Nina Kowalczyk

RADIOGRAPHIC PATHOLOGY for TECHNOLOGISTS

EIGHTH EDITION

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RADIOGRAPHIC PATHOLOGY for TECHNOLOGISTS

EIGHTH EDITION

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PREFACE

The eighth edition of *Radiographic Pathology for Technologists* has been thoroughly updated and revised to offer students and radiologic science and imaging professionals information on the pathologic appearance of common diseases in a variety of diagnostic imaging modalities. It also presents basic information on the pathologic process, signs and symptoms, diagnosis, and prognosis of the various diseases. The eighth edition includes the latest information concerning recent advances in imaging modalities used in daily practice, including interventional and multimodality hybrid imaging procedures. The authors have attempted to present this material in a succinct, but reasonably complete, fashion to meet the needs of professionals in various imaging specialties. With each new edition, the authors have also reviewed the scope of the material covered in the text to provide the reader with a relevant and broad base of knowledge.

NEW TO THIS EDITION

- Full color design to enhance the understanding of content, as well as improved anatomic and pathologic images.
- Almost 150 new images have been added or updated to complement new, updated, or expanded material.
- Updated content to reflect the latest ACR Appropriateness criteria and ASRT curriculum guidelines.
- Chapters 2, 5, 6, and 8 have been significantly updated to reflect diagnostic imaging modalities most commonly used in the diagnosis and treatment of pathologies of the skeletal system, abdomen, gastrointestinal, hepatobiliary, and nervous systems.
- Several new terms have been added to the glossary, and other definitions have been expanded or updated.

LEARNING ENHANCEMENTS

- Each chapter includes a list of learning objectives, an outline, and key terms.
- Chapter content is followed by a summary and multiple-choice and short answer review questions, which can be used by the reader to assess acquired knowledge or by the instructor to stimulate discussion.
- Bold print has been used to focus the reader's attention on the key terms in each chapter, which are defined in the glossary at the end of the book along with other relevant terms.

USING THE BOOK

The presentation of the eighth edition presumes that the reader has some background in human anatomy and physiology, imaging procedures, and medical and imaging terminology. The reader may build on this knowledge by assimilating information presented in this text. To facilitate a working knowledge of the principles of radiologic pathology, study materials presented in the eighth edition remain sophisticated enough to be true to the complexity of the subject, yet simple and concise enough to permit comprehension by all readers. For student radiographers, sonographers, radiation therapists, and nuclear medicine technologists, this text is best used in conjunction with formal instruction from a qualified instructor. The practicing imaging professional may use this book as a self-teaching instrument to broaden and reinforce existing knowledge of the subject matter and also as a means to acquaint himself or herself with changing concepts and new material. The book can serve as a resource for continuing education because it provides an extensive range of information.

ANCILLARIES

Evolve Resources

Evolve is an interactive learning environment designed to work in coordination with *Radiographic Pathology for Technologists.* Included on the Evolve website are a test bank in Exam View containing approximately 400 questions, an electronic images collection consisting of images from the textbook, PowerPoint presentations per chapter, and the answers to the multiple-choice review questions in this book. Instructors may use Evolve to provide an Internet-based course component that reinforces and expands the concepts presented in class.

Evolve may be used to publish the class syllabus, outlines, and lecture notes; set up "virtual office hours"

and e-mail communication; share important dates and information through the online class calendar; and encourage student participation through chat rooms and discussion boards. Evolve also allows instructors to post examinations and manage their grade books online.

For more information, visit http://evolve.elsevier.com/Kowalczyk/pathology/ or contact an Elsevier sales representative.

ACKNOWLEDGMENTS

As I mentioned in the seventh edition, the first edition of this textbook was published in 1988. It is hard to believe that I have dedicated over 33 years to this endeavor. It is difficult to walk away after putting so much time and energy into this textbook, but it is time to provide younger educators with an opportunity to ensure *Radiographic Pathology for Technologists* will continue to be updated and published. This will be my last edition as the sole author. I am certain future editions will be authored and reviewed by knowledgeable professionals to ensure the content remains up to date. Medical imaging and radiation therapy continues to play a large role in the diagnosis and treatment of oncological disorders, cardiopulmonary disease, neuroscience and most recently in response to the COVID-19 pandemic. It never ceases to amaze me how new technological advances keep our professions on the forefront of innovation, from interventional techniques to hybrid imaging. I hope educators, students, and imaging professionals continue to find this textbook to be a credible resource in their daily practice. As always, I could not have completed the eighth edition of this text without a great team of contributors, many of whom are new to this edition. Thank you! I also want to thank the editorial team at Elsevier who worked diligently to keep me on track throughout the revision process. The images in this book come from a variety of fine organizations that are to be thanked for graciously allowing us to use their material. They include the American College of Radiology, the Ohio State University Wexner Medical Center, OhioHealth, Nationwide Children's Hospital, all located in Columbus, Ohio, Forsyth Technical Community College, Winston-Salem, North Carolina and Northcentral Technical College, Wausau, Wisconsin.

Nina Kowalczyk

CONTENTS

1 **Introduction to Pathology, 1**

2 **Skeletal System, 18**

3 **Respiratory System, 53**

4 **Cardiovascular System, 89**

5 **Abdomen and Gastrointestinal System, 128**

6 **Hepatobiliary System, 210**

7 **Urinary System, 251**

8 **Nervous System, 304**

9 **Hematopoietic System, 349**

10 **Reproductive System, 372**

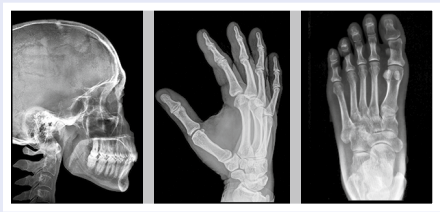
11 **Endocrine System, 406**

12 **Traumatic Disease, 427**

Glossary, 481

Bibliography, 491

Index, 496



Introduction to Pathology

Additional resources are available online at: http://evolve.elsevier.com/Kowalczyk/pathology/

CHAPTER OUTLINE

Introduction, 2
Pathologic Terms, 2
Monitoring Disease Trends, 3
Health Care Resources, 5
Human Genetic Technology, 7
Altered Cellular Biology, 9
Disease Classifications, 10
Congenital and Hereditary Disease, 10
Inflammatory Disease, 11
Degenerative Disease, 12
Metabolic Disease, 12
Traumatic Disease, 13
Neoplastic Disease, 13

LEARNING OBJECTIVES

On completion of Chapter 1, the reader should be able to do the following:

1. Define common terminology associated with the study of disease.
2. Differentiate between signs and symptoms.
3. Distinguish between disease diagnosis and prognosis.
4. Describe the different types of disease classifications.
5. Cite characteristics that distinguish benign from malignant neoplasms.
6. Describe the system used to stage malignant tumors.
7. Identify the difference in origin of carcinoma and sarcoma.

KEY TERMS

Acute
Asymptomatic
Atrophy
Autoantibodies
Autoimmune disorders
Benign neoplasm
Carcinoma
Chronic
Congenital
Degenerative
Diagnosis
Disease
Dysplasia
Epidemiology
Etiology
Genetic mapping
Genome
Haplotype
Hematogenous spread
Hereditary
Hyperplasia
Hypertrophy
Iatrogenic
Idiopathic
Incidence
Infection
Inflammatory
Invasion
Lesion
Leukemia
Lymphatic spread
Lymphoma
Malignant neoplasm
Manifestations
Metabolism
Metaplasia
Metastatic spread
Morbidity rate
Morphology

Mortality rate
Neoplastic
Nosocomial
Pandemic
Pathogenesis
Physical mapping
Prevalence
Prognosis
Sarcoma
Seeding
Sequelae
Sign
Single-nucleotide polymorphisms
Symptom
Syndrome
Traumatic
Virulence

INTRODUCTION

Pathology is the study of disease. Many types of disease exist, and many conditions can be readily demonstrated by imaging studies. Image-guided interventional procedures and therapeutic protocols are often utilized in the management of disease. Therefore, it is critical for radiologic science professionals to have a thorough understanding of basic pathologic processes. This foundation begins with a working knowledge of common pathologic terms, an understanding of the effect and prevention of disease on US health care expenditures, and the role of genetics in the individualized treatment of different pathologic processes. It is also important to understand the role of the Centers for Disease Control and Prevention (CDC) in terms of tracking, monitoring, and reporting trends in health and aging. This information is captured and reported by the National Center for Health Statistics (NCHS).

This chapter serves as a brief introduction to terms associated with pathology, recent health trends, and reviews cellular biology and genetics.

PATHOLOGIC TERMS

Any abnormal disturbance of the function or structure of the human body as a result of some type of injury is called a **disease**. After injury, **pathogenesis** occurs. *Pathogenesis* refers to the sequence of events producing cellular changes that ultimately lead to observable changes known as **manifestations**. These manifestations may be displayed in a variety of fashions. A **symptom** refers to the individual's perception of the disease. Symptoms are subjective, and only the individual can identify these manifestations. For example, a headache is considered a symptom. A **sign** is an objective manifestation that is detected by the physician during examination. Fever, swelling, and skin rash are all considered signs. A group of signs and symptoms that characterizes a specific abnormal disturbance is a **syndrome**. For example, respiratory distress syndrome is a common disorder in premature infants. However, some disease processes, especially in the early stages, do not produce symptoms and are termed **asymptomatic**.

Etiology is the study of the cause of a disease. Common agents that cause diseases include viruses, bacteria, trauma, heat, chemical agents, and poor nutrition. At the molecular level, a genetic abnormality of a single protein may also serve as the etiologic basis for some diseases. Proper infection control practices are important in a health care environment to prevent hospital-acquired **nosocomial** disease. Staphylococcal infection that follows hip replacement surgery is an example of a nosocomial disease, that is, one acquired from the environment. The cause of the disease, in this case, could be poor infection control practices. **Iatrogenic** reactions are adverse responses to medical treatment itself (e.g., a collapsed lung that occurs in response to a complication that arises during arterial line placement). If no causative factor can be identified, a disease is termed **idiopathic**.

The length of time over which the disease is displayed may vary. **Acute** diseases usually have a quick onset and last for a short period, whereas **chronic** diseases may manifest more slowly and last for a very long time. An example of an acute disease is pneumonia, and multiple sclerosis is considered a chronic condition. An acute illness may be followed by lasting effects termed **sequelae**, which is a condition that is caused by a previously acquired disease. For example, a stroke or cerebrovascular accident resulting in long-term neurologic deficits. Similarly, chronic illnesses often manifest in acute episodes, for example, an individual diagnosed with diabetes mellitus experiencing hypoglycemia or hyperglycemia.

Two additional terms refer to the identification and outcome of a disease. A **diagnosis** is the identification of a disease an individual is believed to have, and the predicted course and outcome of the disease is called a **prognosis**.

The structure of cells or tissue is termed **morphology**. Pathologic conditions may cause morphologic changes that alter normal body tissues in a variety of ways. Sometimes, the disease process is destructive, decreasing the normal density of a tissue. This occurs when tissue composition is altered by a decrease in the atomic number of the tissue, the compactness of the cells, or by changes in tissue thickness; for example, **atrophy** from limited use. Such disease processes are radiographically classified as *subtractive*, *lytic*, or *destructive* and require a decrease in the exposure technique. Conversely, some pathologic conditions cause an increase in the normal density of a tissue, resulting in a higher atomic number or increased compactness of cells. These are classified as *additive* or *sclerotic* disease processes and require an increase in the exposure technique. It is important for the radiographer to know common pathologic conditions that require an alteration of the exposure technique so that high-quality radiographs can be obtained to assist in the diagnosis and treatment of the disease.

Government agencies compile statistics annually with regard to the incidence, or rate of occurrence, of disease. **Epidemiology** is the investigation of disease in large groups. Health care epidemiology is grounded in the belief of distributions of health states. For example, good health, disease, disability, or death. These distributions are not random within a population and are influenced by multiple factors, including biologic, social, and environmental. Health care epidemiologists conduct research primarily by working with medical statistics, data associations, and large cohort studies. The **prevalence** of a given disease refers to the number of cases found in a given population. The **incidence** of disease refers to the number of new cases found in a given period. Diseases of high prevalence in an area where a given causative organism is commonly found are said to be *endemic* to that area. For example, histoplasmosis is a fungal disease of the respiratory system endemic to the Ohio and Mississippi River valleys. It is not uncommon to see a relatively high prevalence of this disease in these areas. However, its appearance in great numbers in the western United States could represent an epidemic. An epidemic is defined as the rapid, widespread occurrence of a disease in a large number of people in a given population. A **pandemic** is an epidemic affecting the majority of a population of a large region or an epidemic occurring at the same time in many different parts of the world. Beginning in late 2019/early 2020, the world experienced a major pandemic associated with a novel coronavirus outbreak first identified in Wuhan, China, an incident that has not happened since the Spanish flu pandemic in 1918. The term *novel* refers to a new coronavirus that has not previously been seen in humans, and the World Health Organization (WHO) named this novel virus the *coronavirus disease 2019*, abbreviated to COVID-19. COVID-19 is caused by a specific coronavirus termed SARS-CoV-2, a betacoronavirus similar to Middle East respiratory syndrome (MERS-CoV), a novel virus reported in Saudi Arabia in 2012, and severe acute respiratory syndrome (SARS-CoV), which originated in China in 2002. The COVID-19 pandemic has caused most countries to shut down businesses, resulting in massive layoffs which has greatly affected the world economy, induced panic buying, and threatened our food supply as well as our health. All individuals, with the exception of essential workers such as health care workers and persons working in the food supply chain, essential construction, and first responders/safety services, were ordered to stay at home. When it was required to leave home for essential items, people were ordered to maintain safe distancing from others and wear a face mask while in public. At the time of this revision in early May 2020, according to the CDC, 1,152,372 cases of COVID-19 had been confirmed in the United States and 67,456 people had died from this disease. This pandemic created a stress on the US health system that had never been experienced before, including a limited supply of personal protective apparel, ventilators, testing equipment and processing, and manpower.

MONITORING DISEASE TRENDS

Over the past century, life expectancy in the United States has continued to increase. The majority of children born at the beginning of the 21st century are expected to live well into their seventh decade (Fig. 1.1). In 2018, life expectancy was 78.7 years. Over the past 100 years, the principal causes of death have shifted from acute infections to chronic diseases. These changes have occurred as a result of biomedical and pharmaceutical advances, public health initiatives, and social changes (Fig. 1.2). Experts are uncertain of increased life expectancy continuing into the 21st century. Some believe that increased knowledge of disease etiology and continued development of medical technology in combination with screening, early intervention, and treatment of disease, especially malignant neoplasms, could have

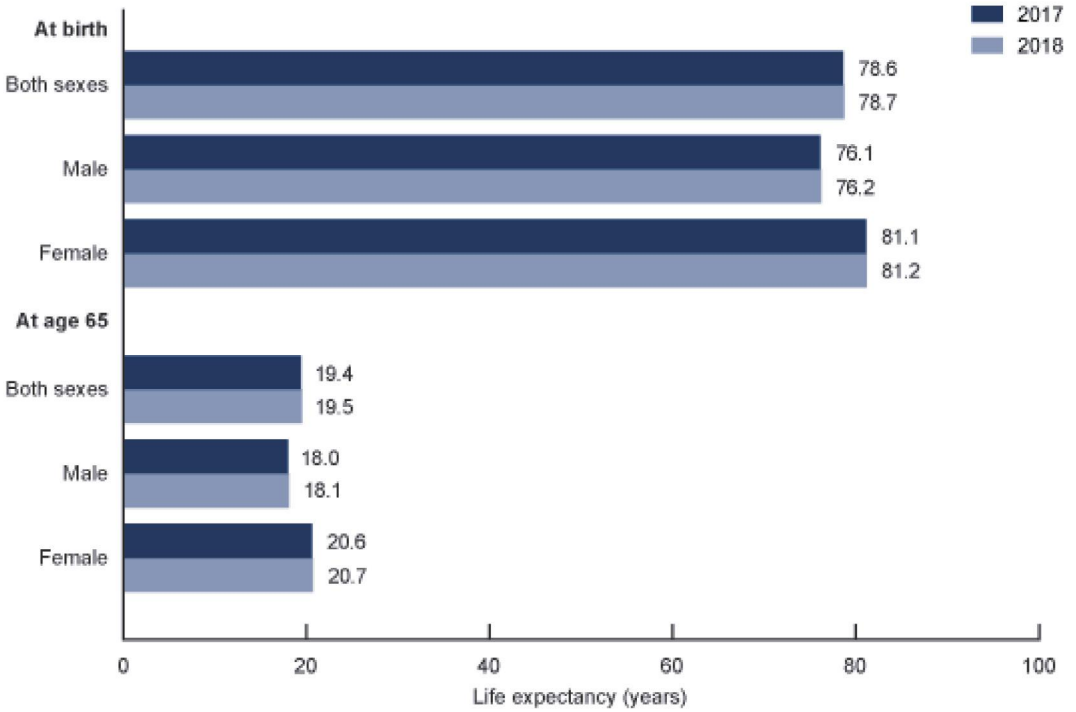


FIG. 1.1 Life expectancy at selected ages, by sex: United States 2017 and 2018. https://www.cdc.gov/nchs/products/databriefs/db355.htm#fig1. (From Centers for Disease Control and Prevention [CDC].)

positive results. However, many experts express concern about the quality of life of older adults. In other words, the possibility of older adults spending their added years in declining health and lingering illness, instead of being active and productive, is a concern.

The **mortality rate** is the average number of deaths caused by a particular disease in a population. Death certificates are collected by each state, forwarded to the NCHS, and subsequently processed and published as information on mortality statistics and trends. The NCHS and the US Department of Health and Human Services (USDHHS) monitor and report mortality rates in terms of leading causes of death according to gender, race, age, and specific causes of death such as heart disease or malignant neoplasia. Trends in these mortality patterns are identified by age, gender, and ethnic origin and tracked to help identify necessary interventions. For instance, the age-adjusted death rate for heart disease has steadily decreased for both females and males in the United States. This trend demonstrates a 30% to 40% decline over the past 20 years, resulting, in part, from health education and changes in lifestyle behaviors. Because mortality information is gathered from death certificates, changes in the descriptions and coding of "cause of death" and the amount of information forwarded to the NCHS may alter these statistics. For instance, there were changes in the way deaths were recorded and ranked in terms of the leading causes of death occurring between 1998 and 1999. Since 1999, mortality data and cause-of-death statistics have been gathered and classified according to the *International Classification of Diseases, Tenth Revision* (ICD-10), and in 2007 additional ICD-10 codes were added to clarify the underlying causes of death.

Chronic diseases continue to be the leading causes of death in the United States for adults aged 45 years and older. The 10 leading causes of death in the United States in 2018 accounted for 73.8% of all deaths. Heart disease and malignant neoplasia remained the top two causes of deaths in 2018 for both males and females. The third, fourth, and fifth top causes of death, respectively, in 2018 were unintentional injuries as a result

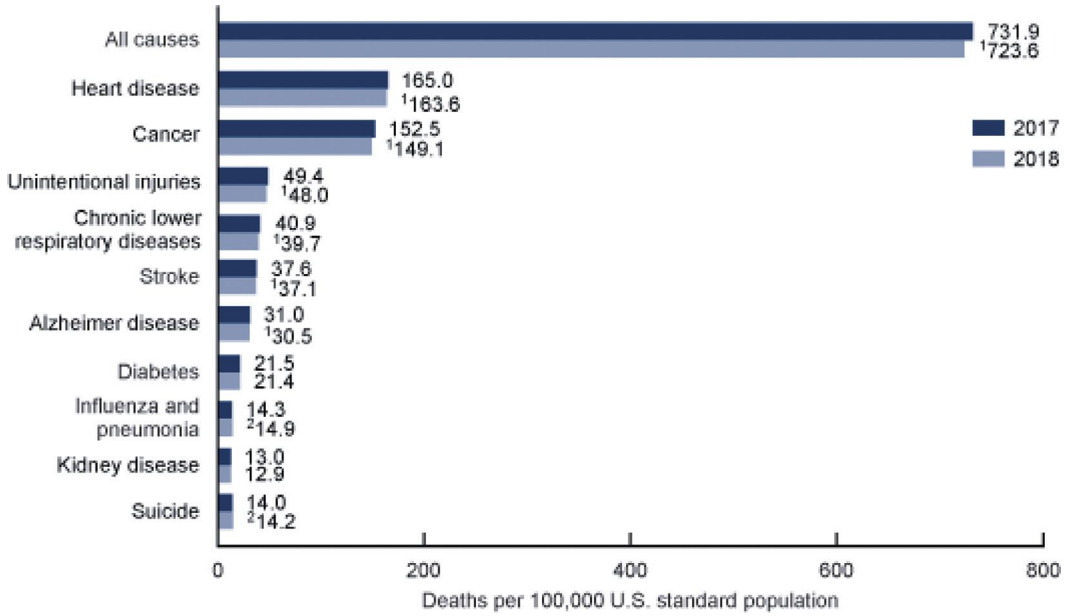


FIG. 1.2 Age-adjusted death rates for all causes and the 10 leading causes of death in 2018: United States, 2017 and 2018. https://www.cdc.gov/nchs/products/databriefs/db355.htm#fig1. (From Centers for Disease Control and Prevention [CDC].)

of accidents, chronic lower respiratory disease, and stroke. Alzheimer disease continues to be ranked as the sixth leading cause of death in 2018, followed by diabetes, influenza/pneumonia, kidney disease, and suicide. Emphasis has been placed on reducing the deaths associated with the top two causes, heart disease and cancer, and a slight decline was noted through 2018. The decrease in deaths as a result of heart disease may be clearly attributed to advances in the prevention and treatment of cardiac disease. An increased understanding of the genetics of cancer is certainly responsible for better screening and individualized treatment for many types of neoplastic disease. Advances in diagnostic and therapeutic radiologic procedures have also played a role in the reduction of deaths associated with these chronic diseases. Among children and young adults (age 1–44 years), injuries such as motor vehicle accidents, homicides and falls remain the leading cause of death (Fig. 1.3). According to the CDC, approximately 124,000 individuals die from injury every year.

As the mortality rates for heart disease and cancer have declined, increases have been noted in Alzheimer disease and diabetes mellitus.

Mortality rates from any specific cause may fluctuate from year to year, so trends are monitored over a 3-year period. These data are used to evaluate the health status of US citizens and identify segments of the population at greatest risk for specific diseases and injuries. Current data are available on the NCHS website and may be accessed at www.cdc.gov/.

The incidence of sickness sufficient to interfere with an individual's normal daily routine is referred to as the **morbidity rate**. The CDC is also responsible for trending morbidity rates in the United States. States must submit death certificates to the NCHS, making it fairly easy to obtain accurate data about the mortality rate of a specific population. It is more difficult to obtain accurate data about the morbidity rate. This information comes primarily from physicians and other health care workers reporting morbidity statistics and information to the various governmental and private agencies.

Health Care Resources

Health care delivery in the United States has two fundamental and diverse functions, with one area focused on healthy lifestyle for prevention and the second

10 Leading Causes of Death by Age Group, United States – 2017

Rank	Age Groups										
	<1	1-4	5-9	10-14	15-24	25-34	35-44	45-54	55-64	65+	Total
1	Congenital Anomalies 4,580	Unintentional Injury 1,267	Unintentional Injury 718	Unintentional Injury 860	Unintentional Injury 13,441	Unintentional Injury 25,669	Unintentional Injury 22,828	Malignant Neoplasms 39,266	Malignant Neoplasms 114,810	Heart Disease 519,052	Heart Disease 647,457
2	Short Gestation 3,749	Congenital Anomalies 424	Malignant Neoplasms 418	Suicide 517	Suicide 6,252	Suicide 7,948	Malignant Neoplasms 10,900	Heart Disease 32,658	Heart Disease 80,102	Malignant Neoplasms 427,896	Malignant Neoplasms 599,108
3	Maternal Pregnancy Comp. 1,432	Malignant Neoplasms 325	Congenital Anomalies 188	Malignant Neoplasms 437	Homicide 4,905	Homicide 5,488	Heart Disease 10,401	Unintentional Injury 24,461	Unintentional Injury 23,408	Chronic Low. Respiratory Disease 136,139	Unintentional Injury 169,936
4	SIDS 1,363	Homicide 303	Homicide 154	Congenital Anomalies 191	Malignant Neoplasms 1,374	Heart Disease 3,681	Suicide 7,335	Suicide 8,561	Chronic Low. Respiratory Disease 18,667	Cerebro-vascular 125,653	Chronic Low. Respiratory Disease 160,201
5	Unintentional Injury 1,317	Heart Disease 127	Heart Disease 75	Homicide 178	Heart Disease 913	Malignant Neoplasms 3,616	Homicide 3,351	Liver Disease 8,312	Diabetes Mellitus 14,904	Alzheimer's Disease 120,107	Cerebro-vascular 146,383
6	Placenta Cord. Membranes 843	Influenza & Pneumonia 104	Influenza & Pneumonia 62	Heart Disease 104	Congenital Anomalies 355	Liver Disease 918	Liver Disease 3,000	Diabetes Mellitus 6,409	Liver Disease 13,737	Diabetes Mellitus 59,020	Alzheimer's Disease 121,404
7	Bacterial Sepsis 592	Cerebro-vascular 66	Chronic Low. Respiratory Disease 59	Chronic Low Respiratory Disease 75	Diabetes Mellitus 248	Diabetes Mellitus 823	Diabetes Mellitus 2,118	Cerebro-vascular 5,198	Cerebro-vascular 12,708	Unintentional Injury 55,951	Diabetes Mellitus 83,564
8	Circulatory System Disease 449	Septicemia 48	Cerebro-vascular 41	Cerebro-vascular 56	Influenza & Pneumonia 190	Cerebro-vascular 593	Cerebro-vascular 1,811	Chronic Low. Respiratory Disease 3,975	Suicide 7,982	Influenza & Pneumonia 46,862	Influenza & Pneumonia 55,672
9	Respiratory Distress 440	Benign Neoplasms 44	Septicemia 33	Influenza & Pneumonia 51	Chronic Low. Respiratory Disease 188	HIV 513	Septicemia 854	Septicemia 2,441	Septicemia 5,838	Nephritis 41,670	Nephritis 50,633
10	Neonatal Hemorrhage 379	Perinatal Period 42	Benign Neoplasms 31	Benign Neoplasms 31	Complicated Pregnancy 168	Complicated Pregnancy 512	HIV 831	Homicide 2,275	Nephritis 5,671	Parkinson's Disease 31,177	Suicide 47,173

Data Source: National Vital Statistics System, National Center for Health Statistics, CDC.
Produced by: National Center for Injury Prevention and Control, CDC using WISQARS™.

Centers for Disease Control and Prevention
National Center for Injury Prevention and Control

FIG. 1.3 Ten leading causes of death by age group, United States – 2017. https://www.cdc.gov/injury/wisqars/LeadingCauses.html. (From Centers for Disease Control and Prevention [CDC]).

area focusing on restoration of health after a disease has occurred. Over the past 10 years, much emphasis has been placed on healthy lifestyle choices as a way to decrease escalating health care costs in the United States. Technologic changes in healthcare equipment and delivery, paired with electronic communications, have continued to shift medical services from the inpatient to the outpatient setting. In 2017, the total number of hospital outpatient visits in the United States reached 880,451,000 compared with 693,510,000 in 2007. Hospital admission growth rates continue to slow and the revenue gap between inpatient and outpatient revenue continues to narrow. Ambulatory care centers range from hospital outpatient centers, surgical centers, and emergency departments to urgent care centers and minute clinics to physicians' offices. In response to this shift, emphasis has been placed on increasing the number of physician generalists, including family practitioners, internal medicine physicians, and pediatricians, as well as physician extenders such as physician assistants, nurse practitioners, and radiologist assistants. Emergency department visits continue to steadily increase, with many emergency departments reporting admissions exceeding their capacity (Fig. 1.4).

The rate of growth in US health expenditures is staggering, and they cover a wide range of categories (Fig. 1.5). In 2018, US health spending accounted for 17.7% of the gross domestic product, a larger share than in any other major industrialized country, with US health care expenditures totaling $3.6 trillion. According to the Center for Medicare and Medicaid Service (CMS), the share of the economy allocated to health spending actually decreased slightly from 2017 to 2018. A major source of funding for health care includes Medicare, funded by the federal government for older adults and disabled individuals. Enrollment

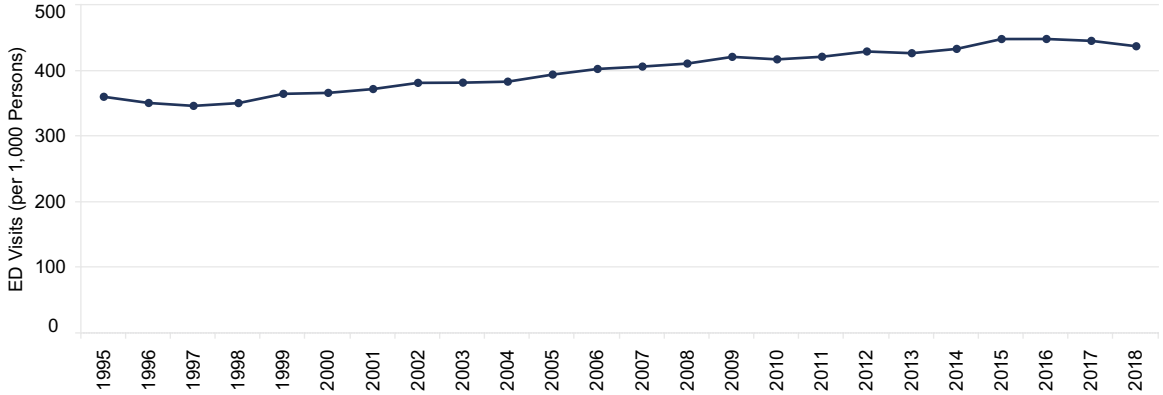


FIG. 1.4 Number of hospital emergency department visits per 1,000 persons, 1995 – 2018. (Reprinted from American Hospital Association: TrendWatch Chartbook 2020 by permission, Copyright 2020, by American Hospital Association.)

in Medicare continues to accelerate as baby boomers age, creating growth in hospital care and prescription drug sectors. The major three sources of funding for health care include Medicare, funded by the federal government for older adults and disabled individuals; Medicaid, funded by federal and state governments for the poor; and privately funded health care plans. Enrollment in Medicare continues to accelerate as baby boomers age creating higher growth in hospital care and prescription drugs. The growth of Medicaid enrollees decreased slightly in 2018, but is expected to grow over the next few years due to an expansion of the program in at least five states. Private health insurance spending growth has remained relatively steady over the past 3 years because some individuals have chosen not to enroll in health insurance plans due to portions of the Affordable Care Act that have been repealed. However, out-of-pocket spending continues to accelerate, as average deductible fees levied on private insurance enrollees increase.

HUMAN GENETIC TECHNOLOGY

The Human Genome Project was a 13-year (1990–2003) project coordinated by the US Department of Energy and the National Institutes of Health. The goals of the project were to identify the 30,000 genes in human deoxyribonucleic acid (DNA); to determine the sequences of the 3 billion chemical base pairs that make up human DNA; to electronically store the data; to improve tools for data analysis; and to address the ethical, legal, and social issues that arose from the project.

With the exception of reproductive (germ) cells, each cell in the human body contains 22 pairs of autosomal chromosomes, two sex chromosomes (XX or XY), and the small chromosome found in each mitochondria within the cell. Collectively, this is known as the **genome**. The genome contains between 50,000 and 100,000 genes that are located on approximately 3 billion base pairs of DNA and form the basic unit of genetics. Genetics play a significant role in the diagnosis, monitoring, and treatment of disease; thus, it is imperative that radiologic science professionals have a basic understanding of the role of genetics and genetic markers in the development and treatment of disease.

The Human Genome Project resulted in the identification of thousands of DNA sequence landmarks and the development of two types of gene maps (Fig. 1.6). **Physical** maps are used to determine the physical location of a particular gene on a specific chromosome. **Genetic maps** are used to assign the distance between genetic markers, that is, mapping or linking DNA fragments to a specific chromosome. Genetic linkage maps are useful in tracking the inheritance of traits and diseases that are transmitted from parent to child, as genetic markers that are in proximity increase the probability that the genes will be inherited together.

As more information was discovered through the Human Genome Project, researchers determined that the genome sequence was 99.9% identical for all humans, leaving only a small percentage of variation among people. However, this 0.1% variation greatly affects an individual's predisposition to certain diseases and his or her response to drugs and toxins. Researchers were able to identify common DNA pattern sequences

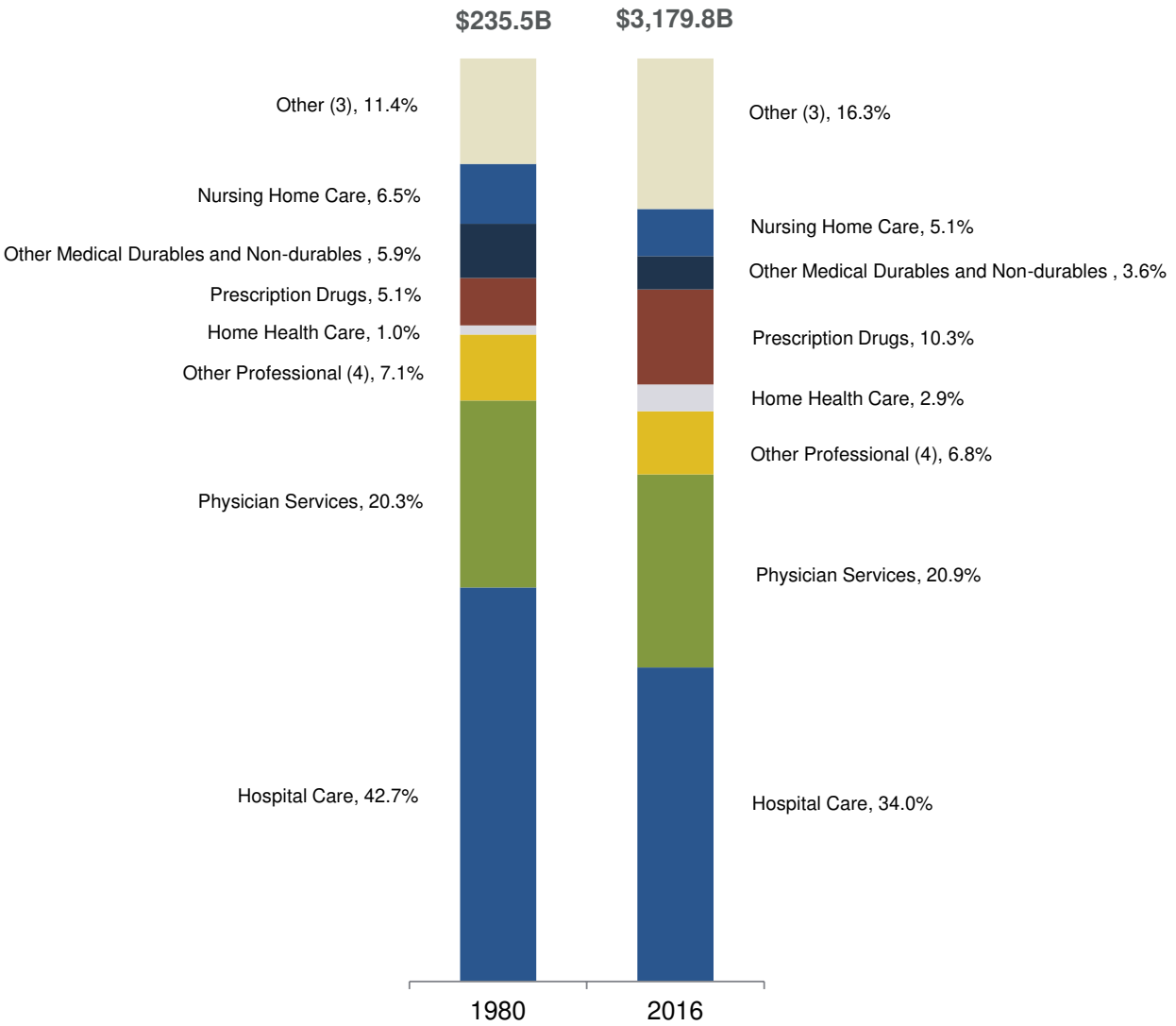


FIG. 1.5 National expenditures for health services and supplies by category, 1980 and 2016. (Centers for Medicare & Medicaid Services, Office of the Actuary. Data released December 6, 2017.)

and common patterns of genetic variations of single DNA bases, termed **single-nucleotide polymorphisms** (SNPs). This led to the development of haplotype mapping, often referred to as the *Hap Map*. A **haplotype** comprises closely linked SNPs on a single chromosome, and it is a very important resource in identifying specific DNA sequences that affect disease, response to pharmaceuticals, and response to environmental factors.

This continued research has led to improved diagnosis of disease, earlier detection of genetic predispositions to disease, gene therapy, newborn screening, customized pharmaceutical applications, DNA fingerprinting, and DNA forensics. This serves as the basis for the current emphasis on individualized medicine, as no two persons are the same. It also has resulted in the ability to predict the development of certain diseases, thus allowing earlier intervention. Additional information about the National Human Genome Institute can be found at https://ghr.nlm.nih.gov/primer/hgp/elsi.

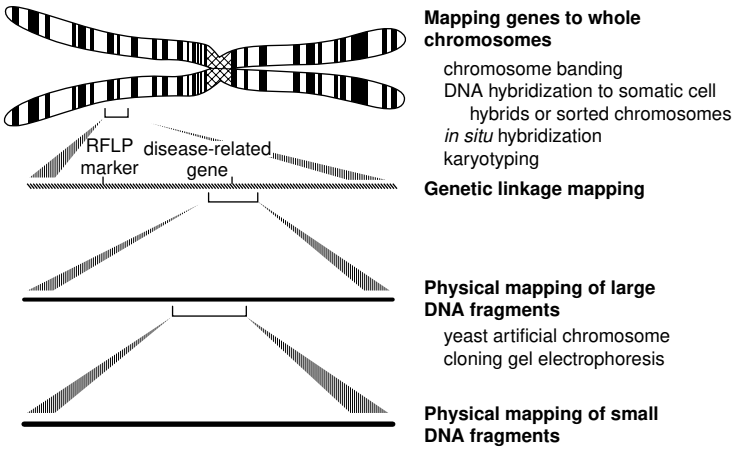


FIG. 1.6 Mapping genes to whole chromosomes at different levels of resolution. (From Cutter MG, Drexler E, McCullough LB, et al: *Mapping and sequencing the human genome: science, ethics, and public policy,* Colorado Springs, Colorado, 1992, BSCS and the American Medical Association.)

ALTERED CELLULAR BIOLOGY

To protect themselves and avoid injury, cells adapt by altering the genes responsible for their function and differentiation in response to their environment. When a cell is injured and unable to maintain homeostasis, it can respond in several ways. It may adapt and recover from the injury, or it may die as a result of the injury (Fig. 1.7). Many cells adapt by altering their pattern of growth, as demonstrated in Fig. 1.8. **Atrophy** is a generalized decrease in cell size. An example of atrophy is when muscle cells decrease in size after the loss of innervation (supply of nerves to a part) and use. **Hypertrophy** is a generalized increase in cell size. If the aortic valve is diseased, then the left ventricle enlarges because of the increased muscle mass needed to pump blood into the aorta. **Hyperplasia** is an increase in the number of cells in a tissue as a result of excessive proliferation. An estrogen-secreting ovarian tumor causing endometrial epithelial cells to multiply is an example of hyperplasia. **Metaplasia** is the conversion of one cell type into another that is not normal for that tissue (Table 1.1). The epithelial cells in the respiratory tract of a smoker undergo metaplasia as a response to chronic irritation from the chemicals in cigarette smoke. **Dysplasia** refers to abnormal changes occurring in mature cells. Individual cells within a tissue vary in size, shape, and color, and they are often

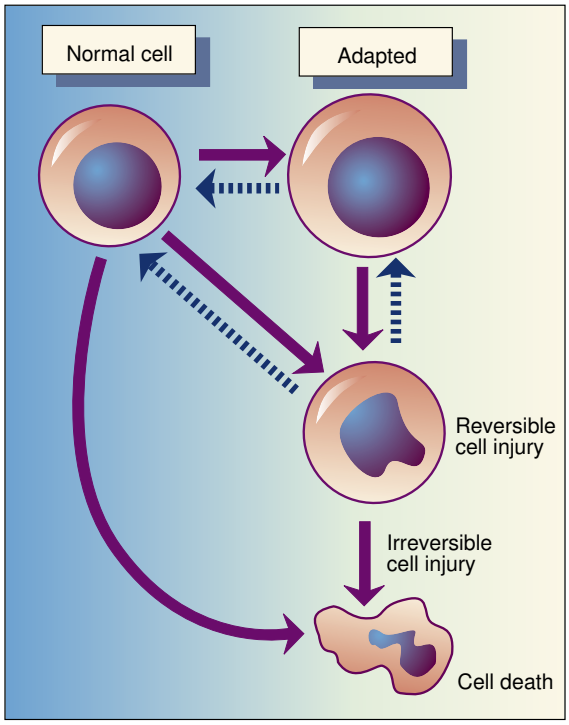


FIG. 1.7 Cellular injury and responses of normal adapted and reversibly injured cells and cell death. (From McCance KL, Huether SE: *Pathophysiology: the biologic basis for disease in adults and children*, ed 5, St. Louis, 2005, Mosby.)

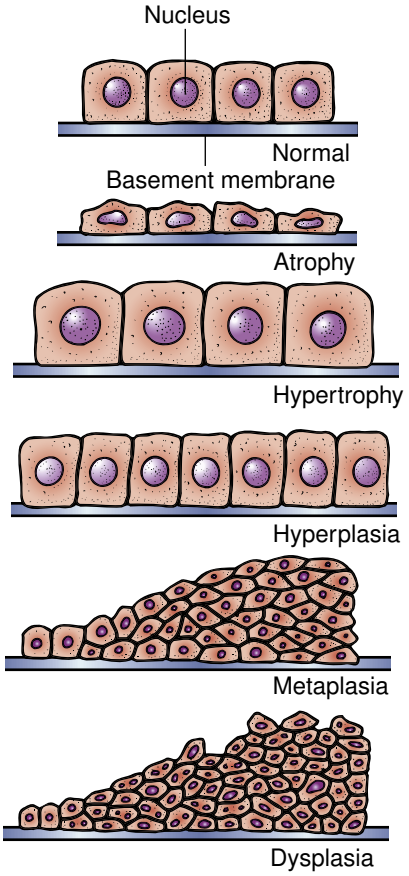


FIG. 1.8 Adaptive alterations in simple cuboid epithelial cells. (From McCance KL, Huether SE: *Pathophysiology: the biologic basis for disease in adults and children*, ed 5, St. Louis, Mosby; Crowley LV: *Introductory concepts in pathology*, Chicago, 1972, Mosby.)

nonfunctional. Dysplastic adaptations are considered precancerous and are most commonly associated with neoplasms within the reproductive system and the respiratory tract.

TABLE 1.1 Altered Cellular Biology

Cell State	Description
Anaplasia	Absence of tumor cell differentiation, loss of cellular organization
Dysplasia	Abnormal changes in mature cells; also termed *atypical hyperplasia*
Metaplasia	Abnormal transformation of a specific differentiated cell into a differentiated cell of another type

DISEASE CLASSIFICATIONS

Diseases are grouped into several broad categories. Those in the same category may not necessarily be closely related, but groupings such as those discussed in the following sections tend to produce lesions that are similar in morphology, that is, their form and structure. Pathologies discussed in this text are generally grouped into the following classifications:

- Congenital and hereditary
- Inflammatory
- Degenerative
- Metabolic
- Traumatic
- Neoplastic

Congenital and Hereditary Disease

Diseases present at birth and resulting from genetic or environmental factors are termed **congenital**. It is estimated that 2% to 3% of all live births have one or more congenital abnormalities, although some of these may not be visible until a year or so after birth. A major category of congenital disease is caused by abnormalities in the number and distribution of chromosomes. In somatic cells, chromosomes exist in the nucleus of each cell in pairs, with one member from the male parent and the other from the female parent. In humans, chromosomes are normally composed of 22 pairs of autosomes (those other than the sex chromosomes) and one pair of sex chromosomes. Down syndrome is a congenital condition caused by an error in autosomal mitosis that leads to an extra chromosome 21, so the affected individual has 47 chromosomes rather than the normal 46.

Hereditary diseases are caused by developmental disorders genetically transmitted from either parent to a child through abnormalities of individual genes in chromosomes, and are derived from ancestors. For example, hemophilia is a well-known hereditary disease in which proper blood clotting is absent. A genetic abnormality present on the sex chromosome is a sex-linked inheritance; an abnormality on one of the other 22 chromosomes is an autosomal inheritance. The inherited disease may be *dominant* (transmitted by a single gene from either parent) or *recessive* (transmitted by both parents to an offspring). Amniocentesis, a standard procedure typically guided by sonography, is used prenatally to assess the presence of certain hereditary disorders.

A congenital defect is not necessarily hereditary because it may have been acquired in utero. Intrauterine injury during a critical point in development may have been caused by maternal infection, radiation, or drug use. Abnormalities of this type occur sporadically and cannot generally be recognized before birth. However, their likelihood is greatly lessened by following proper precautions against infection, avoiding radiation (particularly during the early term of pregnancy), and avoiding drugs or agents not specifically recognized by a physician as safe for use during pregnancy.

Inflammatory Disease

An **inflammatory** disease results from the body's reaction to a localized injurious agent. Types of inflammatory diseases include infective, toxic, and allergic diseases. An infective disease results from invasion by microorganisms such as viruses, bacteria, or fungi. Viruses consist of a protein coat surrounding a genome of either ribonucleic acid (RNA) or DNA, without an organized cell structure. They are classified by the type of viral genome and are not capable of replicating outside of a living cell. Bacteria are unicellular organisms that lack an organized nucleus. They tend to colonize on environmental surfaces and are extremely adaptable, which allows them to become resistant to antibiotics over time. Fungi are microorganisms that can form complex structures containing organelles and may grow as mold or yeast. For instance, pneumonia is a type of inflammatory disease that may result from a viral, bacterial, or fungal infection. Toxic diseases are caused by poisoning of biologic substances, and allergic diseases are an overreaction of the body's own defenses.

Some diseases in this classification are considered autoimmune disorders. Under normal conditions, antibodies are formed in response to foreign antigens. In certain diseases, however, they form against and injure the individual's own tissues. These are known as **autoantibodies**, and diseases associated with them are termed **autoimmune disorders**. Rheumatoid arthritis is an example of an autoimmune disorder.

An inflammatory reaction (i.e., inflammation) is a generalized pathologic process that is nonspecific to the agent causing the injury. The body's purpose in creating an inflammatory reaction is to localize the injurious agent and prepare for subsequent repair and healing of the injured tissues. Substances released from the damaged tissues may cause both local and systemic effects (Fig. 1.9). Those effects seen local to the injury include

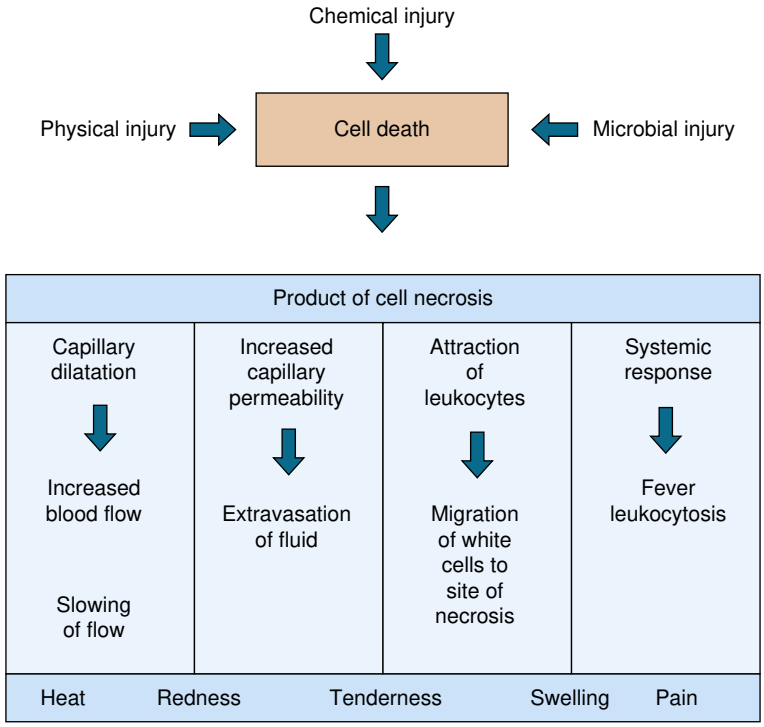


FIG. 1.9 Local and systemic effects of cell necrosis induced by various agents.

capillary dilatation to allow fluids and specifically leukocytes to infiltrate into the area of damage. Cellular necrosis (death) is common in acute inflammation, and the leukocytes serve to remove dead material through phagocytosis (the ingestion of other cells or particles). The characteristics of such acute inflammation include heat, redness of the skin, swelling, pain, and some loss of function as the body tends to protect the injured part. If the inflammatory process is significant, systemic effects such as an elevation of body temperature become evident.

Chronic inflammation differs from the acute stage in that damage caused by an injurious agent may not necessarily result in tissue death. In fact, necrosis is relatively uncommon in cases of chronic inflammation. It differs also in the duration of the inflammation, with chronic conditions lasting for long periods, such as the presence of neuropathy resulting in an individual with chronic diabetes mellitus.

The repair of tissues damaged by an inflammatory process attempts to return the body to normal. Tissue regeneration is the process by which damaged tissues are replaced by new tissues that are essentially identical to those that have been lost. Although this is the most desirable type of repair, tissues vary in their ability to replace themselves. Damaged nerve cells, for example, are not likely to readily regenerate. Fibrous connective tissue repair is the alternative to regeneration, but it is less desirable because it leads to scarring and fibrosis. Damaged tissues are replaced by a scar and lack the structure and function of the original tissue.

Debridement (removal of dead cells and materials) is an essential component of the healing process. It may be accomplished both at the cellular level and through human intervention, as in the case of burns or removal of foreign objects such as pieces of glass. The repair process begins with the migration of adjacent cells into the injured area and replication of the cells via mitosis to fill the void in the tissue. This new growth includes capillaries, fibroblasts, collagen, and elastic fibers. Remodeling of the new tissue, the last phase in the healing process, occurs in response to normal use of the tissue. For instance, remodeling of the bone after a skeletal fracture may take months, but the results often return the injured bone to its original contour.

Infection refers to an inflammatory process caused by a disease-causing organism. Under favorable conditions, the invading pathogenic agent multiplies and causes injurious effects. Generally, localized infection is accompanied by inflammation, but inflammation may occur without infection. **Virulence** refers to the ease with which an organism can cause disease. An organism with high virulence is likely to produce progressive disease in susceptible persons; one with low virulence produces disease only in highly susceptible persons under favorable conditions. A variety of factors such as the presence of dead tissue or blockage of normal body passages may predispose an individual to bacterial infection.

Degenerative Disease

Degenerative diseases are caused by deterioration of the body. Although they are usually associated with the aging process, some degenerative conditions may exist in younger persons. For instance, an individual may develop a degenerative disease following a traumatic injury, regardless of age.

The process of aging results from the gradual maturation of physiologic processes that reach a peak and then gradually fade (i.e., degenerate) to a point at which the body can no longer survive. Heredity, diet, and environmental factors are known to affect the rate of aging. Over time, the functional abilities of tissues decrease because either their cell numbers are reduced or the function of each individual cell declines, with both typically participating in pathologies resulting from aging. Atherosclerosis, osteoporosis, and osteoarthritis are three diseases commonly associated with the aging process. Each is discussed later in this text.

Metabolic Disease

Metabolism is the sum of all physical and chemical processes in the body. Diseases caused by a disturbance of the normal physiologic function of the body are classified as metabolic diseases. These include endocrine disorders such as diabetes mellitus and hyperparathyroidism, and disturbances of fluid and electrolyte balance.

Endocrine glands secrete their products (hormones) into the bloodstream to regulate various metabolic functions. The major endocrine glands include the pituitary, thyroid, parathyroid, adrenal glands, pancreatic islets, ovaries, and testes. An endocrine disorder may consist of hypersecretion, which causes an overactivity of the target organ, or hyposecretion, which results in underactivity. The clinical effects of an endocrine disturbance depend on the degree of dysfunction as well as the age and sex of the individual.

Dehydration is the most common disturbance of fluid balance. It is caused by insufficient intake of water or excessive loss of it. Electrolytes are mineral salts (most commonly sodium and potassium) that are dissolved in the body's water. They may be depleted because of vomiting, diarrhea, or the use of *diuretics* (substances that promote the excretion of salt and water). Disturbance of either fluid balance or electrolyte balance upsets *homeostasis*, the body's normal internal resting state.

Traumatic Disease

Another general classification of diseases is **traumatic** diseases. These diseases may result from mechanical forces such as crushing or twisting of a body part, or from the effects of ionizing radiation on the human body. In addition, disorders resulting from extreme hot or cold temperatures, for example, burns and frostbite, are also classified as traumatic.

Trauma may injure a bone, resulting in *fractures*, which are covered extensively in Chapter 12. It may also injure soft tissues. A *wound* is an injury of soft parts associated with rupture of the skin. Traumatic injuries may damage soft tissues even if the skin is not broken. Bleeding into the tissue spaces as a result of capillary rupture is known as a *bruise* or a *contusion.*

Neoplastic Disease

Neoplastic disease results in new, abnormal tissue growth. Normally, growing and maturing cells are subject to mechanisms that direct cell proliferation and cell differentiation, controlling their growth rate. *Proliferation* refers to cell division, and *differentiation* refers to the process of cellular specialization. When this control mechanism goes awry because of mutations within the chromosomes of the cell (genetic instability), an overgrowth of cells develops and results in a neoplasm. Cells are classified as either differentiated or undifferentiated, depending on the resemblance of the new cells to the original cells in the host organ or site. If the differences are small, the growth is termed *differentiated* and has a low probability for malignancy. If the cells within the neoplasm exhibit atypical characteristics, they are termed *poorly differentiated* or *undifferentiated* and have a higher probability of malignancy. Neoplastic cells are similar to normal cells in that they include both parenchymal and supporting tissues. In neoplastic disease, parenchymal cell proliferation and differentiation are altered, and because the parenchymal tissue is the functional tissue of the cell, it must receive adequate blood supply to survive. Classification of the neoplasm depends on the type of altered parenchymal cells, that is, tissue type of the tumor (Table 1.2).

Neoplasms originate from mutations within the genetic code (Box 1.1), which may silence the genes, *tumor-suppressor genes*, or cause them to become overactive, *oncogenes* (Fig. 1.10). This abnormal growth of cells leads to the formation of either a benign tumor or a malignant tumor (a neoplasm). A **benign neoplasm** is composed of well-differentiated cells with uncontrolled growth. Thus, a benign neoplasm remains localized and is generally noninvasive. A **malignant neoplasm** exhibits the loss of control of both cell proliferation and cell differentiation, which changes its functional capabilities. Malignant neoplasms grow at a faster rate compared with benign neoplasms and tend to spread and invade other tissues. Malignant neoplasms may be solid tumors confined to a specific organ or tissue, or they may be hematologic in nature, affecting the blood and lymph systems.

Sometimes, it is difficult to classify abnormal cells as either benign or malignant because they may exhibit characteristics of both types. Thus, the abnormal growth is graded, depending on the composition of particular cells.

The spread of malignant cancer cells resulting in a secondary tumor distant from the primary lesion is termed *metastasis.* **Metastatic spread** may occur in a variety of ways. If the cancerous cells invade the circulatory system, they may be spread via blood vessels, and this process is termed **hematogenous spread**. The cells may spread via the lymphatic system, and this is termed **lymphatic spread**. The lymph node into which the primary neoplasm drains is termed the *sentinel node.* If the cancerous cells spread into surrounding tissue by virtue of proximity, it is termed **invasion**. However, if the cancerous cells travel to a distant site or organ system, it is termed **seeding**. Certain types of cancer occur more often as metastases rather than originating in a given organ.

Lesion is a term used to describe the many types of cellular changes that may occur in response to disease. Some lesions may be visible immediately; others may be detectable initially only through diagnostic means such as laboratory testing. *Cancer* is a general term often used to denote various types of malignant neoplasms. Note

TABLE 1.2 Tissue Types and Tumors[a]

Connective Tissue	Benign Tumors	Malignant Tumors
Adult fibrous tissue	Fibroma	Fibrosarcoma
Fat	Lipoma	Liposarcoma
Cartilage	Chondroma	Chondrosarcoma
Bone	Osteoma	Osteosarcoma
Connective tissue (fibrous)	Fibrous histiocytoma	Malignant fibrous histiocytoma
Endothelium and Mesothelium	**Benign Tumors**	**Malignant Tumors**
Blood vessels	Hemangioma, hemangiopericytoma	Hemangiosarcoma, angiosarcoma
Lymph vessels	Lymphangioma	Lymphangiosarcoma
Mesothelium		Mesothelioma
Hemopoietic cells	Preleukemias, myeloproliferative disorders	Leukemia (various types)
Lymphoid tissue	Plasmacytosis	Plasmacytoma, multiple myeloma, Hodgkin lymphoma, non-Hodgkin lymphoma
Muscle	**Benign Tumors**	**Malignant Tumors**
Smooth muscle	Leiomyosarcoma	Leiomyosarcoma
Striated muscle	Rhabdomyoma	Rhabdomyosarcoma
Epithelial Tissue	**Benign Tumors**	**Malignant Tumors**
Stratified squamous	Papilloma, seborrheic keratosis, some adnexal tumors	Squamous cell carcinoma, epidermoid carcinoma, some malignant adnexal tumors
Glandular epithelium	Adenoma, hepatic adenoma, renal tubular adenoma, bile duct adenoma	Adenocarcinoma, hepatoma, hepatocellular carcinoma, renal cell carcinoma, hypernephroma, cholangiocarcinoma
Transitional epithelium	Transitional cell papilloma	Transitional cell carcinoma
Placenta	Hydatidiform mole	Choriocarcinoma
Testis		Seminoma, embryonal cell carcinoma
Neural	**Benign Tumors**	**Malignant Tumors**
Glial cells		Glioma (grades I–III), glioblastoma multiform Nerve cells (grade IV)
Nerve cells	Ganglioneuroma	Neuroblastoma, medulloblastoma
Meninges	Meningioma	Malignant meningioma
Nerve sheath	Schwannoma, neurilemmoma, neurofibroma	Malignant meningioma, malignant schwannoma, neurofibrosarcoma

[a]This list is intended to provide only an introduction to tumor nomenclature. Modified from Surveillance, Epidemiology and End Results (SEER) Training Modules, *Tumor List*. US National Institutes of Health, National Cancer Institute. 23 March 2017. https://training.seer.cancer.gov/disease/categories/tumors.html.

BOX 1.1 Types of Genetic Lesions in Cancer

1. Point mutations
2. Subtle alterations (insertions, deletions)
3. Amplifications
4. Gene silencing
5. Exogenous sequences (tumor viruses)

that the terms *cancer* and *carcinoma* are not synonymous. A **carcinoma** is one type of cancer and is derived from epithelial tissue. Adenocarcinoma of the colon is an example of a type of carcinoma. Other cancers include **sarcoma**, which arises from connective tissue (e.g., fibrosarcoma); **leukemia**, which arises from blood cells; and **lymphoma**, which arises from lymphatic cells. Both benign and malignant tumors are also named according to the tissue type of origin (see Table 1.2). In the case of a benign neoplasm, the suffix "oma" is added to the word root, for instance, *adenoma.* Malignant neoplasms are named by adding the name of the tissue type to the word root, for instance, *adenocarcinoma.* Medical imaging plays a major role in the diagnosis and staging of a variety of neoplastic diseases. The primary diagnostic and staging methods include imaging procedures such as computed tomography (CT), magnetic resonance imaging (MRI), positron emission tomography (PET), single photon emission computed tomography (SPECT), hybrid imaging using both CT/PET and CT/SPECT, radiography, and ultrasonography. Other diagnostic methods include endoscopic procedures, identification of tumor markers in blood, clinical laboratory tests of cells and tissues, and gene profiling. Treatment modalities often include radiation therapy in combination with surgery, chemotherapy, hormone or antihormone therapy, immunotherapy using biologic response modifiers such as interferons and interleukins, and targeted drug therapies. The choice of a modality or a combination of modalities depends on many factors, including the type of cancer, its location and stage, and the treating oncologist. The goal of treatment may be curative, allowing the person to remain free of disease for 5 years or more, or palliative, which is designed to relieve pain when a cure is not possible and to improve the quality of life.

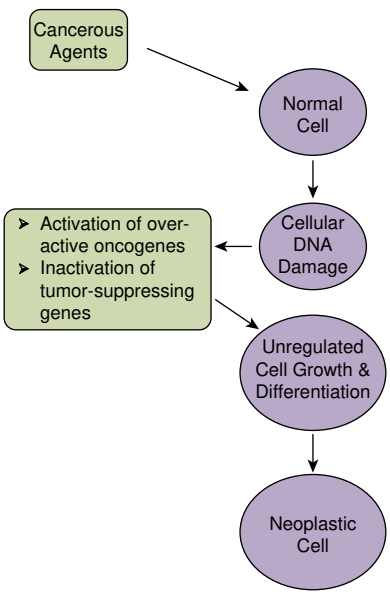


FIG. 1.10 Development of neoplastic cells. (From McCance KL, Huether SE: *Pathophysiology: the biologic basis for disease in adults and children*, ed 6, St. Louis, 2010, Mosby.)

Staging and Grading Cancer

Decisions regarding the appropriate treatment of malignant tumors and in determining prognosis and end results are guided by classifications that stage and grade the disease. Although several clinical classifications of cancer exist, the TNM (tumor–node–metastasis) system emerged in the 1950s and is now considered a recognized standard and is endorsed by the American Joint Committee on Cancer (AJCC). The AJCC is cosponsored by several prominent health organizations, including the American Cancer Society and the American College of Radiology.

The TNM system is based on the premise that cancers of similar histology or origin are similar in their patterns of growth or extension. The "T" refers to the size of the untreated primary cancer or tumor. As the size increases, lymph node involvement (N) occurs, eventually leading to distant metastases (M). The addition of numbers to these three letters indicates the extent of malignancy and the progressive increase in size or involvement of the tumor. For example, T0 indicates that no evidence of a primary tumor exists, whereas T1, T2, T3, and T4 indicate an increasing size or extension. Lack of regional lymph node metastasis is indicated by N0, and N1, N2, and N3 indicate increasing involvement of regional lymph nodes. Finally, M0 indicates no distant metastasis, and M1 indicates the presence of distant metastasis.

Neoplastic cells are examined histologically, and these growths are graded according to their degree of differentiation based on a scale of I (well differentiated) to IV (poorly differentiated). The combination of tumor classification and grading serves as a shorthand notation for the description of the clinical extent of a given malignant tumor. It facilitates treatment planning, provides an indication of prognosis, assists in evaluating treatment results, facilitates information exchange among treatment centers, and allows unambiguous categorization of malignancies to aid in the continuing investigation of cancer.

SUMMARY

Technologic advances in the field of radiology have, without a doubt, done much to relieve human suffering, but medical imaging alone cannot provide a definitive diagnosis. Medical imaging must be used in conjunction with other diagnostic and therapeutic modalities to provide the best treatment for each specific disease process. The following chapters provide the student radiographer with a better understanding of the disease processes of the various physiologic systems. This information should help students analyze and critique each radiograph to ensure that it provides optimal information to assist physicians in their diagnosis.

REVIEW QUESTIONS

1. The prediction of the course and end of a disease and an outlook based on that prediction best define its:
   a. Diagnosis
   b. Etiology
   c. Prognosis
   d. Syndrome
2. A compression fracture of the lumbar spine that results from steroid treatments for pain reduction of arthritis would be an example of _____ disease.
   a. Degenerative
   b. Iatrogenic
   c. Idiopathic
   d. Traumatic
3. A disease such as Tay-Sachs syndrome that is transmitted genetically is termed:
   a. Congenital
   b. Hereditary
   c. Metabolic
   d. Neoplastic
4. Sickness sufficient to interfere with one's normal daily routine refers to its:
   a. Etiology
   b. Morbidity
   c. Mortality
   d. Pathogenesis
5. Which of the following would be considered a symptom of a disease process?
   a. Bloody stool
   b. Nausea
   c. Skin rash
   d. Swelling
6. A disease that manifests slowly and is present for a long period is said to be:
   a. Acute
   b. Asymptomatic
   c. Chronic
   d. Congenital
7. Which of the following disease classifications is usually associated with the normal aging process?
   a. Congenital
   b. Degenerative
   c. Inflammatory
   d. Metabolic
8. If 4000 cases of a given disease are found in a given population, the _____ of the disease is defined.
   a. Incidence
   b. Morphology
   c. Metabolism
   d. Prevalence
9. The relative ease with which an organism can overcome normal bodily defenses refers to its:
   a. Infection
   b. Necrosis
   c. Pestilence
   d. Virulence
10. A neoplastic growth is evaluated to determine its degree of histologic differentiation. This is termed:
    a. Grading

b. Metastasis
c. Morphology
d. Staging

11. Generalized increase in cell size refers to:
a. Hypertrophy
b. Atrophy
c. Metaplasia
d. Hyperplasia

12. Which of the following terms refers to abnormal changes of mature cells?
a. Hypertrophy
b. Dysplasia
c. Metaplasia
d. Hyperplasia

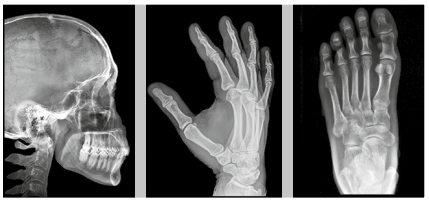
13. Explain the concept of neoplastic disease. Are all neoplasms cancer?

14. What is the difference between mortality and morbidity rate? How is each important to the practice of medicine and to public health agencies?

15. Differentiate between an acute and chronic illness. Give two examples of each.

2

Skeletal System



Additional resources are available online at: http://evolve.elsevier.com/Kowalczyk/pathology/

CHAPTER OUTLINE

Anatomy and Physiology, 19
Imaging Considerations, 21
- Radiography, 21
- Magnetic Resonance Imaging, 21
- Computed Tomography, 21
- Nuclear Medicine Procedures, 22

Congenital and Hereditary Diseases, 22
- Osteogenesis Imperfecta, 22
- Achondroplasia, 24
- Osteopetrosis, 24
- Hand and Foot Malformations, 26
- Developmental Dysplasia of the Hip, 27
- Vertebral Anomalies, 27
- Cranial Anomalies, 29

Infectious and Inflammatory Disorders, 31
- Osteomyelitis, 31
- Tuberculosis, 32
- Arthropathies, 33

Neoplastic Diseases, 39
- Osteochondroma (Exostosis), 41
- Osteoma, 42
- Osteoid Osteoma and Osteoblastoma, 42
- Enchondroma, 43
- Simple Unicameral Bone Cyst, 43
- Aneurysmal Bone Cyst, 44
- Giant Cell Tumor (Osteoclastoma), 44
- Osteosarcoma (Osteogenic Sarcoma), 46
- Ewing Sarcoma, 47
- Chondrosarcoma, 48
- Metastases from Other Sites, 49

LEARNING OBJECTIVES

On completion of Chapter 2, the reader should be able to do the following:

1. Describe the anatomical components of the skeletal system on a macroscopic level and basic microscopic level.
2. Identify and explain the criteria for assessing technical adequacy of skeletal radiographs.
3. Characterize a given condition as congenital, inflammatory, or neoplastic.
4. Specify the etiology, signs and symptoms, and prognosis of the skeletal pathologies cited in this chapter.
5. Explain the role of various imaging modalities in the diagnosis and treatment of skeletal pathologies.

KEY TERMS

Achondroplasia
Albers-Schönberg disease
Anencephaly
Aneurysmal bone cyst
Ankylosing spondylitis
Arthritis
Bursitis
Cancellous bone
Chondrosarcoma
Clubfoot
Compact bone
Craniosynostosis
Craniotubular dysplasias
Developmental dysplasia of the hip (DDH)

Diaphysis
Diploë
Enchondroma
Epiphysis
Escherichia coli
Ewing sarcoma
Exostoses
Fibrous dysplasia
Ganglion
Giant cell tumor
Gouty arthritis
Hyperostosis frontalis interna
Involucrum
Juvenile idiopathic arthritis (JIA)
Klippel-Feil syndrome
Medullary cavity
Metaphysis
Osteoarthritis
Osteoblastoma
Osteoblasts
Osteochondroma
Osteoclastoma
Osteoclasts
Osteogenesis imperfecta (OI)
Osteoid osteoma
Osteoma
Osteomyelitis
Osteopetrosis
Osteophytes
Osteosarcoma
Periosteum
Polydactyly
Pott disease
Psoriatic arthritis
Reactive arthritis (Reiter syndrome)
Rheumatoid arthritis (RA)
Scheuermann disease
Scoliosis
Sequestrum
Simple unicameral bone cyst
Spina bifida
Staphylococcus aureus
Syndactyly
Tendonitis
Tenosynovitis
Trabeculae
Trabecular pattern
Transitional vertebra
Tuberculosis of the bone and joint

ANATOMY AND PHYSIOLOGY

The adult skeletal system is composed of 206 separate bones and is responsible for body support, protection, movement, and blood cell production. It contains more than 98% of the body's total calcium and up to 75% of its total phosphorus. The system is commonly divided into the axial skeleton, which contains 80 bones, and the appendicular skeleton (Fig. 2.1), which contains 126 bones. Bone is a type of connective tissue, but it differs from other connective tissue because of its matrix of calcium phosphate. The construction of this matrix further classifies bone tissue as either compact/cortical (dense) or cancellous (spongy) (Fig. 2.2).

The outer portion of bone is composed of **compact bone**, and the inner portion, termed the **medullary cavity**, is made up of **cancellous bone**. Bone marrow, or myeloid tissue, is located within the medullary cavity and is interspersed between the **trabeculae**. This intricate, web-like bony structure is visible on a properly exposed radiograph of the skeletal system and is often referred to as the **trabecular pattern**. The term **diploë** is specific to the cancellous bone located within the skull that separates the inner and outer layers of the compact bone.

Bone marrow is either red or yellow depending on the type of myeloid tissue. The red bone marrow is responsible for hematopoiesis or the production of erythrocytes, leukocytes, and thrombocytes. In an adult, red bone marrow is found primarily in the bones of the trunk, such as the pelvis, sternum, ribs, and vertebrae. Fat tissue gradually

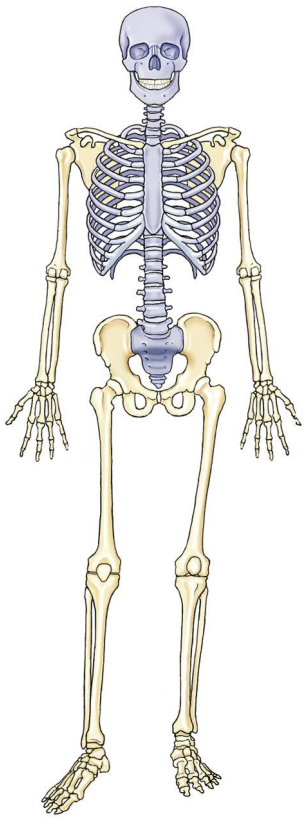


FIG. 2.1 Axial skeleton and appendicular skeleton. (From Bontrager KL, Lampignano JP: *Textbook of radiographic positioning and related anatomy*, ed 8, St. Louis, 2014, Mosby.)

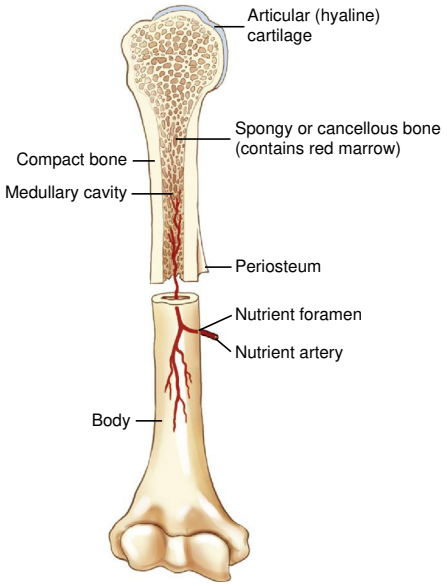


FIG. 2.2 Bone composition. (From Bontrager KL, Lampignano JP: *Textbook of radiographic positioning and related anatomy*, ed 8, St. Louis, 2014, Mosby.)

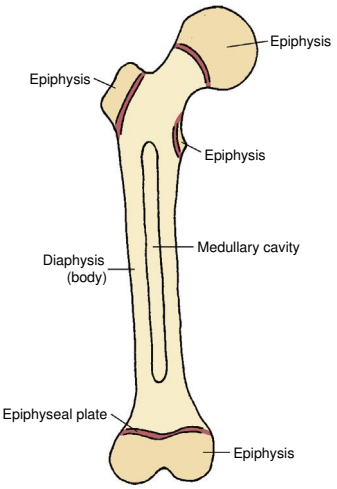


FIG. 2.3 Endochondral ossification. (From Bontrager KL, Lampignano JP: *Textbook of radiographic positioning and related anatomy*, ed 8, St. Louis, 2014, Mosby.)

replaces the red bone marrow, and at the approximate age of 20 years the majority of the red bone marrow has been replaced by the fatty yellow bone marrow.

Osteoblasts are the bone-forming cells that line the medullary cavity and are interspersed throughout the periosteum. They are responsible for bone growth and thickening, ossification, and regeneration. **Osteoclasts** are specialized cells that are responsible for bone remodeling. They break down bone to enlarge the medullary cavity and allow for bone growth. This production and breakdown of bone plays an important role in serum calcium and phosphorus equilibrium. Certain metabolic disease processes may alter the percentage of calcium in the blood, resulting in either hypocalcemia or hypercalcemia.

The bones of the skeletal system are classified according to their shape to include long, short, flat, irregular, and sesamoid bones. The **diaphysis** of a long bone refers to the shaft portion and is the primary site of ossification, whereas the **epiphysis** refers to the expanded end portion and is the secondary site of ossification (Fig. 2.3). The **metaphysis** refers to the growth zone between the epiphysis and the diaphysis. It is the area of greatest metabolic activity in a bone. A cartilaginous growth plate is located between the metaphysis and the epiphysis in the bone of a growing child. Radiographically, these growth areas appear radiolucent. As the body matures, this cartilage calcifies and is no longer radiographically visible in the adult.

The **periosteum** is a fibrous membrane that encloses all of the bone, except at the joint surfaces of long bones, and it plays a crucial role in supplying blood to the underlying bone. Osteoblasts located within the periosteum increase bone thickness relative to individual activities. In a healthy person, bone grows and remodels in response to the forces placed upon it. This is known as Wolff's Law. The more physical stress a bone is under, the more thickly the compact portion develops; therefore, it is common medical practice to allow patients with healing fractures of the hip or femur to bear weight on the injured bone, which helps shorten the healing period. Disuse atrophy occurs when a bone is not allowed to bear weight and results in significant decalcification and thinning of the bone (Fig. 2.4).

The 206 bones of the body are connected to one another by one of three types of joints: (1) *fibrous (synarthrodial) joints* form firm, immovable joints such as the sutures of the skull; (2) *cartilaginous (amphiarthrodial) joints*, such as those found between the vertebral bodies, are slightly movable; and (3) *synovial (diarthrodial) joints*, such as the knee, are freely movable. The synovial joints are found at the ends of the bones, are lined with articular cartilage, and are held together by ligaments. The joint capsule is lined by a synovial membrane responsible for the secretion of synovia, a lubricating fluid containing mucin, albumin, fat, and mineral salts. The joint capsule also contains a rich nerve supply, making them sensitive to stretching.

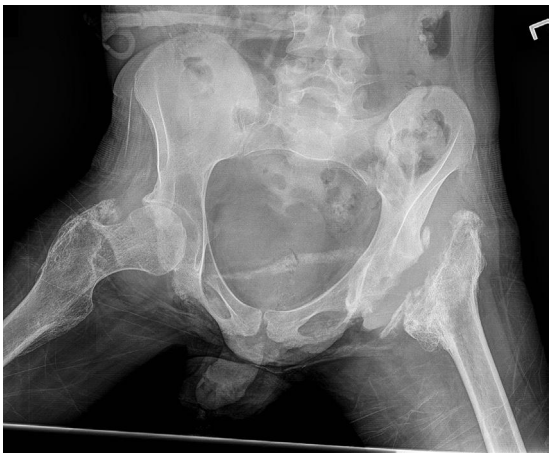


FIG. 2.4 Radiography demonstrating muscle atrophy and bone thinning as a result of a lack of weight-bearing activity. (From The Ohio State University Wexner Medical Center, Columbus, Ohio.)

IMAGING CONSIDERATIONS

Radiography

In examining a skeletal radiograph, it is important to begin by properly displaying the image and recognizing the radiographic projection. The radiographic exposure technique and histogram selected is very important for achieving a proper diagnosis. Proper technique is achieved when the soft tissues and bony structures of interest are both adequately penetrated and the trabecular pattern is visible. Any motion of the anatomy of interest impairs the visibility of detail present.

Soft tissue areas often hold clues to the diagnosis and are examined by the interpreting physician. Any signs of muscle atrophy, soft tissue swelling, calcifications, opaque foreign bodies, or the presence of gas may indicate disease. Analysis of the configuration of the bone and its relationship to other bones serves to detect or exclude fractures, dislocations, congenital anomalies, or acquired deformities.

The interface between cortical (compact) bone and soft tissue is also important. Any new periosteal bone formation seen may be a response to trauma, tumors, or infection. Juxtaarticular erosions are often seen in cases of arthritis. Cortical resorption may be demonstrated as a smudgy, irregular loss of the cortical margin. In addition, the internal bone structure is important and should be examined for abnormally altered texture, alterations in the amount of mineralization, or foci of destruction. Careful consideration of all areas mentioned assists the physician in arriving at the correct diagnosis.

Magnetic Resonance Imaging

Magnetic resonance imaging (MRI) is an important modality used in imaging of skeletal pathology, particularly in providing soft tissue detail because of its superior contrast resolution and ability to image in multiple planes. It is considered the modality of choice for the detection and staging of soft tissue tumors involving the extremities. It is also extremely useful in the evaluation of joints, particularly the knee and the shoulder (Fig. 2.5). Newer imaging techniques and improved equipment allow MRI to detect a greater number of musculoskeletal subtleties with higher resolution imaging (Fig. 2.6). Sometimes these subtleties mimic bone pain but involve soft tissues instead, which is an important distinction. Bone marrow imaging done with MRI is superior to other modalities in visualizing subtle abnormalities within the musculoskeletal system. Also, MRI may play a larger role in trauma medicine, particularly with the refinement of open-bore and short-bore technologies. It is also a nonionizing trauma imaging option for pediatric and pregnant individuals.

Computed Tomography

Computed tomography (CT) is an important tool in skeletal imaging because the examination can be performed quickly and noninvasively, even in cases of trauma. CT can define the presence and extent of fractures or dislocations to assess abnormalities in joints and associated soft tissues,

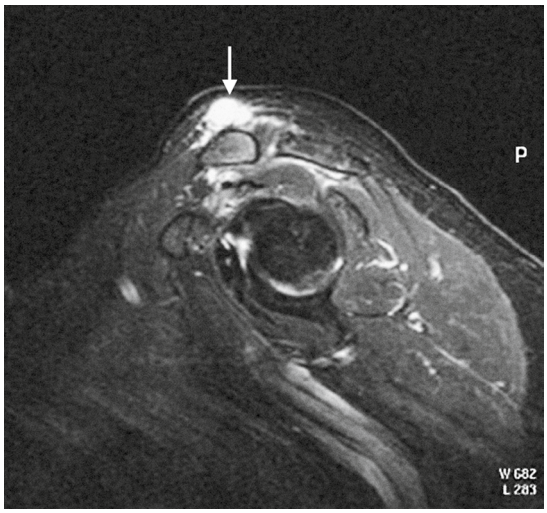


FIG. 2.5 Magnetic resonance imaging scan (short-τ inversion recovery sequences) showing a subcutaneous cyst on the scapula *(arrow)*. (From The Ohio State University Wexner Medical Center, Columbus, Ohio.)

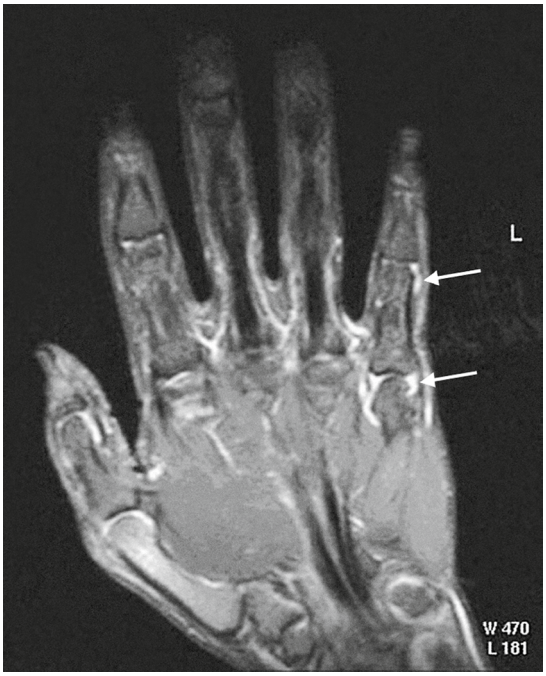


FIG. 2.6 Magnetic resonance imaging scan (short-τ inversion recovery sequences) showing synovitis of the metacarpophalangeal and interphalangeal joints *(arrows)*. (From The Ohio State University Wexner Medical Center, Columbus, Ohio.)

and to help diagnose spinal disorders (Fig. 2.7). Cortical bone gives no signal in MRI, whereas CT provides ready visualization of bone details and is often used as a follow-up to conventional radiographic imaging for improved detail. Bone tumors, in particular, are now usually imaged with spiral or helical CT because of its excellent ability to display bone margins and trabecular patterns, and to assess both bone and soft tissue involvement of tumors. Although CT results in greater contrast resolution compared with radiography, much of the role for imaging other related soft tissues has been replaced by MRI.

Nuclear Medicine Procedures

Nuclear medicine retains an advantage not offered by either MRI or CT in skeletal imaging: the ability to look at the entire body at one time in a convenient fashion (Fig. 2.8). It provides decision making as to whether any pathology shown is an old injury or a new problem, with activity indicating that the bone involved is affected by some new process. In addition, the bone scan is still the standard of care for examination of metastatic processes

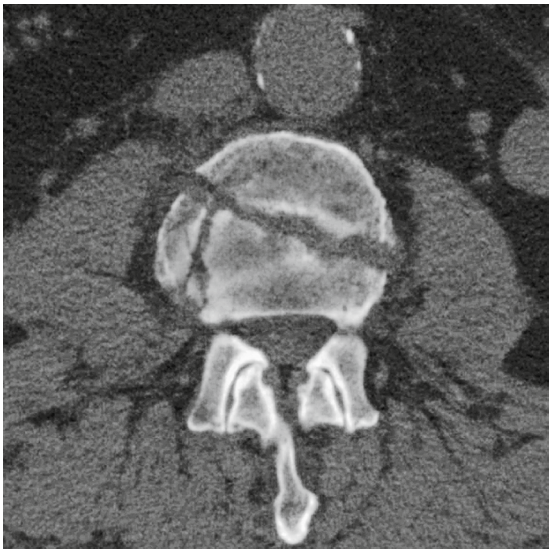


FIG. 2.7 Computed tomography scan demonstrating a burst fracture of the third lumbar vertebra. (From The Ohio State University Wexner Medical Center, Columbus, Ohio.)

because it demonstrates metabolic reaction of the bone to the disease process and is more sensitive than comparative radiographic studies. This is also true in many other traumatic or inflammatory diseases of the skeletal system. However, the utilization of positron emission tomography (PET) scanning in skeletal pathologies has started to increase, particularly the use of ^{18}F-NaF (2-deoxy-2-[^{18}F]fluoro-D-glucose). Although primarily used in diagnosing and staging metastatic disease, it may be appropriate in certain individuals with back pain and for the diagnosis of inflammatory, necrotic, degenerative, and metabolic diseases, as well as bone graft viability and complications related to prosthetic joints.

CONGENITAL AND HEREDITARY DISEASES

Osteogenesis Imperfecta

Osteogenesis imperfecta (OI), sometimes referred to as *brittle bone disease*, is a serious but rather rare heritable or congenital disease affecting the connective tissue. It is most commonly the result of an autosomal dominant defect. The eight recognized types are classified as type I to VIII, with type I being the mildest and type VIII the most severe. Prenatal testing of cultured skin fibroblasts (CSFs) helps diagnose types II, III, and IV. OI is caused

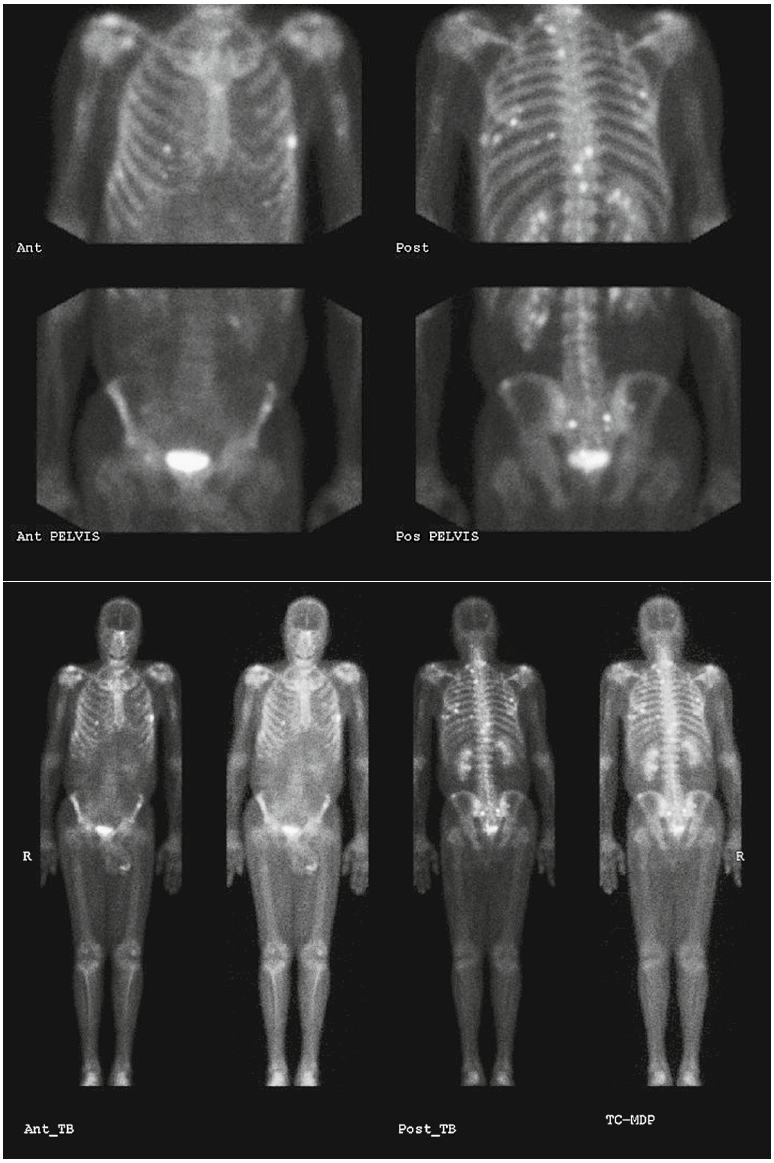


FIG. 2.8 Bone scan demonstrating metastatic disease throughout the ribs, thoracic vertebrae, and pelvis resulting from carcinoid disease. (From The Ohio State University Wexner Medical Center, Columbus, Ohio.)

by mutations in the two structural genes that encode the α_1- and α_2-peptides of type I collagen, the main collagen of bone, tendon, and skin. The specific mutations occur in the *COL1A1*, *COL1A2*, *CRTAP*, and *LEPRE1* genes, thus deficient and imperfect formation of osseous tissue, skin, sclera, inner ear, and teeth are noted in individuals with this disease. The two main clinical groups of OI are based on the age of onset and the severity of the disease.

1. *Osteogenesis imperfecta congenita* is present at birth. Infants with this disease usually have multiple fractures at birth that heal only to give way to new fractures. This results in limb deformities and dwarfism, and may lead to death.
2. In *osteogenesis imperfecta tarda*, fractures might not appear for some years after birth and then generally stop once adulthood is reached (Fig. 2.9).

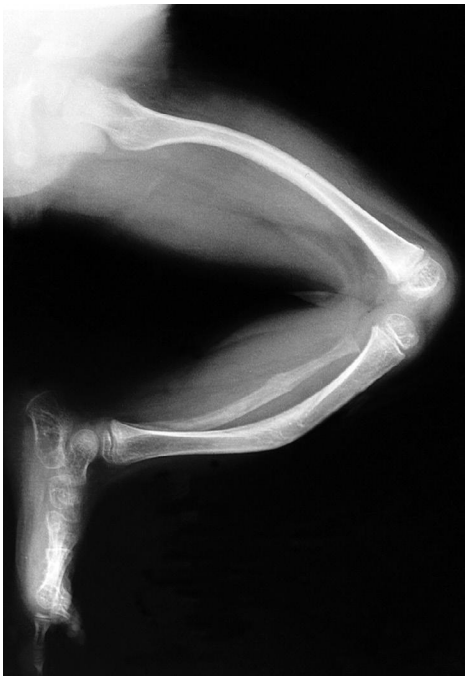


FIG. 2.9 A lateral projection of the lower extremity demonstrating marked bowing of the bones due to softening and multiple fractures that occur as a result of congenital bone dysplasia. (From Mettler FA: *Essentials of radiology*, ed 4, Elsevier, 2019.)

In some cases, otosclerosis, which is the formation of abnormal connective tissue around the auditory ossicles, can result in a hearing disorder. Radiographic evaluation will demonstrate multiple fractures in various stages of healing and a general decrease in bone mass. The bone cortex is thin and porous, and the trabeculae are thin, delicate, and widely separated.

Achondroplasia

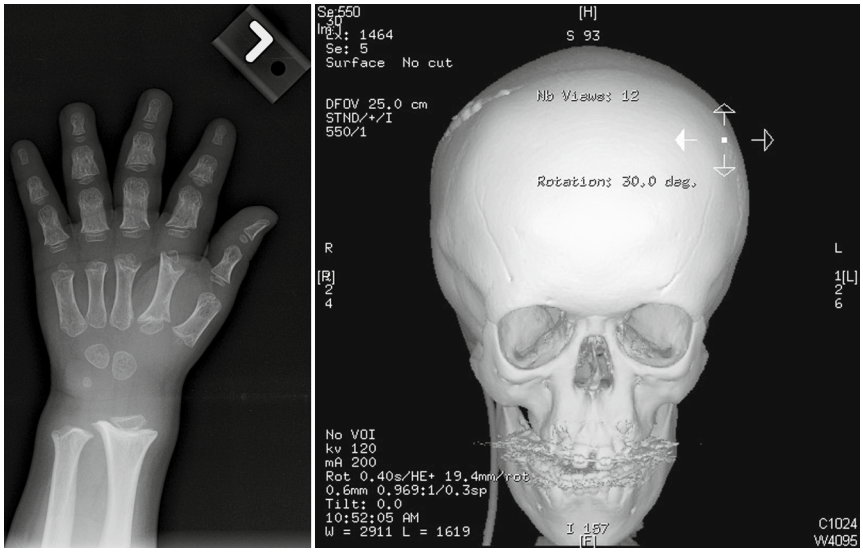
The most common skeletal dysplasia is **achondroplasia**, which results in bone deformity, decreased bone formation and disproportionate dwarfism. Achondroplasia is the most common form of dwarfism. It occurs in 1 in 15,000 to 40,000 newborns. It is caused by an autosomal dominant gene (*FGFR3*) at the 4p chromosome location, and this gene does not skip generations. Individuals with this gene have about a 50% chance of transmitting it to their children.

Because of a disturbance in endochondral bone formation, the cartilage located in the epiphyses of the long bones does not convert to bone in the normal manner, impairing the longitudinal growth of the bones. Thus, individuals with this type of osteochondrodysplasia have a normal trunk size and shortened extremities (Fig. 2.10A). In some instances, ultrasonography may be used for prenatal diagnosis of achondroplasia. Small stature is the signal characteristic of achondroplasia, and an adult is usually no more than 4 feet in height, with lower extremities usually less than half the normal length. Additional clinical manifestations of this disorder include kyphosis, hyperlordosis, spinal stenosis, bowed legs (genu varum), a bulky forehead with midface hypoplasia (see Fig. 2.10B), and a narrowing of the foramen magnum within the skull, which causes neural compression. Occasionally, orthopedic surgery may be necessary in the management of complications associated with achondroplasia. The Ilizarov procedure has also been used in an attempt to lengthen the shortened limbs. This procedure was perfected by Dr. Gavriil Ilizarov and has been used for over 30 years. It consists of a corticotomy of the limb, followed by attachment of an Ilizarov fixator, which consists of two circular frames that surround the limb, wires, and rods. By using this method, bones may be made to grow at a rate of approximately 1 mm per day. Most recently, clinical trials have involved growth hormone (GH) injections in the treatment of children with achondroplasia beginning at an early age, generally between the ages of 1 and 6 years. Conclusive results cannot be determined until the children in the current study reach their adult heights. Early research indicates that introduction of GH may have an adverse effect on the cardiovascular system. In addition, these patients may receive genetic and social counseling.

Bone age radiographic studies of the left hand to include the distal radius may be used to monitor persons with achondroplasia. The images are analyzed to compare the chronologic age with the radiographic bone age by using one of two methods: (1) the atlas matching method, which was established by Greulich and Pyle (GP) in the 1950s; or (2) the point scoring system of Tanner and Whitehouse, which was developed in the 1960s. A new digital atlas was developed by Vicente Gilsanz and Osman Ratibin in 2005. The images of the new GR atlas are much more precise and have a better quality than those of the older GP atlas.

Osteopetrosis

Osteopetrosis and *marble bone disease* are terms used to characterize a variety of dysplasias involving an increase in bone density and defective bone contour, often referred to as *skeletal modeling*. Mutations in at least nine genes



A B

FIG. 2.10 A, Bone age radiograph of a 3-year-old demonstrating an abnormal flared appearance of the metaphyses and shortened, broad phalanges consistent with achondroplasia. B, Three-dimensional reconstruction of computed tomography scan demonstrating midface hypoplasia typical of achondroplasia. (From The Ohio State University Wexner Medical Center, Columbus, Ohio.)

cause the various types of osteopetrosis. Seventy-five percent of autosomal dominant osteopetrosis results from mutations in the *CLCN7* gene. The spectrum of osteopetrosis is distinguished by the pattern of inheritance and includes: (1) infantile malignant *CLCN7*-related autosomal recessive osteopetrosis (ARO), which has its onset in infancy; (2) intermediate autosomal osteopetrosis (IAO), which develops in childhood; and (3) autosomal dominant osteopetrosis type II (ADOII), which occurs in late childhood or adolescence. Mutations in any of the genes associated with osteopetrosis lead to missing or abnormal osteoclasts, resulting in abnormally dense and compact but nevertheless brittle bones. All bones are affected, but the most significant changes occur in the long bones of the extremities, vertebrae, pelvis, and base of the skull. The disorders characterizing osteopetrosis include osteosclerosis, craniotubular (affecting the cranium and tubular long bones) dysplasias, and craniotubular hyperostosis. It is important for the technologist to be aware that both the osteosclerotic and craniotubular hyperostotic disorders are additive conditions and require an increase in exposure factors to adequately penetrate the bony anatomy because of abnormal bone density (Fig. 2.11). In some cases, adequate radiographic density may never be achieved. Radiographs demonstrate an increase in the density and thickness of the cortex and an increase in the number and size of trabeculae, with a marked reduction of the marrow space.

Albers-Schönberg disease, or autosomal dominant osteopetrosis type II (ADOII), is the most common form of osteosclerotic osteopetrosis. This autosomal dominant, delayed, benign skeletal anomaly involves increased bone density in conjunction with fairly

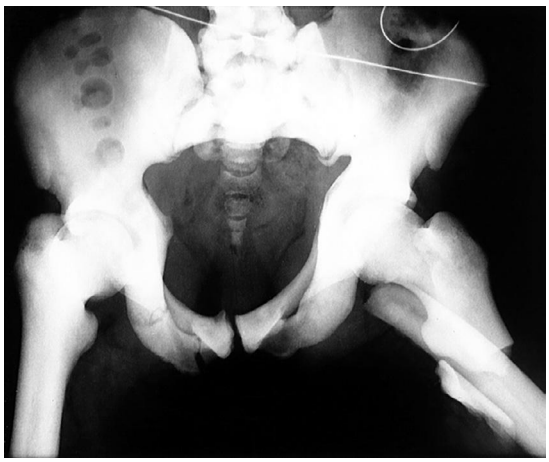


FIG. 2.11 Pelvic radiograph demonstrating a fractured femur in an individual with osteoporosis who fell out of bed. (From Mettler FA: *Essentials of radiology*, ed 4, Elsevier, 2019.)

normal bone contour. In fact, many people with Albers-Schönberg disease are asymptomatic, and it is often discovered after radiographing the individual for an unrelated problem. The bone sclerosis is not radiographically visible at birth, so, as the person ages, radiographic manifestations of the osteopetrosis become visible, especially in the region of the cranium and spine; however, the general health of the individual is unimpaired.

Craniotubular dysplasias are a group of rare autosomal recessive or dominant hereditary diseases which mainly result in abnormal or defective bone contour of the cranium and long bones. They are generally caused by a defect in the osteoclasts. Radiographs are useful in demonstrating this alteration in contour, sclerosis, and changes within the cortical bone. Craniotubular hyperostosis includes a variety of rare hereditary diseases, causing both an increase in bone density and abnormal bone modeling, with pronounced sclerosis in the cranial vault and long bones. Both craniotubular anomalies manifest in childhood. Although these disorders do not normally impair the individual's general health, bony overgrowth may constrict cranial nerves, resulting in some dysfunction such as facial palsy or deafness.

A rare idiopathic condition characterized by the proliferation of fibroblasts in the medullary cavity is termed **fibrous dysplasia**. This disorder begins in childhood and results in a decrease in bone density, bone softening, skin hyperpigmentation and endocrine dysfunction. Fibrous dysplasia arises from a mutation in the GNAS gene and can present as a single lesion (monostotic) or as multiple lesions (polyostotic). Although fibrous dysplasia can occur anywhere, the long bones are most commonly affected. Radiographically, fibrous dysplasia presents as well-circumcised lesions with no periosteal reaction and a "ground glass" matrix due to the decrease in bone density. Bone scans are used to determine the extent of the disease, whereas CT is useful to determine the extent of cortical involvement. Treatment includes bisphosphonate therapy to reduce pain and reduce the risk of pathological factors. Surgery may be indicated to treat skeletal deformities or fractures.

Hand and Foot Malformations

A variety of abnormalities of the fingers and toes may occur during fetal development but can be surgically corrected at birth. Failure of the fingers or toes to separate is called **syndactyly** and causes the physical appearance of webbed digits (Fig. 2.12). Syndactyly is associated with Apert syndrome, which is a genetic syndrome involving mutations of the *FGFR2* gene and is characterized by skeletal abnormalities and craniosynostosis. **Polydactyly** (Fig. 2.13) refers to the presence of an extra digit or digits, and treatment includes surgical intervention and therapy.

Clubfoot (talipes equinovarus) is a congenital malformation of the foot that prevents normal weight bearing. It is a plantar flexion deformity characterized by the fixation of the foot in adduction, supination, and varus with corresponding soft tissue abnormalities. This congenital malformation is more common in males than in females and may occur bilaterally. Clubfoot is generally corrected by casting or splinting the foot in the correct anatomic position.

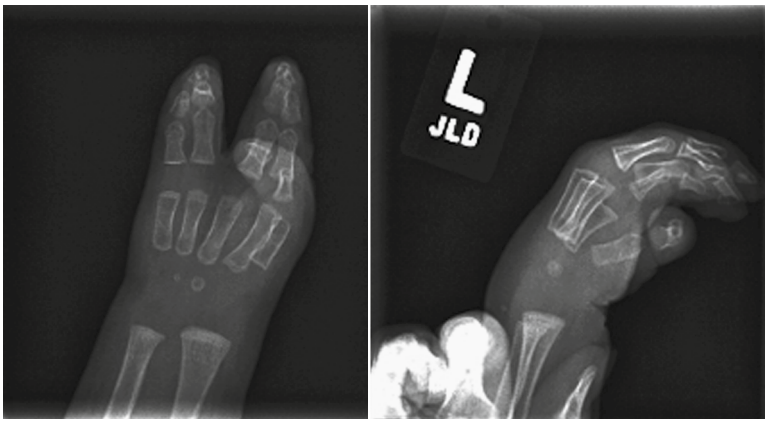


FIG. 2.12 Hand radiograph of an infant demonstrating acrosyndactyly. (From The Ohio State University Wexner Medical Center, Columbus, Ohio.)

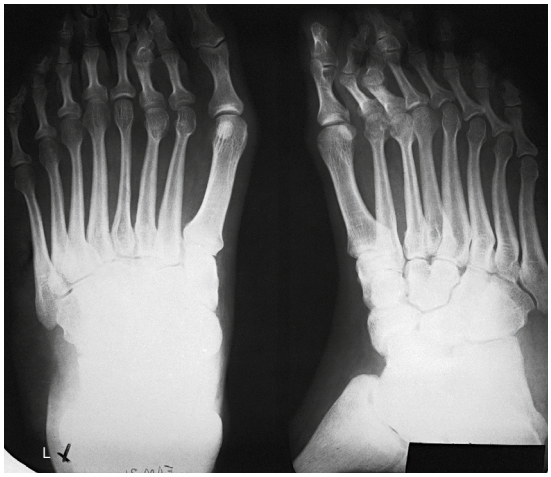


FIG. 2.13 Foot radiograph demonstrating additional digits associated with familial polydactyly. (From American College of Radiology, Reston, Virginia.)

Developmental Dysplasia of the Hip

A malformation of the acetabulum often results in **developmental dysplasia of the hip (DDH)**. Because the acetabulum is shallow, the head of the femur is displaced superiorly and posteriorly (Fig. 2.14). In addition, there may be corresponding femoral head dysplasia where the femoral epiphysis is absent or small. Often, the ligaments and tendons responsible for proper placement of the femoral head are also affected. DDH may be unilateral or bilateral and occurs more frequently in females than in males. Risk factors include a breech position in utero, being the first child, or low levels of amniotic fluid during gestation. DDH affects approximately 1 in 1000 births and may be associated with cerebral palsy, myelomeningocele, arthrogryposis, and Larsen syndrome. Larsen syndrome is a disorder that affects the development of bones and is caused by a mutation of the *FLNB* gene affecting the production of filamin B protein.

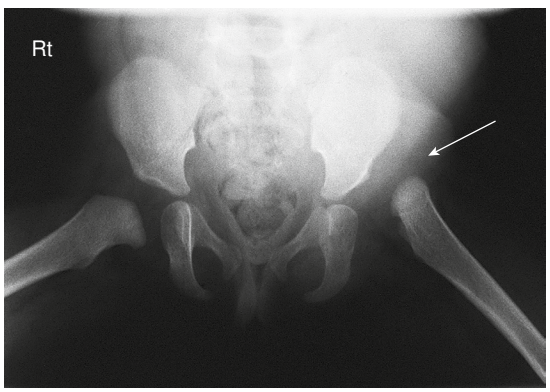


FIG. 2.14 Frog-leg lateral projection of the pelvis of an infant demonstrating congenital dislocation of the left hip *(arrow)*. (From American College of Radiology, Reston, Virginia.)

Early diagnosis and treatment are critical to provide the best functional outcome. Sonography may be used to diagnose this anomaly early in life through visualization of the cartilaginous structures of the hip. Conventional radiographs of the hip are often difficult to interpret in the neonate. Radiographic measurements of the anteroposterior (AP) pelvis and bilateral frog-leg views are obtained and compared with standardized lines. DDH should be treated early with immobilization through casting or splinting the affected hip to allow the development of the femoral head and acetabulum, and the formation of a functional joint. If left untreated, this anomaly may result in uneven limb length, hip muscle weakness, and an uneven gait. Avascular necrosis of the femoral head is the most common complication in children.

Vertebral Anomalies

Scoliosis refers to an abnormal lateral deviation of the spine, most commonly with vertebral rotation (Fig. 2.15). The lateral deviations are usually convex to the right in the thoracic region and to the left in the lumbar region of the spine. The causes of scoliosis vary and are classified as structural or functional. Structural scoliosis remains fixed and does not disappear with changes in position. Up to 80% of all structural scoliosis cases are idiopathic, although factors such as connective tissue disease and diet have been implicated. Scoliosis generally does not become visually apparent until adolescence. It tends to affect females more frequently than males and may cause numerous complications, including cardiopulmonary complications, degenerative spinal arthritis, fatigue, and joint dysfunction syndromes. Functional or nonstructural scoliosis, in which the primary issue is outside the spine, can be the result of spinal cord injuries, unequal leg lengths, or compensatory postural changes affected by chronic pain elsewhere in the body. Functional scoliosis usually presents with significant lateral deviation with little or no rotation of the vertebrae.

Radiography is important in the diagnosis and treatment of scoliosis. Primary evaluation requires initial AP or posteroanterior (PA) and lateral standing radiographs

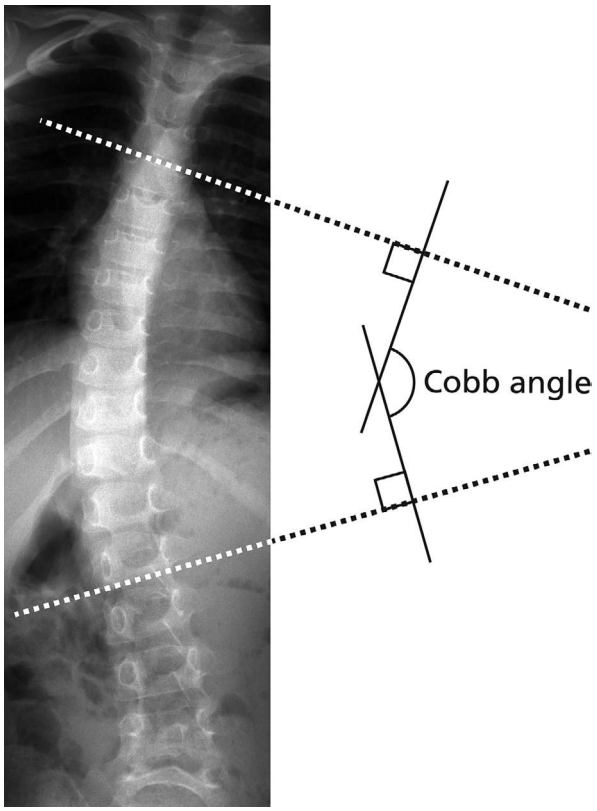


FIG. 2.15 Anteroposterior radiograph of the spine on an individual with scoliosis showing measurement of the Cobb angle. (From Grant LE, Griffin N: *Grainger & Allison's diagnostic radiology essentials*, ed 2, Elsevier, 2019.)

and follow-up radiographs on a fairly routine basis. Radiologists use one of several methods to measure the spine's curvature, so consistent quality from one examination to another is important. Effective radiation protection techniques are vital because of the large size of the exposure field, the young age of the patient, and the frequency of the examinations. Special attention is necessary in shielding the breasts of young female patients during radiographic examination throughout the treatment process. The PA projection should be obtained whenever possible because it significantly reduces the radiation dose to the breast area. Scoliosis may be corrected by placing the individual in a brace or body cast in persons with curves of 25 to 35 degrees. Surgical treatment with spinal fusion is prescribed for curves greater than 40 degrees.

A **transitional vertebra** takes on the characteristics of both vertebrae on each side of a major division of the spine. Such vertebrae occur at the junction between the thoracic and lumbar spine and at the junction between the lumbar spine and the sacrum. The first lumbar vertebra and the seventh cervical vertebra may have rudimentary ribs articulating with the transverse processes (Fig. 2.16). A cervical rib most commonly occurs at C7 and may exert pressure on the brachial nerve plexus or the subclavian artery, requiring surgical removal of the rib.

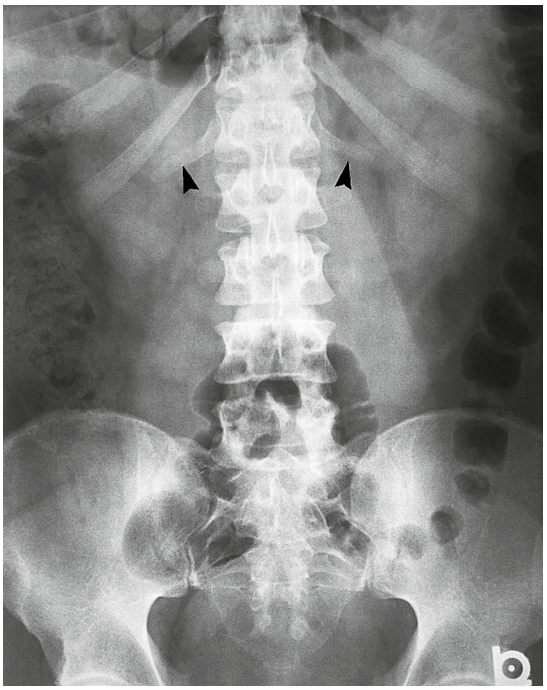


FIG. 2.16 Anteroposterior lumbar spine radiograph demonstrating bilateral lumbar ribs *(arrowheads)*. (From Riverside Methodist Hospital, Columbus, Ohio.)

Spina bifida is the failure of the lamina to unite posteriorly, resulting in an incomplete closure of the vertebral canal. Spina bifida is particularly common in the lumbosacral area (Fig. 2.17). In severe cases, the spinal cord or nerve root may be involved, which results in varying degrees of paralysis. Other individuals may have no visible abnormality or neurologic deficit, but failure of fusion of the two laminae is visible radiographically (spina bifida occulta). Treatment of spina bifida is determined on the basis of the extent of the anomaly and requires the services of a variety of physicians.

A condition of the thoracic spine typically seen in adolescents and characterized by an increase in thoracic and thoracolumbar kyphosis is known as **Scheuermann disease** (Scheuermann kyphosis) (Fig. 2.18). The cause

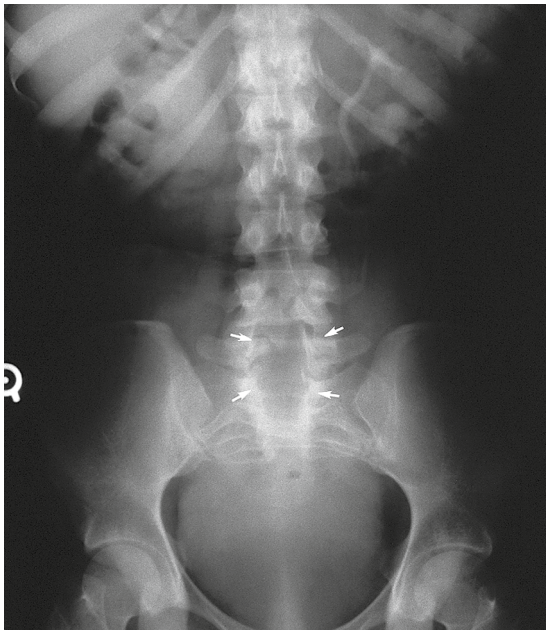


FIG. 2.17 Abdominal radiograph of a patient with spina bifida occulta of the lower lumbar vertebrae *(arrow)*. (From Riverside Methodist Hospital, Columbus, Ohio.)

of Scheuermann disease is unknown; however, growth irregularities, genetic factors, and poor bone quality may play a role. Diagnosis is obtained through thoracic radiography and is defined by the presence of irregular vertebral endplates and anteriorly wedged vertebrae. Individuals may have back pain and fatigue caused by postural stress and can be treated with bracing, physical therapy, and antiinflammatory medication. Surgical intervention is indicated in patients who do not respond to conservative treatment.

Klippel-Feil syndrome is a congenital syndrome characterized by multiple nonsegmentations and fusions of the cervical spine (Fig. 2.19), spina bifida, Sprengel deformity (undescended scapula), and scoliosis. Klippel-Feil syndrome is caused by gene mutations and can be inherited in an autosomal dominant or recessive manner. Individuals with Klippel-Feil syndrome can present with chronic headaches and pain in both the neck and back. Radiography is used to demonstrate cervical spine fusion. Supplementary spinal images will be obtained to rule out further spinal deformities. MRI and ultrasound are also used to rule out additional anomalies such as spinal stenosis, rib abnormalities, or kidney involvement.

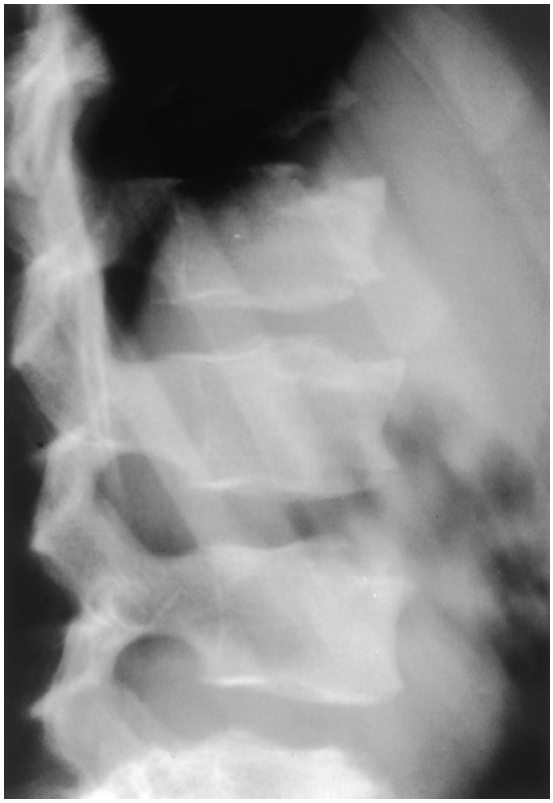


FIG. 2.18 The lateral spine radiograph shows avascular necrosis of the apophyseal rings of the vertebral bodies is called associated with Scheuermann disease. (From Helms CA: *Fundamentals of skeletal radiography*, ed 5, Elsevier, 2020.)

Cranial Anomalies

A congenital premature closure of one or more of the cranial sutures before the brain is fully formed is called **craniosynostosis**. The cranium continues to grow in the other parts of the skull where the sutures remain unfused to accommodate brain growth, which alters the shape of the head (Fig. 2.20). It is often associated with Apert syndrome. Although this defect may be corrected with surgery, brain damage may occur.

Anencephaly is a congenital abnormality in which the brain is underdeveloped and the cranial vault is incomplete (Fig. 2.21). In most cases, only the facial bones are formed. This abnormality results in death shortly after birth and may be diagnosed before birth by ultrasonography. Anencephaly is a neural tube defect. It is suspected that anencephaly may be caused by a combination of multiple genetic (*MTHFR* gene)

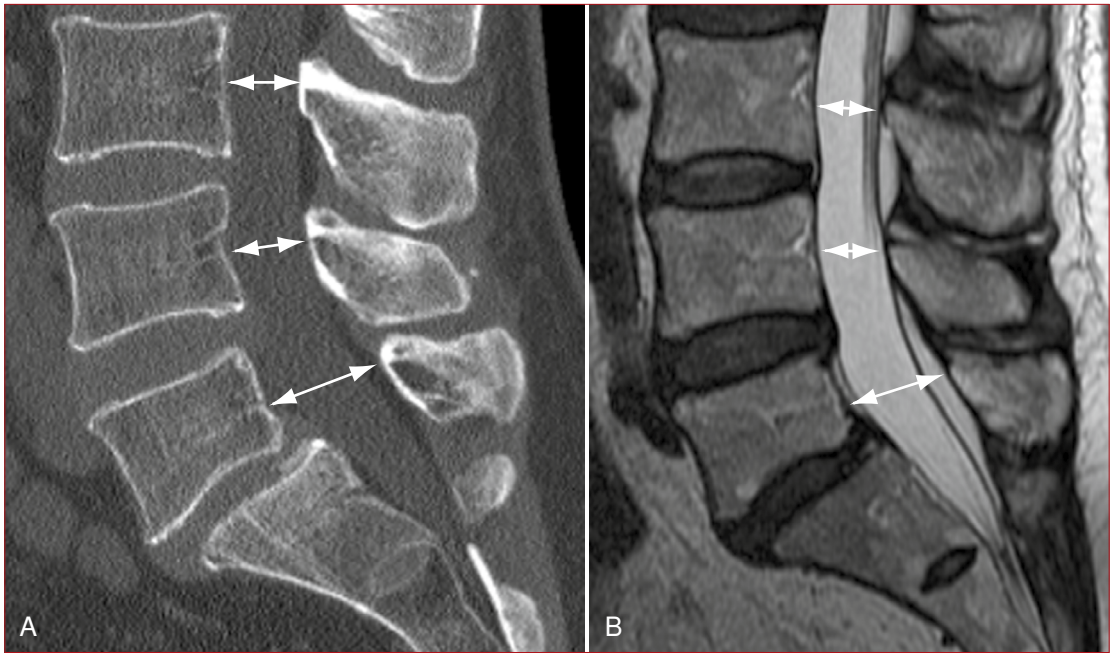


FIG. 2.19 Lateral cervical spine radiograph (A. sagittal CT; B. sagittal MRI) demonstrating absent segmentation of several cervical segments associated with Klippel-Feil syndrome *(arrows)*. (From Manaster BJ, May DA, Disler DG: *Musculoskeletal imaging: the requisites*, ed 3, Mosby Elsevier, 2007.)

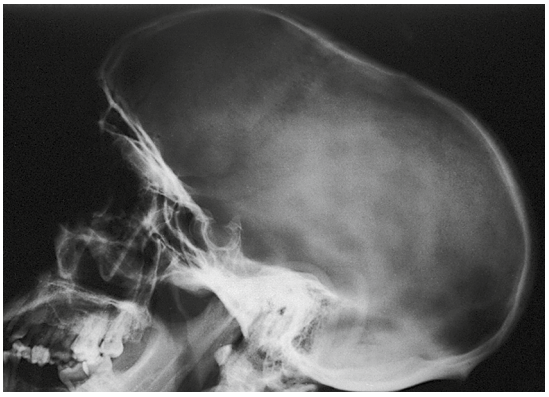


FIG. 2.20 Lateral skull radiograph demonstrating premature closure of the sagittal suture. This results in dolichocephaly and prominent convolutional markings caused by the increased intracranial pressure. (From American College of Radiology, Reston, Virginia.)

and environmental factors such as deficiency of folate, diabetes mellitus, exposure to high heat in early pregnancy, or use of certain antiseizure medications during pregnancy.

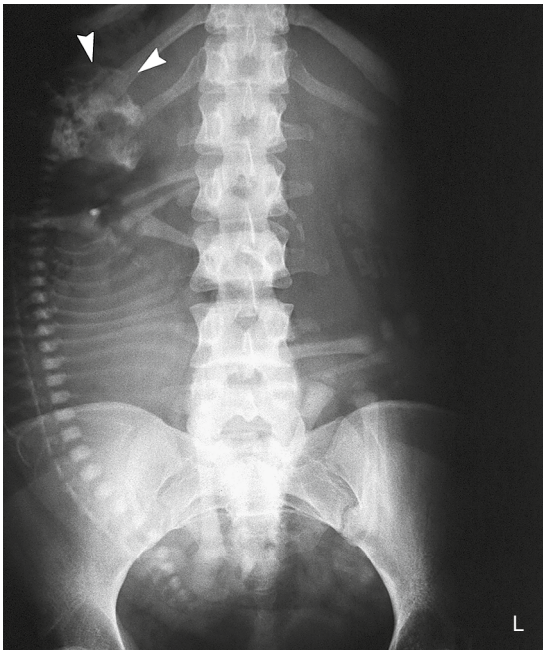
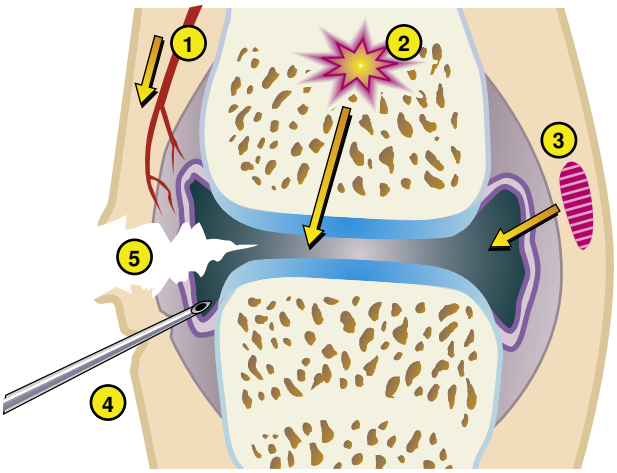


FIG. 2.21 Abdominal radiograph of a pregnant woman carrying a fetus with anencephaly. Note the absence of the cerebral cranial bones *(arrowheads)*. (From Riverside Methodist Hospital, Columbus, Ohio.)

INFECTIOUS AND INFLAMMATORY DISORDERS

Osteomyelitis

Osteomyelitis is an infection of the bone marrow and surrounding bone caused by a pathogenic microorganism spread via the bloodstream (hematogenous) from an infection within a contiguous site, or through direct introduction of the microorganism (Fig. 2.22). Signs and symptoms may include dull pain, heat swelling, and redness in the affected area, and varying degrees of fever. Generally, hematogenous osteomyelitis develops at the ends of the long bones. The distal femur, proximal tibia, humerus, and radius are most commonly affected in children and the vertebrae in adults. Infants and children are more commonly affected by acute hematogenous osteomyelitis because of increased vascularity and the rapid growth of their long bones. In addition, children often have a lowered resistance to the pathogenic organism, most commonly ***Staphylococcus aureus***. Infection may be spread to the marrow space via the nutrient artery from an infection of the skin, ear, or pharynx. In infants, hematogenous osteomyelitis may also be caused by group B streptococci and ***Escherichia coli***. In adults, hematogenous osteomyelitis is commonly secondary to bacteremia caused by genitourinary tract, soft tissue, or respiratory infections. As in children, *S. aureus* and streptococci are the pathogenic microorganisms primarily responsible for the infections.



1. The hematogenous route
2. Dissemination from osteomyelitis
3. Spread from adjacent soft tissue infection
4. Diagnostic or therapeutic procedures
5. Penetration damage by puncturing or cutting

FIG. 2.22 Routes of infection to the joint. (From McCance KL, Huether SE: *Pathophysiology: the biologic basis for disease in adults and children*, ed 7, St. Louis, 2014, Mosby.)

Osteomyelitis resulting from contiguous infections is often associated with burns, sinus disease, periodontal infection, soft tissue infection, or skin ulcers resulting from peripheral vascular disease. Pathogenic microorganisms may also be directly introduced to bones by penetrating wounds, open fractures, fractures treated with internal fixation devices, or prosthetic replacements.

No specific bone changes may be demonstrated radiographically in the very early stage of infection. However, the infection spreads rapidly, with the acute stage of osteomyelitis characterized by the formation of an abscess, leading to an inflammatory reaction within the bone that causes a rise in internal bone pressure. Osteomyelitis may be diagnosed with evidence of an elevated erythrocyte sedimentation rate (ESR) or C-reactive protein (CRP) level; however, normal laboratory values should not exclude this diagnosis. Because of the constriction of the periosteum, blood vessels compress and thrombose, leading to bone necrosis within 24 to 48 hours. Unfortunately, not until 10 to 14 days after onset is new periosteal bone repair radiographically evident to indicate the presence of the disease. Therefore, it is imperative that the condition be recognized clinically and treated with antibiotics and local drainage.

With the effective use of antibiotics, osteomyelitis seldom passes the acute stage. When it does, treatment with antibiotics in combination with surgical drainage of pus from under the periosteum often results in a complete cure of the bone lesion in the majority of cases. Chronic osteomyelitis is characterized by extensive bone destruction with irregular, sclerotic reactions throughout the bone (Fig. 2.23). A **sequestrum** is dead, devascularized bone that appears very dense. An **involucrum** is a shell of new supporting bone laid down by the periosteum around the sequestrum. An accurate diagnosis is extremely important to distinguish osteomyelitis from neoplastic bone disease.

Initially, radiography may demonstrate soft tissue swelling in the area around the affected bone. MRI demonstrates water-like signal characteristics. Follow-up radiography may be performed 10 to 14 days after medical treatment to aid in the diagnosis. Radiography is not

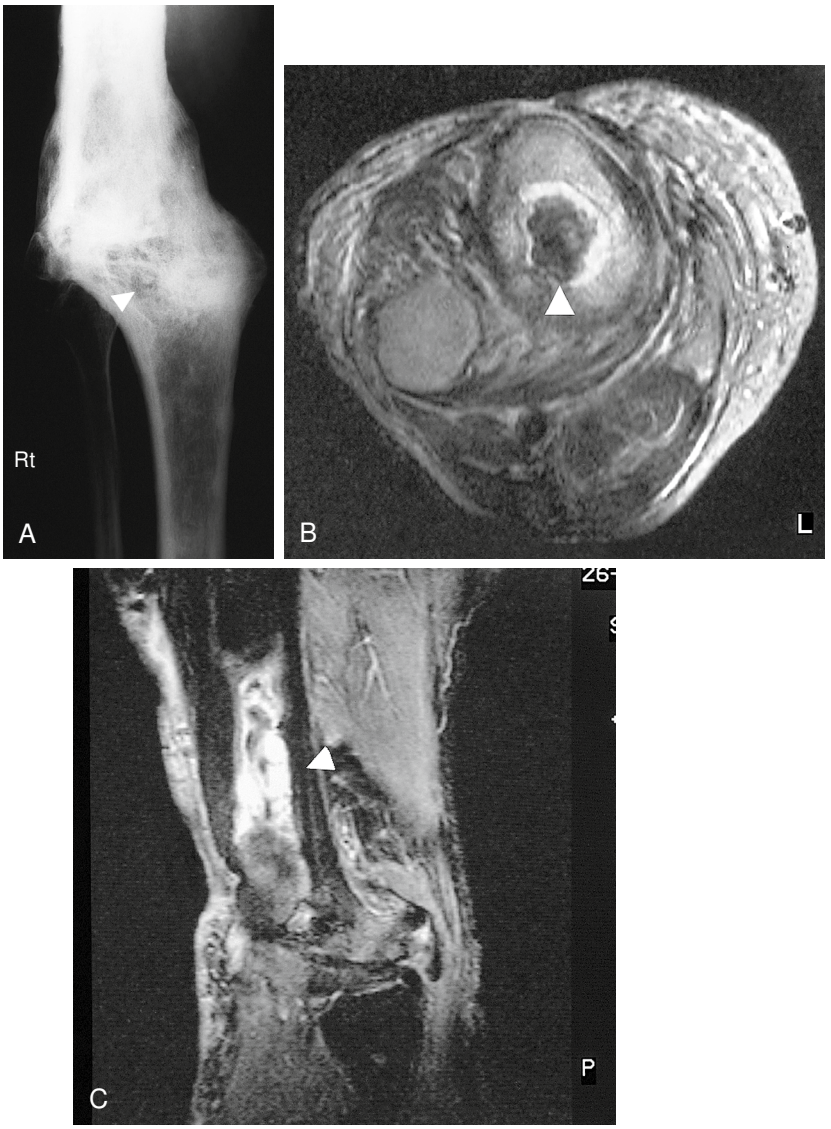


FIG. 2.23 A, Chronic osteomyelitis demonstrated in a knee with prior fusion. An involucrum surrounded by fluid densities is seen in the middle of a large intramedullary cavity approximately 3 cm above the fusion site *(arrowhead)*. B, The involucrum demonstrated on a sagittal magnetic resonance imaging (MRI) scan from the same patient *(arrowhead)*. C, The sequestrum demonstrated on an axial MRI image from the same patient, appearing as very dense bone as a result of devascularization *(arrowhead)*. (From McCance KL, Huether SE: *Pathophysiology: the biologic basis for disease in adults and children*, ed 7, St. Louis, 2014, Mosby.)

a very sensitive means of diagnosing acute osteomyelitis because a 30% to 50% loss of bone calcium is required before the destructive changes of osteomyelitis are radiographically visible. Nuclear medicine three-phase bone scan studies and MRI are much more sensitive in detecting acute and secondary osteomyelitis.

Tuberculosis

Bone and joint tuberculosis (osteoarticular tuberculosis [TB]) is a chronic inflammatory disease caused by *Mycobacterium tuberculosis*. This infection usually arises secondary to pulmonary TB and tends to be more advanced and is often left untreated for a longer period

compared with pulmonary tuberculosis. Bone and joint tuberculosis most commonly affects the hip, knee, and spine. Radiographically, the ends of the long bones display a "worm-eaten" appearance, with the disease slowly destroying the epiphyses, spreading to the articular cartilage, and, in some cases, infecting the joint space (Fig. 2.24). Tuberculosis of the spine is also called **Pott disease**. Recognized in ancient times, it has been described in Egyptian mummies dating back to 3000 BCE. It destroys the spine, causing softening and eventual collapse of the vertebrae, which results in paravertebral abscess formation and exerts abnormal pressure on the spinal cord (Fig. 2.25).

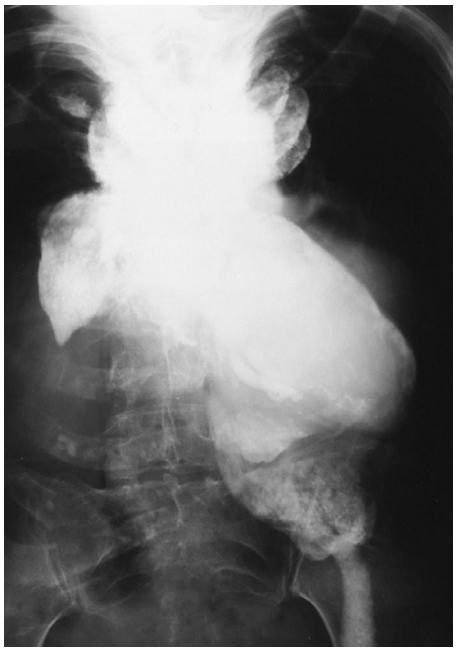


FIG. 2.24 Old tuberculosis of the spine with soft tissue calcification due to large paravertebral abscesses. (From Grant LE, Griffin N: *Grainger & Allison's diagnostic radiology essentials*, ed 2, Elsevier, 2019.)

Arthropathies

Arthropathy, a collective term used to denote disorders of the joints, includes, but is not limited to, arthritis, bursitis, tendonitis, and tenosynovitis. Joint inflammation is known as **arthritis** and may be caused by a variety of etiologic factors. For many years, osteoarthritis was believed to be a noninflammatory type of arthritis; however, current research has indicated that all types of arthritis involve inflammation of the joints. An accurate clinical history is of extreme importance because different types of arthritis are characterized by

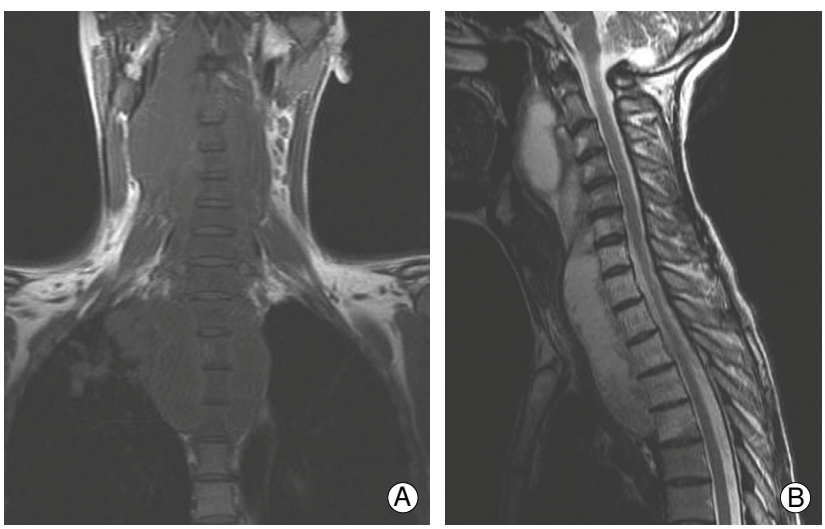


FIG. 2.25 A, Coronal T1WI and B, sagittal T2WI magnetic resonance images demonstrating a large prevertebral collection, abnormal vertebrae, and abnormal material in the epidural space surrounding and narrowing the spinal cord due to tuberculosis and osteomyelitis. (From Grant LE, Griffin N: *Grainger & Allison's diagnostic radiology essentials*, ed 2, Elsevier, 2019.)

specific features. For example, it is important to identify the number of joints involved, the location of the joints involved, and the presence of any other disease process. Some types of arthritis involve several joints, while others involve only one joint. In addition, certain types of arthritis have a preference for specific joints while sparing others. Finally, some types of arthritis are associated with specific disease processes caused by a host of factors such as bacteria or autoimmune response. Arthritis may be further classified as *acute* or *chronic*; the most common forms are chronic and disabling.

Infectious Arthritis

Infectious arthritis, or septic arthritis, is caused by a variety of pathogens including *S. aureus*, streptococci, and *Neisseria gonorrhoeae*. The infectious agents may enter the joint through a break in the skin, via extension from an adjacent infection such as osteomyelitis or an infected wound, or as a result of bacteremia. Common clinical symptoms of acute bacterial infectious arthritis are rapid onset of pain, redness, and swelling of the affected joint, which is often accompanied by fever. Diagnosis is generally made by analysis of blood and synovial fluid from the infected area. Some of the laboratory tests that may be requested include a culture, gram stain, ESR, or CRP following aspiration of the joint. Infectious arthritis usually responds rapidly to antibiotic therapy. Early radiographic changes demonstrate soft tissue swelling and joint effusions, with joint space narrowing that is only visible approximately 2 weeks after the infection. Radiographs obtained during the healing stage demonstrate recalcification and sclerosis, which often results in joint ankylosis or joint fusion.

Psoriatic arthritis is an inflammatory arthritis associated with psoriasis of the skin and involves a rheumatoid-like destructive process that predominantly affects the distal interphalangeal (DIP) joints of the hands and feet. It may cause asymmetric destruction of digits. Radiographic findings characteristic of psoriatic arthritis include bony ankylosis of the interphalangeal (IP) joints of the hands and feet and resorption of the terminal tufts of the distal phalanges. A distinctive radiographic difference between psoriatic arthritis and **rheumatoid arthritis (RA)** is that in psoriatic arthritis bone density is usually preserved.

Rheumatoid Arthritis

RA is a chronic autoimmune disease that may fluctuate in severity. It is triggered by exposure of an immunogenetically susceptible host to an arthritogenic antigen and is characterized by chronic inflammation and overgrowth of the synovial tissues, most often in the extremities. RA develops slowly, and as synovial tissues proliferate, they progressively destroy cartilage, bone, and supporting structures. Genetic factors are also believed to predispose an individual to RA. An analysis of blood chemistry identifies the presence of an autoantibody against γ-globulin, also known as the *serologic rheumatoid factor* (RF). RA usually occurs between the ages of 30 and 40 years, and is three times more common in females than in males. In the United States, approximately 2.5 million adults are affected by RA. Symptoms include pain, swelling, and stiffness of the affected joint, with periods of activity or exacerbations and remissions of the disease process.

Although any joint may be involved, RA typically begins in the peripheral joints, particularly in the small bones of the hands and feet, as well as in the knee. The radiographic changes seen early in this disease are soft tissue swelling and osteoporosis of the affected bones (Fig. 2.26). As the disease progresses, cortical erosion with joint space narrowing occurs because of the

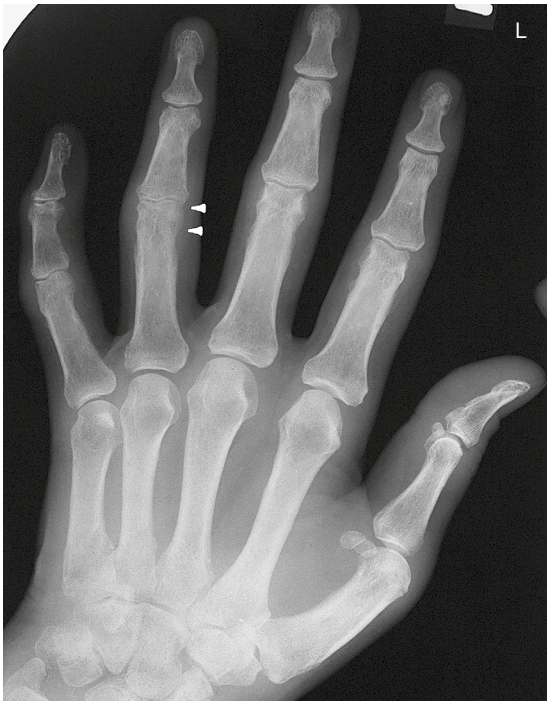


FIG. 2.26 Hand radiograph demonstrating soft tissue joint swelling associated with early rheumatoid arthritis *(arrowheads)*. (From American College of Radiology, Reston, Virginia.)

overgrowth of synovial tissue into the articular spaces. This severe damage makes the joint unstable and leads to deformity caused by displacement of the bones in the joint. The late changes of this condition may be quite severe, resulting in bone and cartilage destruction and subluxation or dislocation of the involved joint (Fig. 2.27). Eventually, the joints become ankylosed, which necessitates surgical intervention. Surgical procedures such as synovium excision, dislocation corrections, joint reconstructions, and prosthetic joint replacements may be performed to improve joint function (Fig. 2.28). New advancements in disease-modifying antirheumatic drugs (DMARDs) such as methotrexate and the availability of new biologic agents have enhanced the success of the management of RA. Diagnosis of RA in adults was originally based on the 1987 revised classification criteria of the American College of Rheumatology (ACR); however, in 2010, a new set of criteria was developed by the ACR and European League Against Rheumatism (EULAR). These new criteria present a specific approach for identifying patients earlier in the disease process so that intervening treatment may begin sooner. The 2010 criteria indicating the presence of RA are as follows:

- confirmed presence of synovitis in at least one joint;
- absence of an alternative diagnosis that better explains the synovitis;
- achievement of a total score of 6 or greater (out of a possible 10) from the individual scores in the following four domains:
  - number and site of involved joints (score range 0–5);
  - serologic abnormality (score range 0–3);
  - elevated acute-phase response (score 0–1);
  - symptom duration (2 levels, range 0–1).

Juvenile idiopathic arthritis (JIA), also known as Still disease, affects children under the age of 16 years and is similar to the adult form of RA. However, differences in the pattern of involvement and prognosis do exist. Generally, fibrosis and proliferation are less than in the adult form. It is estimated that JIA affects nearly 300,000 children in the United States. Symptoms include pain, swelling, and stiffness of the affected joint, with

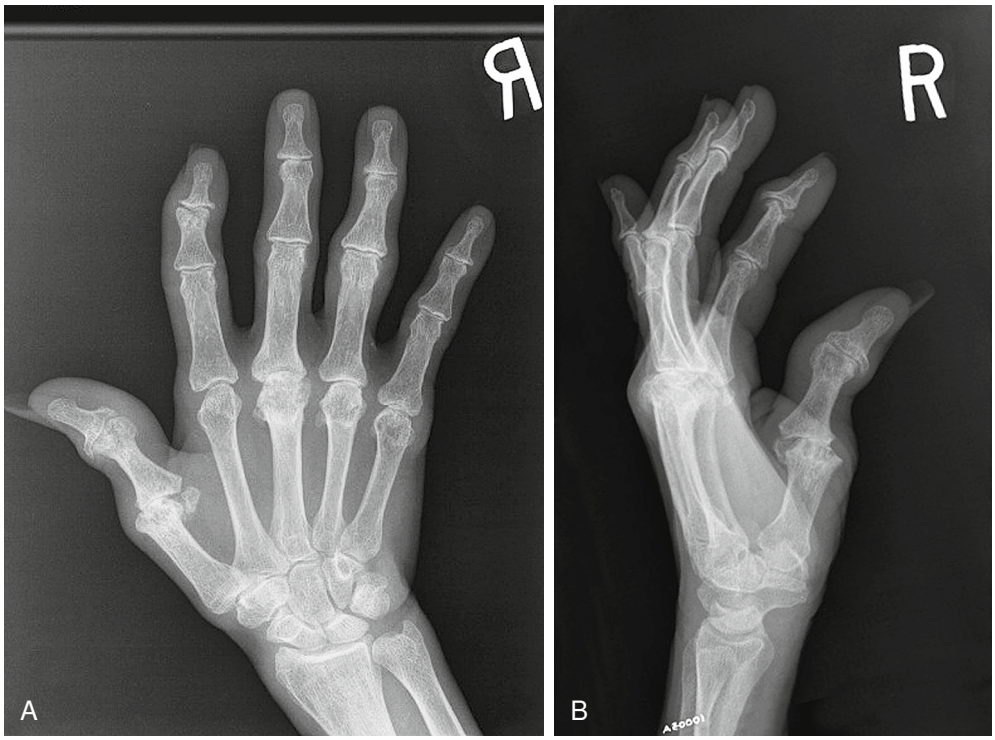


FIG. 2.27 A, Posteroanterior and B, lateral hand images demonstrating advanced rheumatoid arthritis with subluxation of the first metacarpophalangeal joint. (From The Ohio State University Wexner Medical Center, Columbus, Ohio; and Riverside Methodist Hospital, Columbus, Ohio.)

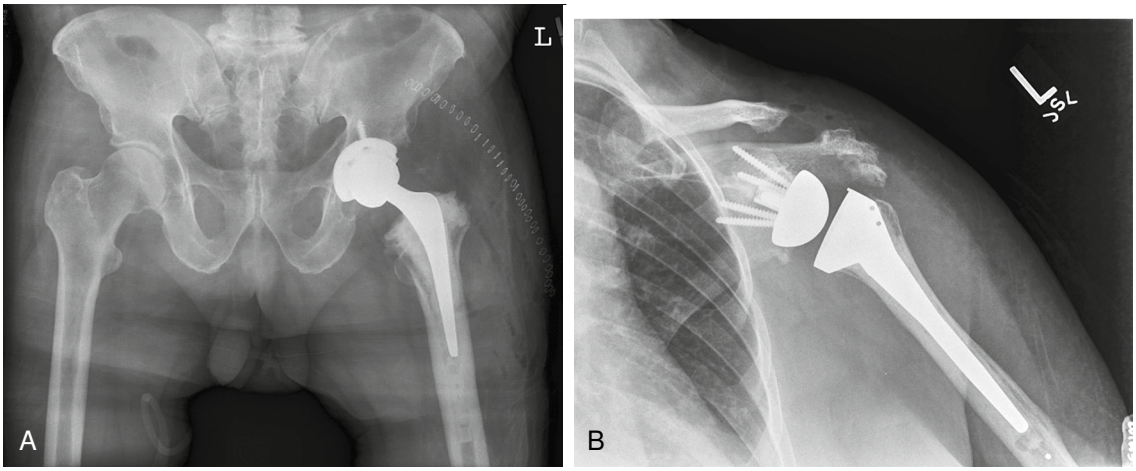


FIG. 2.28 A, Radiograph of an anteroposterior pelvis demonstrating proper placement of a prosthetic hip replacement. B, Radiograph of an oblique shoulder demonstrating proper placement of a prosthetic shoulder replacement. (From The Ohio State University Wexner Medical Center, Columbus, Ohio.)

periods of activity or exacerbations and remissions of the disease process. The majority of children have long periods of remission without significant joint damage. The prognosis is generally good, with fewer than 20% having progressive destructive disease. The ACR criterion for the diagnosis of JIA differs from that of adult RA. JIA is indicated if

- the child is younger than 16 years at the onset of the disease;
- symptoms of arthritis (swelling or effusion) are present in one or more joints for at least 6 weeks; and
- the onset can be assigned to one of several JIA onset types, including:
  - oligoarticular,
  - polyarticular,
  - systemic, or
  - enthesitis-related arthritis.

Oligoarticular JIA is the most common form and it is more common in females than in males. It affects five or fewer joints, most commonly the knee, ankle, and elbow joints. Polyarticular RA affects five or more joints, generally those in the hands, feet, and weight-bearing joints. Systemic JRA is the least common form of RA in children and it can affect many areas of the body, including joints and internal organs.

Reactive arthritis (Reiter syndrome) is a variant of RA occurring most commonly in young males and is associated with arthritis, urethritis, and conjunctivitis. It has been associated with bacterial infections of the gastrointestinal (GI) and genitourinary systems by organisms such as *Chlamydia trachomatis*, *Shigella*, *Salmonella*, *Yersinia*, or *Campylobacter*.

The sacroiliac joints, heels (calcanei), and toes are generally affected in this syndrome, sometimes referred to as "lover's heel." Although the radiographic appearance may mimic RA, Reiter syndrome affects the feet instead of the hands. It is characterized by asymmetric involvement of the joints of the lower extremities, ill-defined erosions of bone with adjacent areas of proliferation, and a tendency to produce heterotrophic bone.

Nuclear medicine bone scans are helpful in diagnosing early-stage reactive arthritis in all peripheral joints, especially small joints within the limbs, and the disease may be imaged before any findings are visible on a conventional radiograph. The preferred treatment is nonsteroidal antiinflammatory drugs (NSAIDs).

Ankylosing Spondylitis

Ankylosing spondylitis (Marie-Strümpell disease) is a progressive form of arthritis resulting in the chronic inflammation of axial ligaments characterized by initial laxity and progressive ankylosing, mainly involving the spine. In this disease, the joints become ankylosed, especially the sacroiliac joints. It tends to affect males between the age of 20 and 40 years and is believed to have a genetic predisposition because it is 20 times more common in the first-degree relatives of individuals known to have this disorder. Most commonly, an individual will

report low back pain of varying intensities, often nocturnal in nature and associated with morning stiffness. Other early signs and symptoms include low-grade fever, fatigue, weight loss, and anemia.

Early radiographic changes demonstrate bilateral narrowing and fuzziness of the sacroiliac joints. Eventually, the sacroiliac joints become obliterated and the condition progresses up the spine. Later radiographic changes show calcification of the bones of the spine and ossification of the vertebral ligaments. The articular cartilage is destroyed and fibrous adhesions develop. These adhesions lead to bone fusion and calcification of the annulus fibrosis of the intervertebral discs, as well as the anterior and lateral spinal ligaments. The spine becomes a rigid block of bone, giving the condition its characteristic nickname, "bamboo spine" (Fig. 2.29). In addition to radiographic indications, blood serum analysis is used in the diagnosis of ankylosing spondylitis. The human leukocyte antigen B27 (HLA-B27) test may be ordered individually or as part of a group of tests that includes RF, ESR, or CRP. Ankylosis spondylitis is treated with NSAIDs, cyclooxygenase 2 (COX-2) inhibitors, therapeutic exercise, and postural training.

Osteoarthritis

The most common type of arthritis is **osteoarthritis**, also known as *degenerative joint disease* (DJD). It affects males and females equally, although they are usually asymptomatic until they are in their 50s. Osteoarthritis is a disease of cartilage and is classified as *primary* or *secondary*. Primary osteoarthritis may be inflammatory or erosive and destructive, resulting from a non-inflammatory deterioration of the joint cartilage that occurs with normal wear and tear. In some cases, individuals may have a genetic predisposition for developing osteoarthritis. Secondary osteoarthritis occurs as a result of bone stress associated with trauma, congenital anomalies, or other diseases that alter the hyaline cartilage and surrounding tissue. Osteoarthritis generally affects the large, primary weight-bearing joints of the body such as the hip, where it is particularly disabling, or the knees and ankles (Fig. 2.30). Osteoarthritis may also affect the IP joints of the fingers. Osteoarthritis of the fingers, which is thought to be hereditary, affects females, especially after menopause, more than it affects men. With this condition, fingers become enlarged and often develop

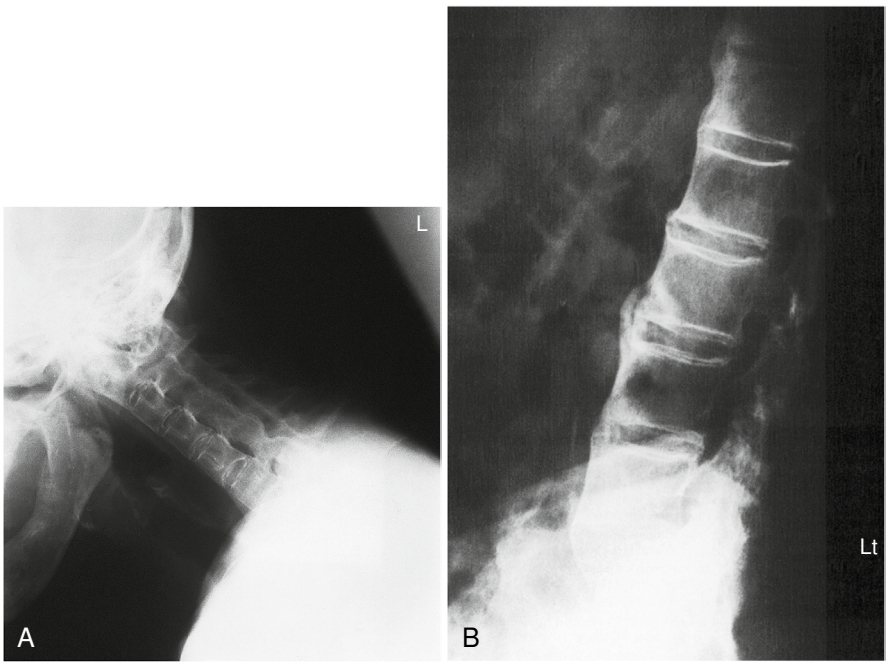


FIG. 2.29 A, Lateral cervical spine radiograph depicting ankylosing spondylitis with granulation tissue beneath the anterior longitudinal ligament destroying the corners of the contiguous vertebra. B, Lateral lumbar spine radiograph of a 64-year-old man with ankylosing spondylitis. Note the fusion of the vertebrae into a solid block of bone. (From American College of Radiology, Reston, Virginia.)

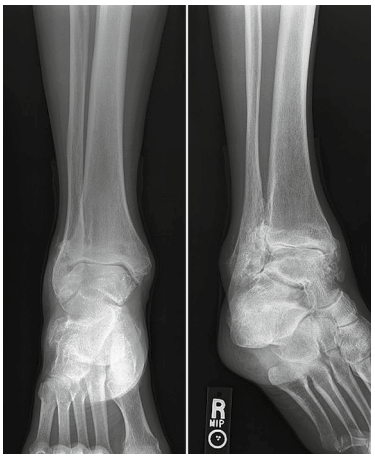


FIG. 2.30 Anteroposterior and oblique ankle radiographs demonstrating osteoarthritis. (From The Ohio State University Wexner Medical Center, Columbus, Ohio.)

bony knobs at the joints termed *Heberden nodes* at the DIP joints and *Bouchard nodes* at the proximal interphalangeal joints. Osteoarthritis of the fingers is most often managed with medications, splints, and heat treatments.

In joints affected by this disease, articular cartilage deteriorates and is gradually worn away, exposing underlying bone. Radiographically, this loss of articular cartilage appears as a narrowing of the joint space. An overgrowth of articular cartilage occurs on the peripheral surfaces of the joint and often calcifies, which results in **osteophytes** or bone spurs that are radiographically visible (Fig. 2.31). In terms of radiographic diagnosis, the formation of osteophytes is indicative of osteoarthritis and helps distinguish it from other types of arthritis.

Clinically, an individual with osteoarthritis experiences pain and progressive stiffening of the affected joint. Methods of slowing its gradual progression are few; it is second only to cardiovascular disease in causing long-term disability. Treatment consists of the use of medications such as NSAIDs, COX-2 inhibitors, and acetaminophen. Exercise is one of the best treatments to decrease pain, increase flexibility, and help with weight complication of gout is the formation of radiolucent kidney stones caused by increased excretion of uric acid by the kidneys. Treatment of gout consists of lifestyle control. The use of corticosteroid injections, walking aids, rest, and heat treatment may also be incorporated in the treatment regimen. Surgery may be used to resurface or reposition bones or remove loose pieces of bone or cartilage. In cases of severe pain, surgical prosthetic joint

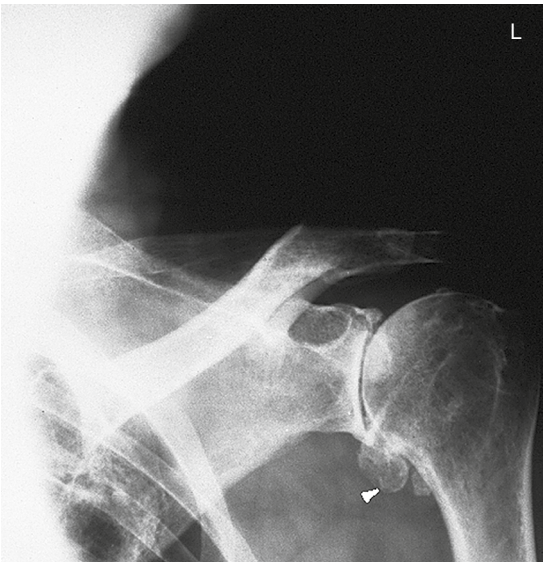


FIG. 2.31 Shoulder radiograph demonstrating the formation of an osteophyte at the inferior lip of the glenoid labrum *(arrowhead)* caused by primary osteoarthritis. (From American College of Radiology, Reston, Virginia.)

replacement provides great relief and allows return of joint mobility.

Gouty Arthritis

Gouty arthritis (gout) is one of the most common rheumatic diseases of adulthood, caused by a disorder in the metabolism of purine. Excess amounts of uric acid are produced and deposited in the joint and adjacent bone. The condition occurs more frequently in males, most commonly affects the metatarsophalangeal joint of the great toe, and is characterized by acute attacks with intervals of remission. This disease results from a combination of genetic, constitutional, and environmental factors, and may occur in individuals placed on long-term diuretics, for instance, to treat congestive heart failure.

The crystallization of uric acid within the joint causes an acute inflammatory reaction. Large masses of these sodium urate crystalline deposits in joints and other sites are called *tophi*. Bone changes include erosion (Fig. 2.32) with overhanging edges. One long-term complication of gout is the formation of radiolucent kidney stones caused by increased excretion of uric acid by the kidneys. Treatment of gout consists of lifestyle modifications and medications either to promote excretion of uric acid by the kidneys or to inhibit the production of uric acid within the body.

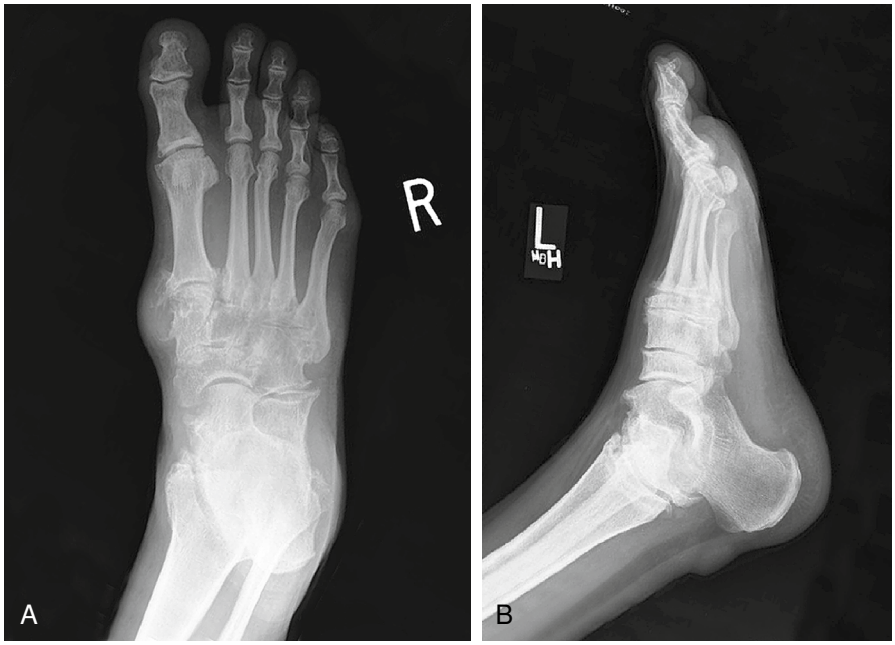


FIG. 2.32 A, Posteroanterior and B, lateral foot radiographs demonstrating erosion of the tarsal bones from gout. (From The Ohio State University Wexner Medical Center, Columbus, Ohio.)

Inflammation of Associated Joint Structures

The specialized connective tissues that attach muscle to bone are called *tendons*. Tendons are enclosed in a synovial sheath. **Tendonitis** is inflammation of a tendon, and inflammation of the tendon sheath is a condition known as **tenosynovitis** (Fig. 2.33). Tenosynovitis may spread to the associated tendon, resulting in tendonitis. Chronic tendonitis may also cause the formation of calcium deposits in either the affected tendon or an associated sheath. Such calcium deposits that form in the shoulder joint as a result of chronic trauma often cause rotator cuff tears, which can be detected by shoulder radiographs, shoulder arthrogram studies, and MRI examinations of the shoulder (Fig. 2.34). Bursae, which are sacs lined with a synovial membrane, are found in locations where tendons pass over bony prominences. If the bursa becomes inflamed, it is called **bursitis**. Inflammation of these associated structures may be caused by acute or chronic trauma (e.g., "housemaid's knee"), acute or chronic infection, inflammatory arthritis, gout, and, rarely, infection by pyogenic or tuberculous organisms. These inflammatory conditions are characterized by pain, localized tenderness, and limited motion of the involved joint. In cases of chronic bursitis, the walls of the bursa become thickened and calcium deposits may be radiographically visible within the bursa. Common areas for bursitis are the shoulder, elbow, knee (prepatellar), and greater trochanter of the hip.

Medical treatment of bursitis and tendonitis includes NSAIDs in combination with analgesics. In severe cases, aspiration of any accumulated fluid and corticosteroid injections may be included in the treatment. Surgical intervention is necessary when tendons or bursae ossify, especially in conjunction with rotator cuff tears. A **ganglion** is a cystic swelling that develops in connection with a tendon sheath or joint membrane (Fig. 2.35). Ganglions commonly occur around the dorsum of the wrist and on the fingers, but they can occur in any joint space. If symptomatic, ganglion cysts are treated with simple aspiration, aspiration with corticosteroid injection, or surgical excision.

NEOPLASTIC DISEASES

Many varieties of bone tumors are seen in persons of all ages; however, primary bone tumors are more common in children than in adults, and metastatic bone lesions far outnumber the incidence of primary bone neoplasms in the adult. The most common benign tumors are

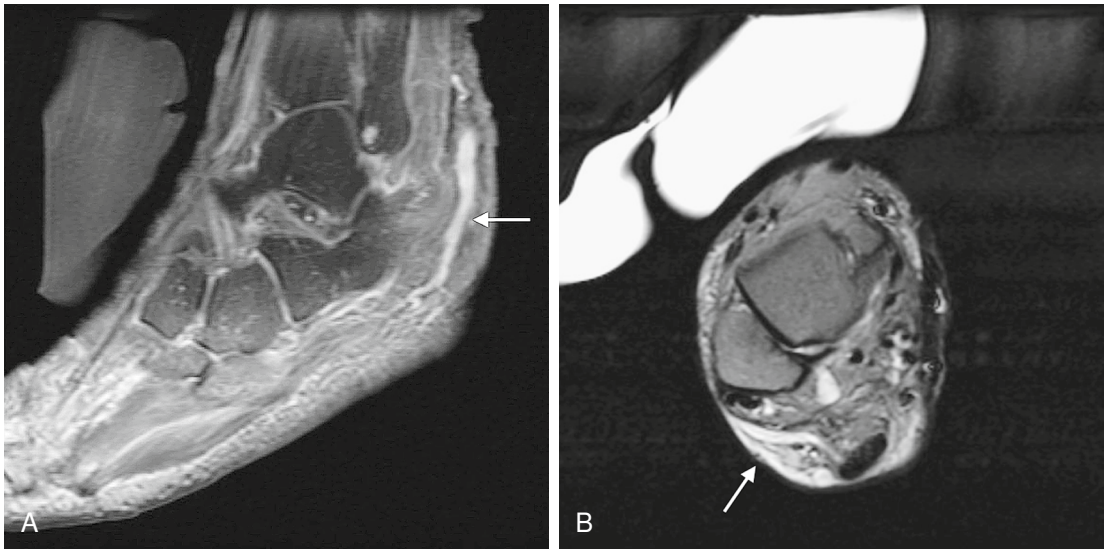


FIG. 2.33 Magnetic resonance imaging scans (A, sagittal; B, axial) of a right ankle demonstrate tenosynovitis involving the posterior tibialis muscle following a strain injury *(arrows)*. (From The Ohio State University Wexner Medical Center, Columbus, Ohio.)

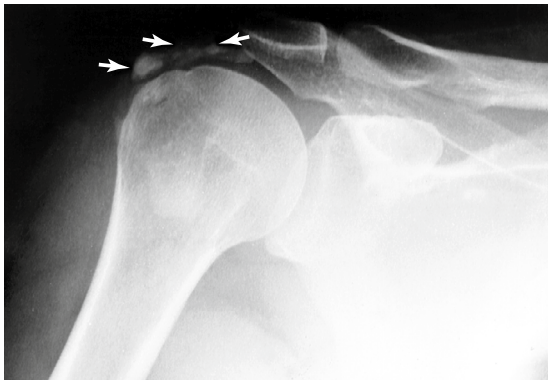


FIG. 2.34 Shoulder radiograph showing calcific tendonitis with small calcifications located over the superior and lateral portions of the humeral head *(arrows)*. (From Mettler FA: *Essentials of radiology*, ed 4, Elsevier, 2019.)

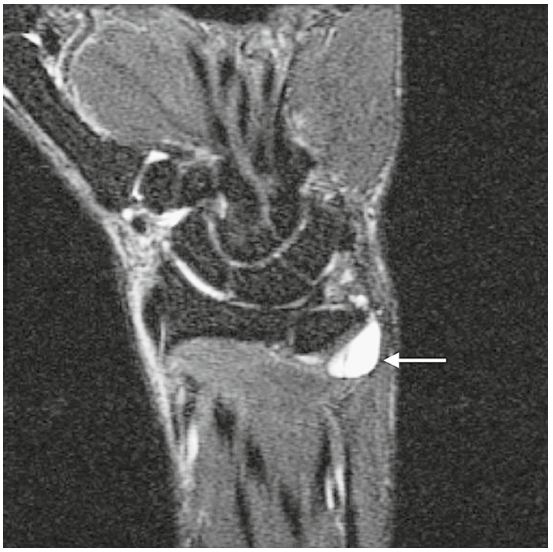


FIG. 2.35 Coronal magnetic resonance image of the wrist demonstrating a cystic lesion on the volar aspect of the wrist along the ulnar side *(arrow)*. (From Riverside Methodist Hospital, Columbus, Ohio.)

osteoma, osteochondroma, and giant cell tumor (GCT). The primary malignant bone tumors are osteosarcoma, Ewing sarcoma, and multiple myeloma (see Chapter 9).

The diagnosis of a bone abnormality is often made radiographically based on the individual's age, the pattern of bone destruction, the location of the tumor, and the tumor's position within the bone. In terms of age, benign tumors and most primary bone tumors occur within the first three decades of life; a bone tumor in older adults is likely to be malignant. The pattern of bone destruction in benign lesions is expansion of bone and sharp, sclerotic margins. Malignant neoplasms often infiltrate, permeate, and destroy anatomic margins. The location of a tumor is also important. For example, half of all osteosarcomas appear in the distal femoral or proximal tibial metaphysis. Similarly, **chondrosarcomas**

tend to involve the trunk, shoulder girdle, and proximal long bones.

Bone tissue markers such as alkaline phosphatase, osteonectin, osteocalcin, and collagen can be used to monitor the activity and treatment of bone neoplasms. However, because the levels of bone turnover markers vary from person to person and can vary according to the time of day, diagnostic imaging may be more beneficial for a proper diagnosis.

Radiographic studies contribute greatly to the diagnosis and management of patients with bone tumors. Radiographs are used to disclose the lesions and show the growth characteristics that assist in determining their benign or malignant nature. In conjunction with CT, plain radiographs identify malignant growth patterns and the proper site for biopsy. Sometimes, seemingly unrelated examinations such as a barium enema or chest radiograph may be ordered by the physician to rule out distant metastases.

CT plays a key role in the primary diagnosis and continued evaluation of neoplasms of the skeletal system because of its ability to produce images with excellent soft tissue and contrast resolution. Sectional images of the area of interest provide physicians with the exact location and extent of the specific tumor, allowing the surgeon to identify the optimal surgical procedure and possibly limiting the surgical resection of the affected bone as well as assisting in the postsurgical management of the disease process. CT is also commonly used to assist during bone biopsy procedures.

As mentioned earlier in this chapter, radionuclide bone scans are helpful in assessing neoplastic diseases because the bone scan reflects the metabolic reaction of bone to the neoplastic disease process. Nuclear medicine procedures may also be performed during the initial stages of treatment planning to identify possible metastatic involvement of other anatomic sites as well as post-treatment follow-up to monitor effectiveness of the treatment.

Because cortical bone does not produce a signal, MRI clearly demonstrates fat and bone marrow due to the abundance of hydrogen protons in fat and water. The differentiation is due to the increased fluid related to the response of the pathology in the tissue being imaged. This information is helpful in differentiating between normal bone marrow and tumor tissue in the assessment of many neoplastic diseases of the skeletal system.

It is important to note that many neoplastic lesions may have similar radiographic appearances or are difficult to differentiate with imaging procedures alone. Therefore, the final diagnosis must include a biopsy of the abnormality. Some biopsies may be performed under CT, MRI, or fluoroscopic guidance, whereas others must be performed surgically to obtain sufficient tissue for analysis. Histopathologic diagnosis is required for a definitive diagnosis.

A staging system for both benign and malignant bone tumors was developed by Enneking in 1980. Arabic numerals are used for benign lesions (1, 2, 3) and Roman numerals (I, II, III) for malignant lesions. For benign lesions, three stages exist: (1) stage 1, which includes benign, inactive tumors; (2) stage 2, in which the bone tumor is benign but active; and (3) stage 3, which includes aggressive benign lesions with bone destruction, soft tissue extensions, or pathologic fractures. Malignant bone lesions need to be staged after biopsy and histologic analysis have been done. Staging for malignant skeletal lesions includes histologic grade (low G1 or high G2), local extent of tumor (intracompartmental T1 or extracompartmental T2), and presence or absence of metastatic disease. The classification examples of IA, IB, IIA, IIB, III, and so on are assigned based on the tumor characteristics, lymph node involvement, metastasis, and grade of the neoplasm.

Osteochondroma (Exostosis)

The most common benign bone tumor is **osteochondroma** (Fig. 2.36), which is slightly more common in males than in females. An osteochondroma arises from

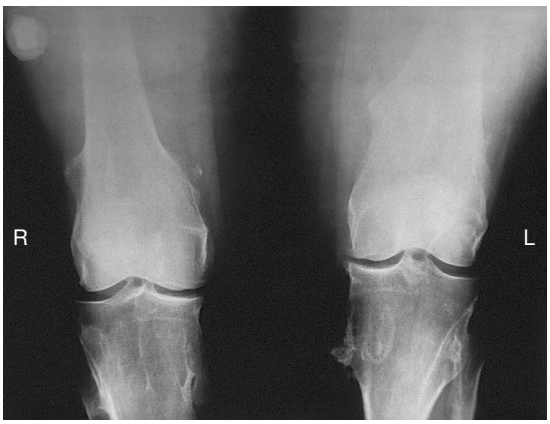


FIG. 2.36 Bilateral anteroposterior knee radiographs demonstrating osteochondroma with exostoses within the knee joint. (From The Ohio State University Wexner Medical Center, Columbus, Ohio.)

the growth zone between the epiphysis and diaphysis of long bones, also called the *metaphysis*. Most commonly, it involves the lower femur or upper tibia and is capped by growing cartilage attached to the skeleton by a bony stalk. The cortex of an osteochondroma blends with normal bone, and the growth tends to protrude up and away from the nearest joint, most commonly the knee. **Exostoses** is excessive bone proliferation that deforms the bone found in immature skeletons of children and adolescents. These growths may appear as singular or multiple lesions. Multiple hereditary exostoses (MHE) is an inherited disorder that usually appears at an earlier age than compared with the single-lesion osteochondroma. MHE has been linked to mutations in the following genes: *EXT1* on chromosome 8q23-q24, *EXT2* on chromosome 11p11-p12, and *EXT3* on the short arm of chromosome 19. It is theorized that the *EXT* genes also have the function of tumor suppression. In addition, MHE may transform into malignant neoplasms such as chondrosarcoma. Osteochondromas are often asymptomatic unless the affected long bone is traumatized, which results in a pathological fracture of the diseased bone. An osteochondroma has an osteosclerotic or osteoblastic radiologic appearance. CT and MRI are used in initial differentiation between an osteochondroma and a malignant lesion.

Osteoma

An **osteoma** is a less frequent benign growth most commonly located in the skull. These lesions are composed of very dense, well-circumscribed, normal bone tissue that usually projects into the orbits or paranasal sinuses. They are generally slow-growing tumors of little significance unless they cause obstruction, impinge on the brain or eye, or interfere with the oral cavity. **Hyperostosis frontalis interna** is a very rare form of osteoma which presents with irregular thickening of the frontal bone

Osteoid Osteoma and Osteoblastoma

Other common benign tumors of the skeletal system are **osteoid osteoma** and **osteoblastoma**. Although similar in histologic features, they differ in size, origin, and symptoms. Osteoid osteomas are less than 2 cm in dimension, whereas osteoblastomas are larger. Osteoblastomas more frequently involve the spine, and pain is less severe than osteoid osteoma or may not be present. Furthermore, they are not associated with a marked bone reaction or new bone production and are classified radiographically as osteolytic lesions. Osteoblastomas have a higher recurrence rate compared with osteoid osteomas and, in rare cases, may undergo malignant transformation to osteogenic sarcoma.

Osteoid osteomas occur twice as often in males than in females, and almost always develop before the age of 30 years. It has been discovered that genetic markers include an elevated amount of E2 but may also include F2 alpha, 6-keto-F1 alpha, and thromboxane B2. Osteoid osteomas are most commonly found in the femur, tibia, or spine of the young adult. They arise within the cortical bone and erode underlying bone tissue, resulting in a lytic lesion called a *nidus*. The area of erosion is surrounded by a zone of dense, sclerotic bone, making the radiographic appearance of osteoid osteomas very distinctive (Fig. 2.37). Osteoid osteomas are characterized radiographically by a central radiolucent nidus surrounded by dense reactive sclerosis, thus this tumor is classified as an osteosclerotic lesion. CT is the modality of choice because of its value in identifying, localizing, and providing biopsy guidance in

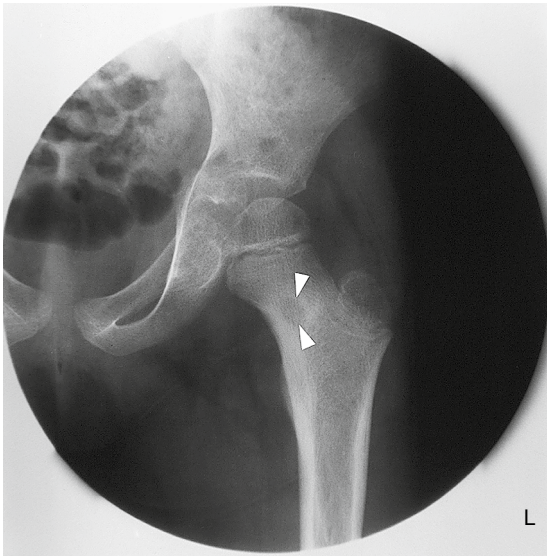


FIG. 2.37 Anteroposterior hip radiograph of a 7-year-old girl who complained of a 2-month history of pain. The radiograph demonstrates an osteoid osteoma as evidenced by the well-defined defect in the cortical area of the femoral neck *(arrowheads)*. (From The Ohio State University Wexner Medical Center, Columbus, Ohio.)

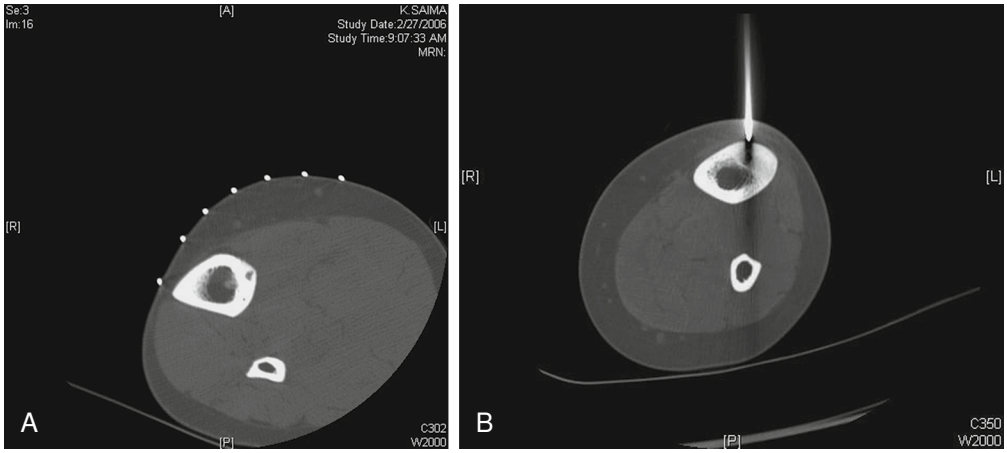


FIG. 2.38 A, Axial computed tomography (CT) scan demonstrating an osteoid osteoma in preparation for B, CT-guided needle biopsy. (From American College of Radiology, Reston, Virginia.)

the diagnosis of osteoid osteomas (Fig. 2.38). MRI is also a common modality used to assist in the diagnosis (Fig. 2.39). The erosion of surrounding tissue and the presence of prostaglandin and nerve fibers in the nidus cause extreme pain, often at night, which is readily relieved by NSAIDs. CT-guided laser ablation and surgical removal are common treatments for these benign lesions.

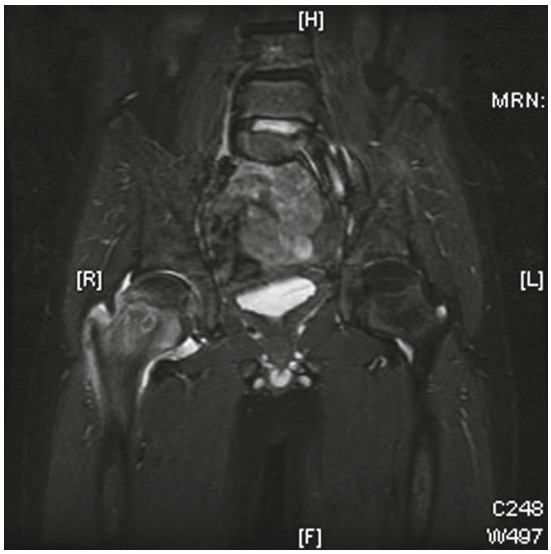


FIG. 2.39 Coronal magnetic resonance images demonstrating an osteoid osteoma in the right femoral neck. (From The Ohio State University Wexner Medical Center, Columbus, Ohio.)

Enchondroma

An **enchondroma** is a slow-growing intramedullary benign tumor composed of mature hyaline cartilage and is hypothesized to be a result of incomplete endochondral ossification. It grows in the marrow space and most commonly affects the tubular bones of the hands and feet of individuals between the ages of 30 and 40 years. These locally aggressive tumors do not invade surrounding tissue as they grow; however, they do expand the cortical bone, causing thinning. Radiographically, enchondromas appear as small radiolucent lesions containing small, stippled calcifications with sharply defined margins (Fig. 2.40). In the majority of cases, enchondromas remain asymptomatic and require no treatment. However, the erosion of the cortex may cause pain and swelling and increase the incidence of pathological fractures. Multiple growths, principally located in the metaphyseal regions, are termed *enchondromatosis* (Ollier disease). Enchondromatosis presents in childhood and, like multiple osteochondromas, may undergo malignant transformation with a risk of 25% to 30%. CT and MRI are useful in distinguishing enchondromas from chondrosarcomas, and both modalities may be used to guide a biopsy of the neoplasm.

Simple Unicameral Bone Cyst

A **simple unicameral bone cyst** (UBC) is a benign, fluid-filled cavity in the bone lined with compressed fibrous tissue. These frequently occur in the long bones of children, most commonly in the humerus and proximal

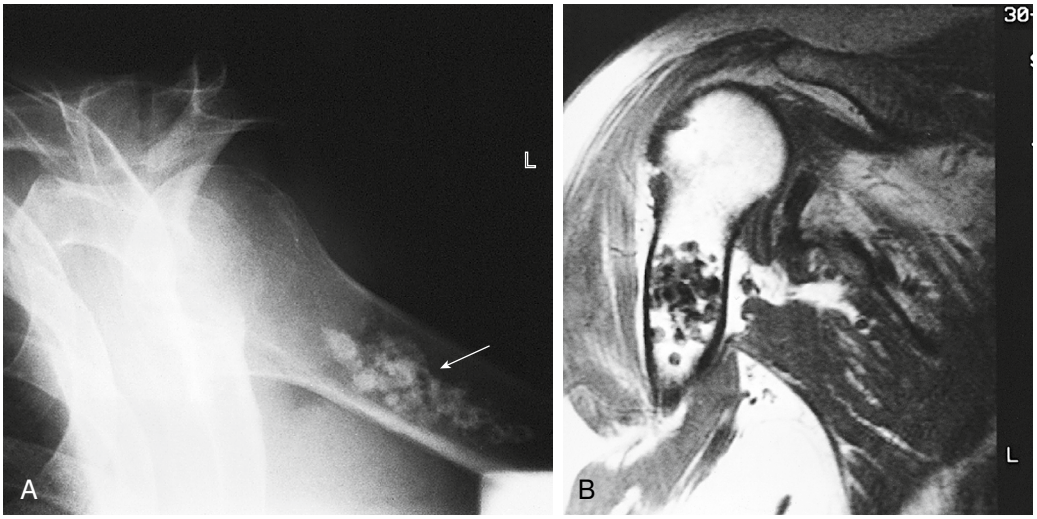


FIG. 2.40 A, Conventional shoulder radiograph in a 66-year-old man demonstrates calcification in the proximal diaphysis of the right humerus *(arrow)*. B, Follow-up magnetic resonance image demonstrates an intramedullary lesion without breakthrough of the cortex, consistent with an enchondroma. (From American College of Radiology, Reston, Virginia.) (Riverside Methodist Hospital, Columbus, Ohio.)

femur. Eighty percent of all simple bone cysts occur between 3 and 14 years of age and twice as often in males as in females. The cyst is usually first noticed when the person reports pain caused by increased growth or as a result of a pathological fracture.

Radiographically, UBCs appear radiolucent, with well-defined margins from normal bone surrounding the lesion (Fig. 2.41). In the majority of cases, the cyst is surrounded by a thin rim of sclerotic bone with no periosteal reaction. Small cysts tend to heal and obliterate themselves, whereas larger cysts require surgical intervention. The benign bone cyst is treated by surgical excision and packing with bone chips to obtain complete healing. Introduced in the 1970s, percutaneous steroid injection into the lesion is another form of treatment that is inexpensive and has a decreased morbidity rate compared with surgical intervention.

Aneurysmal Bone Cyst

An **aneurysmal bone cyst** (ABC) is a benign multiloculated cystic lesion of bone consisting of numerous blood-filled arteriovenous communications. These cysts are locally aggressive and generally occur in the metaphysis of long bones in individuals under the age of 20 years. Vertebral lesions usually occur in the lumbar region and account for 15% to 20% of ABCs. Following the Human Genome Project, it has been discovered that this bone cyst is most likely caused by translocation of 17p13 and overactivity of the oncogene *USP6* (ubiquitin-specific protease). ABCs are slow-growing lesions that present as pain and swelling at the site of the cyst. This cystic growth causes a thinning of the cortex that is apparent radiographically and as a well-circumscribed lesion associated with soft tissue extension and periosteal bulging. A bone scan demonstrates peripheral uptake with a centralized decreased uptake. Angiography shows persistent accumulation of contrast media throughout the cyst. CT and MRI may also be used for imaging ABCs. CT better delineates the cyst in the vertebral column, and MRI shows fluid levels or the presence of a soft tissue mass. The most common treatment of an ABC is surgical removal of the lesion and subsequent bone grafting; however, radiation therapy may be used for treatment in some areas in the vertebral region where surgical removal is difficult. Caution is used with radiation therapy because of the risk of postradiation malignancies.

Giant Cell Tumor (Osteoclastoma)

Giant cell tumors (GCTs) are locally aggressive neoplasms characterized by the presence of numerous, multinucleated osteoclastic giant cells. GCTs of the tendon sheath are the second most common benign soft tissue lesions of the hand and wrist. Unlike the previously mentioned neoplastic diseases, GCTs may be either benign or

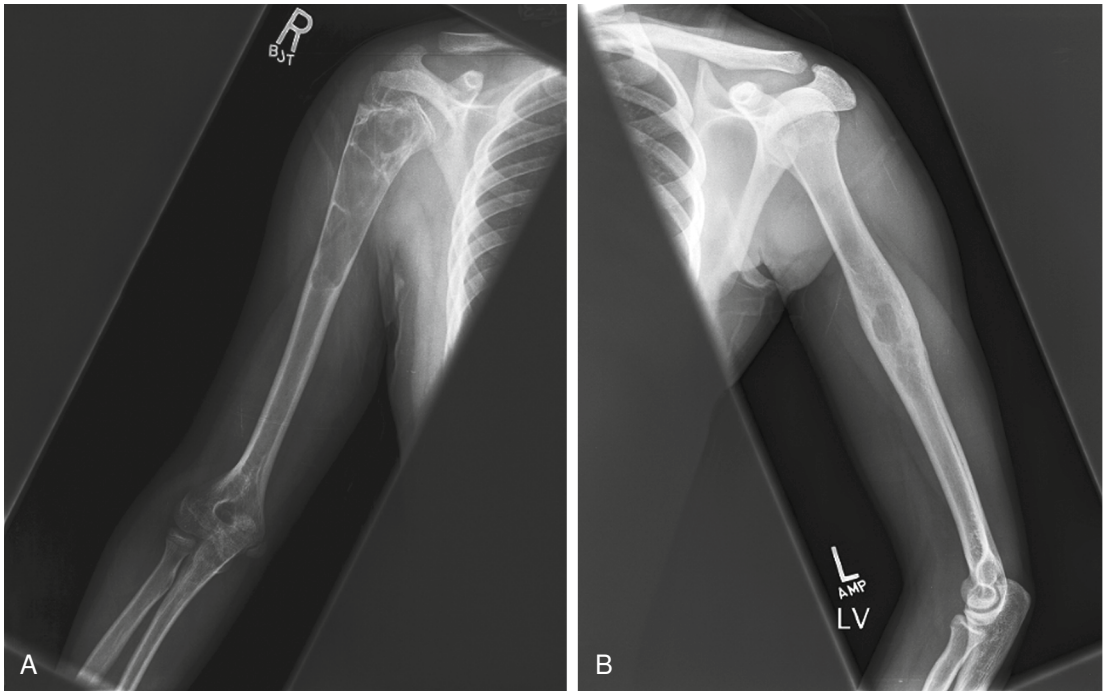


FIG. 2.41 A, Anteroposterior (AP) projection demonstrating multiple well-circumscribed radiolucencies in the proximal humerus consistent with a simple unicameral bone cyst. B, AP humerus radiograph demonstrating a well-circumscribed radiolucency midshaft consistent with a simple unicameral bone cyst. (From The Ohio State University Wexner Medical Center, Columbus, Ohio.)

malignant. Approximately 50% of **osteoclastomas** are benign, 35% to 50% recur after surgical excision, and 15% are aggressively malignant from the beginning. This neoplasm is mildly more prominent in females than in males, and is found in individuals between the ages of 20 and 30 years. Anatomically, this disease tends to affect the epiphyseal-metaphyseal regions of long bones, especially the lower femur, the upper tibia, and the lower radius. Osteoclastomas are eccentrically situated with bony expansion, cortical thinning and erosion. In addition, soft tissue extensions may be present, but the GCT does not involve the joint space.

Clinical signs and symptoms of a GCT are nonspecific and include pain, tenderness, an occasional palpable mass, and an occasional pathological fracture. Because this is an osteoclastic disease process, bone and cartilage formation generally do not occur in these lesions; therefore, the radiographer must decrease exposure factors to avoid overpenetration of the affected bone. Radiographically, a GCT is a mass of osteolytic or cystic areas surrounded by a thin shell of bone, giving it the classic "soap bubble" appearance (Fig. 2.42). Cystic blood-filled cavities within the tumor are also common.

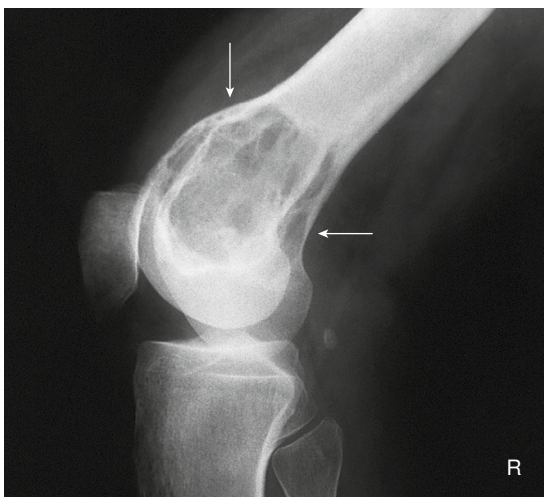


FIG. 2.42 Lateral knee radiograph of a 30-year-old man who complained of a painful knee for approximately 2 months. The radiograph demonstrates a benign osteoclastoma of the knee *(arrows)*. (From The Ohio State University Wexner Medical Center, Columbus, Ohio.)