be imaged using a process called BOLD (blood oxygen level dependent). Prior to the acquisition of the "functional" images, high-resolution

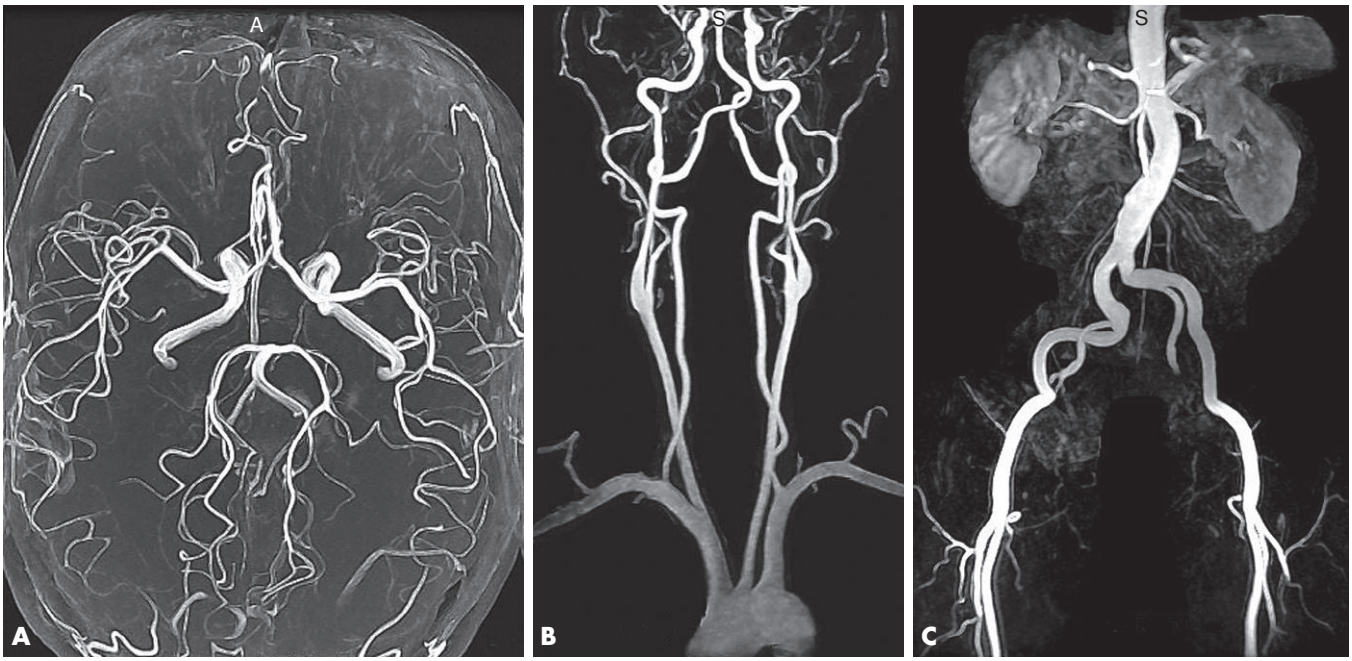


**Fig. 2.17 Magnetic Resonance Angiography.** (A) Collapsed view of the cerebrum showing a normal arterial circle (circle of Willis). (B) Gadolinium enhancement of the aortic arch demonstrating the brachiocephalic, left common carotid, and left subclavian arteries to the base of the skull. (C) Gadolinium enhancement of the abdomen demonstrates renal and mesenteric arteries.

"anatomic" images are acquired. These two sets of images are combined, or overlaid, to allow the diagnostician to precisely plan interventions to spare specific functional areas. Future uses of fMRI include the evaluation of stroke, epilepsy, pain, and behavioral problems.

Higher field strengths, coil development, and 3D volumetric imaging hold the future of MRI. Three Tesla (3T) magnets are becoming commonplace and have replaced some of the 1.5T workhorse magnets of prior years due to their increased signal-to-noise ratios and rapid gradients. Coil development is allowing smaller fields of view and thinner slices while preserving anatomic coverage. The acquisition of 3D volumetric data sets and the ability to postprocess these data will lead to more complete diagnostic information.

## SUMMARY OF MAGNETIC RESONANCE IMAGING—ANATOMIC AND TISSUE IMAGING

| | |
|---|---|
| Image creation | Radiofrequency (RF) pulses emitted to change hydrogen atom energy states |
| Image receptor | Receiver coil to detect energy changes to relaxation times |
| Pulse sequence | T1-weighted—high signals (bright) include fat, subacute hemorrhage, melanin, slow-flowing blood, and intravenous contrast |
| | T2-weighted—high signals (bright) include water; lower signal intensities (intermediate to dark) include muscle and soft tissue; low signal intensities (dark) may indicate cortical bone, calcium, air, or fast-flowing blood (no signal) |
| | Fat suppression—differentiates fat from contrast material to highlight vascular structures |
| | Susceptibility weighted—extremely sensitive to products that create changes in magnetic susceptibility; low signal intensity (dark); hemorrhage, calcium |
| | Diffusion weighted—high signal intensity (bright) where random movement of water is restricted; stroke, liver lesions |

## Nuclear Medicine

In radiography, ionizing radiation interacts with tissue to produce an image. However, in **nuclear medicine**, the patient ingests, or receives an injection (IV, intramuscular [IM], intrathecal [lumbar puncture], or into a shunt) of, a **radiopharmaceutical**. Each radiopharmaceutical is made up of a **radionuclide** (radioactive isotope) and a **pharmaceutical** (R-group) that is united through both chemical and physical reactions. The radiopharmaceutical emits radiation and localizes in the patient based on the attached R-group. An image is created from the gamma rays radiating from the patient (Fig. 2.18). The radiopharmaceutical dose is based on the specific half-life and decay rate of its attached radionuclide. The amount of ionizing radiation given to the patient in a nuclear medicine study may equate to the exposure received from 25 to more than 1000 radiographic images. The amount of pharmaceutical being used is so small that it has very little or no physiologic effects, allowing for the viewing of naturally occurring physiology and not altered physiology, unless indicated. The injected radionuclide does not produce any pharmacologic side effects or complications as seen with radiographic iodinated contrast agents, making the study safer for all patients with an

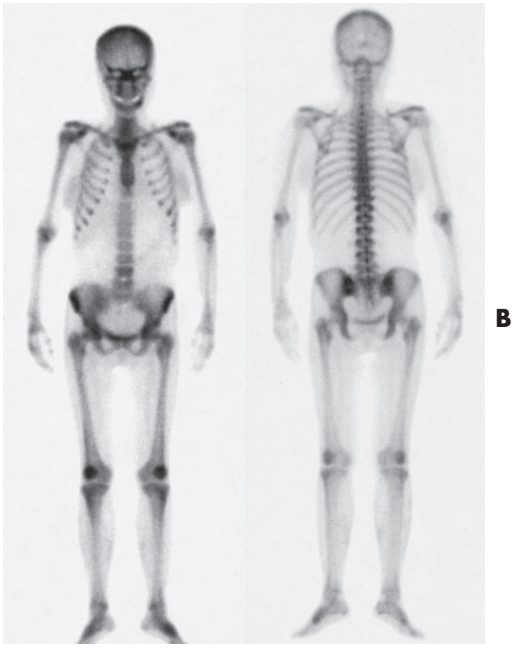


**Fig. 2.18** Nuclear Medicine Bone Scan ($^{99m}$Technetium-Labeled Bone Scintigraphy). This normal scan demonstrates the anterior (A) and posterior (B) perspectives in a patient with hypercalcemia.

iodine allergy. However, all radiopharmaceuticals have some risk, and allergic reactions have been known to occur.

A **gamma camera** with a sodium iodide crystal detects the ionizing radiation emitted from the patient. The gamma rays interact with a crystal within the camera head and scintillate light rays. The light is amplified and converted into a digital signal from which an image is created. Because the gamma rays emit from the patient in all directions, they must be filtered. The gamma camera has a **collimator** made of lead that contains multiple parallel channels. These channels only allow rays that are perpendicular to the camera to pass and be detected while attenuating those that are not. Another form of attenuation also occurs when gamma rays interact with the body to cause Compton scattering and the photoelectric effect, which lead to a loss of image spatial resolution. To compensate for this loss, computer reconstruction software corrects for scatter. The scintigraphic image, which defines the distribution of the radiopharmaceutical, represents the physiologic map of the organ and/or system being imaged.

The physiologic map produced by some nuclear medicine procedures allows earlier detection of pathologic issues compared with plain radiographic images. This is because the functional perspective makes it more sensitive, possibly leading to an earlier diagnosis and thus a better prognosis. Abnormal radionuclide images are demonstrated by hot spots (produced by an increase in uptake that is directly proportional to the emission of gamma radiation) and/or by cold spots (which reflect a decreased uptake).

The images obtained using nuclear medicine techniques are excellent for documenting organ physiology, but they can be lacking in anatomic information. Plain radiographic images can therefore be useful for correlative purposes.

New technology has expanded the role of nuclear medicine to include tumor imaging. These studies help to determine tumor size, location, and recurrence. Because radiopharmaceuticals differ in their ability to demonstrate various tumors, a choice is made on the basis of the suspected diagnosis and biopsy results (Fig. 2.19). The scintigraphic images can be used to document diagnoses and for treatment management.

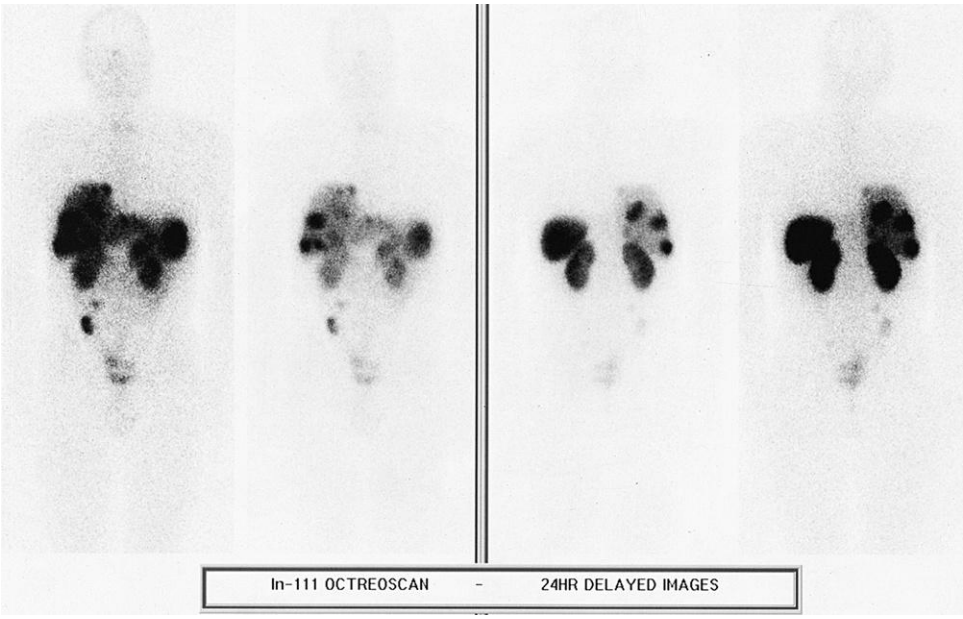


**Fig. 2.19** A 24-Hour Delayed Dual-Intensity $^{111}$Indium Octreotide Scan. The anterior *(left)* and the posterior *(right)* perspective illustrate multiple hepatic carcinoma metastases.

## Single-Photon Emission Computed Tomography

**Single-photon emission computed tomography (SPECT)** represents another aspect of nuclear medicine imaging (Fig. 2.20). To gather the tomographic information, a detector(s) rotates 180 to 360 degrees around the patient, acquiring multiple projections. The equipment is similar to a CT scanner, but in SPECT, instead of the source (the x-ray tube) and the detector array moving simultaneously, the source (the patient) emits the signal while the detector rotates around them. The signal, which the computer reconstruction algorithm analyzes, determines the position and strength of the data to create an image. Because the position and attenuation coefficients are unknown, the information must be inferred by the signal detector system, resulting in decreased resolution and sensitivity. SPECT cameras can use a multitude of reconstruction techniques and filters to re-create 3D slices at any level and/or orientation in the body.

A disadvantage of SPECT is the gamma camera, which allows imaging of only a small region of interest that is only the size of the camera. Due to the limited imaging parameters, the length of the exam is increased. As technology improves, the resolution and sensitivity of this modality will increase. Currently, the main advantage of SPECT is that SPECT imaging provides useful information in evaluating patients as they progress through different disease states: coronary artery disease, ventricular function disorders, ventricular wall motion abnormalities (Fig. 2.21), infection, tumors (evaluation, staging, and restaging), strokes, focal seizures, and traumatic brain injuries.

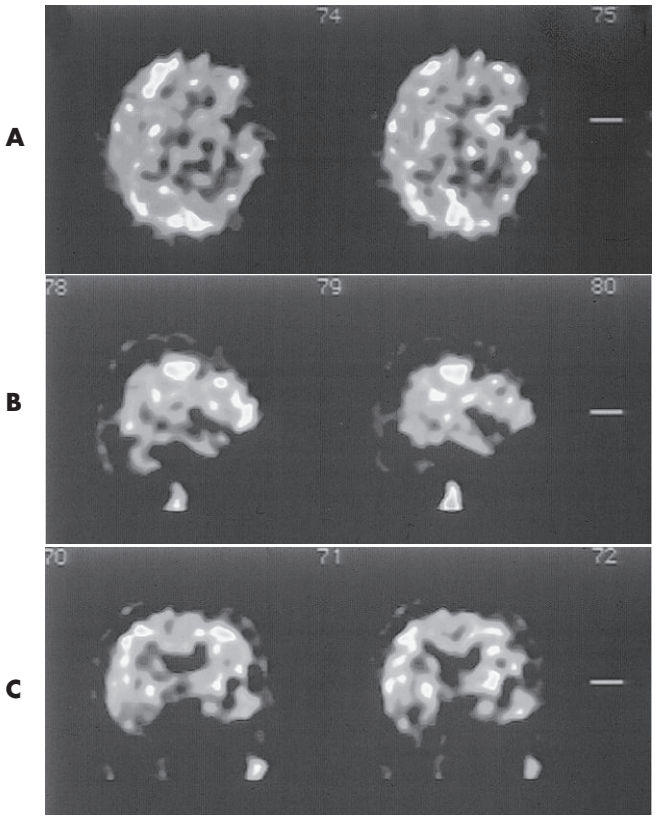


**Fig. 2.20 Single-Photon Emission Computed Tomography Images of the Brain Reconstructed into Three Planes of View.** (A) Transverse, (B) sagittal, and (C) coronal.

### SUMMARY OF IMAGING FOR NUCLEAR MEDICINE AND SINGLE-PHOTON EMISSION COMPUTED TOMOGRAPHY—FUNCTIONAL IMAGING

| | |
|---|---|
| Image creation | Radiopharmaceutical that emits gamma radiation |
| Image receptor | Nuclear medicine (NM)—gamma camera that detects gamma radiation emitted from patient |
| Imaging descriptors | Single-photon emission computed tomography (SPECT)—rotating gamma camera for multiplanar gamma radiation collection |
| | Hot spot—increased uptake directly proportional to the emission of gamma radiation |
| | Cold spot—reflection of decreased uptake directly proportional to the emission of gamma radiation |

## Positron Emission Tomography

**Positron emission tomography (PET)** is very similar to general nuclear medicine procedures with one difference—the type of radiation emitted (Fig. 2.22). Radionuclides used during general nuclear medicine procedures emit radiation directly from the nucleus of the atom, whereas in PET, a positron (a positively charged electron) is emitted. Upon emission, the positron travels until it interacts with an electron. With enough energy (1.22 MeV), the combination of a positron and an electron causes an **annihilation**. As a result, the positron and electron are completely converted into energy in the form of two gamma rays (0.511 MeV), which are emitted in opposite directions (approximately 180 degrees). PET camera systems are designed to detect both photons produced. By detecting both photons, the camera can calculate where the annihilation originally occurred based on the time it took for each ray to reach the camera. The theoretical pathway taken by the photons from the point of the annihilation to interaction with the camera is referred to as the "line of response." When both rays are detected by the camera, it is called a "true" event. Detection of only a single photon is not recorded and is considered a "random" or "scattered" event. The combination of millions to billions of true events can be used to slowly formulate an image.

Radionuclides used in PET are elements commonly found within the human body, such as carbon, oxygen, and nitrogen. The most common PET radionuclide is fluorine because its biologic and chemical properties are very similar to that of hydrogen. Fluorine is substituted into a glucose molecule to create the most widely used PET radiopharmaceutical, $^{18}$F-fluorodeoxyglucose ($^{18}$F-FDG). The imaging distribution of this agent creates a finely detailed metabolic representation of the area of interest. The metabolism of the body or organ illustrates the biochemistry of the tissue. This can be used to distinguish diseased or dead tissue from healthy tissue and

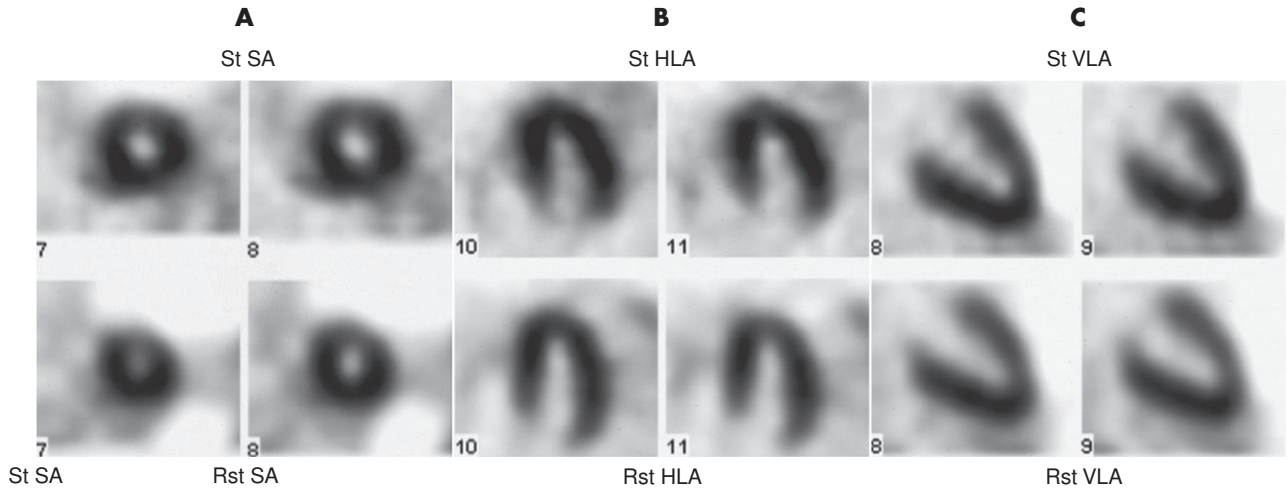


**Fig. 2.21** Single-photon emission computed tomography images of the normal heart in three planes of view, completed at rest *(Rst)* and stress *(St)* levels, with image reconstruction. (A) Short axis *(SA)* shows the coronal heart plane. (B) Horizontal long axis *(HLA)* shows the oblique transaxial plane. (C) Vertical long axis *(VLA)* shows the oblique sagittal plane.

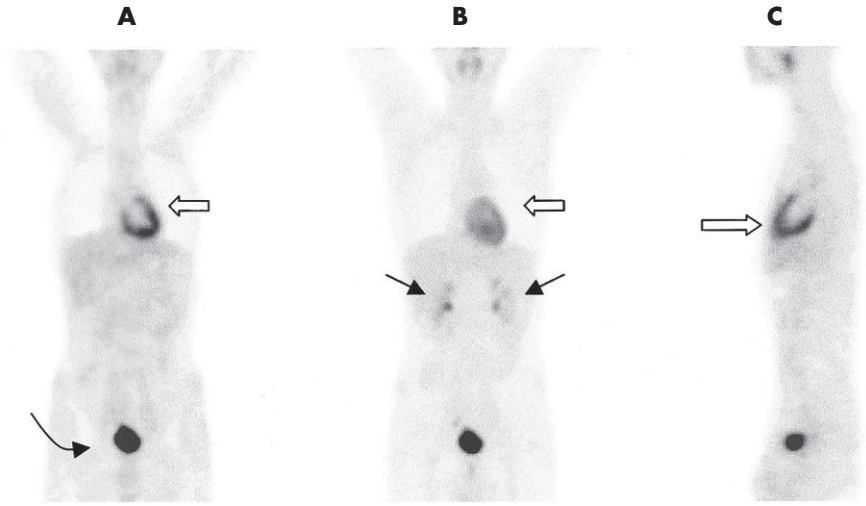


**Fig. 2.22** **Normal Positron Emission Tomography Scan with Multiplanar Body Imaging.** (A) Coronal plane, (B) projection plane, and (C) sagittal plane. Bladder *(curved arrow),* heart *(open arrows),* and kidney *(solid arrows)* are shown.

demonstrate tissue viability. Thus PET images the distribution of the gamma rays in the specific organs of interest and provides diagnosticians with a biologic map.

With PET imaging, multiple detectors (sometimes in excess of 8000) receive the signal, and computerized software converts the raw data to a 3D image in three planes: axial, coronal, and sagittal. In PET imaging, attenuation correction is required and is resolved by performance of a transmission scan on each patient. The computer reconstruction software then corrects for each patient's individual body contour and attenuation factor. This attenuation correction to the image increases the resolution of PET images and produces higher-quality images than SPECT. Radiation exposure rates to the patient in PET imaging are similar to those in general nuclear medicine exams and similar to that of a diagnostic CT. For the technologist, handling concentrated doses of radiopharmaceuticals and patient care lead to a higher radiation exposure.

PET is especially useful in three medical specialties: oncology, cardiology, and neurology. For oncology patients, this imaging modality can accurately image the whole body (cone of the head to the thigh), permitting the detection of metastases in multiple organs and aiding in tumor staging. Because PET produces a metabolic image, follow-up scans can be used to demonstrate the effectiveness of radiation or chemotherapy treatment by documenting any changes (Fig. 2.23). In cardiology patients, PET imaging assists in screening for coronary artery disease by demonstrating myocardial perfusion (flow rates, flow reserves, and viable myocardium) (Figs. 2.24 and 2.25).

In neurology patients, PET can be used to evaluate for a variety of dementias (i.e., Alzheimer, frontotemporal, and

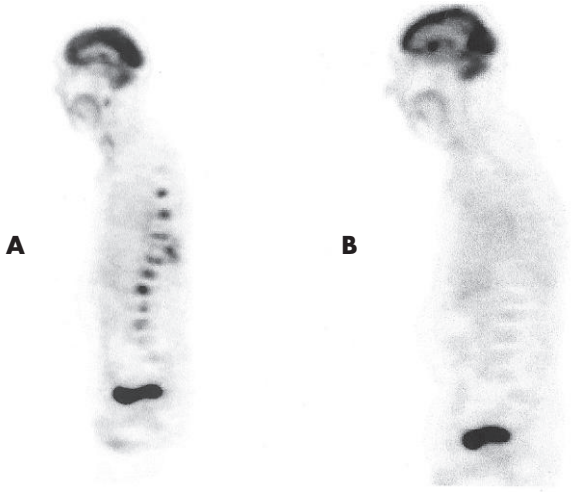


**Fig. 2.23** Positron Emission Tomography Used to Assess Effectiveness of Chemotherapy. (A) Image before therapy. (B) After chemotherapy, the image demonstrates decreased uptake of $^{18}$F-fluorodeoxyglucose.

Parkinson dementia) and to identify epileptic foci for surgical intervention (Fig. 2.26). The scanning environment (i.e., sound and light) may influence the scan results because these stimuli can affect the metabolism of the temporal and occipital regions of the brain; therefore the environment needs to be strictly controlled. $^{18}$F-FDG is the tracer that is used in brain imaging to demonstrate different aspects of cerebral metabolic function. Unlike the anatomic map produced by CT and MRI, the physiologic map provided by PET may permit earlier detection of abnormalities by demonstrating pathology before morphologic changes, leading to prompt treatment interventions and a better prognosis.

## SUMMARY OF IMAGING FOR POSITRON EMISSION TOMOGRAPHY—MOLECULAR IMAGING

| | |
|---|---|
| Image creation | Radiopharmaceutical that emits a positron—through the collection following annihilation, two gamma rays are created |
| Image receptor | Two opposite gamma cameras that detect gamma radiation simultaneously emitted from patient |
| Imaging descriptors | Three dimensional—three planes of colored images to demonstrate the biochemistry of tissue (biologic map)<br>Distinguishes diseased or necrotic tissue from healthy or normal tissue<br>Demonstrates tissue viability |

## Fusion Imaging

Currently, physicians are using top-of-the-line technologies to combine anatomic images with physiologic functional images. This imaging integration provides a high degree of clarity to view the pathophysiologic changes without the need to examine each modality separately. Fusing the morphology and physiology enables the diagnosis to be made much more quickly and with increased accuracy.

**Integrated imaging** is accomplished with the use of special software designed to overlay or fuse multidimensional computed data from MRI, CT, nuclear medicine, SPECT, or PET into a single set of images. Many angles viewed in this manner provide improved visualization of the anatomic site of interest.

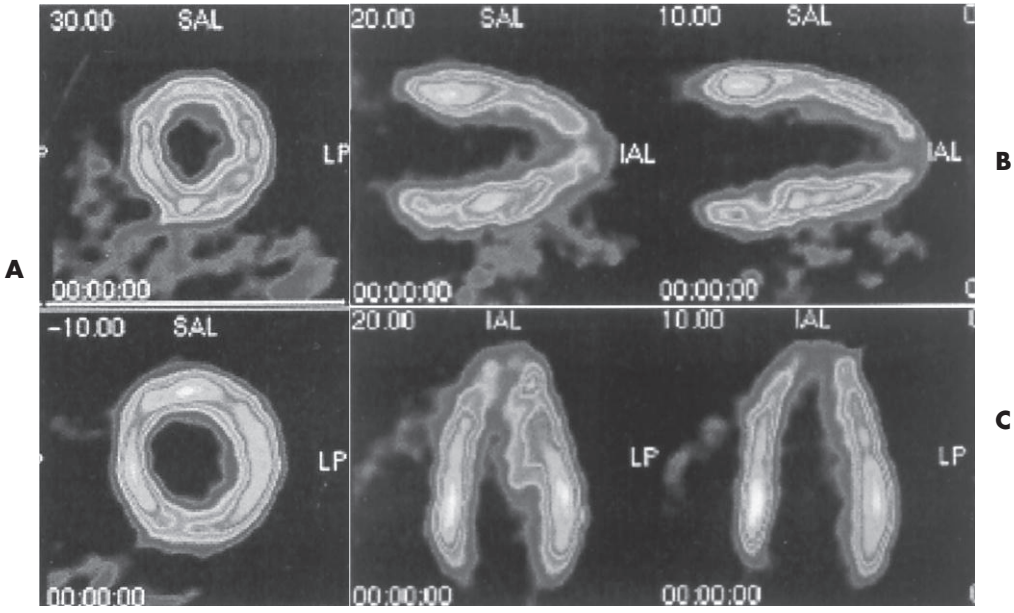


**Fig. 2.24** Normal Positron Emission Tomography Images of the Heart. Cardiology procedure demonstrating (A) short axis, (B) long vertical axis using $^{18}$F-FDG, and (C) horizontal long axis *(HLA)* with normal perfusion.

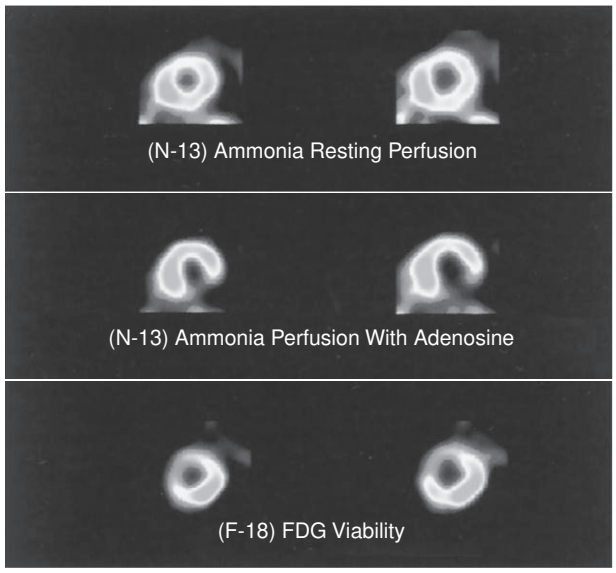


**Fig. 2.25 Positron Emission Tomography Images Demonstrating Myocardial Viability.** Cardiac resting and artificial stress (adenosine) perfusion images of the short axis using $^{13}NH_3$ {ΣY}–{/ΣY} ammonia (N-13). (A) At rest, perfusion is normal. (B) After artificial stress, uptake in the inferolateral wall is decreased. (C) Viability scan with $^{18}$F-fluorodeoxyglucose suggests ischemia of the right coronary artery and the left circumflex coronary artery. Perfusion of the region indicates that the myocardium remains viable.

Currently, **direct fusion** equipment (also known as hybrid technology) for PET/CT, PET/MR, and SPECT/CT is available (Fig. 2.27). The examinations are completed simultaneously (preferred) or separately, and then fusion software puts the data together. PET/CT with hybrid imaging demonstrates increased sensitivity compared with either modality alone, especially for lymph node staging. Additional training and certifications may be required for the technologist responsible for producing these special images to ensure the use of the lowest radiation dose. In addition, more education may be required to correctly demonstrate anatomic structures or molecular-physiologic relationships.

## SUMMARY OF FUSION IMAGING—ANATOMIC AND MOLECULAR IMAGING

| | |
|---|---|
| Image creation | Combination of two imaging modalities—most common positron emission tomography/computed tomography |
| | Integrated imaging—software creates images overlaying modality image data set |
| | Direct fusion—simultaneous image creation |
| Image receptor | Two imaging receptors of modalities used |
| Imaging descriptors | Specific to the imaging modalities used to create fused images |

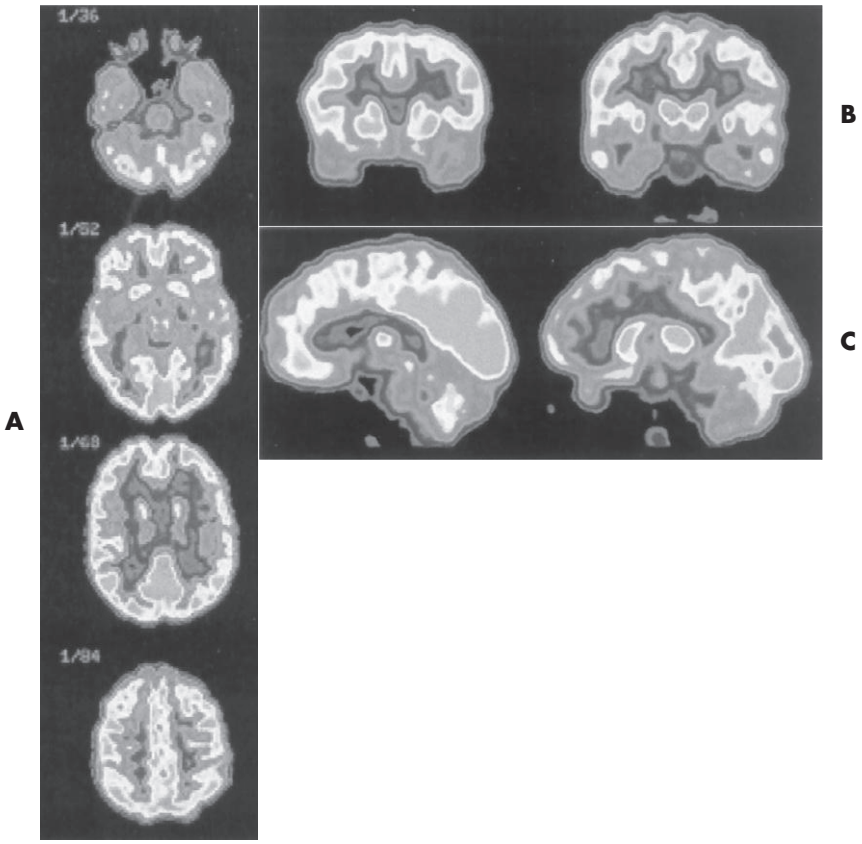


**Fig. 2.26 Positron Emission Tomography Image of the Brain.** Normal $^{18}$F-fluorodeoxyglucose uptake in the brain is indicated by the symmetric and consistent blood flow and metabolism in three planes: (A) axial or transverse, (B) coronal, and (C) sagittal.

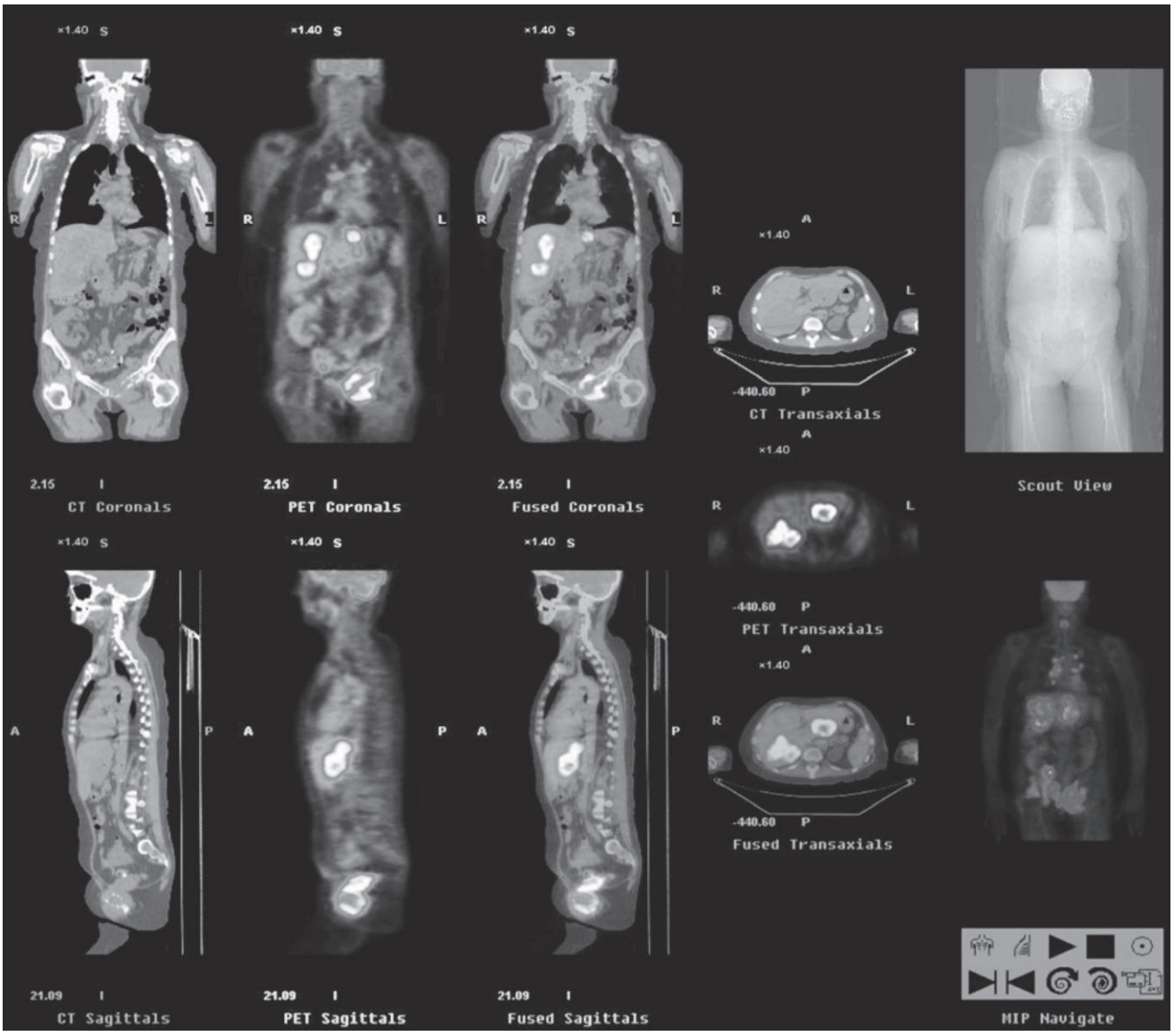


**Fig. 2.27 Positron Emission Tomography/Computed Tomography of the Body.** (A) This fusion provides the anatomic landmarks in the coronal and sagittal planes using the computed tomography images. (B) Positron emission tomography coronal and sagittal images demonstrate increased molecular uptake. (C) The fused images provide greater detail by locating the increased uptake in its anatomic position. (D) The axial projection through the liver.

## REVIEW QUESTIONS

1. The _____ describes where the pathophysiologic changes are visualized in relative position to the other organs or vessels in the body.
2. A pathophysiologic change that appears as a similar tissue structure is termed _____.
   **a.** heterogeneous
   **b.** isodense
   **c.** sharply marginated
   **d.** hyperdense
3. Pathophysiologic changes described as tubular, nodular, and diffuse are descriptors of _____.
4. Screening mammography recommends that _____ and _____ projections be performed.
   **a.** craniocaudal, mediolateral oblique
   **b.** mediolateral oblique, 90-degree mediolateral
   **c.** craniocaudal, 90-degree mediolateral
   **d.** craniocaudal, mediolateral oblique, and 90-degree mediolateral

5. Ultrasound depends on the echo of the high-frequency sound waves produced by the transducer. Tissue that produces a strong reflection is known as _____.
   **a.** hypoechoic
   **b.** anechoic
   **c.** isoechoic
   **d.** hyperechoic or echogenic
6. Ultrasound is limited by acoustic barriers, such as _____.
   **a.** liver and splenic tissue
   **b.** air and bone
   **c.** urine in the bladder
   **d.** gallstones or kidney stones
7. The modality that views tissue from multiple angles using a narrow x-ray beam is _____.
   **a.** CT
   **b.** SPECT
   **c.** PET
   **d.** MRI
8. The CT technique using continuous scanning while the table moves the patient through the gantry is _____.
   **a.** helical scanning
   **b.** conventional single-slice scanning
   **c.** high-resolution scanning
   **d.** CTA
9. Currently, the term multidetector CT indicates _____.
   **a.** multitransducer crystals
   **b.** a two-detector array
   **c.** 16- to 320-multidetector array
   **d.** 128- to 256-channel array
10. Which of the following is *not* a postprocessing imaging technique for CT?
    **a.** volume rendering
    **b.** VR
    **c.** maximum intensity projection
    **d.** fat suppression
11. To create an image in MRI, the technology depends on _____.
    **a.** hydrogen atoms and their response to radiofrequency pulses
    **b.** x-radiation attenuation
    **c.** radiopharmaceuticals
    **d.** electrical stimulation of transducer crystals
12. Multiple-pulse sequences may be required to illustrate pathophysiologic changes. Examples of MRI pulse sequences are _____.
    **a.** T1- and T2-weighted images
    **b.** positron emission (gamma)
    **c.** single-photon emission
    **d.** 2-MHz to 15-MHz images
13. Nuclear medicine and SPECT imaging rely on scintillation cameras to detect _____.
    **a.** multiple-photon emission
    **b.** electron annihilation
    **c.** gamma rays
    **d.** photoelectric interaction
14. PET imaging is especially useful to evaluate _____.
    **a.** chest for pneumothorax
    **b.** reproductive organs for cysts
    **c.** preradiation and postradiation or chemotherapy
    **d.** cerebral ventricle displacement
15. Hybrid imaging equipment combines two _____.
    **a.** image modalities using software to fuse images
    **b.** images comparatively viewed side by side
    **c.** modalities simultaneously to produce one set of images
    **d.** technologists and a radiologist viewing images

# 3

# Respiratory System

## OBJECTIVES

*After reading this chapter, the reader will be able to:*

- Locate placement for an endotracheal tube, central venous catheter, Swan-Ganz catheter, and transvenous cardiac pacemaker.
- Recognize the most common complications involved with improper placement of these tubes and catheters, and how chest radiography plays an important role in diagnosing them.
- Classify the more common diseases in terms of their attenuation of x-rays.
- Explain the changes in technical factors required to obtain optimal quality radiographs for patients with various underlying pathologic conditions.
- Define and describe all boldface terms in this chapter.
- Describe the physiology of the respiratory system.
- Identify anatomic structures on both diagrams and radiographs of the respiratory system.
- Differentiate the more common pathologic conditions affecting the respiratory system and their radiographic manifestations.

## OUTLINE


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## KEY TERMS

acute respiratory distress syndrome (ARDS)
adenocarcinomas
alveolar, or air-space, pneumonia
asthma
bronchial adenomas
bronchiectasis
bronchioalveolar carcinoma
bronchiolar (alveolar cell) carcinoma
bronchogenic carcinoma
bullae
chronic bronchitis
emphysema
extrinsic asthma
interstitial pneumonia
intrinsic asthma
pulmonary mycosis
small cell (oat cell) carcinomas
squamous carcinoma
surfactant

## RADIOGRAPHER NOTES

Proper positioning and the correct exposure factors are especially important in radiography of the respiratory system because to make a precise diagnosis, radiologists must be able to detect subtle changes in pulmonary and vascular structures. Ideally, follow-up studies should be performed with the same exposure factors used to make the initial radiographs. With the same exposure factors, any density changes can be attributed to true pathologic findings rather than to mere technical differences.

All chest radiography should be performed with the patient in full inspiration (inhalation), except when expiration images are used for those few pathologic conditions requiring expiration images. In an ideal image, the upper 10 posterior ribs should be visualized above the diaphragm. Poor expansion of the lungs may cause a normal-sized heart to appear enlarged and makes it difficult to evaluate the lung bases. To obtain a full-inspiration radiograph, the patient should be instructed to take a deep breath, exhale, and inhale again (thus accomplishing maximal inspiration), at which time the exposure should be made. This technique avoids the Valsalva effect, which is a forced expiration against the closed glottis that increases the intrapulmonary pressure. The Valsalva effect results in compression and a large decrease in the size of the heart and adjacent blood vessels, which make it difficult to evaluate heart size and pulmonary vascularity accurately.

The patient must be precisely positioned for chest radiography to ensure symmetry of the lung fields and a true appearance of the heart and pulmonary vasculature. Whenever possible, all chest radiographs should be taken with the patient in the erect position. The only exception is for the patient with a suspected pathologic condition that requires a lateral decubitus position. Although recumbent radiographs may be necessary in immobile or seriously ill patients, they are less than satisfactory because in this position the abdominal contents tend to prevent the diaphragm from descending low enough to permit visualization of well-expanded lung bases or fluid levels. A 72-inch source-to-image receptor distance should be used when possible to minimize magnification of the heart and mediastinal structures. Correct positioning with absence of rotation in the frontal projection can be demonstrated by symmetry of the sternoclavicular joints. The shoulders must be rolled forward (anteriorly) to prevent the scapulae from overlying the lungs. In large-breasted women, it is often necessary to elevate and separate the breasts to allow good visualization of the lung bases. Nipple shadows of both men and women occasionally appear as soft tissue masses. If the nature of these soft tissue masses is unclear, it may be necessary to repeat the examination using small lead markers placed on the nipples. Collimation of the radiograph is required to reduce scattered radiation, although it is essential that both costophrenic angles be visualized. However, the radiographer obtains a diagnostic image, and it is necessary to label the image appropriately.

Radiographs exhibiting a long scale of contrast are necessary to visualize the entire spectrum of densities within the thoracic cavity (including those of the mediastinum, heart, lung markings, and pulmonary vasculature) and the surrounding bony thorax. Most authorities agree that a minimum of 120 kilovolts-peak (kVp) should be used with an appropriate ratio grid for all adult chest radiography. If it is necessary to decrease the overall density, this should be accomplished by reduction of the milliampere-seconds (mAs) rather than of the kVp. Decreasing the kVp tends to enhance the bony thorax, which may obscure vascular details and cause underpenetration of the mediastinal structures. In general, the density and contrast should be such that the thoracic vertebrae and intervertebral disk spaces are faintly visible through the shadow of the mediastinum without obscuring the lung markings and pulmonary vascularity. Many facilities have advanced from an analog imaging system to digital imaging systems, either computed radiography (CR) or direct radiography (DR). With digital systems, density (brightness) and contrast are primarily controlled by the algorithm used to process the image, although the technical factors selected also influence final appearance of the image. When producing radiographs for line placement, the technologist should use the appropriate technical factors to demonstrate the line and possible chest pathology (pneumothorax or hemothorax) that may result from line placement.

Short exposure times (10 msec or less) must be used in chest radiography because longer times may not eliminate the involuntary motion of the heart. Automatic exposure devices are generally recommended, and they help to ensure that follow-up studies will have a similar image density. When a digital imaging system is used, the automatic exposure device helps ensure that the exposure index will be within range, thus producing the correct brightness and contrast on the image. An exception is the expiration (exhalation) chest radiograph, which should be exposed with a manual technique because the preset density of an automatic exposure device may cause excessive overexposure of the lungs and thus obscure a small pneumothorax.

Compensatory filters are sometimes needed to overcome the broad range of different tissue densities within the chest. They are especially important to allow good visualization of the mediastinum without overexposing the lungs. The use of compensatory filters generally requires that the radiographic exposure be twice that used when there is no additional filtration.

To demonstrate fluid levels, the patient should be in an erect position for a minimum of 5 minutes (preferably 10 to 15 minutes), and a horizontal x-ray beam must be used. Any angulation of the beam prevents a parallel entrance to the air-fluid interface and obscures the fluid level. In some clinical situations (e.g., when there is a small pneumothorax or pleural thickening as opposed to free pleural fluid), it is necessary to use a horizontal beam with the patient placed in the lateral decubitus position.

Certain pathologic conditions of the respiratory system require that the radiographer alter the routine technical factors. Some disorders produce increased tissue density (fluid), which attenuates more of the x-ray beam, whereas others decrease the tissue density of the lungs (hyperaeration) so there is less attenuation by the pulmonary tissue. It is important to remember that these changes may vary for a single disease because the chest structures attenuate more or less of the x-ray beam depending on the stage of the disease process. Unless the radiographer has access to previous images with recorded techniques, the initial exposures should be made with use of a standard technique chart. Adjustments and technical factors can then be made, if necessary, on subsequent images. (See Box 1.1 for a list of the changes in attenuation factors expected in advanced stages of various disease processes.)

## PHYSIOLOGY OF THE RESPIRATORY SYSTEM

The major role of the respiratory system is the oxygenation of blood and the removal of the body's waste products in the form of carbon dioxide. The respiratory system consists of two separate divisions, the upper tract located outside the thorax and the lower tract found within the thoracic cavity (Fig. 3.1). The upper respiratory system, which consists of the nasopharynx, oropharynx, and larynx, provides structure for the passage of air into the lower respiratory system. The lower respiratory system, which consists of the trachea, bronchi, and bronchioles, is composed of tubular structures responsible for conducting air from the upper respiratory structures. The smallest unit where gas exchange occurs consists of the terminal bronchiole, alveolar ducts, and alveolar sacs. With the use of the upper and lower respiratory structures, the air from outside the body enters the lungs. The single trachea branches out into two bronchi (one to each lung) at the carina (last segment of the trachea), which in turn branch out into progressively smaller bronchioles to produce a structure termed the bronchial tree because its appearance resembles an inverted tree. The tracheobronchial tree is lined with a mucous membrane (the respiratory epithelium) containing numerous hairlike projections called cilia. During inspiration, the air is moistened and warmed as it enters the lungs. The cilia act as miniature sweepers to prevent dust and foreign particles from reaching the lungs. When the ciliary blanket works correctly, the particles are moved away from the lungs to be coughed up or swallowed. Any damage to the respiratory epithelium and its cilia permits particles (entering with the inspired or inhaled air) to proliferate and produce a disease process.

The vital gas exchange within the lung (called external respiration) takes place within the alveoli, extremely thin-walled sacs surrounded by blood capillaries, which represent the true parenchyma of the lung (see Fig. 3.1 *inset*). Oxygen in the inhaled air diffuses from the alveoli into the blood capillaries, where it attaches to hemoglobin molecules in red blood cells and circulates to the various tissues of the body (called internal respiration). Carbon dioxide, a waste product of cellular metabolism, diffuses in the opposite direction, passing from the blood capillaries into the alveoli and then exiting the body during expiration (or exhalation). Because individual alveoli are extremely small, chest radiographs can demonstrate only a cluster of alveoli and their tiny terminal bronchioles, which are the basic anatomic units of the lung. A cluster of alveoli is termed the acinus.

Respiration is controlled by a center in the medulla at the base of the brain. The level of carbon dioxide in the blood regulates the respiratory center. Even a slight increase in the amount of carbon dioxide in the blood increases the rate and depth of breathing, such as when an individual exercises. The accumulation of waste gases that must be removed from the body (and the body's need for additional oxygen) causes the respiratory center to stimulate the muscles of respiration—the diaphragm and the intercostal muscles between the ribs. Contraction of the muscles of respiration causes the volume of the chest cavity to increase. This decreases the pressure within the lungs and forces air to move into the lungs through the tracheobronchial tree. As the respiratory muscles relax, the volume of the chest cavity decreases, and air is forced out of the lungs. Special muscles of expiration (abdominal and internal intercostal muscles) may be needed for difficult breathing or in patients with decreased gas exchange, as occurs in emphysema.

Unlike most other organs, the lung has two different blood supplies. The pulmonary circulation is a low-pressure, low-resistance system through which oxygen enters and carbon dioxide exits the circulatory system. The bronchial circulation, which is a part of the high-pressure systemic circulation, supplies oxygenated blood to nourish (or support) the lung tissue.

A double-walled membrane consisting of two layers of pleura encases the lungs (Fig. 3.2). The visceral pleura is the inner layer that adheres to the lung, whereas the parietal pleura lines the inner chest wall (the thoracic cavity). Between the two layers of pleura is a potential space (pleural space), which normally contains only a small amount of fluid to lubricate the surfaces to prevent friction as the lungs expand and contract. The airtight space between the lungs and the chest wall has a pressure slightly less than that in the lungs. This difference in pressure acts like a vacuum to prevent the lungs from collapsing. An inflammatory or neoplastic process that involves the pleura may produce fluid within the potential space (a pleural effusion).

## INTERNAL DEVICES

### Endotracheal Tube

A chest radiograph should always be obtained immediately after endotracheal intubation to ensure proper positioning of the tube because clinical evaluation (bilateral breath sounds, symmetric thoracic expansion, and palpation of the tube in the sternal notch) does not allow detection of the majority of malpositioned tubes. Daily radiographs are usually taken to ensure that the tube has not been inadvertently displaced by the weight of the respiratory apparatus, the patient's coughing, or other unforeseen events. In addition, imaging permits prompt detection of complications of intubation and barotrauma (positive-pressure breathing), such as pneumothorax and pneumomediastinum.

The relationship between the tip of the tube and the carina (tracheal bifurcation) must be carefully assessed. When the head and neck are in a neutral position, the endotracheal tube tip ideally should be approximately 5 to 7 cm above the carina (Fig. 3.3). With flexion and extension of the neck, the tip of the tube will move approximately 2 cm caudally and cranially, respectively.

Approximately 10% to 20% of endotracheal tubes require repositioning after insertion. A tube positioned too low usually extends into the right mainstem bronchus, where it eventually leads to atelectasis of the left lung (Fig. 3.4). A tube positioned excessively high or in the esophagus causes the inspired air to enter

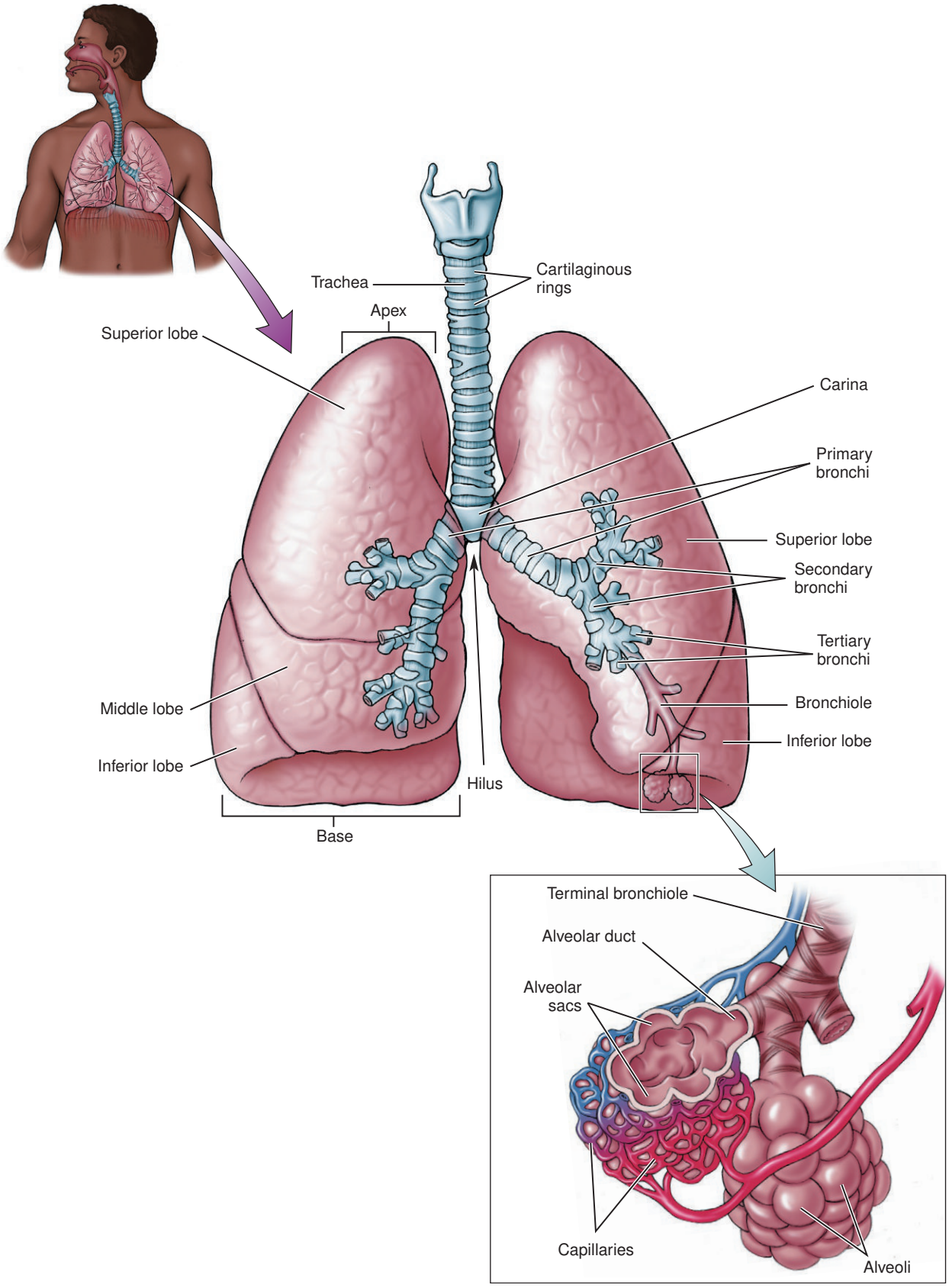


**Fig. 3.1** **Structure Plan of the Respiratory System.** The *inset* shows the alveolar sacs where the interchange of oxygen and carbon dioxide takes place through the walls of the grapelike alveoli. (From Herlihy B: *The human body in health and illness*, ed 6, St. Louis, 2018, Mosby.)

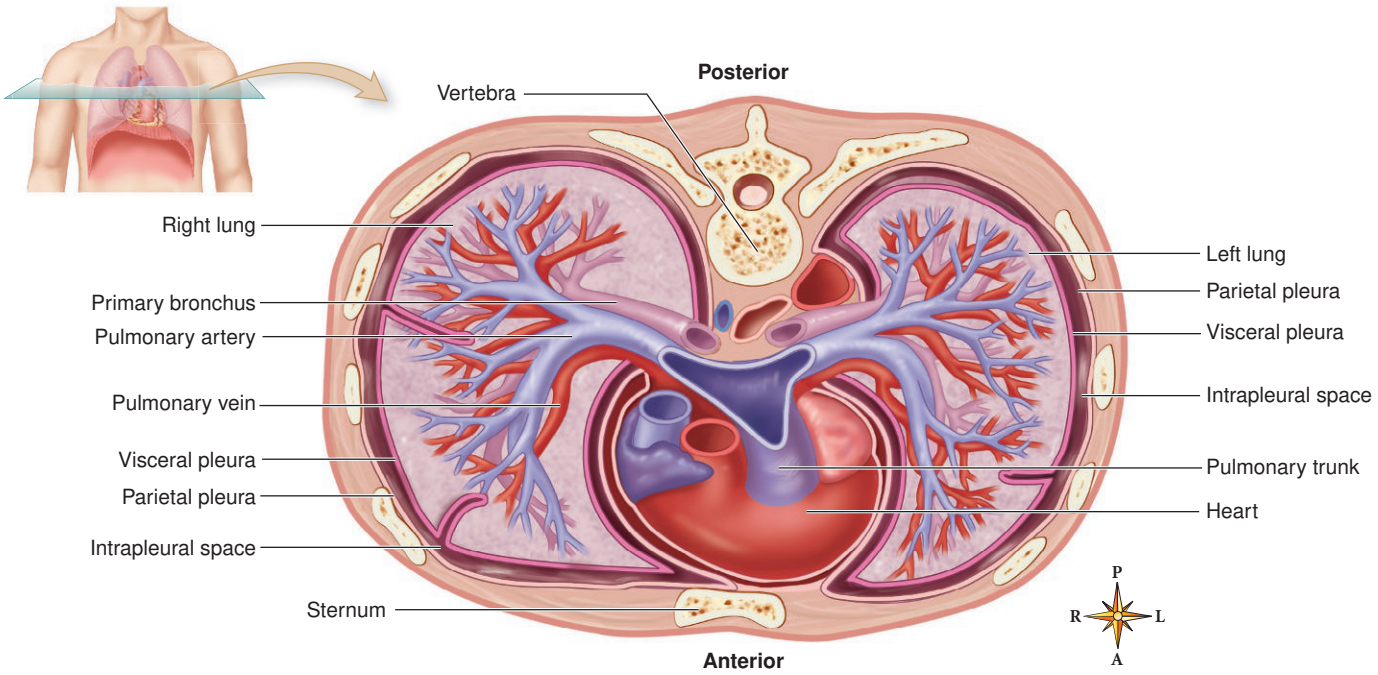


**Fig. 3.2 Lungs and Pleura (Transverse Section).** Note the parietal pleura, which lines the right and left pleural divisions of the thoracic cavity before folding inward near the bronchi to cover the lungs as the visceral pleura. The intrapleural space separates the parietal and visceral pleura. The heart, esophagus, and aorta are shown in the central mediastinum. (From Patton KT: *Anatomy and physiology*, ed 10, St. Louis, 2019, Mosby.)

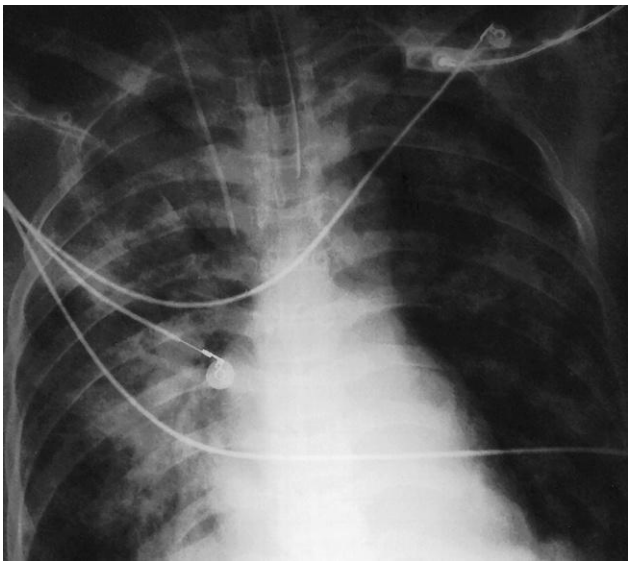

**Fig. 3.3 Endotracheal Tube.** Proper position.

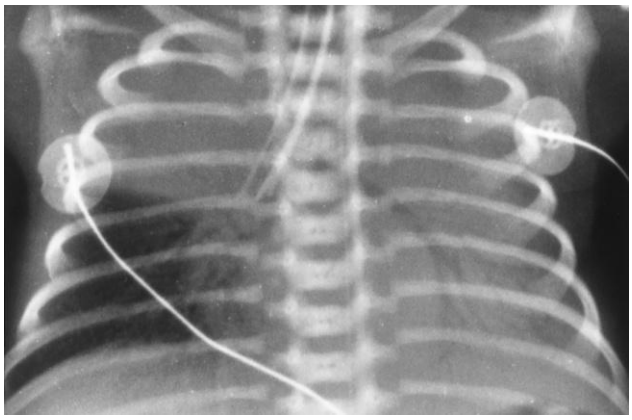

**Fig. 3.4 Malpositioned Endotracheal Tube.** Excessively low position of endotracheal tube in the bronchus intermedius causes collapse of right upper lobe and entire left lung. (From Dunbar RD: Radiologic appearance of compromised thoracic catheters, tubes, and wires, *Radiol Clin North Am* 22:699–722, 1984.)

the stomach, causing severe gastric dilation and a high likelihood of regurgitation of gastric contents and aspiration pneumonia.

## Central Venous Catheters

Central venous catheters inserted into the subclavian vein or a more peripheral vein in the upper extremity are extremely useful for measurement of the central venous pressure (CVP) and for providing a conduit for the rapid infusion of fluid or chronic hyperalimentation. So that the CVP may be correctly measured, the catheter must be located within the true central venous system, beyond all the valves that interfere with direct transmission of right atrial pressure to the catheter. The optimal location is where the brachiocephalic veins join to form the superior vena cava (medial to the anterior border of the first rib on chest radiographs) or within the superior vena cava itself.

Because up to one-third of CVP catheters are initially inserted incorrectly, the position of the catheter should be confirmed by a chest radiograph. The most common aberrant

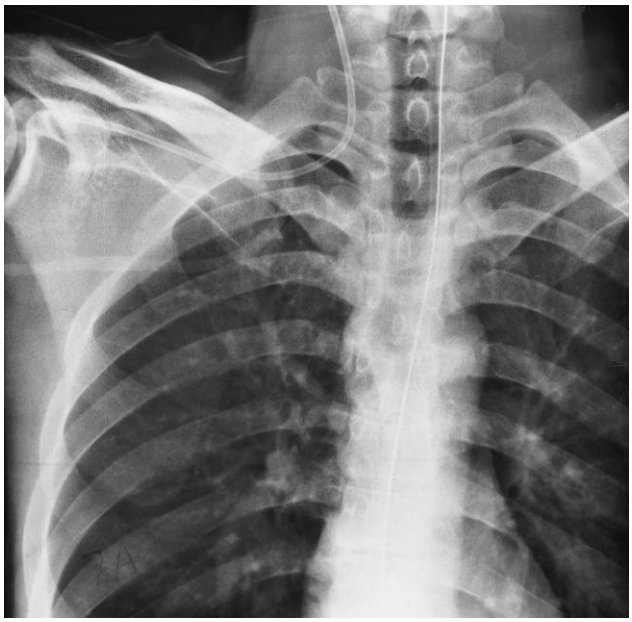

**Fig. 3.5 Central Venous Pressure Catheter.** Located in the right internal jugular vein. (From Eisenberg RL: *Diagnostic imaging in internal medicine,* New York, 1985, McGraw-Hill.)

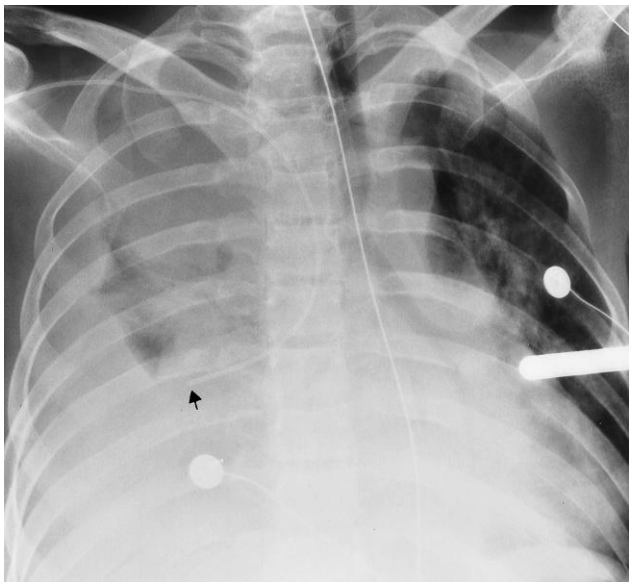

**Fig. 3.6 Central Venous Pressure Catheter with its Tip in the Pleural Space.** A right subclavian catheter, which was introduced for total parenteral nutrition, perforated the superior vena cava and eroded into the right pleural space. Note the tip of the catheter projecting beyond the right border of the mediastinum *(arrow).* The direct infusion of parenteral fluid into the pleural space has led to a large right hydrothorax.

location of a CVP catheter is the internal jugular vein (Fig. 3.5). CVP catheters that extend to the right atrium are associated with an increased risk of cardiac arrhythmias and even perforation. Extension of the catheter into the hepatic veins may result in the infusion of potentially toxic substances (some antibiotics and hypertonic alimentation solutions) directly into the liver. Even after successful placement, CVP catheters may change position as a result of patient motion or medical manipulation. Therefore periodic radiographic confirmation of the catheter position is often recommended.

The anatomy of the subclavian region may lead to complications when a central catheter is introduced via the subclavian vein. Because the pleura covering the apex of the lung lies just deep to the subclavian vein, a pneumothorax may develop. This problem may be difficult to detect clinically, and thus a chest radiograph (if possible with the patient in an upright position and in expiration) should be obtained whenever insertion of a subclavian catheter has been attempted. Another complication is perivascular CVP catheter placement, which may result in ectopic infusion of fluid into the mediastinum or pleural space. This diagnosis should be suggested if there is rapid development of mediastinal widening or pleural effusion after CVP catheter insertion (Fig. 3.6). Other complications include inadvertent puncture of the subclavian artery, air embolism, and injury to the phrenic nerve.

The peripherally inserted central catheter (PICC) has become the long-term venous access device used for home therapy and for patients undergoing chemotherapy (Fig. 3.7).

Catheter breakage and embolization can result from laceration of the catheter by the needle used to insert it, fracture at a point of stress, or detachment of the catheter from its hub. The catheter fragment may lodge in the vena cava, in the right

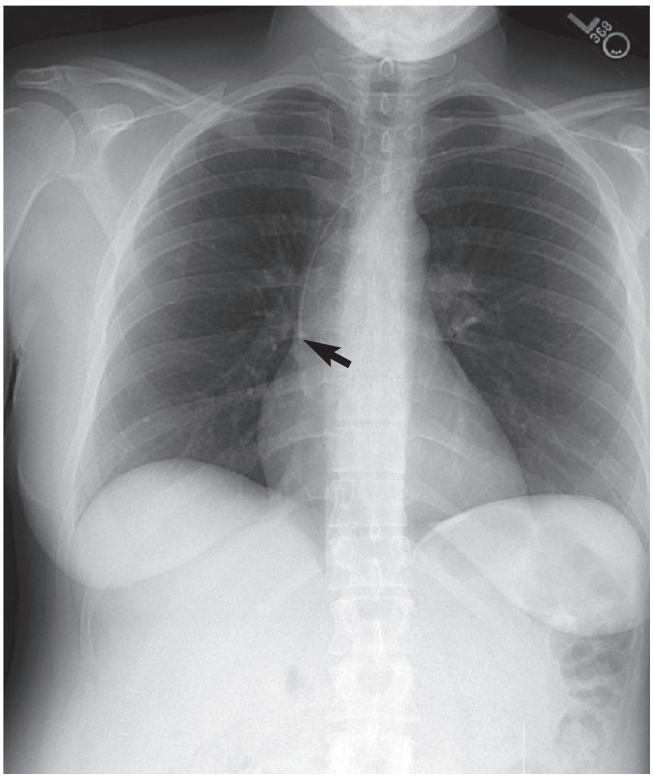

**Fig. 3.7 Peripherally Inserted Central Catheter (PICC) Line Placement.** The PICC line appears in the superior vena cava *(arrow).* (From Eisenberg RL: *Diagnostic imaging in internal medicine,* New York, 1985, McGraw-Hill.)

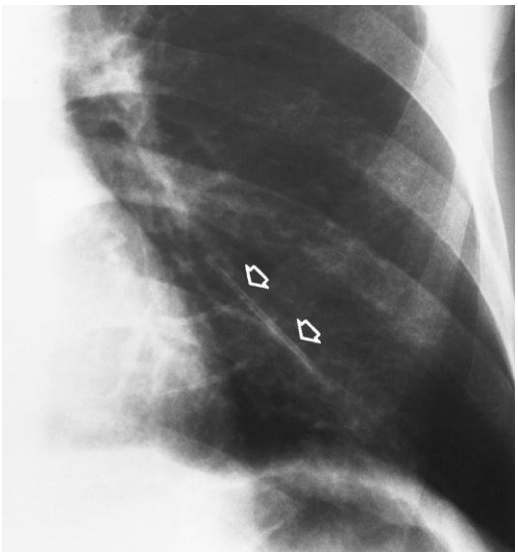

**Fig. 3.8 Broken Central Venous Pressure Catheter.** The sheared-off portion of the catheter *(arrows)* is located in the left lower lobe. (From Dunbar RD: Radiologic appearance of compromised thoracic catheters, tubes, and wires, *Radiol Clin North Am* 22:699–722, 1984.)

side of the heart, or in branches of the pulmonary artery (Fig. 3.8). Adverse results include thrombosis, infection, and perforation.

## Swan-Ganz Catheters

The flow-directed Swan-Ganz catheter consists of a central channel for measuring pulmonary capillary wedge (PCW) pressure and a second, smaller channel connected to an inflatable balloon at the catheter tip. Cardiac output and CVP can also be measured using the Swan-Ganz catheter. It can be inserted at the bedside and floated to the pulmonary artery without the need for fluoroscopic monitoring.

Ideally, the catheter is positioned so that it lies within the right or left main pulmonary artery. Inflating the balloon causes the catheter to float downstream into a wedge position; deflating the balloon permits the catheter to recoil into the central pulmonary artery. Unlike standard intravenous catheters, the Swan-Ganz catheter has a radiopaque strip down its center. Radiographically, the tip of the tube is visualized within the borders of the mediastinum when properly placed; this would substantially decrease the likelihood of occlusion of the distal pulmonary vessel.

The most common complication associated with the use of a Swan-Ganz catheter is pulmonary infarction distal to the catheter tip. Infarction may result from occlusion of a pulmonary artery by the catheter itself (if it is wedged in a too peripheral vessel) or from clot formation in or about the catheter. Pulmonary infarction appears as a patchy air-space consolidation involving the area of the lung supplied by the pulmonary artery in which the catheter lies. The appropriate treatment is simply removal of the Swan-Ganz catheter; systemic heparinization is not required once this source of emboli or obstruction has been removed.

## Transvenous Cardiac Pacemakers

Transvenous endocardiac pacing is the method of choice for maintaining cardiac rhythm in patients with heart block or bradyarrhythmias. Radiographic evaluation plays an important role in the initial placement of a pacemaker and in the detection of any subsequent complications. An overexposed image can demonstrate both the generator (for permanent pacemakers) and the course of the electrodes.

Ideally, the tip of the pacemaker should be positioned at the apex of the right ventricle. One common aberrant location is the coronary sinus. On a frontal radiograph, the tip often appears to be well positioned. A lateral projection is required to show that the tip is directly posterior in the coronary sinus, rather than in its proper position anterior in the right ventricle.

Although electrode fractures have become less common because of the development of new alloys, they are still a significant cause of pacing failure (Fig. 3.9). The usual sites of fracture are near the pulse generator, at sharp bends in the wires, and at the point where the electrodes are inserted into the epicardium. Although most electrode fractures are easily detected on routine chest radiographs, some subtle fractures may be demonstrated only on oblique views or at fluoroscopy.

Perforation of the myocardium by an intravenous electrode usually occurs at the time of insertion or during the first few days thereafter. Perforation should be suspected when the pacemaker fails to sense or elicit a ventricular response. Plain radiographs show the electrode tip lying outside the right ventricular cavity (Fig. 3.10).

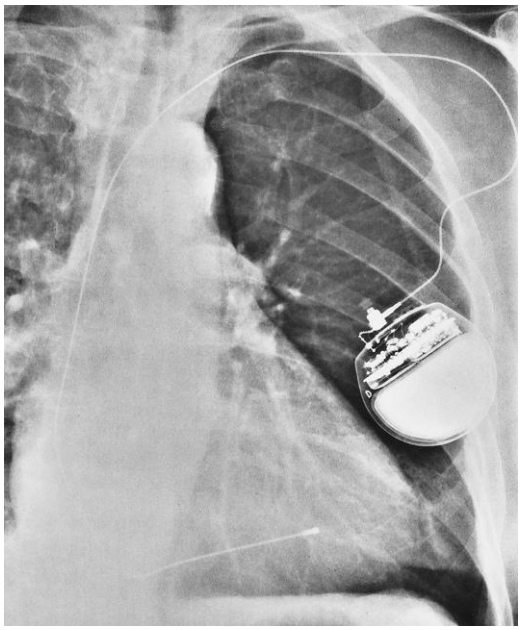

**Fig. 3.9 Pacemaker Tip in Coronary Sinus.** On the frontal projection, the tip of the electrode is angled slightly superiorly, traversing the heart in a higher plane than when it is located in the right ventricle. (From Eisenberg RL: *Diagnostic imaging in internal medicine,* New York, 1985, McGraw-Hill.)

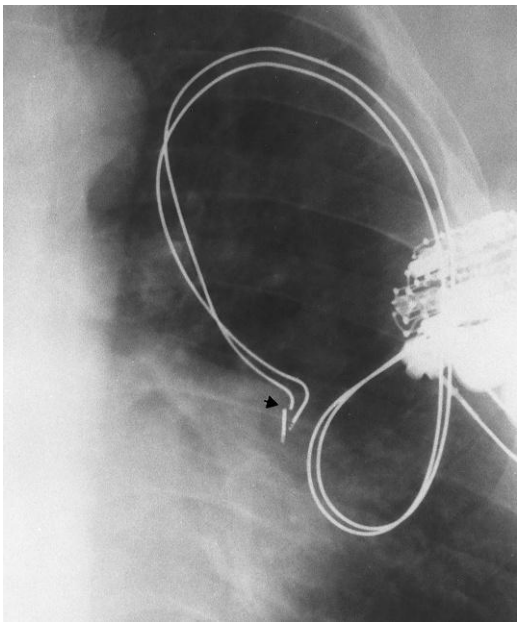

**Fig. 3.10 Cardiac Pacemaker.** Fracture of a pacemaker wire *(arrow)*. (From Swischuk LE: *Radiology of the newborn and young infant,* Baltimore, 1980, Williams & Wilkins.)

## SUMMARY OF FINDINGS FOR INTERNAL DEVICES

| Internal Device | Correct Placement[a] | Complications |
|---|---|---|
| Endotracheal tube | Tip of tube 5–7 cm above the carina | Low placement—atelectasis<br>High placement—air entering the stomach |
| Central venous pressure catheters | Tip of catheter should be in the superior vena cava | Internal jugular vein placement<br>Right atrium—possible arrhythmias or perforation<br>Pneumothorax with placement<br>Infusion of fluid into mediastinum or pleural space |
| Swan-Ganz catheters | Right or left main pulmonary artery seen radiographically within the borders of the mediastinum | Pulmonary infarction |
| Transvenous cardiac pacemakers | Overexpose to demonstrate the tip of the electrode at the apex of the right ventricle | Coronary sinus placement—needs a lateral chest image to distinguish<br>Perforation at initial insertion |

[a]Placement determined by chest radiograph.

# CONGENITAL/HEREDITARY DISEASES

## Cystic Fibrosis

Cystic fibrosis (mucoviscidosis) is a hereditary disease characterized by the secretion of excessively viscous mucus by all the exocrine glands; it is caused by a defective gene in the middle of chromosome 7. Cystic fibrosis is the most common clinically important genetic disorder among white children. This disorder also affects the pancreas and digestive system. However, 90% of the morbidity and mortality related to cystic fibrosis occurs as a result of respiratory involvement.

In the lungs, thick mucus secreted by mucosa in the trachea and bronchi blocks the air passages. The thick mucus is the result of an imbalance of sodium and chloride production and reabsorption. These mucous plugs lead to focal areas of lung collapse. Recurrent pulmonary infections are common because bacteria that are normally carried away by mucosal secretions adhere to the sticky mucus produced in this condition. Because of the recurring nature of the disease, by age 10 years many children have widespread bronchiectasis with the formation of large cysts and abscesses. In the pancreas, blockage of the ducts by mucous plugs prevents pancreatic enzymes from entering the duodenum. This process impairs the digestion of fat, resulting in failure of the child to gain weight and the production of large, bulky, foul-smelling stools. In approximately 10% of newborns with cystic fibrosis, the thick mucus causes obstruction of the small bowel (meconium ileus) (Fig. 3.11). Bowel perforation with subsequent fatal peritonitis may occur.

Involvement of the sweat glands in cystic fibrosis causes the affected child to perspire excessively. The perspiration excess leads to a loss of large amounts of salt (sodium, potassium,

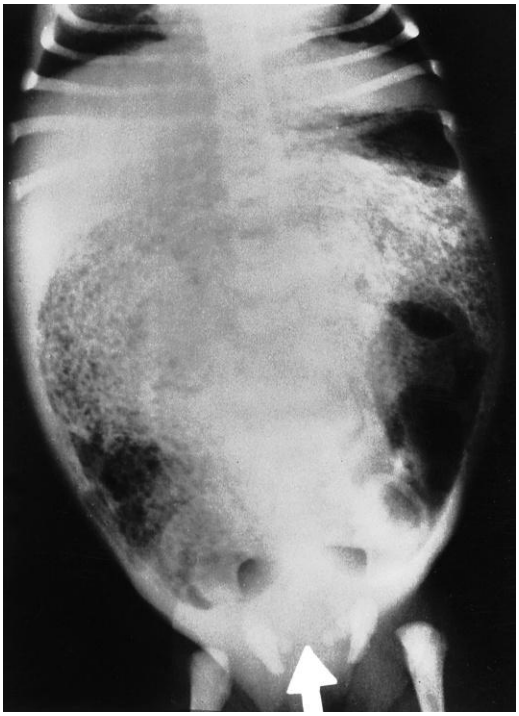

**Fig. 3.11 Meconium Ileus in Cystic Fibrosis.** Massive small bowel distention with profound soap-bubble effect of gas mixed with meconium.