Essentials of Orthopedic Surgery

Third Edition

Essentials of Orthopedic Surgery

Third Edition

Edited by

Sam W. Wiesel, MD

Professor and Chairman, Department of Orthopaedic Surgery, Georgetown University Medical Center, Washington, DC

John N. Delahay, MD

Peter and Rose Rizzo Professor and Vice Chairman, Department of Orthopaedic Surgery, Georgetown University Medical Center, Washington, DC

Springer

Sam W. Wiesel, MD
Professor and Chairman
Department of Orthopaedic Surgery
Georgetown University Medical Center
Washington, DC 20007
USA

John N. Delahay, MD
Peter and Rose Rizzo
Professor and Vice Chairman
Department of Orthopaedic Surgery
Georgetown University Medical Center
Washington, DC 20007
USA

Library of Congress Control Number: 2006920066

ISBN-10: 0-387-32165-9
ISBN-13: 978-0387-32165-3

Printed on acid-free paper.

First edition, Essentials of Orthopaedic Surgery © 1993 W.B. Saunders Company.
Second edition, Essentials of Orthopaedic Surgery © 1997 W.B. Saunders Company.

9 8 7 6 5 4 3 2 1

springer.com

This text is dedicated to
Star Conway Wiesel and Elizabeth Jane Delahay
as they begin their nursing careers.
These two very capable, caring young people
represent the bright future of health care.

Sam W. Wiesel, MD
John N. Delahay, MD

Preface

The third edition of the *Essentials of Orthopedic Surgery* provides a concise overview of orthopedic surgery directed toward third- and fourth-year medical students. In this edition, physical diagnosis is a subsection in each chapter, which we believe gives better continuity. Additionally, at the end of each chapter we have created a number of multiple-choice questions considered appropriate for medical students to be able to answer.

Each chapter has been revised to reflect updated material and, as in previous editions, we have kept to a standardized format as much as possible. The topics are presented from a straightforward practical point-of-view, with the material being condensed to its most salient features.

Algorithms are at the heart of each chapter, with the decision points being based on practice standards and guidelines. This format allows the student, when confronted with a specific clinical problem, to formulate both a diagnostic plan and a treatment plan.

Also, we have enjoyed working with our new publisher—Springer—and with Robert Albano as well as Sadie Forrester, who have guided this text to publication.

Finally, and most importantly, it has been again a very exciting and stimulating experience to work with all the members of the Department of Orthopaedics of Georgetown University Medical Center. Since the last edition we have welcomed seven new members to the faculty, each a subspecialist. Everyone has given very generously of their time. We are most appreciative of each contribution and are proud of the final text.

Sam W. Wiesel, MD
John N. Delahay, MD

Contents

† Deceased.

Contributors

Alan D. Aaron, MD[†]
Associate Professor, Department of Orthopaedic Surgery, Georgetown University Medical Center, Washington, DC 20007, USA

Raymond M. Carroll, MD
Assistant Professor, Department of Orthopaedic Surgery, Georgetown University Medical Center, Washington, DC 20007, USA

Paul S. Cooper, MD
Associate Professor, Department of Orthopaedic Surgery, Georgetown University Medical Center, Washington, DC 20007, USA

John N. Delahay, MD
Peter and Rose Rizzo Professor and Vice Chairman, Department of Orthopaedic Surgery, Georgetown University Medical Center, Washington, DC 20007, USA

Brian G. Evans, MD
Associate Professor and Vice Chairman for Operations and Finance, Department of Orthopaedic Surgery, Georgetown University Medical Center, Washington, DC 20007, USA

Mustafa A. Haque, MD
Assistant Professor, Department of Orthopaedic Surgery, Georgetown University Medical Center, Washington, DC 20007, USA

Kristen Kellar-Graney, BS
Graduate Student, Interdisciplinary Tumor Biology Training Department, Georgetown University, Washington, DC 20007, USA

[†] Deceased.

John J. Klimkiewicz, MD
Assistant Professor, Department of Orthopaedic Surgery, Georgetown University Medical Center, Washington, DC 20007, USA

William C. Lauerman, MD
Professor, Department of Orthopaedic Surgery, Georgetown University Medical Center, Washington, DC 20007, USA

Martin Malawer, MD
Professor, Department of Orthopaedic Surgery, Georgetown University Medical Center, Washington, DC 20007, USA

Scott T. Sauer, MD
Instructor, Department of Orthopaedic Surgery, Georgetown University Medical Center, Washington, DC 20007, USA

Steven C. Scherping, Jr., MD
Assistant Professor, Department of Orthopaedic Surgery, Georgetown University Medical Center, Washington, DC 20007, USA

Sam W. Wiesel, MD
Professor and Chairman, Department of Orthopaedic Surgery, Georgetown University Medical Center, Washington, DC 20007, USA

1
Basic Science of Bone and Cartilage Metabolism

John N. Delahay

Normal Bone Growth and Development

Bone is a biphasic connective tissue consisting of an inorganic mineral phase and an organic matrix phase. The hardness of bone allows it to provide several specialized mechanical functions: the protection of internal organs, the scaffold that provides points of attachment for other structural elements, and the levers needed to improve the efficiency of muscle action. In addition, bone serves two biologic functions: a site for hematopoietic activity and a reservoir of minerals needed for metabolic interchange.

Embryology

The major components of the musculoskeletal system originate from the mesoderm layer of the trilaminar embryo. This "middle layer" is populated by mesenchymal cells that are totipotent and capable of differentiating into a number of tissues. The sequence of events important in bone growth and development begins with the appearance of the limb bud around the fifth week of life. It is at that time that a tubular condensation of mesenchyme develops centrally in the limb bud. Discrete areas, called interzones, are seen between these condensations (Fig. 1-1) and represent the primitive joints.

During the sixth week, the mesenchyme differentiates into cartilage through the process of chondrification (Fig. 1-2). Interstitial and appositional growth occurs from within and from the surface, respectively. In the seventh week, the cartilage model is penetrated by a vascular spindle, which occurs coincidentally with the necrosis of the central cartilage cells. Once this vascular spindle is established, the central portion of the model is populated by osteoblasts. Matrix is secreted and this in turn is ossified, making immature (woven) bone.

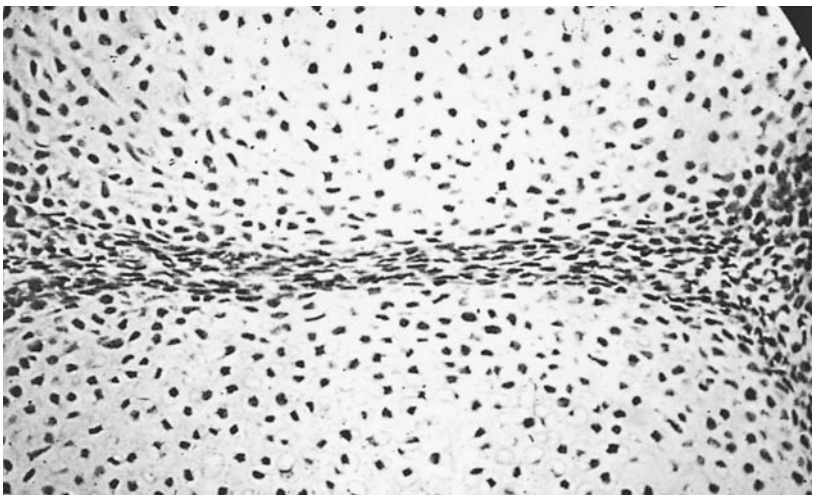


FIGURE 1-1. Histologic study of fetus, approximately 6 weeks gestation, depicting early joint formation. Note the identifiable cartilage and the condensed mesenchymal tissue of the interzone destined to become the joint. (From Bogumill GP. Orthopaedic Pathology: A Synopsis with Clinical Radiographic Correlation. Philadelphia: Saunders, 1984. Reprinted by permission.)

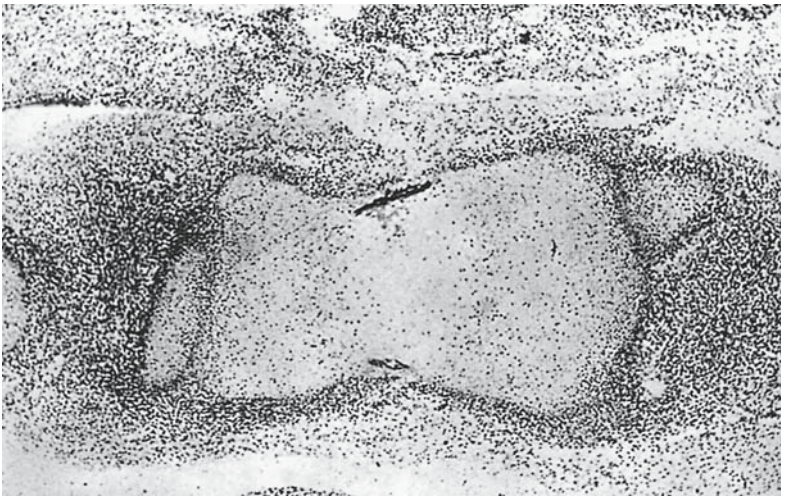


FIGURE 1-2. Histologic study of fetus, approximately 8 weeks gestation. Earliest ossification is depicted here. A sleeve, or collar, of bone is present on the outer surface of the cartilage model. (From Bogumill GP. Orthopaedic Pathology: A Synopsis with Clinical Radiographic Correlation. Philadelphia: Saunders, 1984. Reprinted by permission.)

Once the central portion of the model is ossified, it is referred to as a primary ossification center (Fig. 1-3). Further ossification of the skeleton occurs via one of two mechanisms: (1) enchondral ossification within a cartilage model (i.e., long bones), and (2) intramembranous ossification within a mesenchymal model (i.e., most flat bones and the clavicle).

From the second through the sixth embryonic months, progressive changes occur in the tubular bones. First, the central (medullary) canal cavitates, leaving a hollow tube of bone with a large mass of cartilage persisting at each end (Fig. 1-4). Within these masses of cartilage, the secondary ossification center, or epiphysis, will form (Fig. 1-5). A cartilage plate, the physis or growth plate (Fig. 1-6), persists between the developing epiphysis and metaphysis. This structure is responsible for growth in length, whereas the covering of the bone, the periosteum, is primarily responsible for growth in girth.

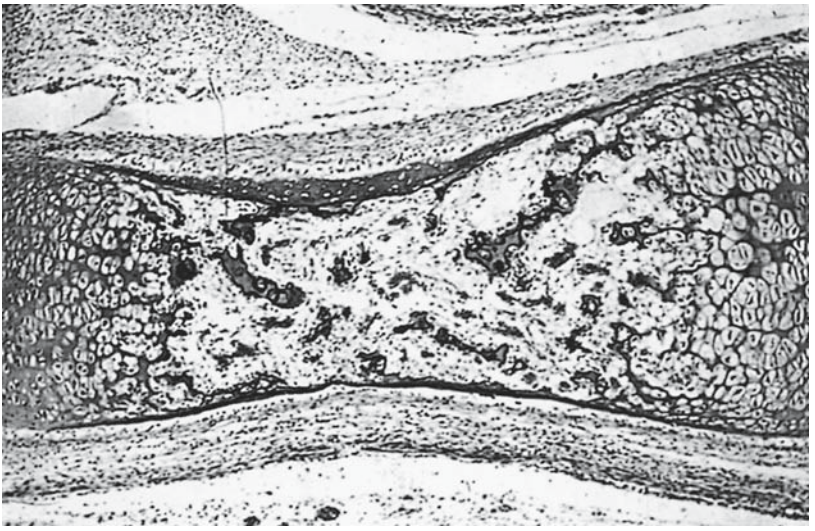


FIGURE 1-3. Primary ossification center of fetus, approximately 14 weeks gestation. The cartilage cells have been removed almost entirely from the center, leaving remnants of acellular cartilage matrix. Bone deposits on the cartilage remnants will form primary trabeculae. Note that the primary sleeve, or collar, of bone has extended along both margins and is located adjacent to the hypertrophied cartilage at each epiphyseal end. (From Bogumill GP. Orthopaedic Pathology: A Synopsis with Clinical Radiographic Correlation. Philadelphia: Saunders, 1984. Reprinted by permission.)

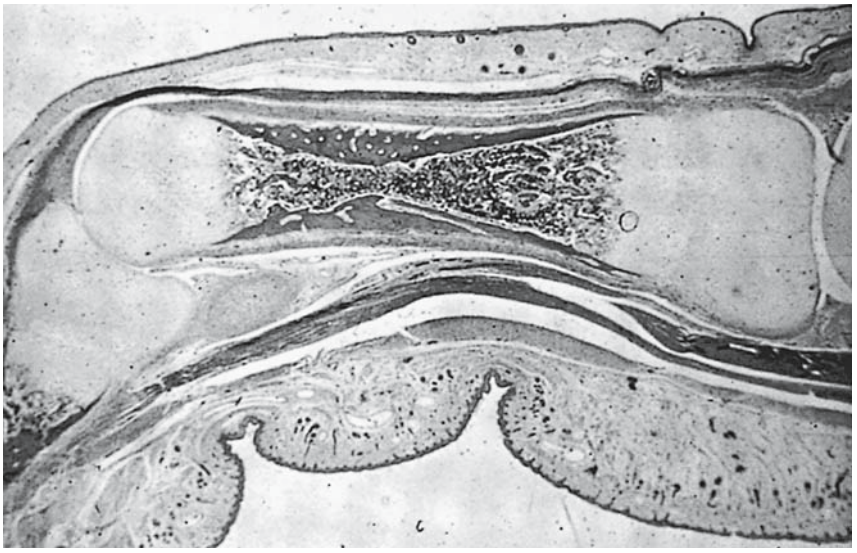
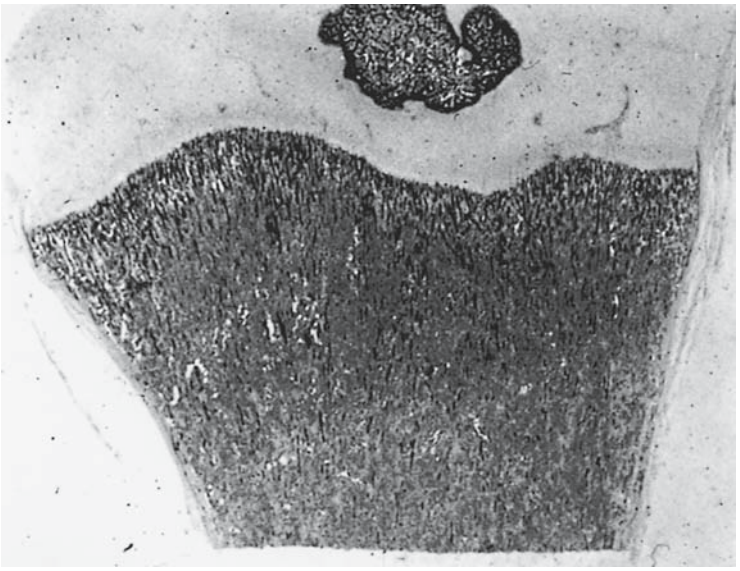


FIGURE 1-4. Primary ossification center, near term. There is complete replacement of cartilage in the diaphyseal portion of the cartilage model. The remaining cartilage is confined to both epiphyseal ends of the model. Note the increasing thickness of the cortical portion of bone, which is a result of conversion of periosteum to bone. A light-staining cambium layer is identifiable. The narrowest portion of the shaft is the site of initial vascular invasion and remains identifiable throughout life in many bones, especially in hands and feet. The eccentric position of this narrowed area indicates the disproportionate contribution to growth in length from each epiphysis. (From Bogumill GP. Orthopaedic Pathology: A Synopsis with Clinical Radiographic Correlation. Philadelphia: Saunders, 1984. Reprinted by permission.)



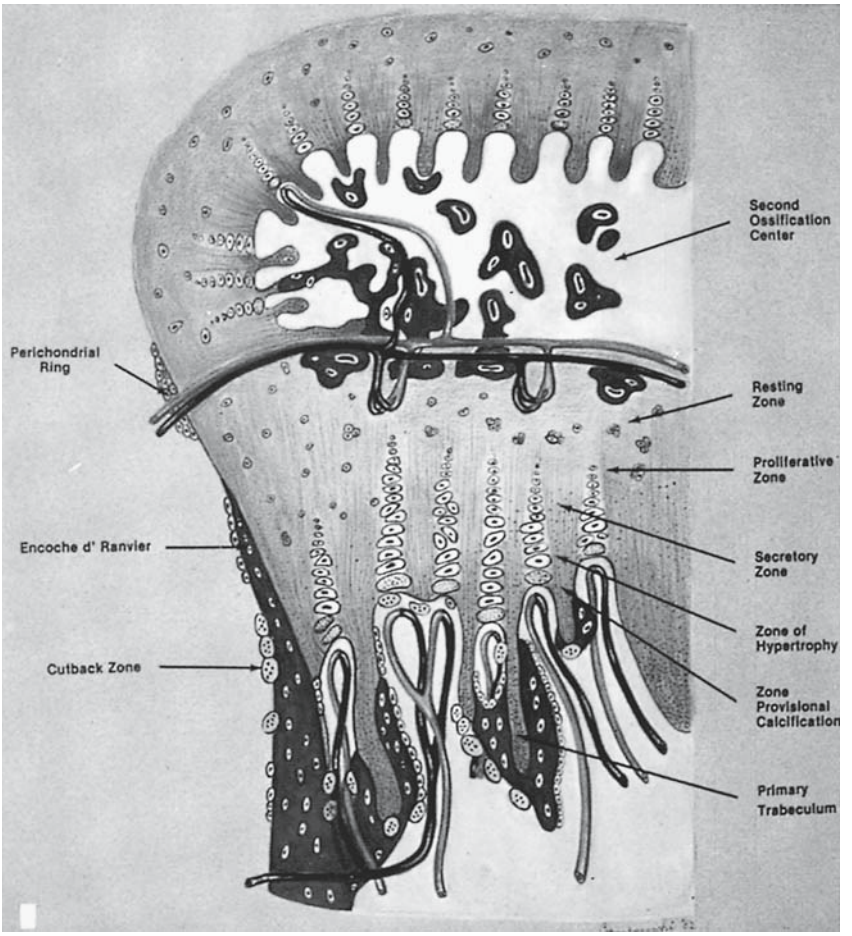


FIGURE 1-6. Schematic diagram of growth plate, consisting of resting zone, proliferative zone, secretory zone, zone of hypertrophy, and zone of calcification. The cross-sectional view helps place events at the growth plate in three-dimensional perspective. (From Bogumill GP. Orthopaedic Pathology: A Synopsis with Clinical Radiographic Correlation. Philadelphia: Saunders, 1984. Reprinted by permission.)

FIGURE 1-5. Early secondary ossification center of mature fetus. The formation of the secondary ossification centers in the lower tibia and upper femur coincide with fetal maturity. The secondary center begins not in the center of the epiphysis but nearer the growth plate. Expansion, therefore, is eccentric. (From Bogumill GP. Orthopaedic Pathology: A Synopsis with Clinical Radiographic Correlation. Philadelphia: Saunders, 1984. Reprinted by permission.)

Postnatal Development

The physis and the periosteum continue to function postnatally in the growth and development of the infantile skeleton. Numerous local and systemic factors impact on their activity; vascular, hormonal, and genetic effects all play important roles. In essence, the reworking or remodeling of bone that is already present occurs so that the bone can meet the mechanical and biologic demands placed on it.

Bone: The Tissue

Bone, whether it is immature or mature, consists of cells and a biphasic blend of mineral and matrix that coexist in a very exact relationship. The matrix phase consists of collagen and glycosaminoglycans, which are dimeric disaccharides. Both are products of the osteoblast. Calcium hydroxyapatite is the basic mineral crystal in bone. Despite the presence of some less structured amorphous calcium phosphate, the bulk of calcium in the skeletal reservoir is bound in the crystals of hydroxyapatite.

Osteoblasts are bone-forming cells that secrete the matrix components described. As ossification progresses, the osteoblasts become trapped in the matrix they produce and are then referred to as osteocytes. These cells are rather inert but are capable of a small degree of bone resorption. Osteoclasts are those cells whose primary function is the degradation and removal of mineralized bone. It is important to remember that the osteoclasts can remove only mineralized bone, and not unmineralized matrix.

Bone Organization

Microscopically, bone is generally described as mature or immature. Mature bone (Fig. 1-7) has an ordered lamellar arrangement of Haversian systems and canalicular communications that give it its classic histologic appearance. Immature bone (Fig. 1-8), in contrast, has a much more random appearance of collagen fibers dispersed in a matrix of irregularly spaced cells. It is produced rapidly by osteoblasts and "remodeled" by the local cell population, until the mature lamellar pattern is achieved. Immature bone is seen in the adult skeleton only under pathologic conditions (i.e., fracture callus, osteogenic sarcoma, myositis, etc.). Macroscopically (Fig. 1-9), the lamellar bone is configured either as dense cortical bone or as delicate spicules called trabeculae. In both areas, the cortex and the trabecular metaphysis, the bone is histologically the same (i.e., mature lamellar bone).

Turnover and Remodeling

Although the tendency is to think of adult bone as an inert tissue, nothing could be further from the truth. Throughout adult life there is a constant ebb and flow of bone formation and bone resorption. These two processes

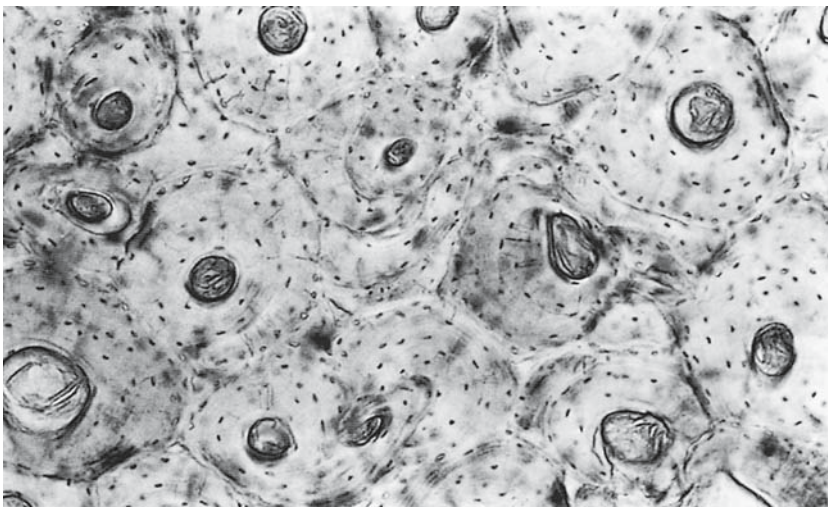


FIGURE 1-7. Mature bone: osteonal structure as seen in undecalcified material. Numerous interstitial fragments (osteonal fragments without an associated Haversian canal) are readily observed. (From Bogumill GP. Orthopaedic Pathology: A Synopsis with Clinical Radiographic Correlation. Philadelphia: Saunders, 1984. Reprinted by permission.)

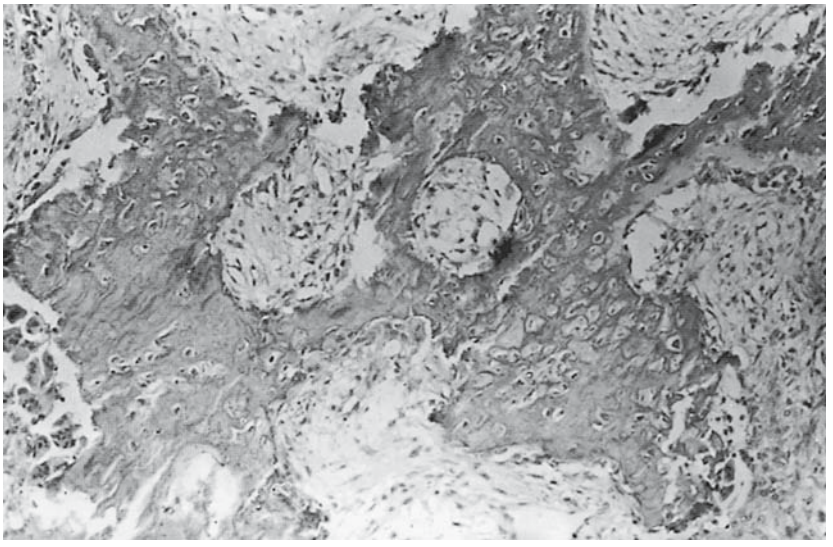


FIGURE 1-8. Immature bone (early callus). Note the large number of osteoblasts and osteocytes. (From Bogumill GP. Orthopaedic Pathology: A Synopsis with Clinical Radiographic Correlation. Philadelphia: Saunders, 1984. Reprinted by permission.)

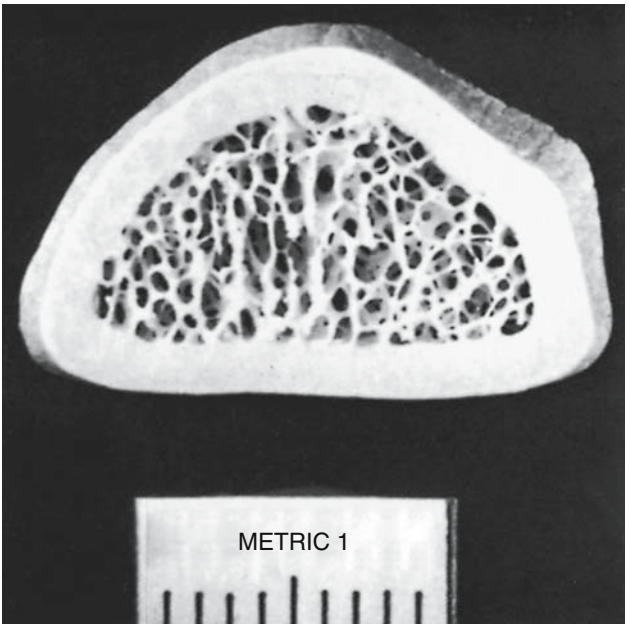


FIGURE 1-9. Cross section of the radius at the distal metaphysis. The majority of bone is cortical bone, in which the annual rate of turnover is only 2%.

are delicately balanced and keep the skeletal mass in a state of equilibrium. A number of authors have popularized the concept of "coupling"; bone formation and bone resorption generally increase or decrease in the same direction. When one process increases, so does the other, and vice versa. It is important, however, to consider the net effect of the rate changes in these two processes. For example, in osteoporosis, both formation and bone resorption increase, but resorption increases at a much greater rate, so that despite a coupled increase in bone formation the net effect is an overall decrease in bone mass. A number of factors, systemic and local, affect these processes and hence impact bone turnover and remodeling. Perhaps the most well defined factor is mechanical stress, which forms the basis for the classic Wolff's law. Simply stated, trabecular, and to a lesser degree cortical, bone remodels along lines of mechanical stress. Bone forms where it is needed to meet mechanical demands, and it is resorbed where the need is less. Current research suggests that bone functions as a transducer, converting mechanical energy from the applied load into electrical energy and a voltage gradient. In turn, this voltage gradient that is generated modulates cellular differentiation. Osteoblastic activity is thus seen in regions where the mechanical demands are the greatest. Osteoclas-

tic activity predominates the pattern when those mechanical demands decrease and less bone is required. This phenomenon has been called the "piezoelectric effect." Specifically, the deformation of bone apatite crystals by superimposed load generates the voltage gradient, which in turn alters the cell population to respond to that load.

Cartilage: The Tissue

Cartilage, like bone, is a connective tissue. Its histologic organization, however, is far less structured. There are three histologic types of cartilage, each serving a different function:

1. *Hyaline cartilage* covers the ends of long bones and provides a smooth, frictionless surface for articulation in a diarthrodial (synovial lined) joint.
2. *Fibrocartilage* is typically found in certain nondiarthrodial joints such as the pubic symphysis. It is also located at the margins of certain diarthrodial joints, forming structures such as the glenoid labrum and acetabular labrum. Following injury to hyaline cartilage, repair of the chondral defect is typically accomplished in the form of fibrocartilage.
3. *Elastic cartilage* is found in certain areas where resiliency is important. Examples include the tip of the nose and the ear lobe.

The most important of the three, hyaline cartilage, is a relatively aneural, avascular, and relatively hypocellular connective tissue. By weight, it is 70% water and 30% ground substance and cells. The ground substance of hyaline cartilage is composed primarily of type II collagen and GAG proteins (glycosaminoglycans). The collagen endows the cartilage with tensile strength, and the GAGs are critical for resiliency.

The cells are called chondrocytes and are dispersed throughout the chondral layers in four zones: tangential (most superficial), transitional, radial, and calcified. These chondrocytes are found in individual lacunae, where they maintain healthy cartilage by actively synthesizing new ground substance components.

The chondral layer receives the bulk of its nutrition by diffusion from the synovial fluid above and from the vasculature at the subchondral plate below. Normal diarthrodial (synovial lined) joint function depends on the presence of normal hyaline cartilage. In its fully hydrated state, hyaline cartilage provides an almost frictionless bearing, hence minimizing wear on the articular surface.

Abnormal Bone Development and Metabolism

Most skeletal diseases are the result of disruption of normal bone growth and development, breakdown of bone once it has been normally formed, or alteration of the normal mechanisms of bone formation or bone resorp-

tion. The etiologies of the pathologic states, as one would expect, are quite varied; but the final manifestations within the musculoskeletal system frequently show striking similarities.

Despite the etiology, damage to the growing skeleton will alter the overall shape of one or more bones, depending on whether the adverse process is localized or generalized. Similarly, disruption of osteoblast function will decrease the amount or the quality of the bone formed. Multiple factors are known to stimulate osteoclast activity, such as parathyroid hormone, the presence of particulate polyethylene, and certain neoplasms, resulting in localized or generalized bone resorption.

As one considers the etiology of skeletal disease, it is helpful to first group the possible differential diagnoses by disease category, which permits one to develop a comprehensive list of possible diagnoses that may explain the findings manifested by the skeleton. The seven disease categories are best remembered using the acronym "VITAMIN":

V, vascular disease
I, infection
T, tumor
A, arthritis
M, metabolic bone disease
I, injury
N, neurodevelopmental causes

The remainder of this chapter focuses on these diagnostic groups and the way in which they affect the skeleton. Specific emphasis is placed on generalized afflictions of the skeleton. In that light, certain disease categories are more likely to adversely affect the skeleton in a generalized fashion, specifically vascular, metabolic, systemic arthritis, and neurodevelopmental etiologies. The other etiologies—infection, injury, and tumor—are more likely to produce localized changes and, therefore, are considered in individual subsequent chapters.

Last, as a reminder, a differential diagnosis is a listing of plausible specific diagnoses that may explain observed findings such as physical or radiographic. It is not adequate to simply list a disease category because appropriate treatment of a given condition depends on identifying a specific etiology.

Metabolic Bone Disease

General Concepts

Disease processes affecting bone often can be understood as a change in the relationship of bone formation and bone resorption. It is therefore important to understand this relationship. Only by doing so can the net effect on the skeleton be appreciated.

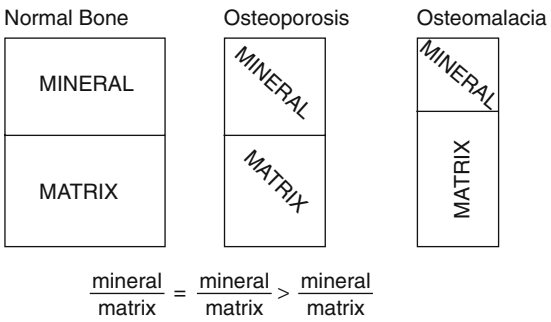


FIGURE 1-10. Ratio of mineral to matrix in certain disease states. In osteoporosis, the ratio remains constant despite an overall decrease in bone mass. However, in osteomalacia there is a decrease in the ratio of mineral to matrix as a result of skeletal demineralization; in addition, there is an overall decrease in bone mass.

The relationship (ratio) of mineral to matrix may be affected in abnormal metabolic states (Fig. 1-10). For example, osteoporosis is a loss of bone mass, but there is an equivalent loss of matrix and mineral; therefore, the ratio remains normal. In contrast, osteomalacia is a relative loss of mineral resulting in a predominance of matrix, hence decreasing the ratio of mineral to matrix. Serum calcium is rarely representative of skeletal activity. Considering that more than 95% of the body's calcium is stored in bone apatite, it is understandable that the 180 mg of ionized plasma calcium represents literally the "tip of the iceberg." Peripheral sampling of the serum calcium provides only a remote clue to the true content of skeletal apatite. It does, however, provide a convenient way to think about and classify metabolic bone disease.

Eucalcemic States: Osteoporosis

As mentioned, osteoporosis is a predominance of bone resorption over bone formation, with the net effect being bone loss (Fig. 1-11). There is a parallel loss of mineral and matrix, so their ratio remains normal. Essentially, osteoporosis is a decrease in bone mass with an increase in cortical porosity and in diaphyseal bone diameter. This latter phenomenon is an attempt by the organism to use what limited bone there is and to disperse it as far as possible from the neutral axis of the long bone. Mechanically, this increases the torsional rigidity of the bone. Numerous etiologies of osteoporosis have been identified (Table 1-1), but clinically most significant is the postmenopausal type, which occurs shortly after the withdrawal of estrogen (naturally or surgically) from the predisposed

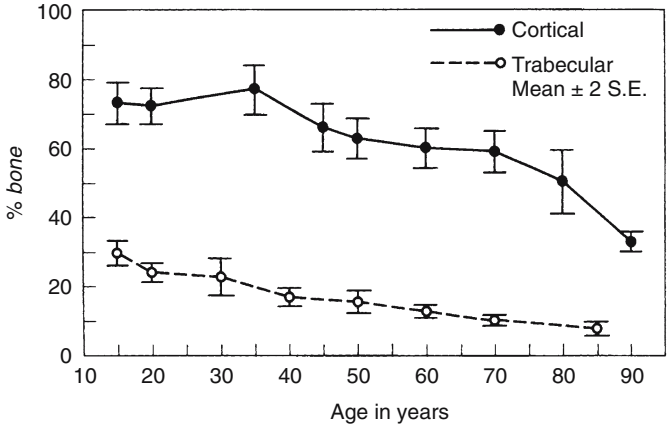


FIGURE 1-11. The relative decrease in cortical and trabecular bone with age in apparently normal persons. Note the relatively rapid loss early in life in trabecular bone and comparatively little loss at this age in cortical bone. The situation is reversed after age 55. (From Jowsey J. Metabolic Diseases of Bone. Philadelphia: Saunders, 1977. Reprinted by permission.)

female (Table 1-2). The yearly cost in dollars, as well as pain and suffering, is overwhelming. Women with this affliction frequently sustain classic osteoporotic fractures. These fractures typically involve the vertebrae, the wrist, the proximal femur, and/or the proximal humerus. In addition to the pathologic fractures, there is frequently a loss of height as a result of the cumulative effect of multiple vertebral fractures, as well as the progressive development of a kyphotic deformity in the thoracic spine, which is referred to as a "dowager's hump" (Fig. 1-12).

Patients present with a history of pain and/or repeated fractures. Occasionally they complain of early satiety because of some abdominal compression resulting from loss of height of the vertebral column. Similarly, the increasing kyphosis in the thoracic region may be responsible for some shortness of breath. On examination, typically one finds the prominent dowager's hump, a barrel chest, a protuberant abdomen, and generalized bone pain with percussion tenderness.

One of the most difficult problems in the past has been to determine bone mass. Typically, a crude estimate of bone density determined by plain radiograph has been used to extrapolate to the amount of bone previously lost. Classically, once osteopenia is noticeable radiographically, it has been estimated that the bone density is decreased by 30% to 50%.

Recently, additional diagnostic techniques have become available to more carefully estimate the amount of bone loss and, therefore, the amount of bone that remains. Isotope measurements, specifically single-photon

absorptiometry, using an iodine compound, or dual-photon absorptiometry, using a gadolinium compound, have been developed. They have significant technical limitations. The single-photon technique, measuring peripheral sites, such as the forearm and heel, is rarely an adequate reflection of the true bone mineral density in the axial skeleton. The dual-photon study, although providing more reliable information about the bone mineral density of the axial skeleton, continues to have some technical limitations.

TABLE 1-1. Causes of osteoporosis.

Primary
- Involutional (postmenopausal or senile)
- Idiopathic (juvenile or adult)

Secondary

Endocrine
- Hypogonadism
- Adrenocortical hormone excess (primary or iatrogenic)
- Hyperthyroidism
- Hyperparathyroidism
- Diabetes mellitus
- Growth hormone deficiency

Nutritional
- Calcium deficiency
- Phosphate deficiency
- Phosphate excess
- Vitamin D deficiency
- Protein deficiency
- Vitamin C deficiency
- Intestinal malabsorption

Drug
- Heparin
- Anticonvulsants
- Ethanol
- Methotrexate

Genetic
- Osteogenesis imperfecta
- Homocystinuria

Miscellaneous
- Rheumatoid arthritis
- Chronic liver disease
- Chronic renal disease

Immobilization
- Malignancy (multiple myeloma)
- Metabolic acidosis
- Cigarette smoking

Source: From Borenstein D, Wiesel SW. Low Back Pain: Medical Diagnosis and Comprehensive Management. Philadelphia: Saunders, 1989:329. Reprinted with permission.

TABLE 1-2. Types of involutional osteoporosis.

	Type 1 (Postmenopausal)	Type 2 (Senile)
Age (years)	51–75	Over 70
Sex ratio (M/F)	1:6	1:2
Type of bone loss	Trabecular	Trabecular and cortical
Fracture site	Vertebrae (crush) Distal radius	Vertebrae (multiple wedge) Hip
Main causes	Menopause	Aging
Calcium absorption	Decreased	Decreased
1,25-$(OH)_2$-vitamin D synthesis from 25-(OH) vitamin D	Secondary decrease	Primary decrease
Parathyroid function	Decreased	Increased

Source: Modified from Riggs BL, Melton LJ III. Involutional osteoporosis. N Engl J Med 1986;314:1676.

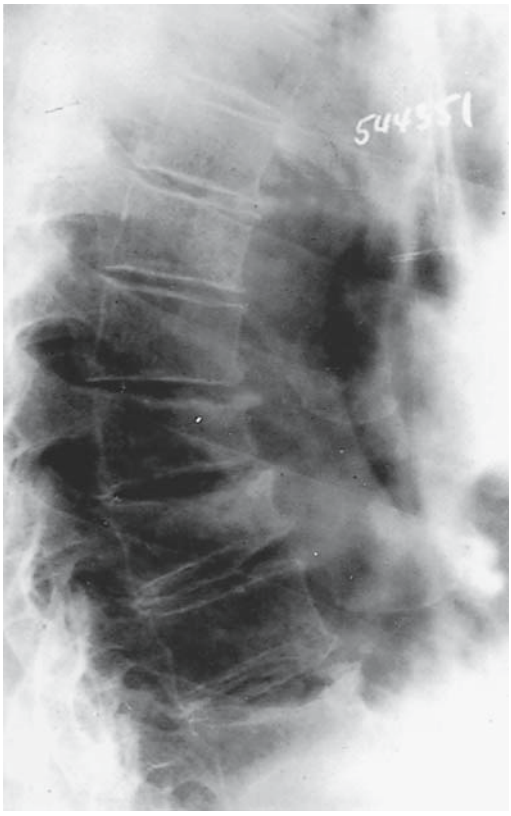


FIGURE 1-12. Radiograph of spine showing osteoporosis. Cortical bone appears accentuated by contrast with osteopenic marrow. Longitudinal trabeculae also appear accentuated because smaller transverse trabeculae are absent. Anterior wedging and endplate compression are present. (From Bogumill GP. Orthopaedic Pathology: A Synopsis with Clinical Radiographic Correlation. Philadelphia: Saunders, 1984. Reprinted by permission.)

As of this writing, it is probably fair to say that both these techniques have been replaced by dual-energy X-ray absorptiometry (DEXA) scanning. The DEXA technique is currently the standard, used in the evaluation of bone mineral density (BMD) in women approaching or following their menopause. This technique allows accurate and reproducible measures of density of the spine and the hip and does so with a minimal amount of radiation exposure. Current guidelines as recommended by the National Osteoporosis Foundation and the World Health Organization allow comparison of an individual's bone density to that of healthy normals. The difference is expressed as a T-score, which essentially represents one standard deviation above or below ideal bone mass. The definitions based on T-scores are as follows:

Normal	0 to –1
Osteopenia	–1 to –2.5
Osteoporosis	Less than –2.5

The unfortunate result of DEXA scanning, however, has been to adulterate the use of the term osteopenia. For many years, this term was defined as a generalized decrease in radiographic bone density. As such, it was nonpejorative and did not speak to a specific metabolic bone disease. In its present accepted context, the implication of using the term osteopenia is to imply a mild form of postmenopausal osteoporosis, which was certainly not the original connotation of the term. Diseases other than osteoporosis, such as hyperthyroidism and multiple myeloma, are characterized by observed decreases in radiographic bone density, hence osteopenia.

Without question, the most definitive diagnostic technique is direct bone biopsy with or without tetracycline labeling. It can clearly give the most reliable information regarding the presence of osteoporosis, its degree, and whether a superimposed osteomalacic state exists. Once the diagnosis has been confirmed and the risk analysis carried out, a treatment protocol can be tailored for the individual patient.

Most treatment regimens are considered either prophylactic or therapeutic. Prophylactic regimens include regular weight-bearing exercise, such as walking or jogging, supplemental calcium administration, and vitamin D administration with or without the administration of postmenopausal estrogen substitutes. The complications of oral estrogen administration, such as its relation to breast and cervical cancer and to heart disease and the incidence of deep venous thrombosis (DVT), make its general use controversial; however, its efficacy in maintaining skeletal mass is beyond question.

Therapeutic regimens, in contrast, are much more debatable. Current therapeutic regimens include the use of any or all of several different pharmacologic agents. Selective estrogen receptor modulators (SERMs) are drugs that behave either as an agonist or antagonist of estrogen. They have been shown, in selective populations, to decrease or minimize bone loss.

These drugs theoretically have an estrogen-like protective effect on bone. It has also been suggested that they have inhibitory (protective) effects on the breast and the endometrium.

Bisphosphonates are structurally similar to naturally occurring pyrophosphates. Because they have a strong chemical affinity for hydroxyapatite, they are potent inhibitors of bone resorption. They, therefore, are able to decrease the rate at which bone remodeling occurs and, as a result, to reduce the amount of bone resorption. It has been said that bisphosphonates are able to "freeze the skeleton." It is hoped that the consequence of decreasing bony resorption will be a coincident increase in bone mass. At the present time, the most popular bisphosphonate in current use is Fosamax, which has been approved for both the prevention and treatment of osteoporosis.

Calcitonin, a naturally occurring polypeptide hormone, is currently being administered in an effort to also decrease the rate of bony resorption by decreasing the number and activity of osteoclasts. The drug is currently being administered in the form of a nasal spray.

The current regimens used for the therapeutic management of osteoporosis include one or more of these drugs in addition to the standard prophylactic measures. Not infrequently, these agents are used cyclically or in an alternating fashion. Because the true measure of any therapeutic regimen for osteoporosis is an increase in bone density and a reduction in fracture risk or in the number of fractures, the true efficacy of these agents and various therapeutic regimens must be evaluated over the long term. As of this writing, the use of SERMs, bisphosphonates, and calcitonin all have shown early promise in this context.

Hypercalcemic States: Hyperparathyroidism

The effect of parathormone on bone is the same whether it is released as a result of a parathyroid adenoma (primary hyperparathyroidism) or by one of several secondary causes. In essence, parathormone stimulates osteoclastic activity, causing an intense resorption of bone (Fig. 1-13). The cavities resulting from this clastic activity fill with vascular fibrous tissue, resulting in the classic "osteitis fibrosa cystica." As the cavities coalesce, they form a single large cyst called a "brown tumor" because of the hemosiderin staining one sees within them. Clinical and radiographic changes result from this cavitation as well as from the erosive changes occurring under the periosteum.

Hypocalcemic States: Rickets and Osteomalacia

The same underlying mechanism accounts for rickets and osteomalacia: there is a general failure to mineralize bony matrix, resulting in the presence of unmineralized osteoid about bony trabeculae. This lack of mineral

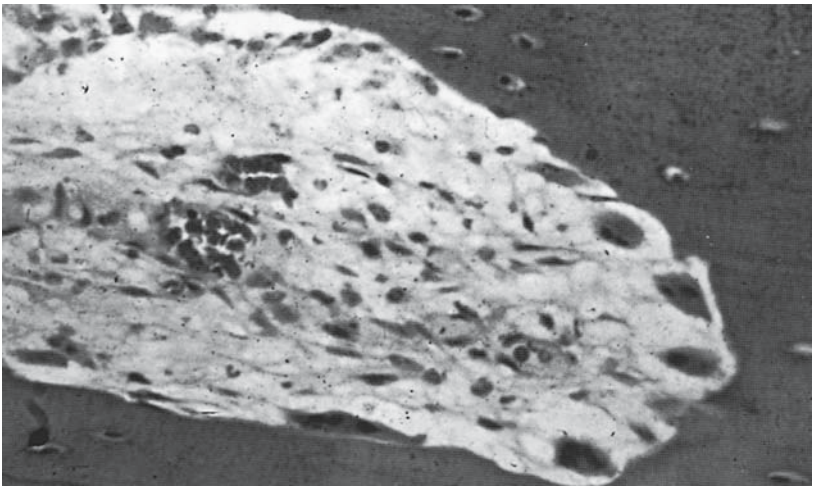


FIGURE 1-13. "Cutting cone." Successive relays of osteoclasts on the right resorb a tunnel of bone, making it longer and wider with each relay. Behind the cutting cone is a "filling cone" of successive relays of osteoblasts secreting osteoid. Resorption is facilitated by high-speed flow of well-oxygenated blood in small vessels, whereas refill is accompanied by dilated sinusoidal vessels with sluggish flow and low oxygen content. (From Bogumill GP. Orthopaedic Pathology: A Synopsis with Clinical Radiographic Correlation. Philadelphia: Saunders, 1984. Reprinted by permission.)

for adequate mineralization can be caused by a number of different etiologies: nutritional deficiency, malabsorption states, or renal disease (Table 1-3) are some of the more common. Despite the etiology, the metabolic effects on the skeleton are similar.

If the failure of mineralization impacts the skeleton before physeal closure, the result is rickets. The affected child will demonstrate the characteristic hallmarks of the disease: bowlegs, frontal bossing, ricketic rosary, and knobby joints (Fig. 1-14). All these findings are due to the presence of large masses of unmineralized osteoid. In addition, abnormalities of the physis and abnormal physeal growth can be anticipated.

If the process impacts the skeleton after physeal closure, the disease that results is osteomalacia. As noted earlier, the ratio of mineral to matrix decreases as a result of the paucity of mineral available to the skeleton. In the adult, these areas of unmineralized osteoid present as radiographically lucent areas in the bone, frequently referred to Looser's lines (Fig. 1-15). In addition, the bones themselves tend to be somewhat malleable and can bow under load; this is in contradistinction to osteoporotic bone, which is very brittle.

TABLE 1-3. Diseases associated with osteomalacia.

Disorder	Metabolic defect
Vitamin D:	Decreased generation of vitamin D_3
Deficiency	
Dietary	
Ultraviolet light exposure	
Malabsorption	Decreased absorption of vitamins D_2 and D_3
Small intestine	
Inadequate bile salts	
Pancreatic insufficiency	
Abnormal metabolism	
Hereditary enzyme deficiency	Decreased 1-alpha-hydroxylation of 25-(OH)-vitamin D
D-dependent rickets (type I)	
Chronic renal failure	Decreased 25-hydroxylation of vitamin D
Mesenchymal tumors	
Systemic acidosis	
Hepatic failure	
Anticonvulsant drugs	
Peripheral resistance	Absent or abnormal 1,25-$(OH)_2$-Vitamin D receptors
Vitamin D-dependent rickets (type II)	
Phosphate depletion:	
Dietary	Inadequate bone mineralization secondary to low serum concentrations
Malnutrition (rare)?	
Aluminum hydroxide ingestion	
Renal tubular wasting	
Hereditary	Decreased serum phosphate concentrations
X-linked hypophosphatemic osteomalacia	
Acquired	
Hypophosphatemic osteomalacia	
Renal disorders	
Fanconi's syndrome	
Mesenchymal tumors	
Fibrous dysplasia	
Mineralization defects:	
Hereditary	Abnormal alkaline phosphatase activity
Hypophosphatasia	
Acquired	
Sodium fluoride	Inhibition of bone mineralization
Disodium etidronate	
Miscellaneous:	
Osteopetrosis	Abnormal osteoclast activity
Fibrogenesis imperfecta	Unknown
Axial osteomalacia	Unknown
Calcium deficiency	Inadequate bone mineralization Secondary to low serum calcium concentration

Source: From Borenstein D, Wiesel SW. Low Back Pain: Medical Diagnosis and Comprehensive Management. Philadelphia: Saunders, 1989:339. Reprinted with permission.

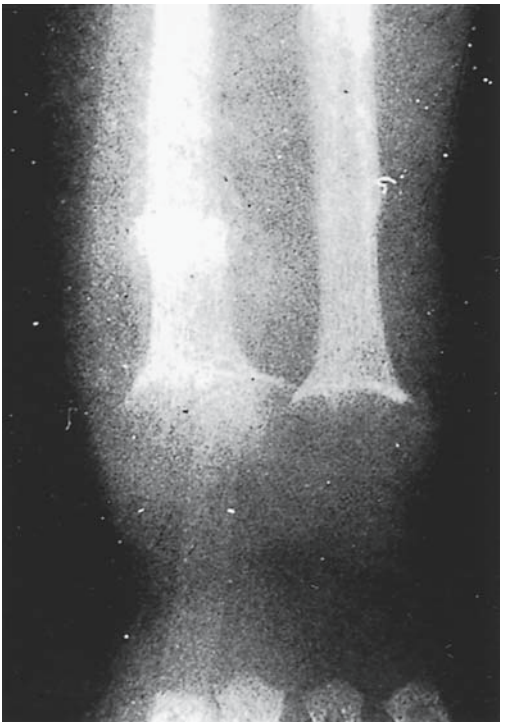


FIGURE 1-14. Radiograph of wrist of child with active rickets exhibiting the irregular widened zone of provisional calcification that is replaced by abnormal osteoid. The cartilage masses are not visible, but the widened epiphyseal growth plate and irregular calcification are readily seen. Note pathologic fracture of radial shaft. (From Bogumill GP. Orthopaedic Pathology: A Synopsis with Clinical Radiographic Correlation. Philadelphia: Saunders, 1984. Reprinted by permission.)

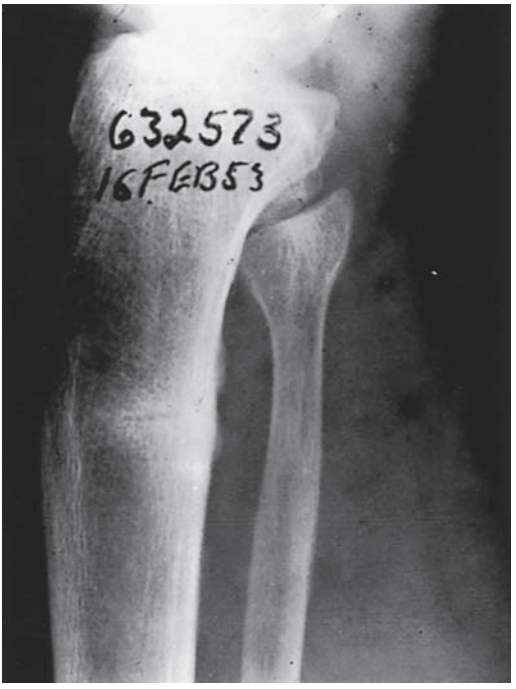


FIGURE 1-15. Radiograph of osteomalacia showing a Looser's transformation zone. These lines appear at sites in which stress fractures would occur. Stress of normal use incites remodeling with removal of bone. In normal individuals, the removed bone is replaced by normal osteons. In persons with osteomalacia, the removed bone is replaced with abnormal osteoid, which fails to mineralize and leaves a linear radiolucency that may persist for years. (From Bogumill GP. Orthopaedic Pathology: A Synopsis with Clinical Radiographic Correlation. Philadelphia: Saunders, 1984. Reprinted by permission.)

Miscellaneous Metabolic Bone Disease: Renal Osteodystrophy

Renal osteodystrophy encompasses the skeletal changes that result from chronic, acquired renal disease. These changes are truly a "collage" of the other metabolic bone diseases. To understand the pathogenesis of renal osteodystrophy is to understand the basis of all the metabolic afflictions of the skeleton (Fig. 1-16). Chronic uremia allows a twofold drive to depress the serum calcium. First, the kidney is unable to excrete phosphate, hence the serum phosphate level rises. The serum calcium level is then of necessity driven down to maintain the fixed solubility product. Coincidentally, because the absence of a functional renal parenchyma stops the output of significant amounts of activated vitamin D, intestinal absorption of calcium is retarded, further depressing serum calcium. This dual mechanism profoundly depresses serum calcium and thus in turn mandates a parathormone response. The changes in the bone reflect the metabolic drives. The vitamin D deficiency is demonstrated by the presence of unmineralized osteoid (Fig. 1-17). The elevated levels of parathormone cause osteitis fibrosis cystica. Unique to this syndrome, the hyperphosphatemia results in a diffuse osteosclerosis. The latter finding causes one of the most pathognomic radiographic findings (Fig. 1-18), the "rugger jersey" spine.

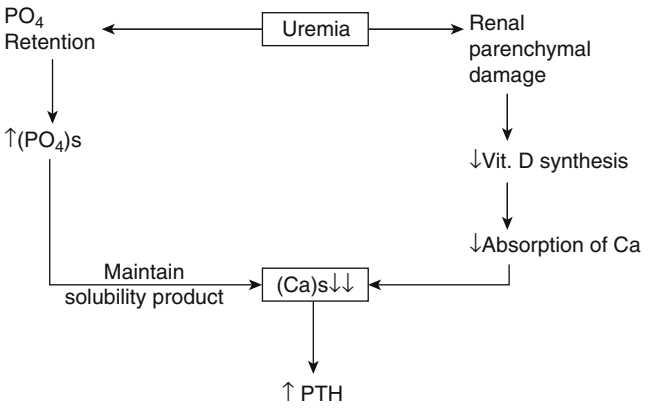


FIGURE 1-16. Pathogenesis of renal osteodystrophy.

FIGURE 1-18. Radiograph of patient with long-standing renal osteodystrophy. Marked osteoporosis attributable to secondary hyperparathyroidism is evident. There is bowing of the proximal femurs, marked lordosis, and pelvic tilt. The deformity of the pelvis is commonly seen in osteomalacia, but it does not usually occur in primary hyperparathyroidism. (From Bogumill GP. Orthopaedic Pathology: A Synopsis with Clinical Radiographic Correlation. Philadelphia: Saunders, 1984. Reprinted by permission.)

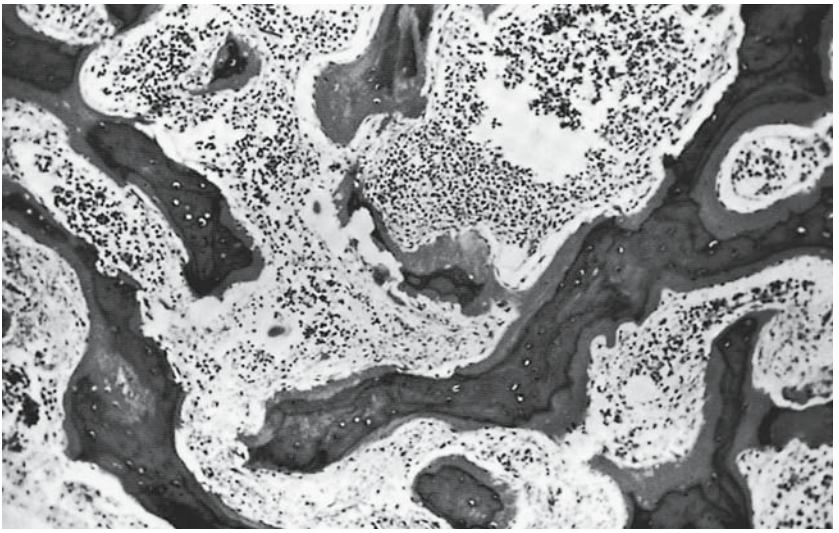
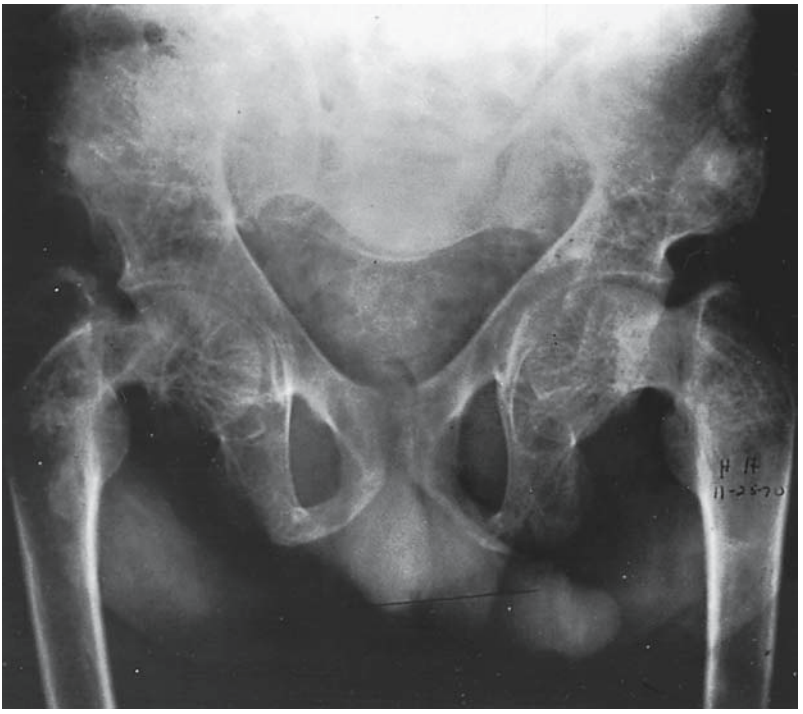


FIGURE 1-17. Renal osteodystrophy. Histologic section of bone exhibiting wide osteoid seams. These seams are seen in patients with primary renal disease, but they are not present in patients with primary hyperparathyroidism because the osteoid produced in primary hyperparathyroidism is normal. (From Bogumill GP. Orthopaedic Pathology: A Synopsis with Clinical Radiographic Correlation. Philadelphia: Saunders, 1984. Reprinted by permission.)



Sick Cell Syndromes: Osteogenesis Imperfecta and Osteopetrosis

The underlying mechanism seen in these conditions is a qualitative, functional deficit in a specific cell population, despite the fact that the population is quantitatively normal.

Osteogenesis imperfecta (Fig. 1-19) is typified by the impotence of the osteoblasts; they are unable to manufacture and secrete normal collagen. Ossification is, therefore, abnormal and results in inferior-quality bone. Clinically and radiographically, there is marked cortical thinning and attenuation of the diaphyseal caliber. The long bones, because of their altered anatomy, are at very high risk for fracture (Fig. 1-20). This bone fragility is the hallmark feature of osteogenesis imperfecta.

Because osteogenesis imperfecta is caused by a genetic mutation in the normal coding for type I collagen, there is significant phenotypic heterogeneity. In an effort to accommodate the variations in phenotype, the Sillence classification has been adopted by most authors. Four specific types are described in this classification:

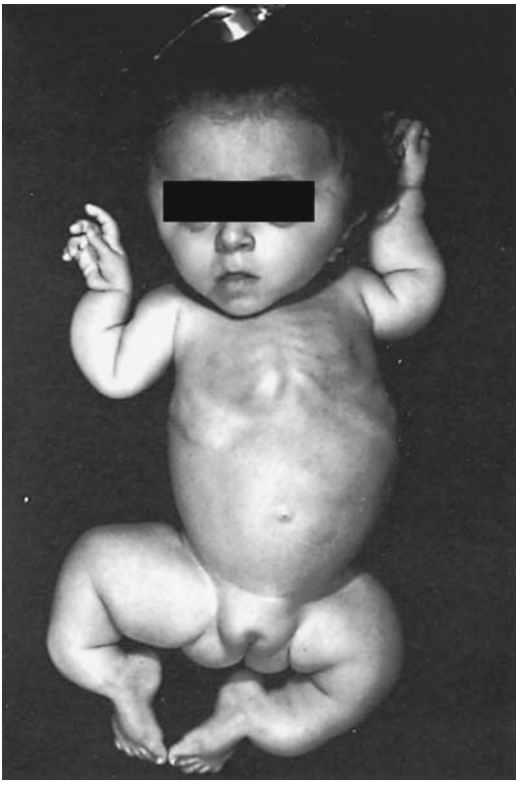


FIGURE 1-19. Deformity in a child with severe osteogenesis imperfecta. Note the prominence of the ribs in the abnormally shaped thoracic cage, the flattening of the skull with frontal bulging, and the malformed ribs. (From Gertner JM, Root L. Osteogenesis imperfecta. Orthop Clin North Am 1990;21(1):153. Reprinted by permission.)

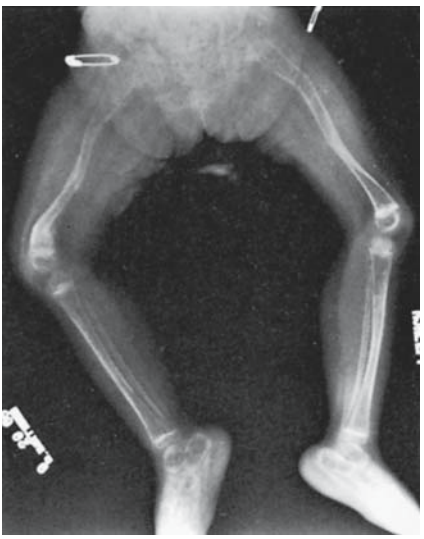


FIGURE 1-20. Radiograph of the lower extremities of a child with osteogenesis imperfecta. The bones are slender and the cortices excessively thin; both femurs have incurred fractures that are partially healed, although deformity still exists. (From Jowsey J. Metabolic Diseases of Bone. Philadelphia: Saunders, 1977. Reprinted by permission.)

Type I is the most common form and the mildest clinically, it is transmitted as an autosomal dominant. These patients demonstrate the classic findings of blue sclera, long bone fractures after the age of walking, and a relatively normal life expectancy.

Type II is the lethal form of the disease. These children are usually stillborn or die shortly after birth, usually as a result of respiratory failure or intracranial hemorrhage.

Type III is the severe nonlethal form, characterized by sclera of normal color, multiple birth fractures, and significant long-term deformity and disability.

Type IV is the intermediate form, with variable manifestations, and is the least common.

Osteopetrosis is similarly considered a sick cell syndrome resulting from the failure of the osteoclasts to remove primary spongiosa bone. This latter osseous material then "piles up" in the skeleton, making it appear very dense radiographically (Fig. 1-21). Despite the fact that the bones look extremely dense and, indeed, lack a medullary canal, they are biomechanically very weak, which results in frequent pathologic fractures. An additional complication is the displacement of marrow elements from the long bones, resulting in a myelophisthic anemia; this in turn generates extramedullary hematopoiesis and the clinical finding of hepatosplenomegaly, usually seen in these patients.

Paget's Disease

Sir James Paget described a syndrome of unknown etiology that bears his name. The initial description referred to the condition as "ostetitis defor-

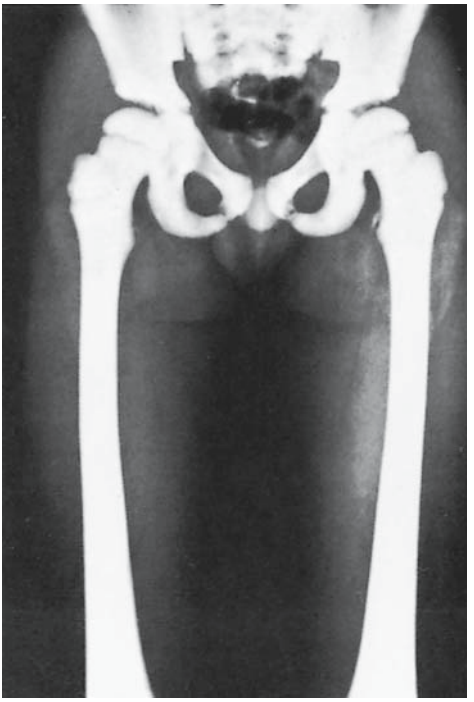


FIGURE 1-21. Radiologic appearance of the femurs and pelvic girdle of a patient with osteopetrosis. There is almost complete absence of the marrow cavity and lack of remodeling of the femoral neck and acetabulum. (From Jowsey J. Metabolic Diseases of Bone. Philadelphia: Saunders, 1977. Reprinted by permission.)

mans." The syndrome is most common in individuals of European descent and in patients typically over the age of 55. Men tend to be more affected than women.

There is strong evidence, specifically the finding of radiodense viral-like particles in the osteoclasts (Fig. 1-22), pointing to a slow virus as the cause of Paget's disease. It is basically a disease of bone turnover wherein bone formation and bone resorption dramatically increase. The two processes occur alternately rather than simultaneously in any given bone. The net effect is bones of increased density with marked trabecular thickening (Fig. 1-23). The skull, pelvis, spine, tibia, and femur are the favorite targets of this process. Sadly, and not unlike osteopetrosis, the pagetic bones are mechanically weak, making pathologic fracture a frequent complication. Despite the presence of abundant quantities of bone, the bone is poorly formed and the mineral and matrix are poorly integrated. Bone pain, spinal stenosis, and hearing defects resulting from disease in the skull base compromising the eighth nerve are frequent problems in these patients.

Several different therapeutic approaches have been attempted. Currently, bisphosphonates and calcitonin are frequently employed therapeutic agents. Similarly as in osteoporosis, they are used in an attempt to inhibit bone resorption and also to a lesser degree to block bone mineralization. The rationale is to "freeze the skeleton" and thereby decrease bone

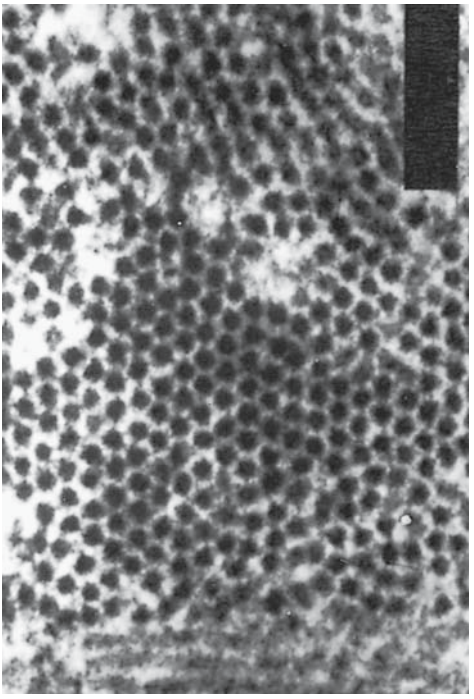


FIGURE 1-22. Viral particles located in osteoclasts within pagetoid bone have been implicated as a causal factor in Paget's disease. (From Merkow RL, Lane JM. Paget's disease of bone. Orthop Clin North Am 1990;21(1):172. Reprinted by permission.)

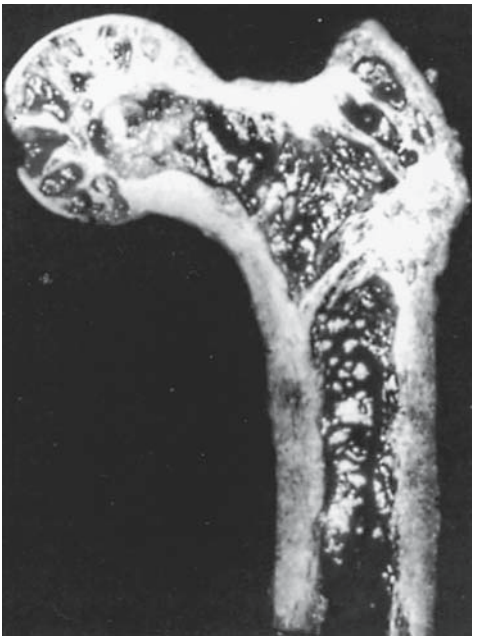


FIGURE 1-23. Example of pagetoid bone demonstrating deformity and thickening of the cortex of the hip. The neck shaft angle has developed varus deformity. (From Merkow RL, Lane JM. Paget's disease of bone. Orthop Clin North Am 1990;21(1):172. Reprinted by permission.)

turnover. Cyclic treatment regimens are currently being employed in hopes of allowing new bone to become mineralized while decreasing the osteoclastic activity. The serum alkaline phosphatase level provides a reliable way of monitoring the response to treatment because it is elevated in the presence of active bone turnover.

Arthritis

Because any significant discussion on this subject is well beyond the scope of this chapter, it is hoped that presentation of some basic concepts will allow consideration of this diagnosis in the scheme of differential diagnosis. It is important to recall that a diarthrodial joint includes three tissues: bone, cartilage, and synovium. Each of the arthritic diseases tends to impact one of these tissues, with changes in the other two resulting as secondary phenomena. The radiographic and microscopic changes encountered represent a composite of the result of the initial injury and the organism's attempt at repair of that injury.

Noninflammatory Arthritis: Osteoarthritis

Osteoarthritis can be primary or secondary, if one considers the degenerative joint disease that can follow trauma or other primary events. The process itself targets the articular cartilage. Whether the initial event is mechanical or biochemical remains controversial. The net result is progressive damage to the articular surface. The secondary bone changes that occur are reparative in nature. Joint space narrowing, subchondral sclerosis, osteophytes, and subchondral cysts, therefore, are the classic radiographic changes. Because this is most typically a disease of weight-bearing joints, the hip and knee are the joints that usually require orthopedic care. Total joint arthroplasty has become the mainstay of surgical management in these patients, producing reliable long-term results.

Inflammatory Arthritis: Rheumatoid Arthritis

Rheumatoid arthritis, and to some degree its variants, target the synovial membrane as the site for the immunologic process that is the root mechanism of this disease. As the synovium hosts this inflammatory process, it becomes hyperplastic and hypertrophic. The thickened synovium destroys the articular cartilage by enzymatic degradation and destroys the underlying bone by pressure necrosis and erosion (Fig. 1-24). In contrast to osteoarthritis, repair changes are, for the most part, abortive. The radiograph reflects this overall atrophic process. Soft tissue swelling, osteopenia on both sides of the joint, and bone erosions are the standard findings (Fig. 1-25). Joint destruction is generally symmetrical and much more global than with osteoarthritis. Extensive alterations in normal anatomy usually necessitate multiple joint arthroplasties.

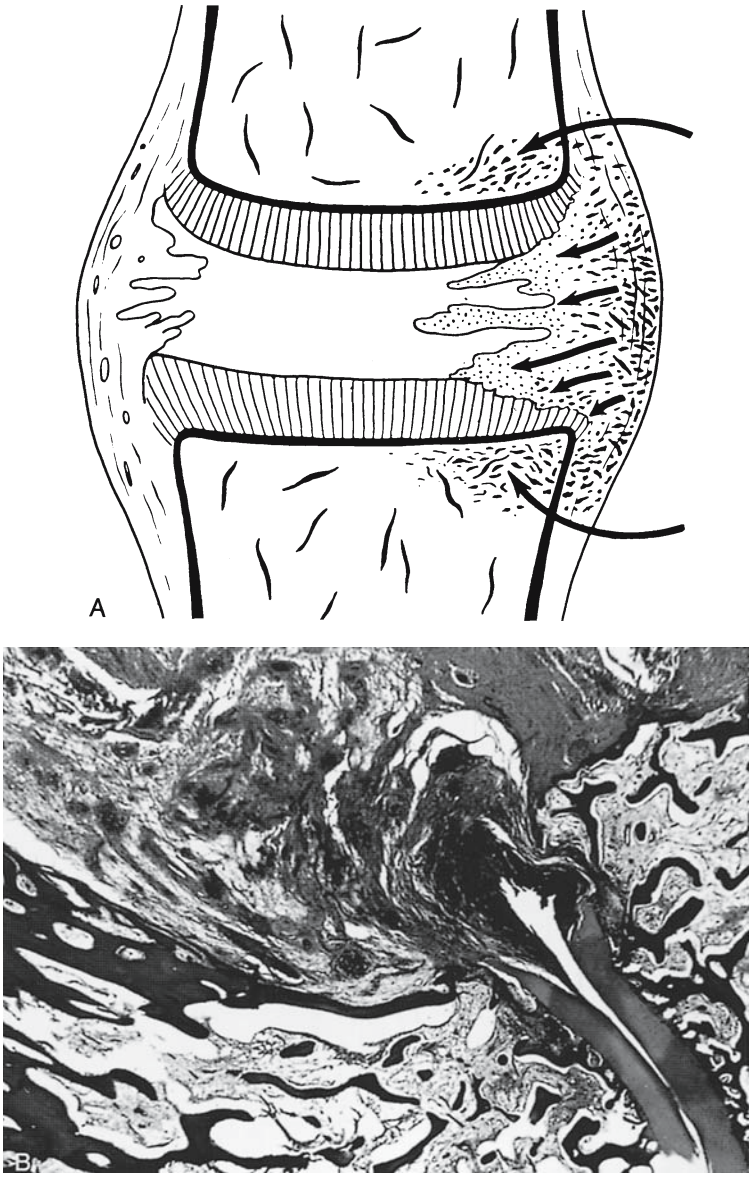


FIGURE 1-24. Diagram (A) and section (B) of a finger joint of a patient with rheumatoid arthritis. The marked synovitis is evident in the synovial recesses with erosions into the bone on both sides of the articular surface (*long curved arrows*). The pannus is beginning to encroach on margins of the joint (*short arrows*). Although the cartilage retains its normal appearance in the center of the joint, the proteoglycan structure is affected by the altered synovial fluid. It is susceptible to rapid removal by wear and tear as well as by the encroaching pannus. Because the pannus grows in from the margins, the earliest radiographic erosions are seen at the margins, and the contract surfaces are spared until relatively late. (From Bogumill GP. Orthopaedic Pathology: A Synopsis with Clinical Radiographic Correlation. Philadelphia: Saunders, 1984. Reprinted by permission.)

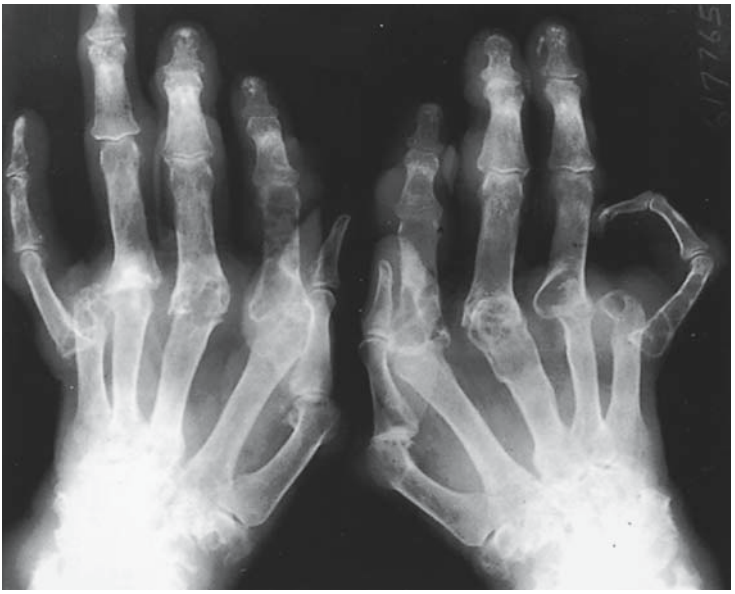


FIGURE 1-25. Radiograph of both hands of a patient with long-standing rheumatic arthritis. Osteoporosis in all bones is marked. The wrist joints show advanced destruction. There is dislocation of the metacarpophalangeal joints of all fingers. Steroid therapy causes expansion of metacarpals and phalanges secondary to changes in the marrow fat (steroid lipomatosis). (From Bogumill GP. Orthopaedic Pathology: A Synopsis with Clinical Radiographic Correlation. Philadelphia: Saunders, 1984. Reprinted by permission.)

Metabolic Arthritides: Crystalline Arthropathy

The common denominator of the metabolic arthritides is the deposition of crystals or metabolic by-products in or around joints. Destructive changes in these joints necessitate rheumatologic and frequently orthopedic care.

In gout, sodium urate crystals are deposited in and around the joints. Finding these crystals in joint fluid is the diagnostic sine qua non of this metabolic imbalance. An intense chemical synovitis and bony erosions can occur. Typically, the first metatarsophalangeal joint is the classic site, but certainly the process can present in any joint, including the spine. The acute onset and signs of acute inflammation should suggest the diagnosis, which is best confirmed by arthrocentesis. The finding of needle-like, negatively birefringent crystals under polarized light confirms the diagnosis. The treatment is usually medical. However, in the presence of late destructive changes, surgical intervention can be considered.

Pseudogout is one of the many causes of chondrocalcinosis and should not be considered synonymous with it. The presence of weakly positively

birefringent crystals, rhomboid in shape, attests to the diagnosis. The calcium pyrophosphate crystals are radiopaque and, as such, can be viewed on standard radiographs as calcification of cartilage, including the menisci and articular surfaces. The condition rarely mandates surgical intervention, and treatment frequently revolves around nonsteroidal antiinflammatory drugs or intraarticular steroid injections.

Ochronosis is an inborn error of metabolism. The error is an absence of homogentisic acid oxidase. As a result, homogentisic acid accumulates and targets articular cartilage for its deposition. The articular cartilage is stiffened by the presence of this by-product and loses its resiliency. The net result is fissuring and fibrillation of the articular surface; these changes radiographically and pathologically mimic osteoarthritis. The unique feature of this condition is the fact that this material pigments and stains the cartilage black (Fig. 1-26), thereby accounting for the blackish tinge of the earlobes and the tip of the nose seen in these patients.

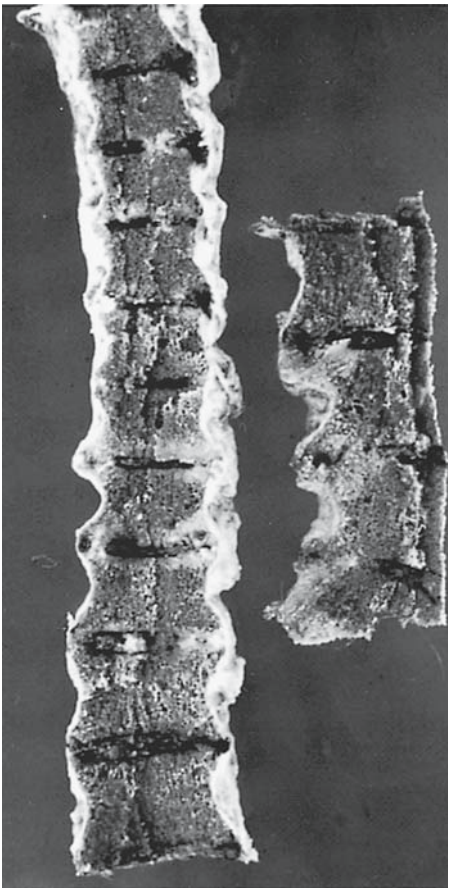


FIGURE 1-26. Gross appearance of vertebral bodies in a patient with ochronosis. Notice the diminution of the intervertebral disks, black discoloration of the cartilage components, virtual disappearance of all joint spaces, and bony bridging. (From Bogumill GP. Orthopaedic Pathology: A Synopsis with Clinical Radiographic Correlation. Philadelphia: Saunders, 1984. Reprinted by permission.)

Vascular Disease

This diagnostic category is a somewhat diverse grouping of clinical entities that are best considered under this heading lest they be overlooked.

Circulatory Disease: Avascular Necrosis

Afflictions of the vascular tree, especially the arterial side, tend to produce similar lesions in bone, despite the etiology. Bone deprived of a portion of its blood supply becomes necrotic, as do all other tissues (Fig. 1-27). Depending on the extent of the vascular involvement, the infarcts can range from small areas of bony necrosis in the metaphysis (Fig. 1-28), which are clinically inconsequential, to extensive involvement at the ends of the long bones that progresses to significant degenerative joint disease.

The radiographic appearance of dead bone is essentially that of sclerosis. In truth, the dead tissue is incapable of changing its density because no viable cells exist. Rather, the viable bone adjacent to the necrotic

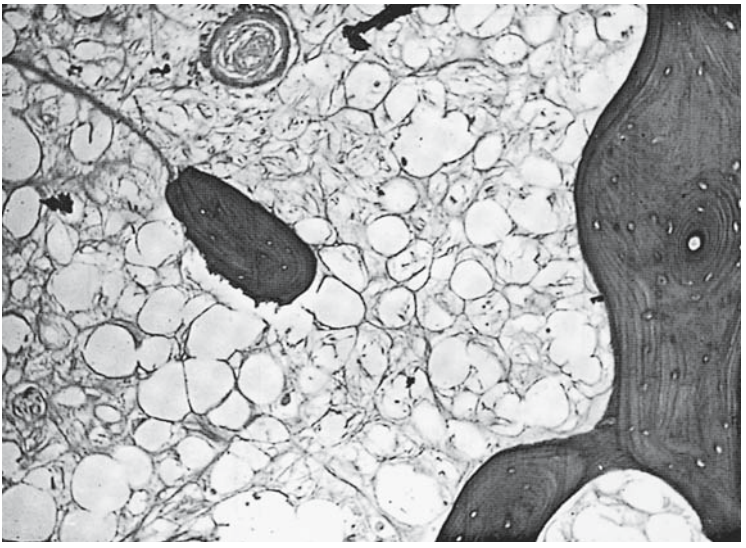


FIGURE 1-27. Bone from central area of infarction, exhibiting infarcted fatty tissue, obliterated vessels, and infarcted bone. Note absence of either osteoclastic or osteoblastic activity. The trabeculae in this zone have retained their original density. (From Bogumill GP. Orthopaedic Pathology: A Synopsis with Clinical Radiographic Correlation. Philadelphia: Saunders, 1984. Reprinted by permission.)

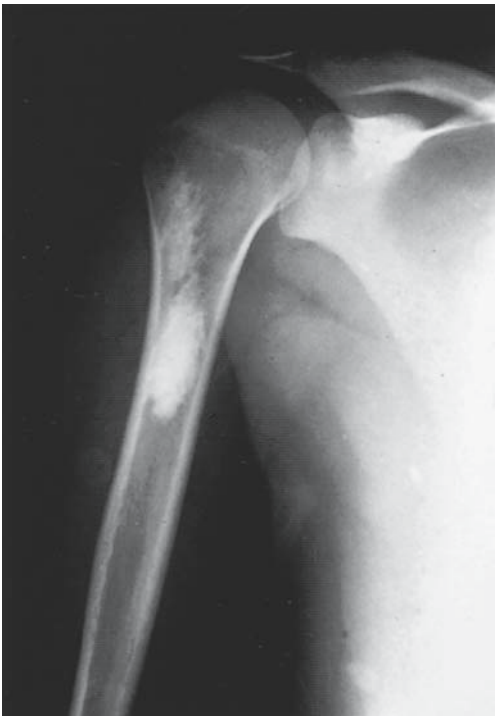


FIGURE 1-28. Radiograph of humerus of patient with history of deep-sea diving. The sclerotic area represents infarction of the marrow cavity with formation of calcium soaps and new bone from the reparative margins. (From Bogumill GP. Orthopaedic Pathology: A Synopsis with Clinical Radiographic Correlation. Philadelphia: Saunders, 1984. Reprinted by permission.)

segment develops a reactive hyperemia and resorbs. The necrotic bone then appears to be more dense on the radiograph—so-called relative radiodensity. There is also some compaction of dead trabeculae; as well as marrow necrosis with subsequent saponification and calcification of the dead fat, to additionally explain the sclerotic changes seen on radiographs.

A number of vasoocclusive phenomena can cause avascular (aseptic) necrosis (AVN). Although AVN can involve any number of different sites, the femoral head is by far the most typical (Fig. 1-29).

Etiologies of AVN can be grouped by causation:

1. *Trauma:* damage to vessels supplying the segment of the bone in question (i.e., fractures of the femoral neck and scaphoid).
2. *Occlusive phenomena:*

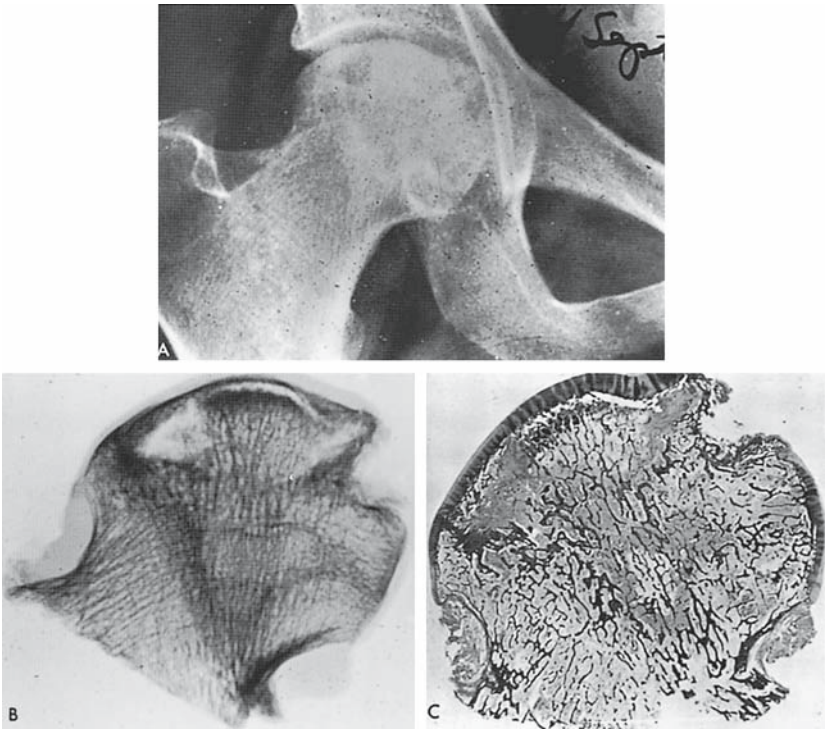


FIGURE 1-29. Clinical radiograph (A), specimen radiograph (B), and corresponding macrospecimen (C) of femoral head from a 26-year-old patient on long-term steroid therapy for idiopathic thrombocytopenic purpura with progressive pain and disability of both hips. Note the crescent sign, a cleft beneath the articular cartilage resulting from compression fractures of dead trabeculae. Also note the lytic areas in the lateral aspect of the femoral head caused by revascularization with removal of dead trabeculae and replacement with viable fibrous tissue. Zones of increased density are also evident. (From Bogumill GP. Orthopaedic Pathology: A Synopsis with Clinical Radiographic Correlation. Philadelphia: Saunders, 1984. Reprinted by permission.)

   a. Emboli: such as fat in alcoholism and pancreatitis; nitrogen as in Caisson's disease
   b. Stasis: coagulopathies and hemaglobinopathies
   c. External constriction: vasculitis such as systemic lupus erythematosus (SLE) and inflammatory bowel disease
   d. External compression: typical of storage diseases (Gaucher's and Fabry's) where stored material compresses intraosseous arterioles
3. *Idiopathic:* the causative factor is unknown, as in steroid-induced osteonecrosis and Chandler's disease.

Hematologic Syndromes

The genetic hemoglobinopathies, although not truly circulatory diseases, are best remembered in this group. Sickle cell disease, and to a lesser degree thalassemia, produce skeletal changes primarily through two mechanisms: myeloid hyperplasia and vasoocclusive phenomena. Because of the anemia these patients suffer, there is a drive to increase medullary hematopoiesis, and this results in dilation of bony contours to accommodate a marrow driven to produce more blood. Widening of the diploe of the skull, dilation of the small bones of the hands and feet, and increased trabecular markings are all radiographic hallmarks of this process. The vasoocclusive effect of these distorted red cells causes bone infarcts similar to those previously discussed (Fig. 1-30).

However, in a select group of patients the infarcts are frequently painful and a component of the "painful crisis." The stasis, sludging, and dead bone create a comfortable environment for bacterial invasion, accounting for the increased incidence of osteomyelitis in these patients.

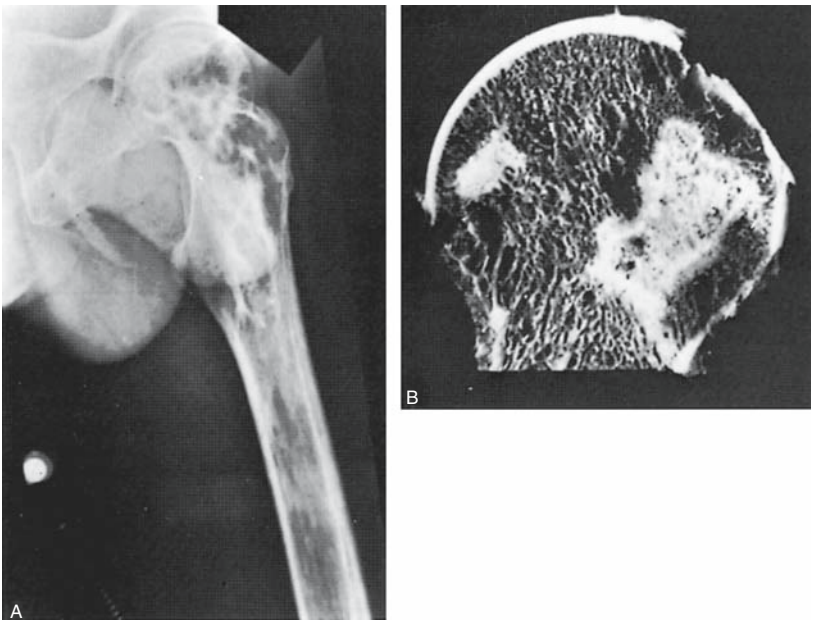


FIGURE 1-30. (A) Radiograph of hip and proximal femur of a 25-year-old man with sickle cell anemia. Areas of mottling and sclerosis are seen, suggestive of bone infarction. Evidence of sequestrum formation is seen in the lateral femoral cortex (bone within a bone). (B) Gross specimen of the femoral head taken from the same patient. Light necrotic areas are well demarcated from viable bone. (From Johanson NA. Musculoskeletal problems in hemoglobinopathy. Orthop Clin North Am 1990;21(1):196. Reprinted by permission.)

Neurodevelopmental Disorders

The final diagnostic category discussed in this chapter is the most heterogeneous of all. There are a few common threads that can be found to tie this eclectic mix of clinical states together. Clearly, they all have an impact on the musculoskeletal system. An attempt is made to describe them generically and use an example in each category to underscore their impact on the skeleton.

Neurologic Diseases

The deficit produced by neurologic diseases can be either sensory, motor, or central in origin. The level of involvement will determine the skeletal changes. Central nervous system deficits are typified by cerebral palsy. Prenatal anoxia can cause damage to the cerebral cortex; this includes damage to neural tissue that normally inhibits or damps muscular tone and keeps it at an acceptable level. Without normal inhibitory influences, these muscles become spastic. Muscle spasticity existing over a protracted period results in muscle imbalance around joints. Ultimately, contractures and chronic joint deformities such as subluxations and dislocations will follow. The hip, for example, is of particular concern in the spastic child.

Poliomyelitis is an example of a motor deficit disease. Viral damage to anterior horn cells results in focal motor weakness in various muscle groups in the extremities. Bone deprived of normal muscle loading tends to become osteopenic. In addition, the variable nature of the involvement again causes muscle imbalance around joints, with its subsequent deformities.

Sensory deficits may result in neuropathic arthritis. Joints deprived of proprioception are rapidly destroyed. The aggressive sequence of microtrauma, repeated effusions, ligamentous incompetence, articular damage, and severe degenerative joint disease is the fate of patients with tertiary lues, diabetes, pernicious anemia, leprosy, and heavy metal intoxications. Although proprioception is the initial sensory component lost, pain fiber deficit usually follows, resulting in destroyed but painless joints.

Spina bifida, or myelodysplasia, may result in mixed deficits. This congenital defect combines motor and sensory deficits to produce skeletal changes that parallel both. Osteopenia, joint deformity, and joint destruction may all be found. The joints, as expected, are insensate, a fact that only compounds the clinical problems.

Developmental/Congenital Defects

It is important to remember that congenital defects (present at birth) need not be genetic, and vice versa. However, any process that impacts on the growing skeleton, whether it be congenital or developmental, can be expected to produce changes. These changes can generally be expected to

be alterations in the configuration of the bone itself. Shortening, bowing, or angular deformities may be seen. Changes in bone density may or may not be seen.

Achondroplasia is the most common dwarfing syndrome. It follows an autosomal dominant inheritance pattern (Fig. 1-31). This syndrome disrupts normal enchondral bone growth and, therefore, results in shortening of all bones that depend on this mechanism for their growth (Fig. 1-32).

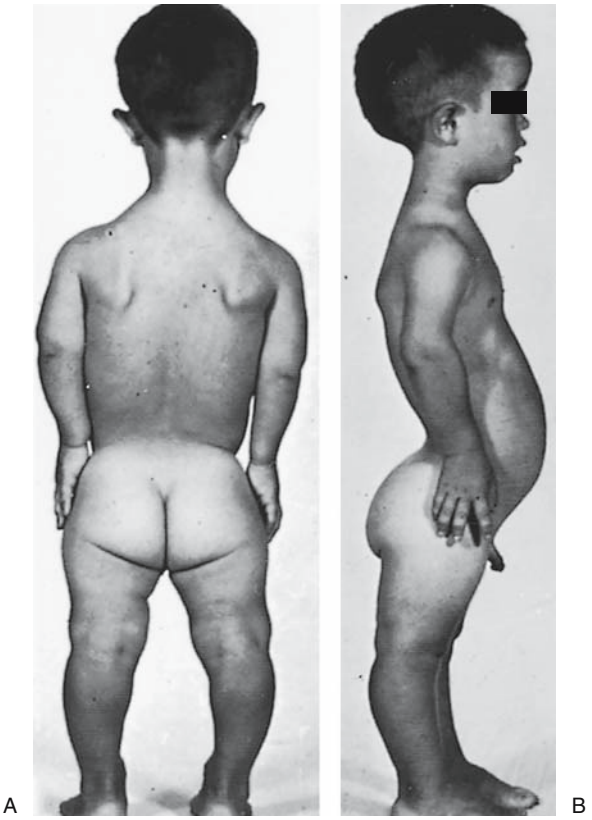


FIGURE 1-31. (A) Posterior photograph of achondroplastic dwarf showing distorted growth of long bones. The proximal limb segments are proportionately shorter than the distal, with the hands reaching only to the hip region. The legs are bowed, and the scapulae and pelvis are smaller than normal. Scoliosis is uncommon. (B) Lateral photograph of child with achondroplasia. Note marked lumbar lordosis with prominent buttocks as a result of pelvic tilt. The lordosis is caused in part by differential growth of vertebral body versus posterior elements. (From Bogumill GP. Orthopaedic Pathology: A Synopsis with Clinical Radiographic Correlation. Philadelphia: Saunders, 1984. Reprinted by permission.)

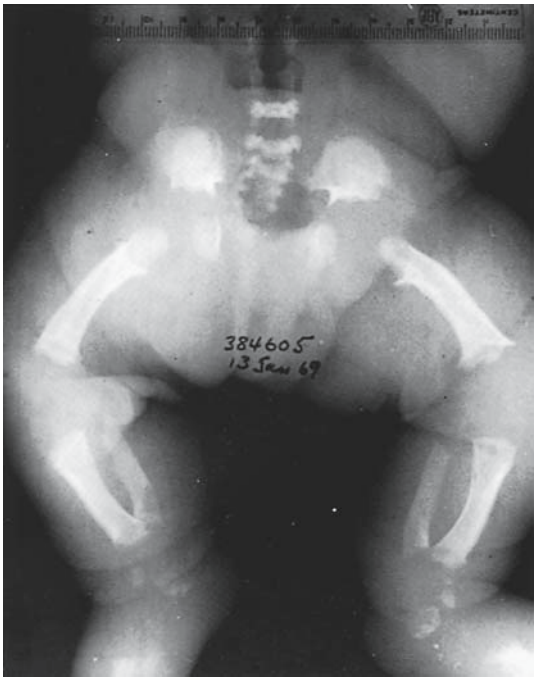


FIGURE 1-32. Radiographic appearance of lower limbs in a patient with achondroplasia. Note the narrow sciatic notch and flat broad acetabulum resulting from inadequate growth of "Y" cartilage in acetabulum. Shortened, thick femurs, fibias, and fibulas are bowed. Bone density is normal. Epiphyses do not yet exhibit secondary ossification centers. (From Bogumill GP. Orthopaedic Pathology: A Synopsis with Clinical Radiographic Correlation. Philadelphia: Saunders, 1984. Reprinted by permission.)

Bone dysplasias (intrinsic defects of bone growth) are, as a general rule, genetic in origin despite the fact that some of the milder (tarda) forms may not be apparent until the child begins growing.

Chromosomal defects, such as Down syndrome**,** are often characterized by severe ligamentous laxity. This is the basis for the numerous orthopedic conditions that are typical in this group. Atlantoaxial instability, flat feet, patellar subluxation, bunions, and subluxation of the hips all point to the inability of the ligamentous structure to stabilize joints. Many of the chromosomal abnormalities involve defects in mesoderm development, which accounts for the common coincidence of musculoskeletal, genitourinary, and cardiac abnormalities.

The clubfoot deformity is probably multifactorial in its etiology. The interplay of heredity and environment is accepted, although poorly understood. Clubfoot, similar to developmental dysplasia of the hip and scolio-

sis, is a defect that is considered to be a reflection of this interplay. Usually identified at birth, clubfoot is a generalized dysplasia of the mesenchymal structures (bone, ligament, muscle) of the foot and perhaps the entire lower extremity. Genetic as well as environmental (intrauterine position) factors have been implicated, but their exact interaction remains unknown.

Summary

Many different pathologic states have impact on the skeletal system, whether they be primary or secondary. Bone has a limited number of ways of responding to abnormal stimuli whether they be chemical, mechanical, infectious, or circulatory. In general, one can expect to see either bone resorption or bone formation, either locally or systemically, dominate the pattern. A working knowledge of the normal mechanism usually allows the observer to anticipate the response to many of these pathologic processes.

In this regard, observing the changes that one sees on standard imaging studies often permits the development of a working differential diagnosis. Using the basic seven disease categories and expanding each into a plausible list of diagnoses should lead, given more data, to a definitive diagnosis and hence appropriate treatment.

Suggested Readings

Bernstein J. Musculoskeletal Medicine. Rosemont, IL: American Academy of Orthopaedic Surgeons, 2003.

Bogumill GP. Orthopaedic Pathology: A Synopsis with Clinical and Radiographic Correlation. Philadelphia: Saunders, 1984.

Buckwalter JA. Orthopaedic Basic Science: Biology and Biomechanics of the Musculoskeletal System. Rosemont, IL: American Academy of Orthopaedic Surgeons, 2000.

Questions

Note: Answers are provided at the end of the book before the index.

1-1. Osteoporosis results in:
   a. Increase in skeletal mass
   b. Decrease in the amount of mineralized bone
   c. No change in the mineral to matrix ratio
   d. Decrease in the cortical diameter of a long bone
   e. Increase in bone mineral density by DEXA scanning

1-2. Paget's disease of bone is:
   a. A disease of decreased bone turnover
   b. Common in young males
   c. Rarely seen in the skull
   d. Is most common in the foot
   e. None of the above

1-3. Bone as a tissue:
   a. Is largely devoid of cells
   b. Contains more water than cartilage
   c. Contains type II collagen in its ground substance
   d. Depends on its lamellar structure for strength
   e. Has amorphous calcium phosphate as its major mineral constituent

1-4. Neurologic diseases such as cerebral palsy, polio, and spina bifida damage the musculoskeletal system. This damage is *primarily* the result of:
   a. Muscle imbalance
   b. Lack of sensation
   c. Recurrent infections
   d. Defects in sensory motor integration
   e. Mental retardation

1-5. Causes of rickets include all except:
   a. Sprue
   b. Genetic renal tubular defects
   c. Vitamin C deprivation
   d. Dilantin therapy
   e. Renal phosphate retention

1-6. Hyaline cartilage:
   a. Is a hypocellular tissue
   b. Depends on the glycosaminoglycans for resiliency
   c. Is primarily water by weight
   d. Is found in diarthrodial joints
   e. All the above

1-7. Achondroplasia:
   a. Is an aberration of epiphyseal growth
   b. Is the most common skeletal dysplasia
   c. Is characterized by knock knees
   d. Is often associated with mental retardation
   e. Is fatal in infancy

1-8. Rheumatoid arthritis:
   a. Is a disease of the articular cartilage
   b. Typically results in hyperostosis around the joints
   c. Commonly causes early fibrosis of the synovium
   d. Is considered a noninflammatory arthritis
   e. Radiographically is characterized by juxtaarticular osteopenia

1-9. All the following are characterized by generalized osteopenia on the radiograph except:
   a. Gout
   b. Hyperparathyroidism
   c. Osteomalacia
   d. Multiple myeloma
   e. Osteoporosis

1-10. Neuropathic arthritis is the result of proprioceptive sensory loss in conjunction with microtrauma and a component of vasomotor instability. All the following can cause a neuropathic arthritis except:
   a. Syphilis
   b. Polio
   c. Diabetes
   d. Heavy metal intoxication
   e. Leprosy

1-11. Avascular necrosis of bone:
   a. Can result from exogenous steroid administration
   b. Is characterized by relative radiodensity
   c. Can involve the femoral head and talus among other bones
   d. Can be associated with sickle cell disease
   e. All the above

1-12. Collagen:
   a. Is a proteoglycan
   b. Is important for the compressive strength of cartilage
   c. Is synthesized by chondroblasts and osteoblasts
   d. Is a large ring molecule
   e. Is not a cross-linked molecule

2
Skeletal Trauma

John N. Delahay and Scott T. Sauer

Skeletal trauma, for the subject of discussion, can be divided into three major groups of injuries to the musculoskeletal system:

Fractures
Dislocations
Fracture/dislocations

A fracture, by definition, is a disruption in the continuity of cortical and/or cancellous bone. A dislocation is a disruption of the normal articulating anatomy of a joint. Dislocations can either be a complete disruption of the normal anatomy or a partial dislocation, in which case the term subluxation is used. A fracture/dislocation is a fracture occurring in or near a joint that results in a subluxation or dislocation of the joint.

Fractures

Fracture Descriptors

A number of different terms can be used to more accurately describe the configuration and features of any given fracture. These descriptors are as follows:

1. Open versus closed: A closed fracture is one in which the skin is intact over the fracture site and an open fracture is one in which the skin is not intact.
2. Simple versus comminuted: A simple fracture is one in which there are only two major fragments and one fracture line. A comminuted fracture is one in which there are multiple fragments of bone and multiple fracture lines.
3. Complete versus incomplete: "Complete" essentially means that the fracture line goes completely across the bone. Incomplete fractures, most typically seen in children, have a fracture line that only crosses one cortex of the bone involved.

Fracture Deformities

A fracture can be deformed in any one of three possible planes. Classic deformations are described as follows (Fig. 2-1):

1. Displacement: Translation of the two fragments in relation to each other in one or more planes. Traditionally, displacement refers to the position of the distal fragment in relation to the assumed stationary proximal fragment. Specific types of displacement include overriding, where the two fragments are shortened in relation to one another, and distraction, where essentially the bone ends are pulled apart.
2. Angulation: Occurs when the two fracture fragments are not aligned and an angular deformity is present. Alignment means that the axes of the proximal and distal fragments are parallel to each other and the joint above and below are in the normal (parallel) relationship. Angulation is typically defined by the direction in which the apex of the angle points—medial, lateral, dorsal, volar, etc.
3. Rotation: Present when there is a torsional relationship between the two fracture fragments.

Fracture Patterns

A number of different fracture patterns have been described (Figs. 2-2 to 2-4):

1. Transverse
2. Spiral
3. Oblique
4. Impacted or compressed
5. Avulsion
6. Torus (buckle)
7. Complex (multiple patterns)

Fracture Mode of Loading

The mechanical environment creating a fracture provides a great deal of information as to the mechanism of injury and the extent of that injury. For that reason, biomechanical analyses have been performed to more clearly elucidate the fracture pattern and such specific modes of loading as these:

1. Bending loading produces a transverse fracture
2. Torsional loading produces a spiral fracture
3. Axial loading produces a compression or impacted fracture
4. Tensile loading produces an avulsion fracture
5. Combined loading, such as bending and axial loading, which together produce an oblique fracture.

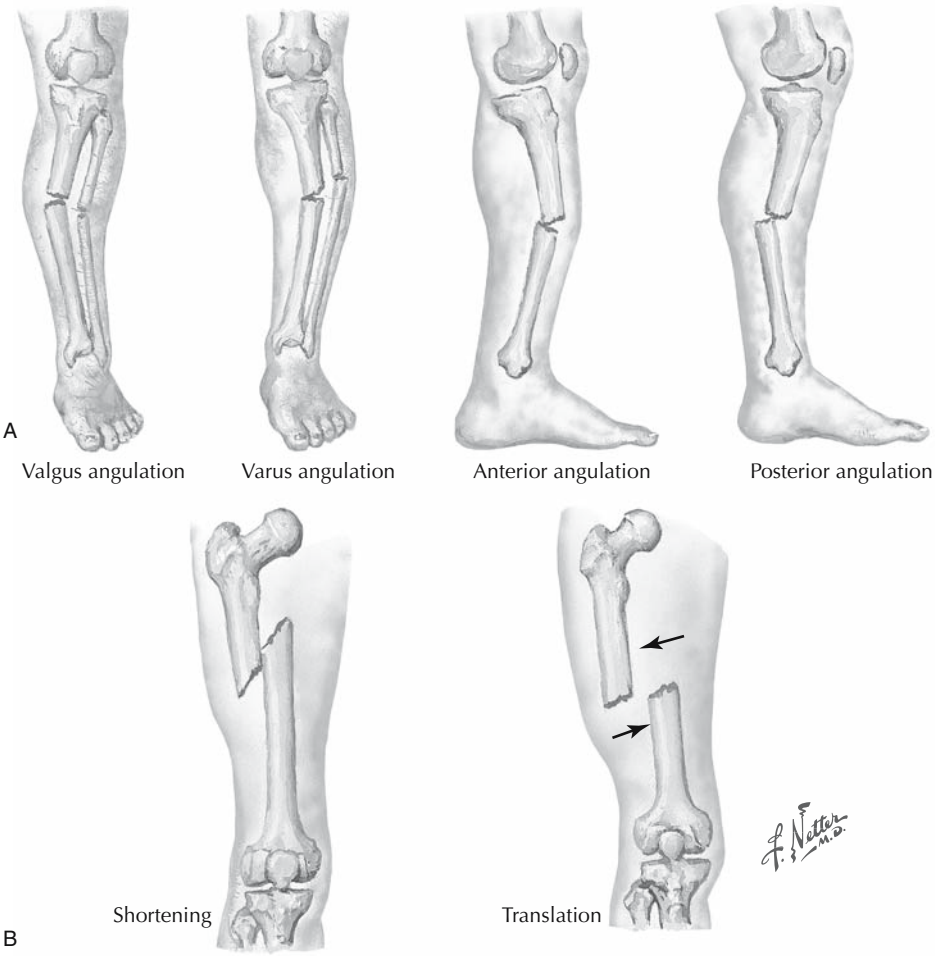


FIGURE 2-1. (A) Angulation is described by the direction in which the apex of the fracture is pointing. (B) Displacement (*arrows*) is defined as the position of the distal fragment in relation to the proximal fragment. (Netter images reprinted with permission from Elsevier. All rights reserved.)

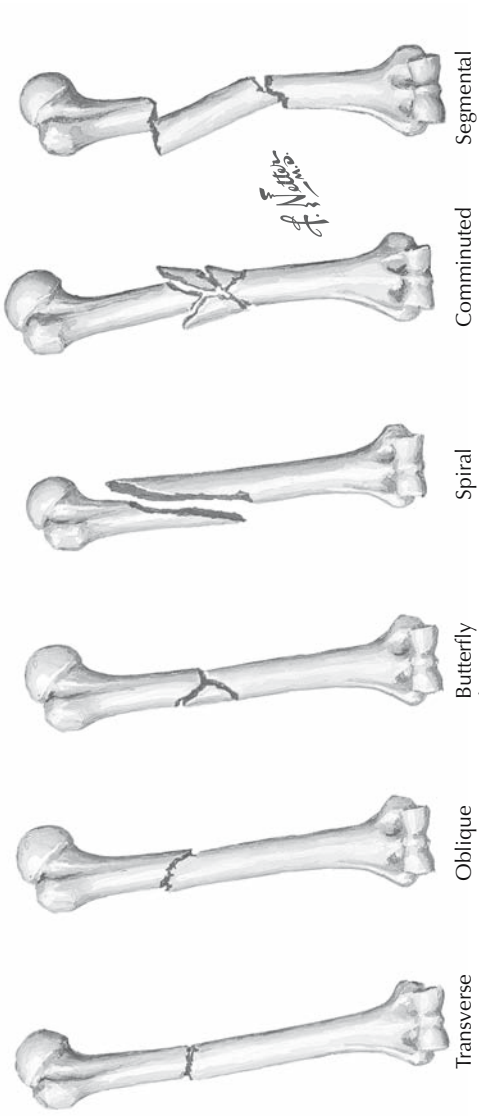


FIGURE 2-2. Fracture patterns. (Netter images reprinted with permission from Elsevier. All rights reserved.)

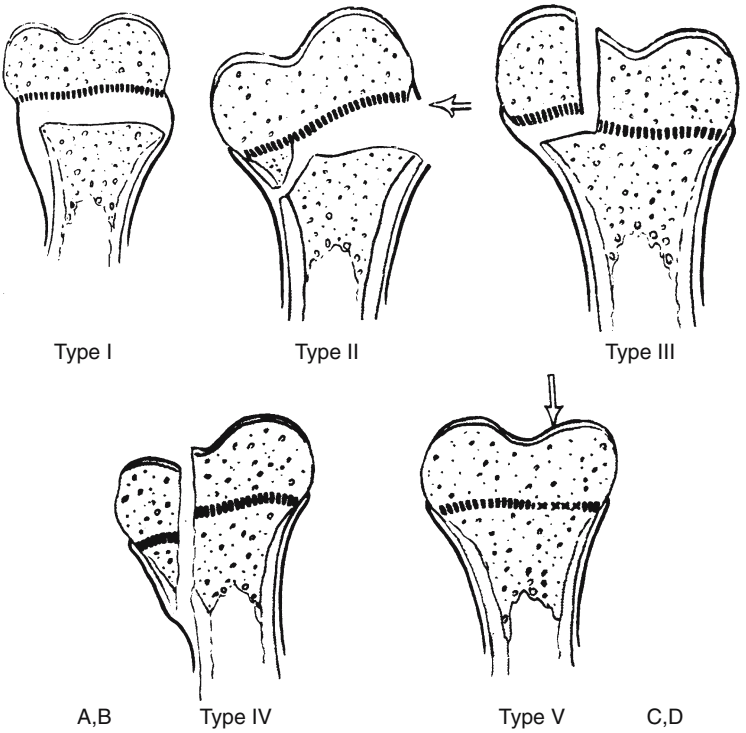


FIGURE 2-3. Salter classification of epiphyseal plate fractures. Type I: separation of epiphysis. Type II: fracture-separation of epiphysis. Type III: fracture of part of epiphysis. Type IV: (A) fracture of epiphysis and epiphyseal plate; (B) bony union causing premature closure of plate. Type V: (C) crushing of epiphyseal plate; (D) premature closure of plate on one side with resultant angular deformity. (From Gartland J. Fundamentals of Orthopaedics, 3rd ed. Philadelphia: Saunders, 1987. Reprinted by permission.)

The significance of fracture patterns is that they suggest the amount of force that was applied; hence, an extrapolation can be made that anticipates the amount of soft tissue damage.

Soft Tissues

As already mentioned, a number of soft tissues can be damaged, including the periosteum, blood vessels, nerves, muscles, tendons, and ligaments. The types of injury involving these tissues are delineated in the following subsections.

Vascular Injury

Vascular injury is a relatively uncommon event when associated with fractures. When it occurs, it is always an emergent situation. The most common vascular injury is a compartment syndrome. Increased pressure within a fascial compartment can cause muscle necrosis in a relatively short period of time. In the front of the leg, for example, a compartment with the following boundaries exists: the tibia, the syndesmotic membrane, the fibula, and the fascia overlying the tibialis anterior muscle. Because none of these four boundaries can be stretched, the contents of the compartment, that is, the tibialis anterior muscle among others, will necrose from increased pressure caused by an increase in fluid content, occurring after trauma;

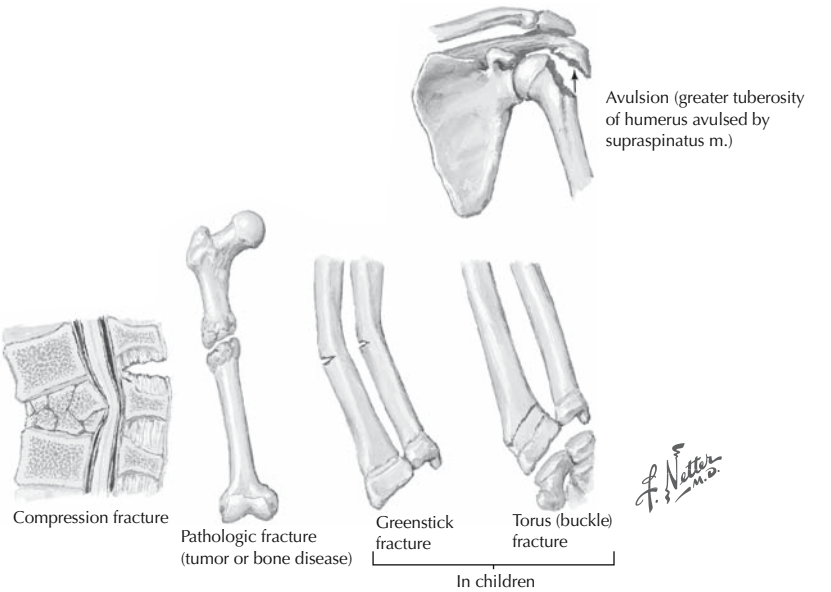


FIGURE 2-4. Descriptive terms for typical fracture patterns. (Netter images reprinted with permission from Elsevier. All rights reserved.)

this can cause muscle necrosis in a relatively short period of time. The diagnosis of this syndrome is essential. Clinical findings and evaluation methods such as tenderness, pain with passive stretch, and compartmental pressure monitoring assist in diagnosis. Once the diagnosis is confirmed, immediate surgical release of the compartment via fasciotomy is required.

Arterial Injury

Injury to arterial vessels is less common because these vessels are elastic and mobile. The vessels can be damaged when they are either inelastic or fixed by soft tissue structures. The most frequent injury is an intramural hematoma in which the classic signs of arterial injury are usually present. Because of the irreparable damage to the vessel wall, a vein graft or prosthesis is usually required for repair. Injury to the artery is classically associated with several specific fractures involving such sites as the clavicle, the supracondylar region of the elbow (especially in children), the femoral shaft, and the area around the knee.

Nerve Damage

Typically, a nerve is compressed, contused, or stretched as a result of a fracture or other injury. Classic examples include radial nerve injury secondary to fractures of the distal humerus and sciatic nerve injury following posterior fracture dislocations of the hip. The classic grades of neural injury are these:

1. Neuropraxia. Death of the axon does not occur. The condition is generally caused by pressure or contusion and usually improves by itself in a few weeks. The nerve is anatomically intact and physiologically nonfunctional.
2. Axonotmesis. Axonotmesis is an anatomic disruption of the axon in its sheath. Improvement follows regeneration, the axon growing at a slow rate of 1 mm a day along the existing axonal sheath.
3. Neurotmesis. Neurotmesis is an anatomic disruption of the nerve itself. Surgical repair is required if recovery is to be anticipated.

Muscle and Tendon

It goes without saying that with any fracture or dislocation there is always some associated muscle damage. The extent of this damage and the results will vary depending on the site in question. Myositis ossificans is a specific complication of muscle damage in which heterotopic bone forms within the damaged muscle. The quadriceps and brachialis are specifically predisposed to develop this complication.

Ligament

The strength of ligaments is constant throughout life. Certain injuries occurring about the joints can damage the ligaments supporting the joints.

Considering the multiplicity of tissues involved in skeletal trauma, age has been shown to be an important determinant in the results of load application. At any given age, the "weak link," or the first structure to fail, varies; it could be bone, ligament, or cartilage growth plates. Once the growth plate closes, however, the ligament is the most likely structure to fail. Ligamentous strength, it has already been noted, is constant throughout life. With aging, there is a decrease in cancellous bone volume and an increase in cortical bone porosity. With increasing age, therefore, bone becomes weaker; hence, cartilage, and ligamentous injury are less likely and bone injury more likely. This change means that the same mode of loading can produce a different injury pattern depending on the age of the patient. The same force, such as a tackle in football or a blow by an automobile on the outer side of the knee, is likely to cause a fracture through the distal femoral growth plate in a 12-year-old child, a tear of the medial and anterior cruciate ligaments in a college football player, and a compression fracture of the lateral tibial plateau in a 70-year-old man.

Fractures: Special Types

A number of "special" fractures have been described in the literature. They are defined in the following subsections.

Incomplete Fractures

An incomplete fracture, typical in a child, is one that traverses only a portion of the bone. Two variations have been described:

1. Greenstick fracture: This occurs on the tension side of the bone and involves the diaphysis or cortical bone.
2. Torus or buckle fracture: Known by either name, this occurs on the compression side of bending and involves cancellous bone.

Stress Fractures

Stress fractures are fractures resulting from repetitive loading, each load being below the endurance limit but summated to produce a level of force that indeed causes a fracture. These injuries are typical in the proximal tibia, the second metatarsal, and the femoral neck. They may heal well if the cause of the force ceases soon enough, that is, if the patient stops running for a period of time.

Pathologic Fracture

Pathologic fractures occur through abnormal or diseased bone. Among the more common examples are those that occur as a result of tumor or metastatic sites in bone, previously infected bone, or metabolically involved bone such as that resulting from osteoporosis.

Physeal Fractures

In children, a fracture through the cartilaginous growth plate is a common event. The Salter–Harris classification system has allowed such injuries to be more precisely characterized. It is important to remember that physeal fractures heal very rapidly, but they may be complicated by complete or incomplete growth arrest, producing shortening or angular deformity of the limb.

Intraarticular Fractures

Intraarticular fractures enter a joint and disrupt the joint surface and its articular cartilage. Intraarticular fractures can specifically be complicated by joint stiffness and/or the development of premature arthritis.

Pediatric Fractures

Pediatric fractures have a number of special features, which are discussed in Chapter 5.

Fracture Healing

The biology of fracture healing is not particularly complex and parallels that of any nonossified tissue. Essentially, fracture healing occurs in three phases (Fig. 2-5):

1. Vascular phase. This phase begins at the time of the insult and proceeds through the development of a hematoma. This hematoma is then infiltrated by cellular elements, which in turn lay down collagen and cause hematoma organization. A vascularization step follows when the organized hematoma is vascularized by small arterial extensions. The end result of the vascular phase is the development of a soft callus.
2. Metabolic phase. This stage begins about 4 to 6 weeks after the injury. During this period, the soft callus is reworked by a number of specific cellular elements to produce a firm, hard callus satisfactory for meeting the mechanical demands placed upon the fracture in the early phase. There are certain biochemical changes, specifically in pH and oxygen tension, that manipulate the environment during this phase of fracture healing.
3. Mechanical phase. This phase begins once a hard callus is present, which is then manipulated according to the rules of Wolff's law. Essentially, mechanical stress is required to produce skeletal remodeling during this phase and ultimately to produce a solid, mechanically strong bone.

Evaluation of the Patient with Skeletal Trauma

Much more can be said about the evaluation of any surgical patient than the scope of this chapter allows. A number of specific points relative to the orthopedic patient are listed as follows:

1. History of injury. The mechanism of injury and the mode of application are frequently important to determine additional injury.
2. Occupation of the patient. Taking this into account is frequently helpful in planning rehabilitation and recuperative efforts once the fracture has been managed.
3. Activity level before injury. This concern frequently mandates the type of treatment given for a specific injury.
4. Deformity and swelling. These changes must be carefully evaluated physically so that complications can be avoided.
5. Neurovascular status. It is imperative that the neurovascular status of the extremity be carefully evaluated to avoid long-term or permanent sequelae. Similarly, it is critical that the neurovascular integrity of the extremity, or lack thereof, be documented.
6. Integrity of the skin is an absolute. Great care must be taken to ensure that there is no violation of the skin in the area of the fracture site.

Fractures: The Principles of Treatment

All fractures require that two basic goals be accomplished in their treatment: (1) reduction and (2) maintenance of that reduction. Different techniques may be used for achieving these two goals. First, the reduction of a fracture can be accomplished by closed manipulative methods, by surgical open reduction, or through the application of traction. Following reduction, the fracture site must be immobilized so that the fracture will heal in the optimum position. Immobilization can be achieved with external methods such as casts, splints, and external fixators; with internal methods, using various devices such as screws, plates, and intramedullary rods; or by the maintenance of the patient in traction (Fig. 2-6).

Orthopedic Emergencies

Relatively few orthopedic problems mandate immediate intervention. However, those that do exist truly represent emergent situations: these are open fractures, dislocations of major joints, and fractures associated with vascular injury, including compartment syndrome.

Complications of Fractures

A number of complications can occur following fractures and joint dislocations:

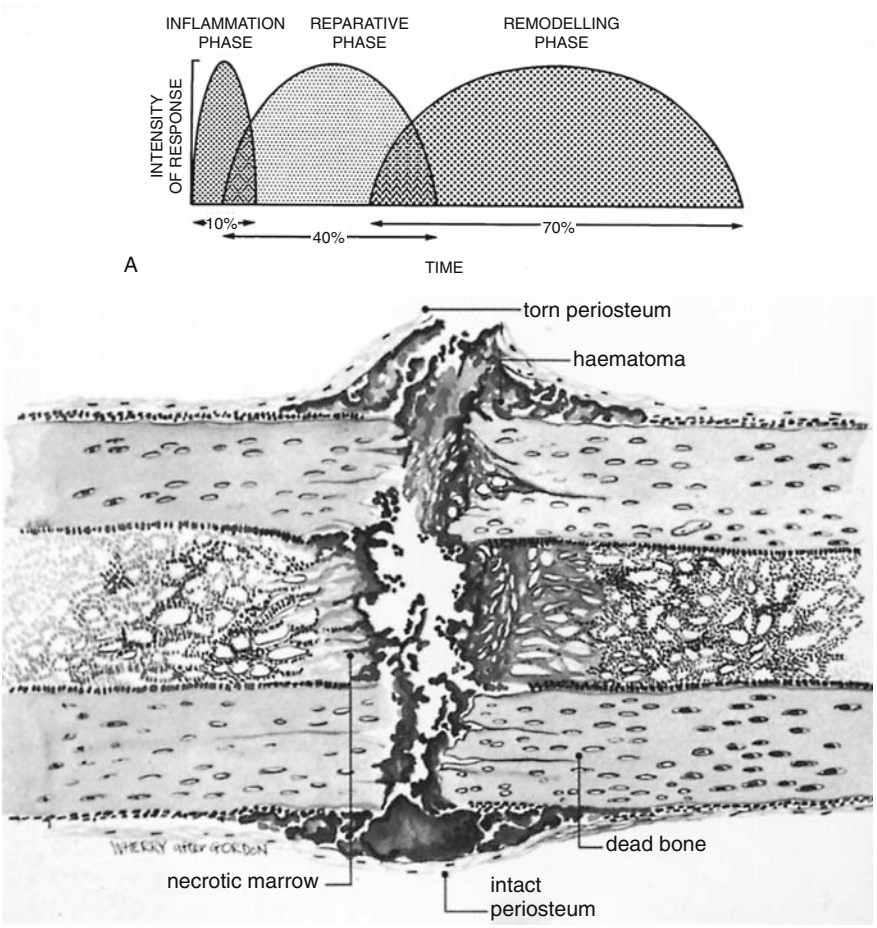


FIGURE 2-5. Phases of fracture healing. (A) An approximation of the relative amounts of time devoted to inflammation, reparative, and remodeling phases in fracture healing. (B) The initial events involved in fracture healing of long bone. The periosteum is torn opposite the point of impact and, in many instances, is intact on the other side. There is an accumulation of hematoma beneath the periosteum and between the fracture ends. There is necrotic marrow and dead bone close to the fracture line. (From Cruess, RL. Healing of bone, tendon, and ligament. In: Rockwood CA Jr., Green DP (eds) Fractures in Adults, 2nd ed, vol 1. Philadelphia Lippincott, 1984, Reprinted by permission.)

1. Problems of union
   a. Malunion: Defined as a healing in poor position for function.
   b. Delayed union: A fracture that has not healed in the usual statistical time frame.
   c. Nonunion: A fracture that has not healed and will not heal because it has lost its "biological drive" (a pseudarthrosis, or "false joint," develops).

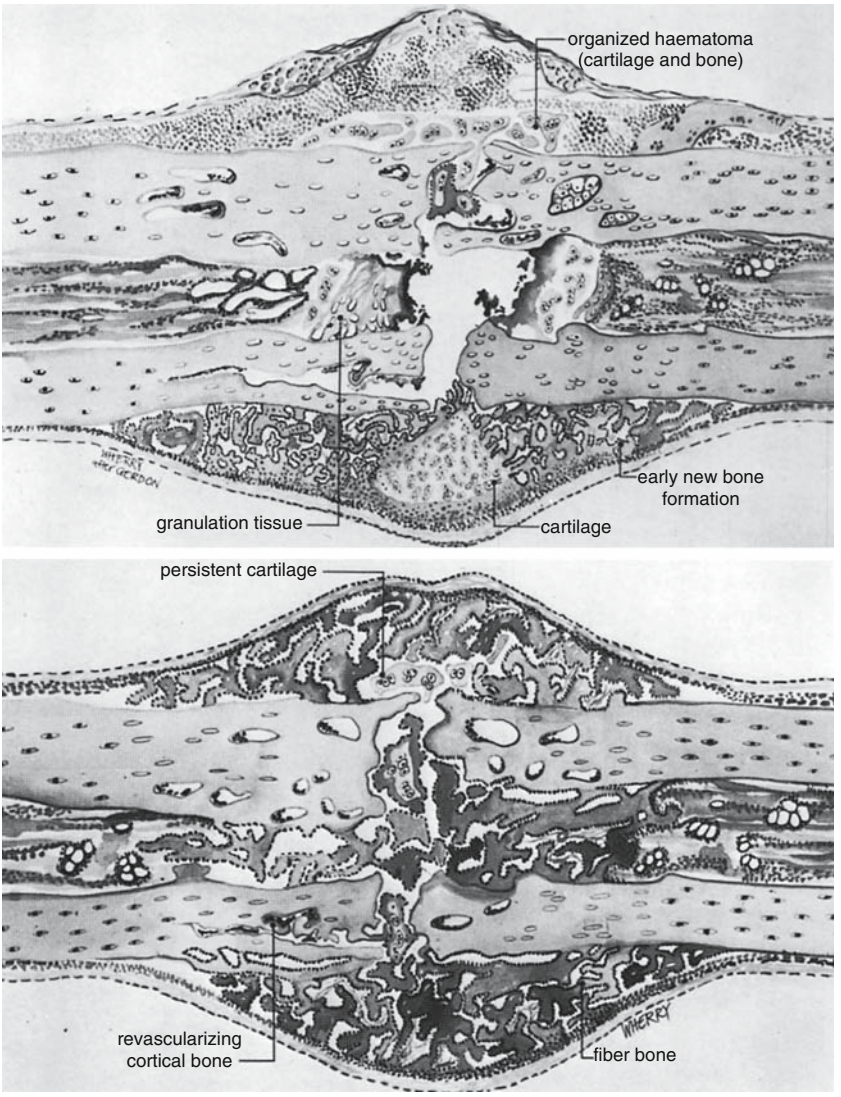


FIGURE 2-5. (continued) (C) Early repair. There is organization of the hematoma, early primary new bone formation in subperiosteal regions, and cartilage formation in other areas. (D) At a later stage in the repair, early immature fiber bone is bridging the fracture gap. Persistent cartilage is seen at points most distant from ingrowing capillary buds. In many instances, these are surrounded by young new bone. (From Cruess RL. Healing of bone, tendon, and ligament. In: Rockwood CA Jr, Green DP (eds) Fractures in Adults, 2nd ed, vol 1. Philadelphia: Lippincott, 1984. Reprinted by permission.)

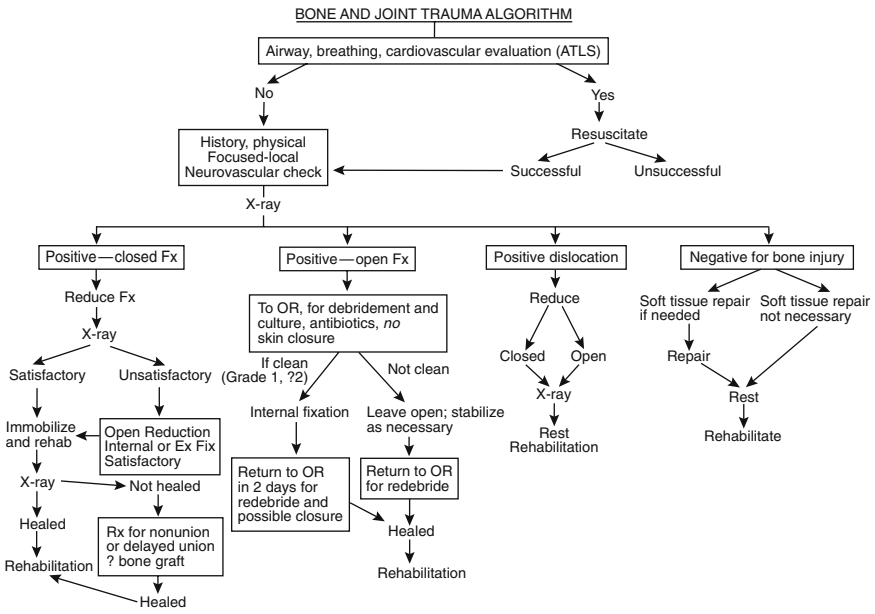


FIGURE 2-6. Bone and Joint Trauma Algorithm.

A number of reasons can be found why fractures do not heal. Excessive motion, infection, steroids, radiation, age, nutritional status, and devascularization locally have all been implicated in the delay of healing. The worst case scenario typically involves skeletal nonunion. If a bone fails to heal, surgical intervention for stabilization is frequently required. In addition to stabilization, biologic stimulation is necessary to make the fracture heal. Usually, this is accomplished through the application of bone graft material, with or without some type of external bone stimulation.

2. Stiffness and loss of motion: These complications commonly occur following many types of fractures, especially intraarticular fractures, in which arthrofibrosis is known to occur. Additional problems such as bony blocks, loose bodies in the joints, nerve palsies, and posttraumatic arthritis may only add to this problem.

3. Infection: Open fractures increase the risk of subsequent sepsis. Closed fractures that have been treated operatively are also at risk. The use of implants increases the risk of infection simply because they provide a substrate for the microcolonization of certain bacteria. These bacteria have the unique ability to sequester themselves under a slime layer called the "glycocalyx," which essentially makes them inaccessible both to culture and to antimicrobial agents. The presence of necrotic bone also contributes to infection risk.

4. Myositis ossificans: This problem, previously mentioned under the heading of "Muscle and tendon" trauma, typically is the development of heterotopic bone in certain muscle groups.

5. Avascular necrosis: Because of the tenuous and frequently retrograde blood flow in certain regional areas, several specific types of fractures are complicated by necrosis of bone. Bones at risk are the head of the femur, the talus, and the scaphoid.

6. Implant failure: The use of many metallic implants places certain fractures at risk. Because of the high fatigue loading of these implants, their use establishes a "race" between the fracture healing and the implant failing. If the implant fails, salvage is frequently a significant clinical problem.

7. Chronic regional pain syndrome (reflex sympathetic dystrophy): This unusual and disastrous complication is typically seen following trivial trauma in a predisposed patient, who then develops abnormal sympathetic tone. The mechanism for the development of symptoms may be associated with a partial nerve injury or contusion. The patients develop an exquisitely painful tender extremity and present a management disaster. Prognosis depends on early recognition of the syndrome and timely initiation of countermeasures such as sympathetic blocks. Stellate ganglion blocks are used for involvement of the upper extremity, whereas epidural blocks and lumbar sympathetic blocks are used in the lower extremity. Early aggressive physical therapy and return to normal function are important to the rehabilitation of patients with these difficult complications.

Fractures and Dislocations by Region: The Upper Extremity

The Shoulder Region

The physician must keep in mind that the purpose of the bones and joints of the upper extremity is primarily that of putting the hand where the patient needs it, that is, allowing the hand to do its work.

Fractures of the Clavicle

The clavicle is the first bone to ossify, and it does so by intramembranous ossification. Fractures of the clavicle are very common in children and occur by either direct trauma or a fall onto the outstretched hand. Fractures of the clavicle in children heal well. The usual treatment consists of a figure-of-eight brace or bandage that holds the shoulders back and tends to reduce the clavicle. Anatomic reduction is unnecessary and impractical. A sling is also a treatment option. In a child, a callus sufficient to provide immobilization and relieve pain will be present in 2 to 3 weeks; shortly thereafter, normal activities are generally possible. The biggest dangers are

overtreatment or a rigid type of bandage that interferes with the circulation of the extremity.

In the adult, fractures of the clavicle require more force than they do in children. Therefore, soft tissue injuries may simultaneously occur. Because of the proximity of the subclavian vessel behind the clavicle and the proximity of the brachial plexus, a careful neurovascular evaluation is imperative. Treatment usually is conservative, using the figure-of-eight brace or a sling. The patient must be told at the time of the fracture that a "bump" or swelling may be noticed after healing has occurred, and the treatment is usually not influenced by this anticipated event. Not all clavicular fractures heal primarily. Rarely, because of nonunion, it becomes necessary to perform an open reduction and internal fixation. In these cases, bone graft can be added. The indications for surgical treatment are few. The physician must remember that complete healing of a fractured clavicle in the adult frequently takes 3 months or more. An open fracture will require operative debridement. Occasionally, the skin is "tented" over a spike of bone, and an open reduction, just before the skin is pierced by the underlying bone, is warranted. Distal fractures of the clavicle, that is, lateral to the coracoclavicular ligaments, may require an open reduction internal fixation, if displaced (Fig. 2-7).

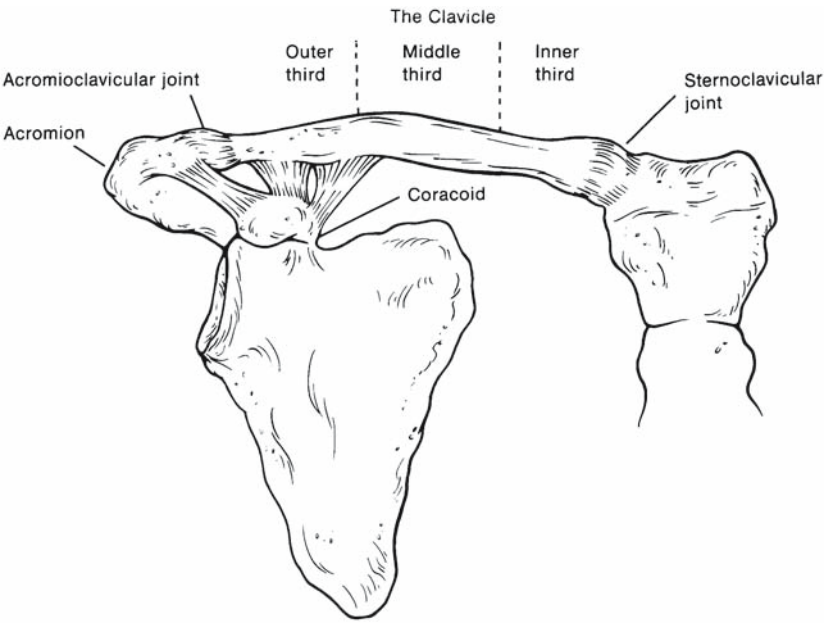


FIGURE 2-7. The clavicle and its articulations.

Fractures of the Proximal Humerus

Fractures just distal to the head of the humerus, the so-called surgical neck of the humerus, are extremely common in elderly osteoporotic bone. Healing of these fractures, even with some displacement, is rarely a problem, but the resulting shoulder stiffness may severely impair the older patient. This stiff and painful shoulder is often referred to as "adhesive capsulitis." Therefore, treatment of the elderly, with this type of fracture, is directed toward early mobilization after a short period of immobilization; several days are usually adequate for initial pain relief. Codman's exercises are usually begun after the first week. These simple pendulum exercises are done with the arm held in what is referred to as a "collar and cuff" or sling, using the weight of the arm itself as a traction mechanism. Codman's exercises are performed by the patient holding on to a table or other steady object with the good hand, and bending 90 degrees at the waist while allowing the injured extremity to hand straight down, hence employing the pull of gravity. This maneuver alone is frequently adequate to minimize shoulder stiffness.

An entirely different injury is seen in the younger patient. Although the pattern may be the same, the mechanism and force vary greatly. The high-energy fracture of the head of the humerus seen mostly in younger adults is frequently the result of sports or motor vehicle accidents and high-velocity falls. These injuries are often combined with dislocations of the shoulder (described next). Intraarticular fractures of the head of the humerus present a significant problem. The Neer classification (Fig. 2-8) can guide treatment of these injuries. The classification defines four segments of the proximal humerus: (1) the actual articular cartilage-covered head, (2) the shaft, (3) the greater tuberosity, and (4) the lesser tuberosity. Any of these fragments that are separated a centimeter or more from the others, or that are tilted by 40 degrees, are considered as a separate fragment. Generally speaking, if conservative treatment cannot hold an adequate reduction in a two- to three-part fracture, open reduction with internal fixation is often performed. A four-part fracture, or one in which the head fragment is actually split, is often treated by the insertion of a humeral head prosthesis replacing the broken segments (Fig. 2-9). Inherent to all treatment protocols is an aggressive rehabilitation program to regain shoulder motion. Therefore, fixation should be strong enough and rigid enough to allow early motion.

Glenohumeral Dislocation

Dislocation of the shoulder is a common event. Typically, most of these dislocations are anterior, with the humeral head moving anterior to the glenoid. The dislocation results when the arm is forcefully abducted and externally rotated, which is a frequent position, unfortunately, in contact sports. This condition is extremely painful and requires early reduction of

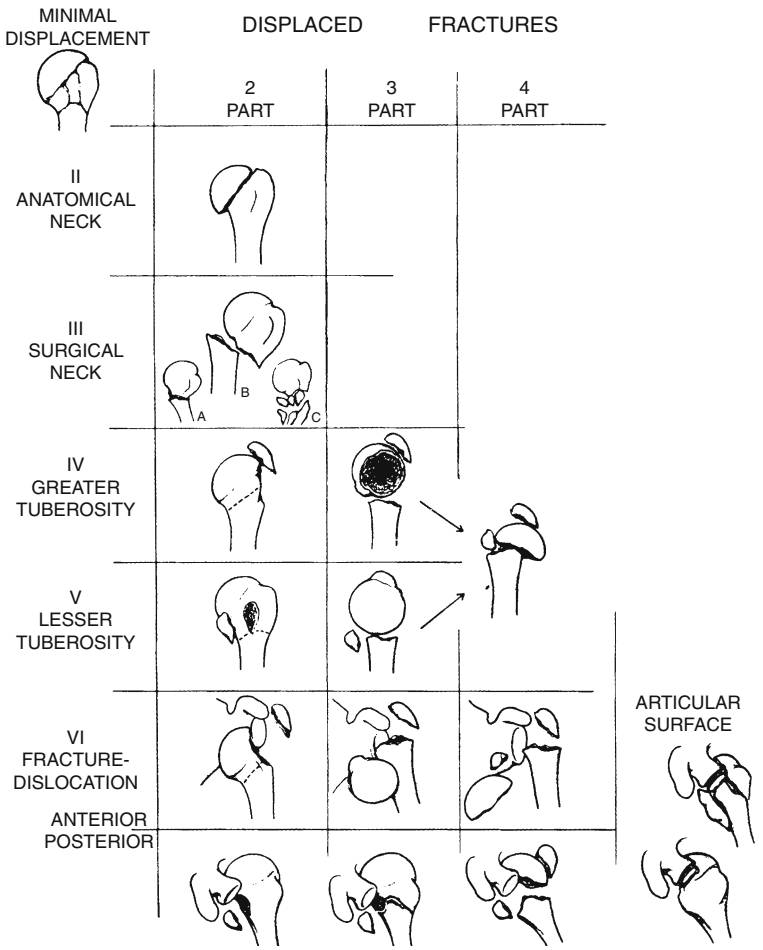
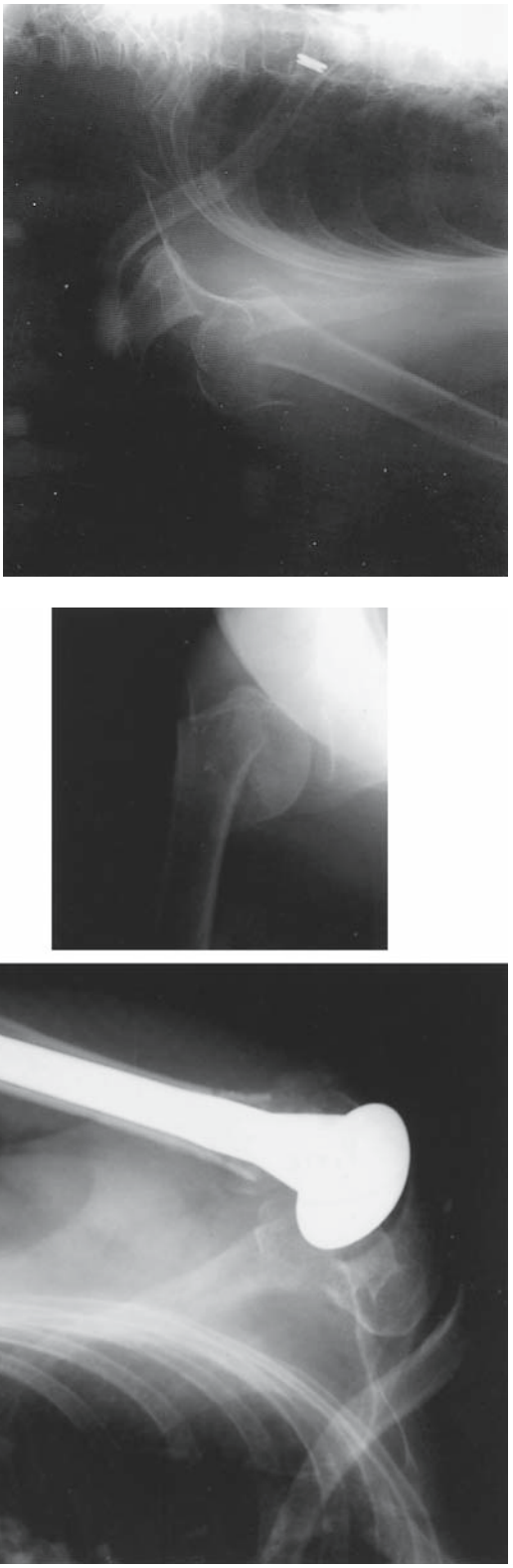


FIGURE 2-8. The Neer classification of proximal humeral fractures. (From Neer CS II. Displaced proximal humeral fractures. I. Classification and evaluation. J Bone Joint Surg 1970;52A:1077–1089. Reprinted by permission.)

the dislocation. If a fracture, such as of the greater tuberosity, coexists with the dislocation, reduction is even more urgent. The patient presents in the emergency room with an obvious "squared" silhouette of the upper arm (the normal roundness of the humeral head being absent). A careful neurologic and vascular exam should be performed, with the appropriate scapular anteroposterior, scapular lateral, and axillary radiographs taken. Reduction is then accomplished by one of several techniques, most of which employ traction and countertraction with the patient relaxed. Relaxation is usually obtained in the emergency room by the intravenous administration of sedatives and narcotics. The neurologic and vascular exams are then

FIGURE 2-9. Four-part humeral fracture.



repeated. It must be stated that even before reduction, the so-called autonomous zone of the axillary nerve, lateral to the shoulder, must be included in this neurologic check. The immediate decrease in pain is striking once the shoulder is reduced. A sling and swathe are generally adequate to immobilize and rest the shoulder; a postreduction X-ray should be taken.

Posterior shoulder dislocations account for only 4% of all dislocations and usually occur in patients during seizures, although occasionally they may occur in such sporting events as wrestling.

The duration of immobilization is not generally agreed. The classic thought, that a month of immobilization will decrease the likelihood of a recurrent dislocation, has unfortunately not proven to be true. The percentage of shoulder dislocations that recur after the first dislocation depends on the age at which the first event occurs. In the late teens and early twenties, the likelihood of a recurrence is very high (80%–90%). In patients more than 50 years old, the likelihood of a recurrence is lower (30%–40%); however, shoulder stiffness is a concern and, therefore, shoulder motion should be instituted early.

In the case of recurrent dislocations in a young person, surgical reconstruction is best performed on an elective basis. Repair of the anterior shoulder capsule and glenoid labrum is usually required.

Rotator cuff tears may occur as part of the dislocation or fracture/dislocation of the shoulder. Rotator cuff structural integrity is imperative for good shoulder function. More is discussed on the rotator cuff in Chapter 8 (The Shoulder).

Acromioclavicular (AC) Separation

Also called "separated shoulder" or "acromioclavicular dislocation," acromioclavicular separation is essentially a ligamentous injury involving the distal clavicle and the acromion. Such separations are frequently sports injuries sustained in a fall on the "point of the shoulder" and can be divided into six classes. Type I is a sprain of the acromioclavicular ligaments, with tenderness in that joint on palpation. A type II injury is a more-pronounced deformity of the joint with some prominence of the distal clavicle felt above the level of the acromion. A complete rupture of the acromioclavicular ligament is seen. The X-ray, taken with the patient standing and the arm hanging down, with or without weight on it, shows the clavicle to be riding higher, but still in some contact with the acromion. Type III acromioclavicular separations occur as a result of a tear of the acromioclavicular ligaments and the coracoclavicular ligaments (conoid and trapezoid ligaments). The muscles that insert on the clavicle tend to pull it up superiorly, resulting in an obvious deformity. This injury may be quite painful, but relatively speaking, is nowhere near as painful, dangerous, or requiring of any emergent treatment as a dislocated shoulder. Type IV injuries involve a posterior displacement of the clavicle from the acromion. These injuries are

difficult to reduce because they may protrude through the fascia of the trapezius. A type V injury is a dislocation of the AC joint with marked superior displacement of the clavicle greater than twice the normal coracoclavicular distance. Type VI injuries are rare, and involve an inferior dislocation of the AC joint with displacement of the clavicle inferior to the coracoid. Type I and II injuries are treated conservatively in a sling until pain subsides enough to undergo gentle range-of-motion exercises, followed by physical therapy. Function should be normal by 2 months. Treatment of type III injuries remains controversial, with the tendency toward operative treatment. Type IV, V, and VI injuries are almost always treated operatively, with surgical stabilization of the AC joint.

Fractures of the Shaft of the Humerus

Humeral shaft fractures are common, and their patterns vary. Displacement is generally caused by eccentric muscular pull with action of the supraspinatus, pectoralis major, and the deltoid determining the displacement of the proximal fragment (Fig. 2-10). The long muscles determine the displacement if the fracture is below the deltoid insertion. Treatment of the humeral shaft fracture has traditionally been conservative; options include coaptation plaster splints, which serve as a functional brace, as popularized by Sarmiento. The brace is a plastic, prefabricated device, usually worn 6 to 10 weeks. Its use permits excellent function of the hand while healing progresses.

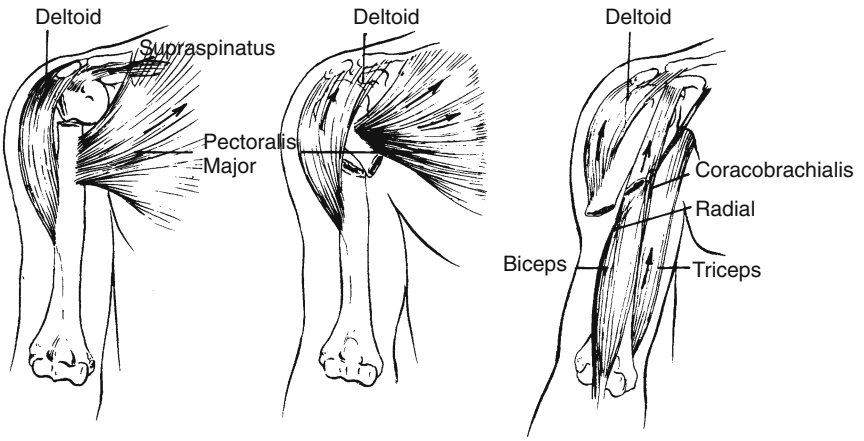


FIGURE 2-10. The deformity of the humeral shaft fracture is dependent on the muscles that insert above and below the fracture. (From Epps CH Jr. Fractures of the shaft of the humerus. In: Rockwood CA Jr, Green DP (eds) Fractures in Adults, 2nd ed, vol 1. Philadelphia: Lippincott, 1984. Reprinted by permission.)

In fractures at the junction of the middle and distal third of the humerus, the radial nerve is vulnerable to injury. Radial nerve function must be documented. Fortunately, most of these nerve injuries are neuropraxias; hence, excellent recovery can be expected. In more-comminuted fractures of the humeral shaft, open reduction and internal fixation are currently popular. The use of plates versus intramedullary locked rods is a current controversy.

Elbow and Forearm

Supracondylar Fractures in Children

This notorious fracture, the supracondylar fracture in children, presents a "minefield" for the orthopedic surgeon. In early stages, one must be vigilant in evaluating the child for vascular compromise, specifically compartment syndrome. Later, these can result in a Volkmann's contracture. Angular deformity resulting from growth plate damage occasionally may be seen. In an effort to minimize these disastrous complications, aggressive early closed reduction and percutaneous pinning currently form the treatment of choice. Alternatives such as open reduction or overhead traction are, nevertheless, available.

Closed reduction is best accomplished in the operating room with adequate anesthesia. Considering the risk of vascular compromise, these fractures should be treated emergently. With the C-arm (fluoroscopy) in place, a closed reduction is performed and two Kirschner wires are driven across the fracture site percutaneously. A plaster splint is then used to hold the elbow initially, with cast application in several days. In 3 weeks, the pins are generally removed, and in 3 more weeks the cast is discontinued. It is normal for there to be a good deal of stiffness after such an event occurs in a child. The key to postoperative management is to emphatically tell the parents not to make the child move the elbow. In other words, if the child is left alone, in a reasonably short time a good deal of motion is automatically regained. There should be no passive manipulation of the child's elbow. Because of the cartilaginous growth centers (physes, epiphyses, and apophyses) around the child's elbow, diagnosis may be difficult. The inexperienced practitioner may benefit from review of comparison views of the normal elbow.

Distal Humeral Fractures in Adults

These intraarticular fractures of the distal humerus are difficult to treat and are often followed by stiffness and arthritis. Therefore, an early open reduction and anatomic restoration of the articular surfaces with rigid fixation of the fragments to the shaft of the humerus give the best result. The ulnar nerve, because of its location, is at risk and generally has to be moved from the cubital tunnel and transported anteriorly. The goal of treatment

is to restore function by an anatomic restoration of the fragments and initiation of early motion. It is generally agreed that if a traumatized elbow is immobilized for 3 weeks or more, a poor result will follow. Functional elbow motion is approximately 30 to 100 degrees; this will allow the hand to reach the mouth (Fig. 2-11).

Dislocation of the Elbow

Most elbow dislocations occur in a fall on the extremity, and the ulna is pushed posterior to the humerus. Reduction of a posterior elbow dislocation is easily accomplished for the most part by closed means using manual traction and manipulation. Intravenous sedation and augmentation with local anesthetic injected into the joint is usually adequate for manipulation. X-rays must confirm the reduction. Short-term immobilization for comfort is all that is required. Following this, active flexion and extension are essential to regain motion. Any elbow trauma in the adult should be accompanied by warning the patient of the likelihood that a few degrees of full extension are usually lost but that this loss will present no functional disability.

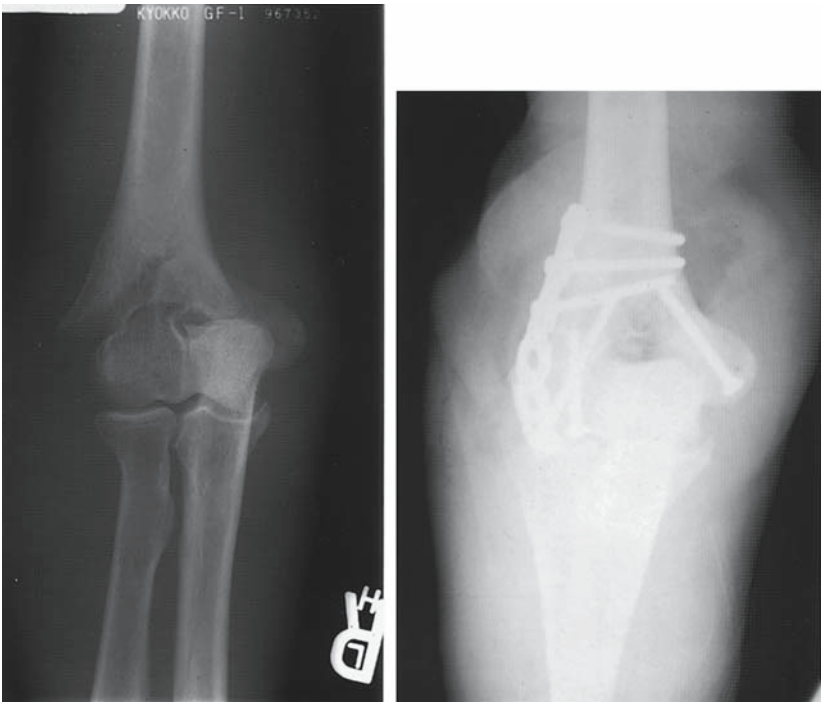


FIGURE 2-11. Distal humerus fracture.

Two specific forearm/elbow injuries must be mentioned. The Monteggia fracture-dislocation, a fracture of the proximal ulna with a dislocation of the radial head, requires not only treatment of the ulna but also reduction of the radial head. Although closed reduction is possible in children, in adults the ulna is almost always treated by open reduction and internal fixation with a plate and screws. Radial head position must be assured with X-rays (Fig. 2-12). The Galeazzi fracture-dislocation includes a fracture of the more-distal radius with a dislocation of the distal radioulnar joint. This radial fracture is treated by open reduction and internal fixation with plate and screws. The ulnar dislocation usually requires positioning of the forearm in supination to achieve reduction (Fig. 2-13).

Fracture of Both Bones of the Forearm

In children, fracture of both forearm bones is almost always treated nonsurgically by closed reduction and immobilization in a long arm cast. Anatomic reduction is not necessary because of the excellent remodeling potential in children. Six to 8 weeks of immobilization is necessary in a child. In adults, because of the concern over loss of pronation and supination and delayed union, operative treatment consisting of open reduction of both the radius and the ulna, done through two separate incisions and fixation with plates, is generally employed.

Fractures of the Olecranon

The triceps muscle inserts into the olecranon process, providing an extensor for the elbow joint. Although nondisplaced fractures of the olecranon may be treated closed, displaced fractures are routinely opened and fixed by means of a tension-band technique. Early motion is allowed after such

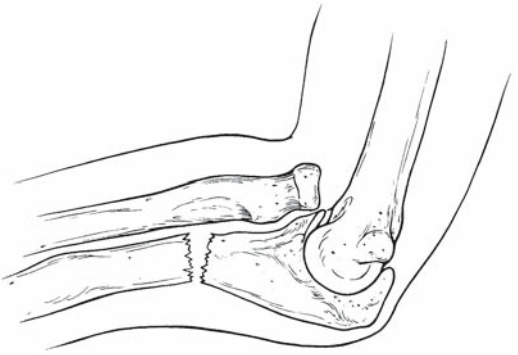


FIGURE 2-12. The Monteggia fracture-dislocation (type 1, anterior).

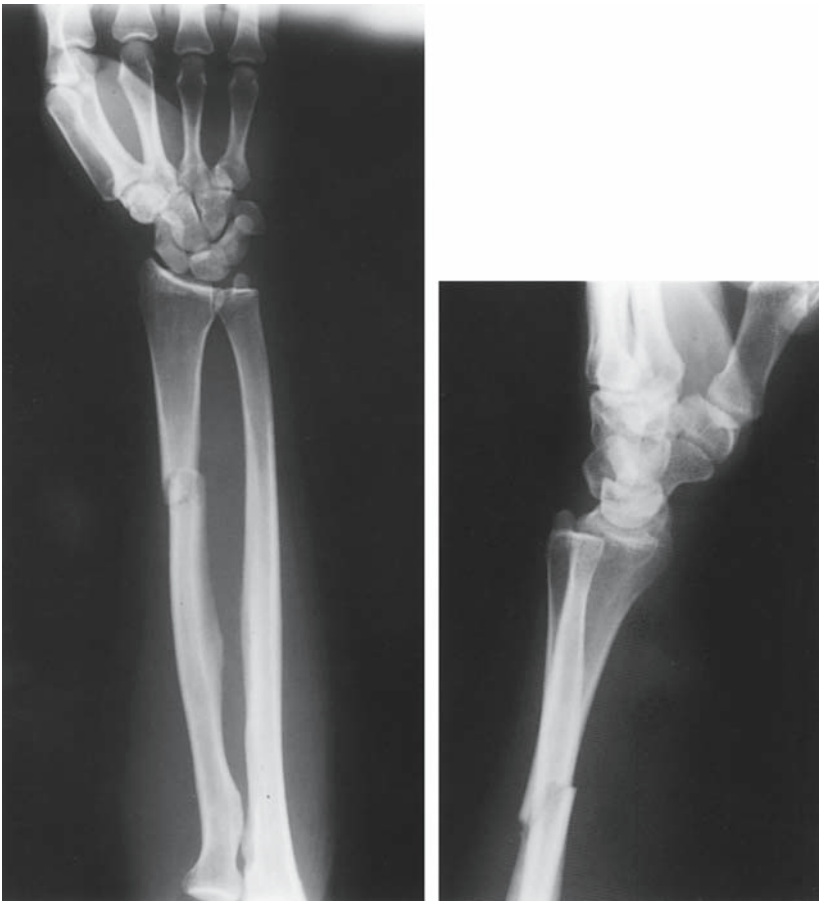


FIGURE 2-13. The Galeazzi fracture.

a procedure, but heavy work, of course, must await bony consolidation, which takes at least 6 weeks (Fig. 2-14).

Fracture of the Head of the Radius (Elbow)

This common intraarticular injury usually occurs from a fall onto the outstretched hand. If displacement is small, conservative treatment provides a good result. This treatment consists of immobilization for comfort for a short time, 3 to 5 days, then institution of several 10-minute periods of active motion consisting of flexion, extension, supination, and pronation. Each exercise may be followed by splint and sling immobilization for comfort in the first 7 to 10 days. The patient must be cautioned against passive motion, which may cause bleeding and stiffness. If more than one-

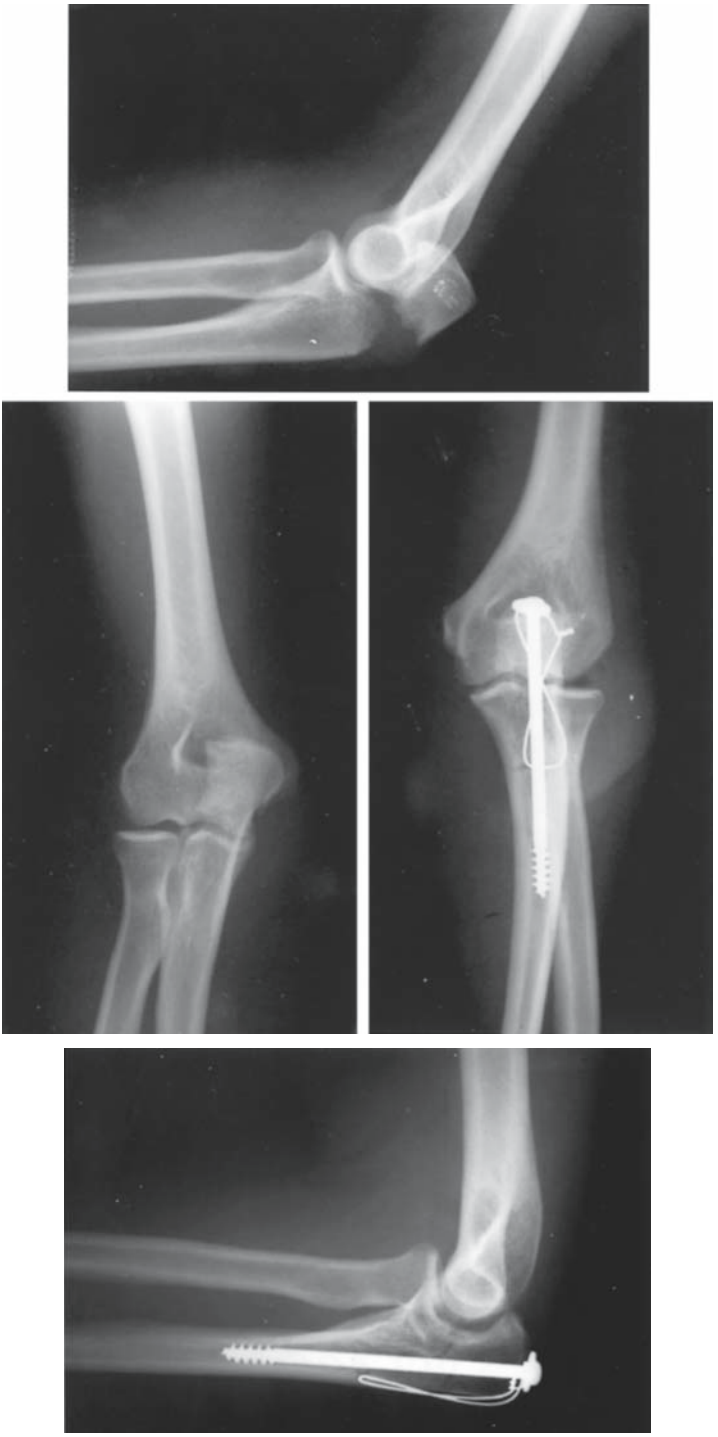


FIGURE 2-14. Olecranon fracture.

third of the head of the radius articular surface is involved, and more than a 3-mm depression or significant angulation occurs, open reduction and internal fixation with a small screw are occasionally performed. In an isolated, comminuted, displaced fracture, removal of the head of the radius can give a good result, with or without a radial head replacement.

Wrists and Hands

Wrist Fractures (Distal Radius)

Wrist fractures in children are commonly of the torus or buckle type. Reduction is rarely necessary; cast immobilization for 4 to 6 weeks, depending on the age of the child, is suggested. Another frequent fracture, usually occurring in older children, traverses the open and actively growing physis. Typically, this is a Salter II fracture (see Fig. 2-3). Reduction by closed means can be readily accomplished, and a cast is applied until healing has been accomplished. Fractures of both bones of the distal forearm, within an inch of the distal end of the bone, are fairly common. Closed reduction under local hematoma block anesthesia with intravenous sedatives works well. Perfect reduction is not needed because of the excellent remodeling potential of the child.

In the adult, the most frequent fracture about the wrist is the classic Colles fracture. The description in 1814 by Abraham Colles of Ireland predated the discovery of X-rays. This is a fracture of the distal radius usually seen in elderly patients, in whom osteoporosis is common. The three classic deformities are (1) dorsal displacement of the distal fragment, (2) volar angulation, and (3) radial shortening. It is the latter that presents the most significant functional problem if not corrected. Although, traditionally, closed reduction and cast application was the treatment of choice, and is frequently still employed, both patients and their orthopedic surgeons in many cases have not been willing to accept less than perfect results. Therefore, surgical repair has become a popular option. Because these fractures usually occur with a fall onto the outstretched hand, comminution, in addition to these three classic deformities, is frequently encountered. A particular type of comminution is the so-called die-punch injury in which the lunate impresses a fragment of distal radius proximally, which requires an open reduction and fixation. The means of fixation range from the use of multiple pins to an external fixator, which consists of two pins in a metacarpal and two pins in the radius with an outside adjustable bar. This device holds the fragments out to length. Actual open reduction and internal fixation of the fragments, using a buttress plate after elevation of the depressed fragment, and the application of bone graft may also be employed. Because many older adults request the best possible wrist they can get, such procedures may be necessary. It is, however, quite usual for people in their later seventies and eighties to prefer not to have an extensive

operation. They are usually satisfied with a simple closed reduction and cast immobilization. Even though the cosmetic result may not be perfect, the functional result is quite good.

Scaphoid (Navicular) Fractures

Vigorous young adults are vulnerable to scaphoid injury. This fracture, like so many others, results from a fall onto the outstretched hand. Any patient who gives this history and has tenderness in the so-called anatomic snuffbox of the wrist should be considered to have a scaphoid fracture and treated in a thumb spica cast. The anatomic snuffbox is the area just distal to the radial styloid and bordered by the extensor pollicis longus dorsally and by the extensor pollicis brevis and abductor pollicis longus volarly. X-rays of the wrist taken soon after the injury frequently fail to reveal a fractured scaphoid. Because of the danger of nonunion at the site, it is generally accepted to treat such a patient with a thumb spica cast and remove this cast 10 to 14 days later. At that time, clinical examination and new radiographs reveal whether there is a fracture. A bone scan, computed tomography, or magnetic resonance imaging occasionally may be needed. Patients often feel that they have had a sprained wrist, but a true "sprained" wrist is very rare. Because of the risk of nonunion and avascular necrosis of the proximal pole of the scaphoid, open reduction is recommended for displaced fractures. Other carpal bones are usually treated simply by immobilization in a cast and generally do well.

Lunate dislocation and perilunate dislocation are uncommon injuries and require significant trauma. Aggressive operative treatment is usually required to produce a satisfactory result.

Phalangeal Fractures

It is critical to remember to evaluate the patient for rotational malalignment. This deformity is frequently subtle unless the fingers are examined in the flexed position. Once reduced, the fracture should be immobilized in the position of function (flexed), never in full extension. Fractures involving articular surfaces must be openly reduced and internally fixed if any displacement is present. Otherwise, severe stiffness and arthritis can result.

Gamekeeper's Thumb

This common and frequently missed injury is a tear of the ulnar collateral ligament of the metacarpophalangeal joint at the base of the thumb. Typically, it occurs during a fall as a valgus stress is applied to the thumb. This stress frequently follows falling with a ski pole in the hand. The result, if overlooked, can be significant instability and impairment in use of the thumb for pinching. Although partial injuries are treated with a thumb spica cast, complete injuries are best treated by surgical repair.

Fractures and Dislocations by Region: The Spine

Injuries to the spine are best understood by considering the anatomy of the spine. For descriptive purposes, the spinal column is divided into anterior, middle, and posterior columns. The anterior column includes the anterior half of the body of the vertebrae and the anterior longitudinal ligament. The middle column includes the posterior half of the body and the posterior longitudinal ligament. The posterior column includes the pedicles and the lamina (Fig. 2-15). If only one column is involved, the

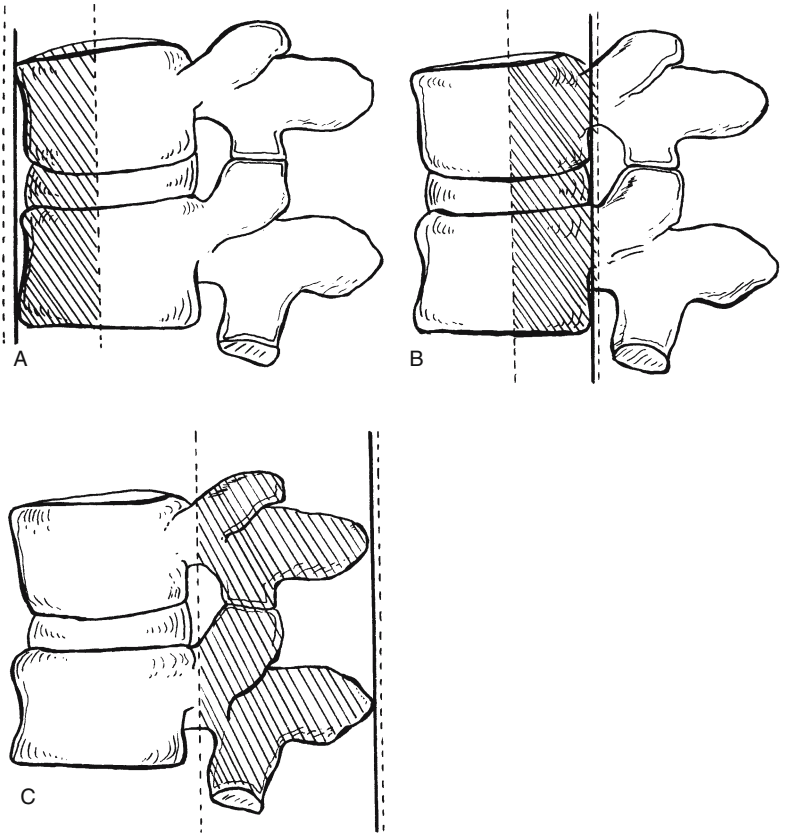


FIGURE 2-15. Schematic diagrams of the components of the three columns of the thoracolumbar spine. (A) Anterior column: anterior longitudinal ligament, anterior half of the body, and anterior half of the disk. (B) Middle column: posterior longitudinal ligament, posterior half of the body, and posterior half of the disk. (C) Posterior column: neural arch, ligamentum flavum, facet joint capsules, and the interspinous ligaments. (From Bucholz RW, Gill K. Classification of injuries of the thoracolumbar spine. Orthop Clin North Am 1986;17(1):70. Reprinted by permission.)

injury usually can be considered stable and is often treated conservatively. If two or more columns are involved, then the injury is considered unstable. Injury includes bony as well as ligamentous structures. Another important observation is for the presence of neurologic compromise. X-rays will reveal much of the bony damage of the spine, and computed tomography (CT) scan can reveal bony fragments in the spinal canal. It must be remembered that the spinal cord ends at the upper border of the second lumbar vertebra, and below it only the cauda equina inhabits the spinal canal. Magnetic resonance imaging is best used to study additional soft tissue injury.

Simple compression fractures of the anterior portion of the body of the vertebra are usually considered stable if they are less than 50% of the height of the vertebral body. If they are more than 50%, it is believed that the next column (the middle) is involved, which makes the fractures unstable. Similarly, burst fractures characterized by fragments of the vertebral body being displaced posteriorly may well encroach on the spinal canal. A CT scan will show the extent of encroachment. Although patients without neurologic symptoms may be treated by prolonged bed rest, modern treatment of spinal trauma with positive neurologic findings generally consists of removal of the bony fragments from the neural elements and stabilization by either posterior or anterior instrumentation. Fractures of the facets and dislocations of the facets are also encountered. Generally speaking, these are reduced and, if unstable, fixed. External fixation by means of casts and braces is not very efficient in immobilizing the spine. Halo fixation can be used, and internal fixation can be an efficient method of definitive treatment. The first and second cervical vertebrae have particular anatomic structures. Certain specific types of injuries, such as the Jefferson fracture, the Hangman's fracture, and the various odontoid fractures (Fig. 2-16), involve the C1–C2 complex. Aggressive immobilization is required for satisfactory results. Treatment may be closed with a halo application or open employing various techniques.

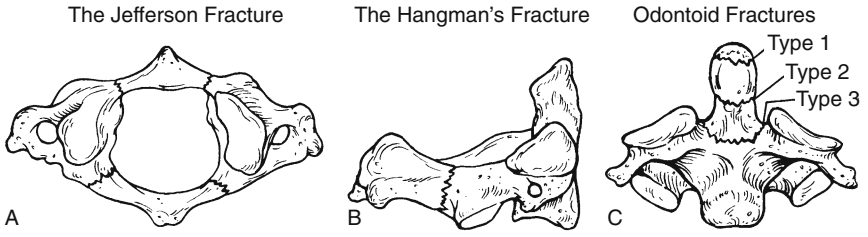


FIGURE 2-16. Fractures of the atlas and axis. (A) The Jefferson fracture. (B) The hangman's fracture. (C) Odontoid fractures.

Fractures and Dislocations by Region: Pelvis

The unique anatomy of the pelvis presents a challenge in management when it is disrupted. The pelvis is a ring structure of three bones: two innominate bones and, posteriorly, the sacrum. They are joined by dense, strong ligamentous structures. Each innominate bone is formed from three bones: an ilium, an ischium, and the pubis, together circumscribing the acetabulum. The juncture between the two innominate bones anteriorly is called the symphysis pubis, and posteriorly there are two sacroiliac joints surrounded by dense sacroiliac ligaments.

Two completely different types of pelvic fractures exist. In elderly and osteoporotic patients, minor trauma, such as a minor fall, may cause a crack of the ischium or pubis. As this may be the only fracture, therefore the fracture is considered stable. Bed rest for a few days or until the pain eases up, followed by mobilization, will allow the patient to become asymptomatic and fully functional in a matter of 6 to 8 weeks.

The other type of pelvic fracture is one following a severe traumatic force. In these injuries, blood loss is often excessive and should be anticipated. Great care in evaluating the patient is essential. A rectal and vaginal examination is required to assure that the fracture is not open through those soft tissue structures. An open fracture of the pelvis with injury to the bowel and the urogenital system still carries with it a mortality rate of 50%. Early treatment in these severe life-threatening pelvic injuries usually mandates the application of an external fixator: three pins in each ilium, with a device in front to hold the fragments together; this procedure seems to be the most effective way of stemming the devastating bleeding. Although embolization has its place, it is not always effective. If the bowel is involved, a diverting colostomy is mandatory to prevent fatal sepsis. Thorough exploration, cleaning, and debridement must be done. Then, open reduction and internal fixation, often using pelvic reconstruction plates, may become necessary, best performed by a surgeon familiar with the operative treatment of pelvic fractures. Fractures through the acetabulum causing articular disruption and, hence, a fracture-dislocation of the hip, are best managed by surgical acetabular reconstruction. With the onset of late osteoarthritis, total hip replacement might be necessary.

Fractures and Dislocations by Region: The Lower Extremity

Femur

Femoral Neck Fractures

The neck of the femur is situated *within* the capsule of the hip joint, which makes fractures of the neck of the femur subject to two problems with regard to the aftermath of trauma: avascular necrosis and nonunion. The

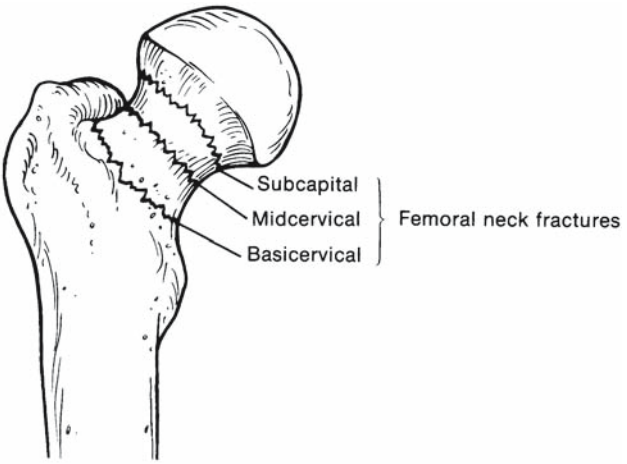


FIGURE 2-17. Locations of femoral neck fractures. Displacement is important to note.

blood supply is precarious. It originates from the medial and lateral femoral circumflex arteries at the base of the femoral neck and the extracapsular arterial ring. These vessels nourish the head of the femur. Any disruption of the femoral neck is likely to interfere with the blood supply of the head of the femur, thus causing avascular necrosis, which occurs in more than one-third of displaced femoral neck fractures. Nonunion, the other complication of femoral neck trauma, is related to the presence of synovial fluid, which bathes the fracture site. It is more difficult for the bone to heal in this environment, and it is difficult to reduce the fragments anatomically. No displaced femoral neck fracture, therefore, can heal when treated nonoperatively.

Fractures of the neck of the femur are classified into nondisplaced and displaced (Fig. 2-17). Nondisplaced (so-called impacted valgus fractures) are inherently stable and may heal without surgery. However, they are generally treated by open reduction and internal fixation (ORIF) using a compression screw placed up in the neck; this may be done percutaneously or through a small incision and is a relatively minimal procedure. These fractures, nondisplaced or valgus impacted, will normally heal, and the patient is allowed to get up and move about with partial weight-bearing until healing takes place; usually this occurs in 6 to 8 weeks. When a fracture of the neck of the femur is displaced, an effort may be made to do a closed reduction in the operating room, which must be confirmed radiographically. Then, similar screws may be put across the fracture site for stabilization. In patients generally under age 60 years and those with a vigorous lifestyle, ORIF is the preferred treatment. In the older and frail patient, it may be

more advantageous to avoid the possibility of nonunion, avascular necrosis, and an invalid life for several months by removing the head of the femur and replacing it with an endoprosthesis. This device enables patients to walk the day after the operation bearing most of their body weight. These prostheses can last anywhere from 10 to 15 years, and, therefore, in a young person every effort should be made to save the native femoral head. If a reduction of the fracture is performed and avascular necrosis or a nonunion occurs, a total hip replacement is the usual solution.

Intertrochanteric Fractures

Intertrochanteric fractures occur at or below the line between the greater and lesser trochanter and lie *outside* the capsule (Fig. 2-18). The blood supply, therefore, is not jeopardized by the fracture. On physical examination in the emergency room, these patients, similar to those with the displaced femoral neck fractures, will manifest shortening and external rotation. If an attempt were made to treat such a fracture without operative intervention, the patient would likely not survive protracted bed rest. Such a patient is likely to die of pneumonia, pulmonary emboli, bedsores, urinary tract infections, or the emotional damage that occurs in an old person when bedridden. Therefore, surgery is the norm. The compression hip screw with side plate is generally used (Fig. 2-19). Review of the X-rays allows one to determine whether the fracture is stable or unstable. When the proximal femur is fractured into three to four separate fragments, and especially if the lesser trochanter with its posteromedial cortex is one of these fragments, the fracture is unstable. In these cases, fixation must be rigid, and full weight-bearing often cannot be allowed for quite a few months. Because of the high incidence of implant failure seen with unstable fractures, other

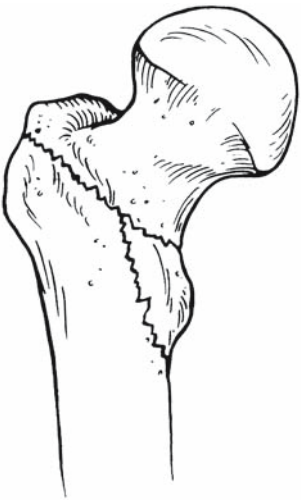


FIGURE 2-18. Intertrochanteric femoral fracture. Involvement of the lesser trochanter defines an unstable fracture pattern.

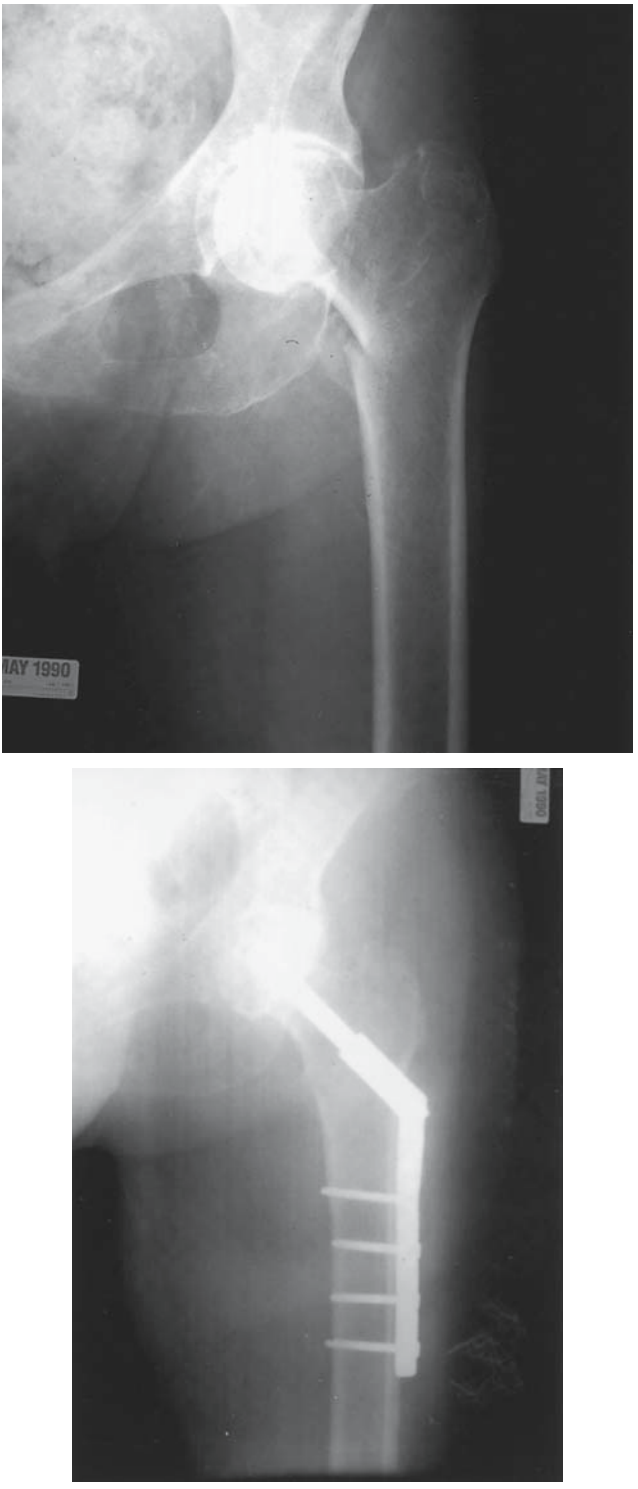


FIGURE 2-19. Intertrochanteric fracture.

solutions have been sought, one of them being a prosthetic replacement of all the fragments that are damaged. This procedure is a larger operation than the endoprosthesis for a femoral neck fracture and, therefore, is not often done. Healing in the intertrochanteric fracture usually proceeds well, assuming the fixation is adequate.

Subtrochanteric Fractures

Subtrochanteric fractures occur through an area below the lesser trochanter and are not quite as rapid to heal as the intertrochanteric injuries. In the younger population, subtrochanteric fractures usually follow the severe trauma of motor vehicle accidents. In the elderly, they are the result of severe osteoporosis or a pathologic process in the subtrochanteric area. Fixation is either by a standard hip screw, as described for the intertrochanteric fracture, but with a longer side plate or an intramedullary nail with proximal and distal locking screws.

In children, intertrochanteric and subtrochanteric fractures are generally treated in traction, whereas the very rare fracture of the femoral neck, even in a child, must be surgically treated in an effort to achieve union and avoid avascular necrosis.

Femoral Shaft Fractures

Femoral shaft injuries usually follow significant trauma. In children, they are treated by skeletal traction with a pin placed in the distal femur, followed by a spica cast. There has been an increased interest in fixation of pediatric fractures with either flexible intramedullary nails or external fixation. In adults, these fractures are almost always treated by intramedullary rods that are locked at both ends, inserted using closed techniques. Although the fractures do not heal faster with this treatment, the patient is able to walk and function, at first with crutches, and soon without crutches, while the fracture heals. This approach markedly decreases the length of the hospital stay (Fig. 2-20).

Dislocation of the Hip

Dislocation of the hip typically occurs from the impact between the dashboard and the knee in a motor vehicle accident. This impact drives the hip out posteriorly and, as expected, often damages the blood supply to the head of the femur as well as the sciatic nerve. The latter happens to lie immediately in the path of the dislocating femoral head. Most dislocations of the hip are posterior, and early reduction will decrease the incidence of avascular necrosis. Reduction in less than 6 to 8 hours is thought to be essential to reduce this risk. A hip that has been dislocated for more than 24 hours almost assuredly will undergo necrosis.

FIGURE 2-20. Femoral shaft fracture.

Fractures About the Knee

Distal Femoral Fractures

Fractures of the lower end of the femur in the region of the condyles may be supracondylar or Y- or T-shaped, the latter types entering the joint. If displaced, these fractures are generally treated surgically, and an effort is made to obtain an anatomic reduction of the articular surfaces. The reconstructed articular surface is then affixed to the distal femoral shaft. Anatomic restoration is necessary to prevent significant traumatic arthritis of

the knee. Fixation to the shaft is necessary to allow early motion. Generally speaking, weight-bearing is delayed for 3 months, but early motion begins within a couple of days of the fixation process. Frequently, a continuous passive motion (cpm) machine is valuable in the early stages to maximize motion.

Fractures of the Tibial Plateau

These intraarticular fractures of the tibial plateau typically occur on the lateral side of the tibia when the patient is struck, for example, by the bumper of a car. A large hemarthrosis can occur and, on aspiration, fat globules floating on the aspirated blood indicate that the bone marrow of the metaphyses has extravasated. Treatment is similar to that of the lower end of the femur and depends on the degree of displacement and comminution. Nondisplaced fractures may be treated by both relieving the patient of weight-bearing and initiating early motion. Displaced fractures are best treated surgically, including anatomic reduction of the fracture fragments, placement of bone graft under the fracture fragments if the bone has been compressed down, and fixation by means of a plate and screws. Early motion is begun immediately, but full weight-bearing should be delayed for 8 to 12 weeks because the cancellous bone is compressible before that time.

Fractures of the Patella

The patella is a sesamoid bone that gives the quadriceps mechanism a mechanical advantage in extending the knee. If the fracture is nondisplaced, closed treatment for up to 6 weeks is preferred. However, there usually is displacement, and then an open reduction and internal fixation is the treatment of choice. As we have seen in the fracture of the olecranon (Fig. 2-21), a tension-banding procedure works well. Rarely, in extremely comminuted fractures, a patellectomy may be the only option to avoid irregular patellar fragments causing painful traumatic arthritis of the patellofemoral joint.

Dislocation of the Knee

This injury is the result of very severe trauma. When a patient gives a history that the "knee came out of place," either the patella dislocated (or subluxed) or a piece of meniscus or loose body of cartilage was caught in the knee joint. True dislocation of the knee is a very serious injury notable for producing arterial damage to the popliteal vessels. The popliteal artery is fixed anatomically at the level of the proximal tibia by the interosseous membrane and, therefore, is placed at great risk when the knee dislocates. Arteriography can be used following immediate closed reduction of the dislocation if vascular compromise is suspected. The results of angiography will then determine whether arterial repair is necessary. Some would argue

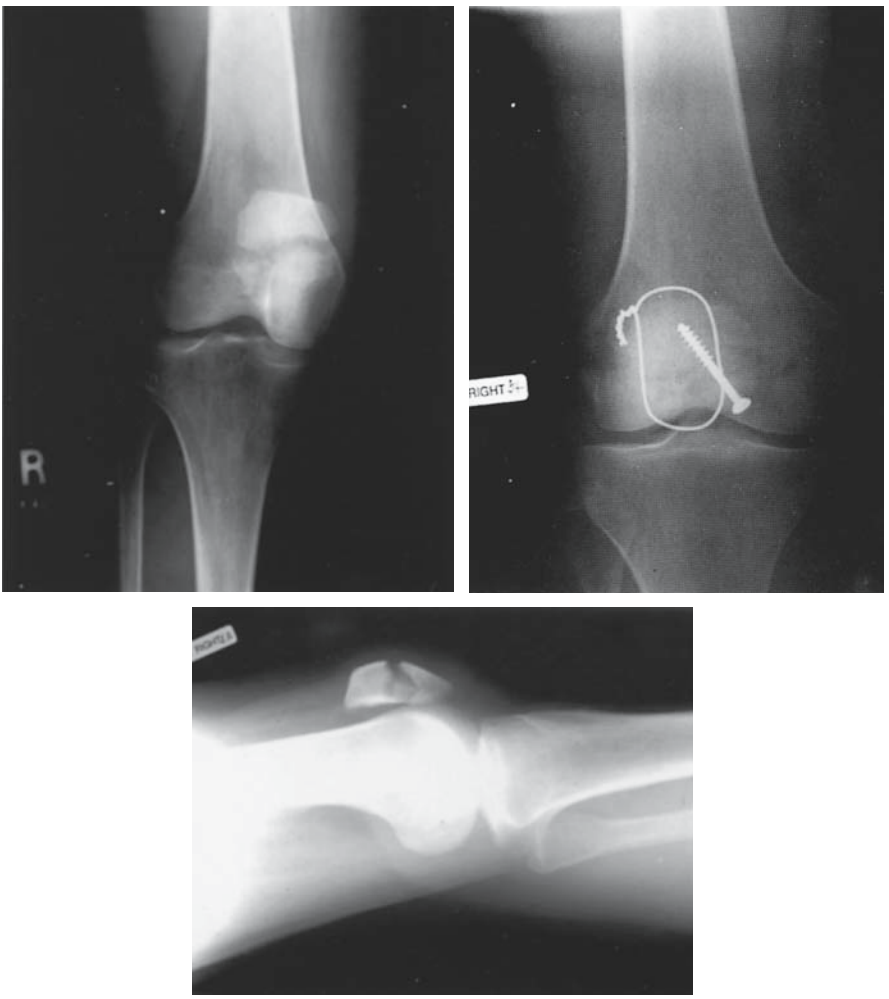


FIGURE 2-21. Patella fracture.

that if pulses do not return after closed reduction, then the patient should be taken to the operating room emergently for vascular exploration or operative angiography. Late ligamentous repair may or may not be necessary after early, emergent reduction and vascular management have been accomplished.

Fracture of the Tibial Shaft

This diaphyseal fracture of the tibial shaft presents a major problem from the standpoint of bony union. Because of the tenuous blood supply of the

shaft of the tibia, fractures, particularly at the junction of the middle and distal third, are notorious for the high incidence of nonunion. Nondisplaced or minimally displaced tibial fractures are generally treated by the application of a long leg cast. When some union has occurred, a shorter, so-called patella tendon-bearing cast may be applied, ideally within 6 to 8 weeks. Operative treatment includes: percutaneous or open plating of distal fractures, external fixation, and intramedullary nailing of displaced and comminuted shaft fractures with locking screws above and below the fracture site. As has been mentioned in other locations, intramedullary nailing allows relatively early function and healing while the patient temporarily depends on the intramedullary rod for stability. As in other bones, one might think in terms of a race occurring between the bone healing and the metal failing from metal fatigue.

Ligamentous Injuries to the Knee

The knee is a relatively incongruous joint that is stabilized through an elaborate system of ligaments; most noted are the medial and lateral collateral ligaments and anterior and posterior cruciate ligaments. Many sports-related ligament injuries of the knee are seen on a regular basis and, generally speaking, are first treated conservatively by immobilization, then by physical therapy and muscle strengthening. After 6 weeks of rehabilitation, gaining quadriceps strength and a good range of motion, repair of the torn anterior cruciate ligament is frequently considered (see Chapter 6, Sports Medicine).

Fractures Around the Ankle

Fractures of the lower end of the tibia, through the articular weight-bearing surface, may be quite serious. They are called pilon fractures, and unless early, excellent anatomic restoration and fixation are accomplished, traumatic arthritis of the ankle will follow. Fractures of the ankle itself—the distal end of the fibula (lateral malleolus), the medial malleolus, and the so-called posterior malleolus (a fragment of the posterior portion of the distal tibia)—are very common. While a nondisplaced fracture of the lateral malleolus may generally be treated by a simple below-the-knee immobilization cast, displaced ankle fractures are a different problem. If the student becomes familiar with any classification system, the Lauge–Hansen (Fig. 2-22) classification of ankle fractures would seem to be recommended. The first word in each heading of this classification system is the position the foot was in at the time the force was applied. The second word denotes the mechanism of load application. In any case, the importance of ankle fractures is the status of the mortise, that is, the joint in which the talar dome lies. Proximal is the distal tibia, medial is

the medial malleolus, and lateral is the distal portion of the fibula or lateral malleolus. The ankle is very unforgiving. Perfect reduction is mandatory to produce an acceptable functional result. Just about all displaced ankle fractures, therefore, are treated surgically. Open reduction and internal fixation are performed, with the fibula being the critical segment; length and rotation must be corrected before fixation. Avoidance of any weight-bearing for 6 weeks is generally advised with or without the cast, depending on the reliability of the patient. Weight-bearing is then gradually advanced. (See Chapter 13 for further details about fractures around the ankle and foot.)

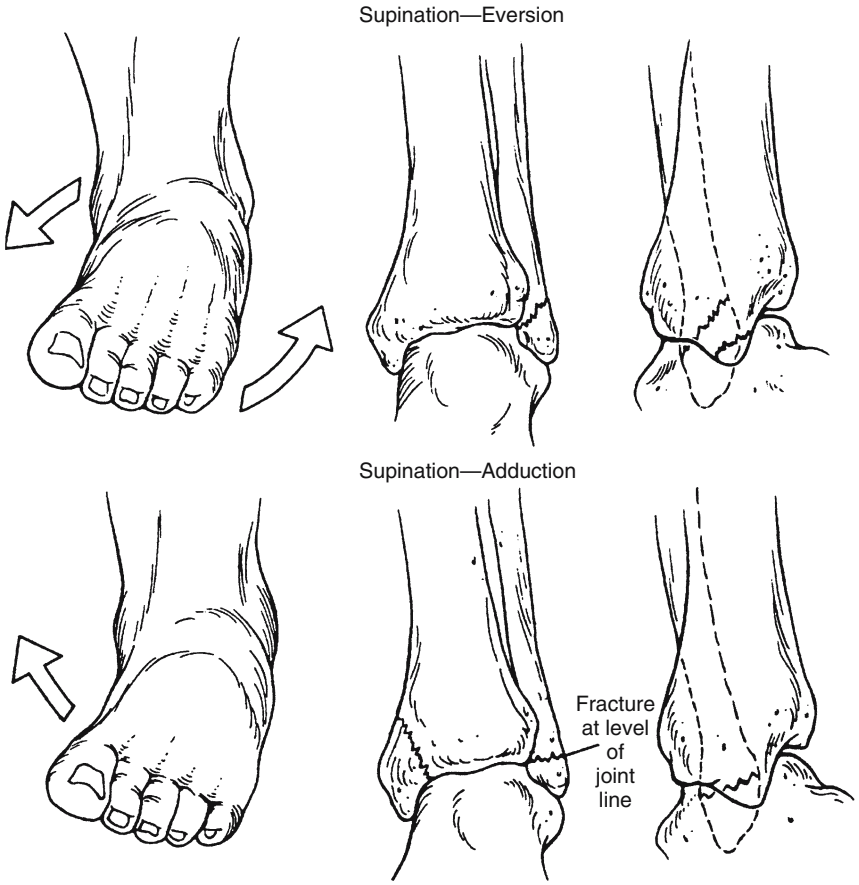


FIGURE 2-22. Lauge–Hansen classification of ankle fractures.

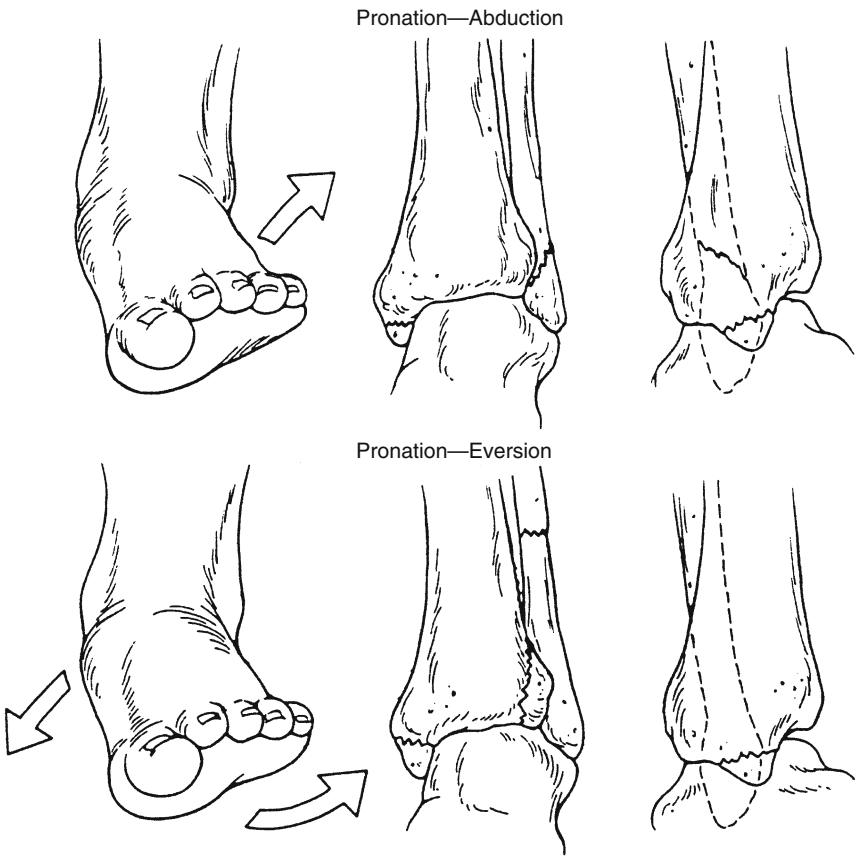


FIGURE 2-22. *Continued.*

Fractures and Soft Tissue Injuries of the Foot

Fractures of the Os Calcis (Heel Bone)

The os calcis is unique in that it is essentially a cancellous bone (not unlike the vertebral body), yet it takes a great deal of load. If that load is applied vertically and quickly, crushing of the calcaneus can occur; this produces injury to the subtalar joint, and ultimately results in a certain degree of stiffness no matter what type of treatment is provided. Concurrent fractures of the lumbar spine are not infrequent and should be sought out. Treatment of the os calcis fracture is often closed, but in expert hands open reduction and fixation may give a better result.

Fractures of the Talar Neck

Similar to the scaphoid bone of the wrist, the talus in the ankle is unusual among bones in that it has a retrograde blood flow. As such, fractures through the neck of the talus are frequently complicated by avascular necrosis of the dome of the proximal segment. Historically, this injury was called aviator's astragalus. In an effort to minimize complications, open reduction and internal fixation with delayed weight-bearing are usually recommended, especially for displaced fractures.

Ankle Sprains

Ankle sprains are common. The distal anterior tibiofibular ligament, the lateral ligament complex, and the medial deltoid ligament are the three important ligament complexes. The biggest mistake in the treatment of ankle sprains is often found in the attitude of the first physician who sees such a patient and utters something to the effect that "This is only a sprain—you will be all right in a few days." Such a statement is, unfortunately, unrealistic and causes a great deal of patient dissatisfaction. Elevation and rest for a few days is generally helpful, but early motion and rehabilitation may also be recommended during this time. It appears that open suturing of torn ligaments at the ankle is very rarely necessary, but the use of a walking cast or fracture boot with the foot in slight dorsiflexion often allows patients to assume their normal activities much faster than otherwise might be the case. The cost of casting, however, is muscular atrophy of the calf and delayed rehabilitation. Various braces are commonly used, and these may then be continued for athletic activities in the subacute period. Pain, swelling, and/or disability lasting more than 2 months after a significant ankle sprain is rare, and other pathologic processes should be investigated.

Achilles Tendon Rupture

Occurring in a sports-related injury in the middle-aged athlete, this tendon rupture may well be overlooked, but it should always been suspected, even though the patient may think that an ankle sprain has occurred. The Thompson test, which consists of squeezing the calf and noting the foot to plantar flex, is most useful. These injuries may be treated by conservative means using a cast in plantar flexion or surgically by direct tendon repair. Occasionally, a sudden pain in the calf may be interpreted as a torn Achilles tendon, but more often only a few fibers of the gastrocnemius tear, similar to the so-called ruptured plantaris. Rest, elevation, and/or walking at first with an elevated heel amazingly relieve discomfort. Nonsteroidal antiinflammatory drugs for prevention of deep venous thrombosis may be added to the treatment regimen. (See Chapter 13 for further details.)

Lisfranc Dislocation of the Foot

The Lisfranc joint, which is the joint between the tarsal bones and the metatarsals, may be injured in sport and other accidents. It is, unfortunately, frequently missed, and X-rays of the ankle are ordered that do not show this area. If the examiner is unsure and the pain and tenderness are in the midfoot rather than over the malleoli, a comparison foot X-ray may be useful. These injuries usually consist of lateral dislocation of one or more of the metatarsal bones, and if not treated (thus restoring perfect anatomical congruity of the joint), long-term disability will result.

Distal Foot Fractures

Most fractures of the metatarsals and toes are treated conservatively; although metatarsal fractures may be immobilized in a walking cast, this is often unnecessary. Fractured toes generally are treated by taping the toe gently to its neighbor for support. The fracture of the base of the fifth metatarsal, which may be caused by avulsion by the peroneus brevis tendon, is quite common and can be benign. This fracture is generally misinterpreted to be an ankle sprain by the patient. Walking cast, stiff-soled shoes, and/or elastic stockings are all acceptable options. Excellent healing is the norm, with pain reduction occurring in about 3 weeks.

Summary and Conclusions

Orthopedic trauma can range from isolated soft tissue or bony injury to a multiply-injured patient with a combination of life-threatening injuries to many organ systems. Knowledge of anatomy and of the common orthopedic injuries mentioned in this chapter is important for diagnostic and treatment purposes. More importantly, however, is a systematic approach to examining every orthopedic trauma patient. It is essential to evaluate and stabilize a patient's airway, breathing, and circulation before any orthopedic evaluation. Advanced Trauma Life Support (ATLS) training is important for all medical personnel who have initial contact with the trauma patient to maximize the efficacy of treatment and provide the best chance of survival.

Suggested Reading

Beaty JH, Kasser JR (eds) Rockwood and Wilkins' Fractures in Children, 5th ed. Philadelphia: Lippincott, 2002.

Bucholz RW, Heckman JD (eds) Rockwood and Green's Fractures in Adults, 5th ed. Philadelphia: Lippincott, 2002.

Questions

Note: Answers are provided at the end of the book before the index.

2-1. In fracture mode of loading, *torsional* loading produces:
   a. Transverse fractures
   b. Compression fractures
   c. Avulsion fractures
   d. Oblique fractures
   e. Spiral fractures

2-2. Neural injury that involves an anatomic disruption of an axon with an intact sheath:
   a. Neuropraxia
   b. Axonotmesis
   c. Neurotmesis

2-3. Phase of fracture healing at about 4 to 6 weeks, when the soft callus is reworked into hard callus:
   a. Vascular phase
   b. Metabolic phase
   c. Mechanical phase

2-4. Complications of fractures include:
   a. Malunion
   b. Nonunion
   c. Stiffness
   d. Infection
   e. Myositis ossificans
   f. Avascular necrosis
   g. Reflex sympathetic dystrophy
   h. All of the above

2-5. Fracture of the upper extremity that is often treated with operative fixation in adults:
   a. Clavicle
   b. Humeral shaft
   c. Midshaft radius and ulna
   d. Surgical neck of humerus
   e. Radial head

2-6. Portion of the thoracolumbar spine that contains the posterior longitudinal ligament:
   a. Anterior column
   b. Middle column
   c. Posterior column
   d. Transverse process

2-7. Open fractures of the pelvis are associated with a mortality rate of:
   a. 10%
   b. 25%

c. 50%
d. 75%
e. 100%

2-8. Femur fractures that are most often associated with a pathologic process:
a. Femoral neck fractures
b. Intertrochanteric fractures
c. Subtrochanteric fractures
d. Shaft fractures
e. Supracondylar fractures

2-9. Injury about the knee that most often results in a vascular injury:
a. Supracondylar femur fracture
b. Patellar fracture
c. Dislocation of the knee
d. Tibial plateau fracture
e. Tibial spine fracture

2-10. Treatment of a displaced bimalleolar ankle fracture should not include:
a. Open reduction internal fixation
b. External fixation
c. Percutaneous fixation
d. Immediate casting

3
Orthopedic Infections

Steven C. Scherping, Jr. and Alan D. Aaron[†]

Because of their relative rarity, as compared to other types of more typical infections, musculoskeletal infections can prove to be extremely difficult to diagnose and treat. Unrecognized infections can be limb threatening and even potentially fatal if not recognized and treated. The most important aspect of caring for patients with a musculoskeletal infection is to come to a timely diagnosis. When a timely diagnosis is made, most musculoskeletal infections can be effectively treated and the morbidity minimized. Open fractures are an extremely common occurrence in orthopedics, and specific attention is given to this topic. In general, appropriately treated open fractures can typically prevent the establishment of any type of chronic musculoskeletal infection or osteomyelitis.

Pathophysiology of Osteomyelitis

The pathogenesis of osteomyelitis, although conceptually similar in all cases, may vary depending upon the age of the host, duration of infection, etiology of infection, and type of host response to the infection. Osteomyelitis is often classified using these parameters, which can assist in defining the severity of infection, identify a mode of treatment, and assess the potential for recovery. Duration of infections is often divided into either acute or chronic osteomyelitis; this also applies to infections involving the joints such as a septic arthritis. Although the distinction is somewhat arbitrary, acute osteomyelitis is usually considered to occur within the first 6 weeks following inoculation, with chronic osteomyelitis being greater than 6 weeks.

The development of bone and joint infections takes place via one of two basic mechanisms, involving either exogenous or hematogenous pathways. Exogenous delivery involves direct inoculation of the bone from either trauma, surgery, or a contiguous focus of infection. Hematogenous spread is via the vascular tree into either osseous or synovial tissue, producing a localized focus of infection. Local tissue compromise (i.e., in the case of

[†] Deceased.

fracture) or systemic tissue (i.e., diabetes) compromise is often associated with an increased risk of bone infection by either method.

Two patterns of response are noted and are often dependent on the infecting organism. Pyogenic organisms elicit a rapidly progressive course of pain, swelling, abscess formation, and aggressive bone destruction. A gram-positive staphylococcus is a classic example of an organism that may produce a pyogenic response. In contrast, less aggressive nonpyogenic organisms invoke a more insidious granulomatous reaction, classically seen with acid-fast bacilli. Age of the host is important in that differences in bone vascular anatomy between adults and children slightly alter the mechanism of hematogenous delivery. In addition, children are susceptible to different organisms depending upon their age.

Exogenous osteomyelitis usually involves a clearly identified anatomic site, is usually inoculated with pyogenic organisms, and is often polymicrobial, frequently in association with foreign debris. The bacteria are inoculated into a compromised local environment, with bone and soft tissue disruption providing ample amounts of necrotic and devascularized material favorable for bacterial growth. In addition, tissue devascularization prevents host response mechanisms from reaching bacterial colonies, thereby permitting unchecked proliferation.

Once a bone infection is recognized by the host, several steps are undertaken. Initial host response to both the injury and infection include activation of inflammatory and immunologic pathways. Inflammatory elements serve to destroy bacteria and remove nonviable material. Humoral and cellular immunologic mechanisms act to recognize specific bacteria and subsequently confer immunity to prevent further bacterial dissemination. The inflammatory response is initiated with increases in blood flow and vascular permeability, with the delivery of polymorphonuclear leukocytes. The leukocytes phagocytize and destroy bacteria and nonviable tissue. Mononuclear cells arrive within 24 to 48 hours and assist in eradication of bacteria and removal of necrotic bone. As a large number of these cells arrive and die, pus is formed, with an abscess often being clinically appreciable.

Eventually, granulation tissue surrounds the infected area in an attempt to wall off the infection. Further isolation is achieved as chronic avascular fibrous tissue is produced around the infected area. Finally, reactive bone formation can occur to further sequester the infection from the host. Within the infected region, dead bone is often prominent, and this is commonly termed the sequestrum, whereas the reactive bone is known as the involucrum. Unfortunately, this sequestered area is isolated from host defense mechanisms by the avascular fibrous tissue and can permit the continued proliferation of bacteria.

Pivotal to treatment of osteomyelitis is obtaining a better understanding of how bacteria achieve a foothold in either damaged tissues or surgical implants. Adhesion to the surface of tissue cells and implants depends on

the physical characteristics of the bacteria, the fluid interface, and the substratum. Initially, bacteria arrive at random near a damaged tissue or implant surface by direct contamination, contiguous spreading, or hematogenous seeding. All surfaces, regardless of whether they are tissue- or implant-derived, acquire a glycoproteinaceous conditioning film when exposed to a biologic environment. This surface is anionic and initially repels bacteria, whose surface is also anionic. However, attractive forces (van der Waals), in conjunction with hydrophobic molecules on the exposed substrate and the bacteria, increase the duration of bacterial juxtaposition to permit the formation of irreversible cross-links between bacteria and host surfaces. Following anchorage of the bacteria, proliferation occurs with formation of a polysaccharide slime layer. The biofilm or slime layer is composed of bacterial extracapsular exopolysaccharides that bind to surfaces, thereby promoting cell-to-cell adhesion, microcolony formation, and layering of the microorganisms. Additional species of bacteria may attach to the surface of the biofilm, resulting in syntropic interactions between differing bacteria. Thriving bacterial colonies may be dispersed by sheer force, enabling a localized colony to establish secondary sites of infection (Fig. 3-1).

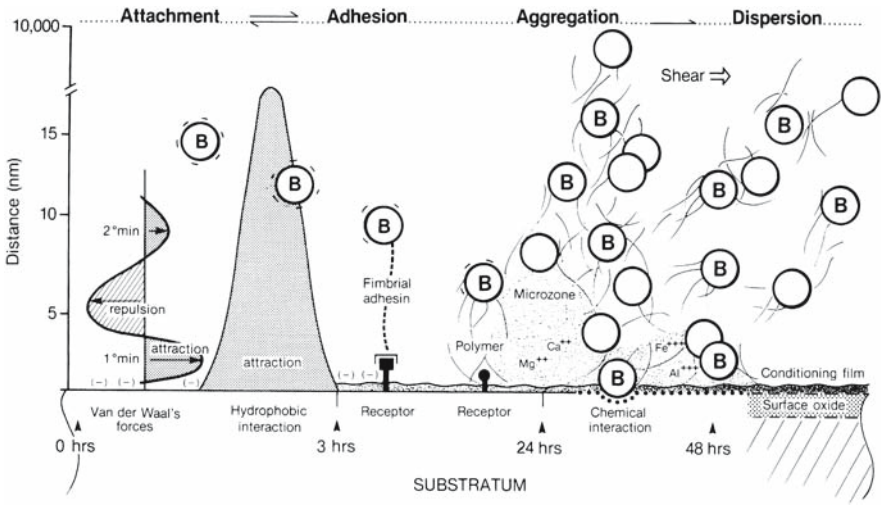


FIGURE 3-1. Molecular sequence in bacterial (*B*) attachment, adhesion, aggregation, and dispersion at substratum surface. A number of possible interactions may occur depending on the specificities of the bacteria or substratum system (graphics, nutrients, contaminants, macromolecules, species, and materials.) (From Gristina AG, Naylor PT, Myrvik QN: Mechanisms of musculoskeletal sepsis. Orthop Clin North Am 22(3):363–371, 1991. Reprinted with permission.)

Bacterial attachment in production of biofilms can lead to antibiotic resistance. Initially believed to result from problems of antibiotic diffusion through the biofilm, more current theories center on decreased metabolic rates and phenotypic changes in surface-adherent bacteria. Therefore, bacteria on surfaces or within microcolonies appear to be physiologically different from free-floating organisms, which may, in part, convey antibiotic resistance. Treatment of osteomyelitis involves the disruption of these bacterial colonies, which is best achieved with aggressive debridement of nonviable tissues to remove an acceptable bacterial substrate and with the disruption of bacterial colonies and their associated biofilm. In the case of osteomyelitis involving a prosthesis or fracture implant, it is often necessary to remove either the prosthesis or implant to eradicate the infection. Possible inhibition of infection may be achieved through modification of implant surfaces to enhance host tissue colonization in preference to bacterial colonization. By promoting tissue–cell integration of these surfaces, inoculated bacteria are confronted with a living substrate capable of enacting a host defense mechanism.

Pediatric Infections

Acute Hematogenous Osteomyelitis

The most common etiology for acute osteomyelitis is via hematogenous inoculation. The vascular anatomy of children's long bones can predispose them to hematogenous inoculation and proliferation of bacteria. The nutrient artery of long bones enters through the cortical bone to divide within the medullary canal, ending in small arterioles that ascend toward the physis (Fig. 3-2). Just beneath the physis, these arterioles bend away from the physis and empty into venous lakes within the medullary cavity. The acute bend in these arterial loops serve as points of diminished blood velocity, promoting sludging of bacteria directly under the physis. In addition, phagocytic capability and reticuloendothelial function may be depressed in these vascular loops, promoting the establishment of bacterial colonies. Trauma, often associated with the emergence of osteomyelitis in children, may actually promote bacterial seating and proliferation in metaphyseal sites (Fig. 3-3).

As previously discussed, an established infection results in the delivery of inflammatory cells and, if the infection remains untreated, purulent material will be produced (Fig. 3-4). This pus can spread in one of three ways: through the physis, toward the diaphysis, or through the adjacent bony cortex (Fig. 3-5). This purulent material tends to seek the path of least resistance, through the metaphyseal cortex, to form a collection of subperiosteal pus. Although this is the most common route of egress, younger children (less than 1 year) with intact transphyseal vessels may

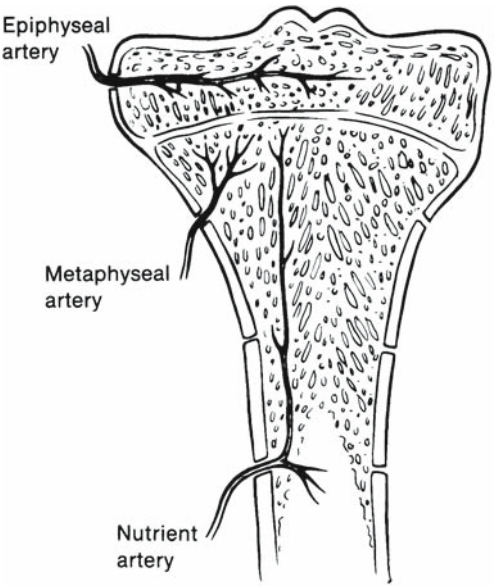


FIGURE 3-2. Schematic representation of the blood supply to a long bone.

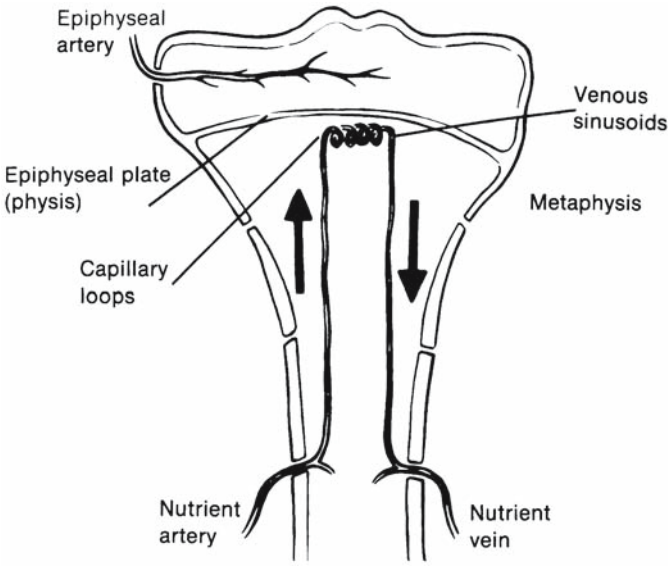


FIGURE 3-3. Microcirculation of the metaphysis predisposes it to sludging and infection.

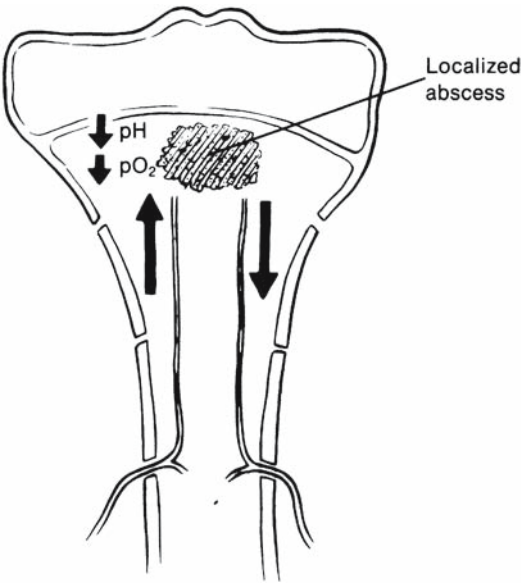


FIGURE 3-4. A localized abscess develops, and the microenvironment is altered.

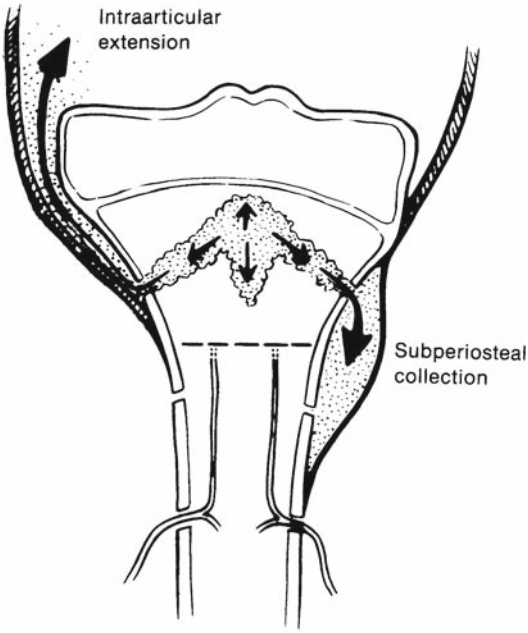


FIGURE 3-5. Abscess perforates the metaphyseal cortex and spreads to the subperiosteal space and joint.

demonstrate epiphyseal spread with the development of epiphyseal abscesses.

In older children, the development of a subperiosteal abscess results in devascularization of the bone both from thrombosis of the endosteal blood supply and from the stripping away of the overlying periosteum. The periosteum, which is extremely thick and loosely adherent in children, is not easily penetrated; in the devascularization process, it is lifted off the bone, with the inner cambium layer producing a layer of new bone. In this case, the devascularized bone is termed the sequestrum, with the reactive periosteal bone being the involucrum (Fig. 3-6). A cellulitic phase precedes abscess formation, with medical management alone being successful to cure the infection. Once an abscess forms, surgical debridement is necessary to remove the nonviable bone, reduce the bacterial population, and provide for a vascularized tissue bed for antibiotic delivery. As the majority of pediatric infections emanate via hematogenous seeding from other sites, the specific organisms may differ depending upon the child's age. The vast majority of osteomyelitis in children is secondary to *Staphylococcus aureus* (90%). In neonates, the most common organisms include *Staphylococcus aureus*, group B streptococci, and gram-negative organisms.

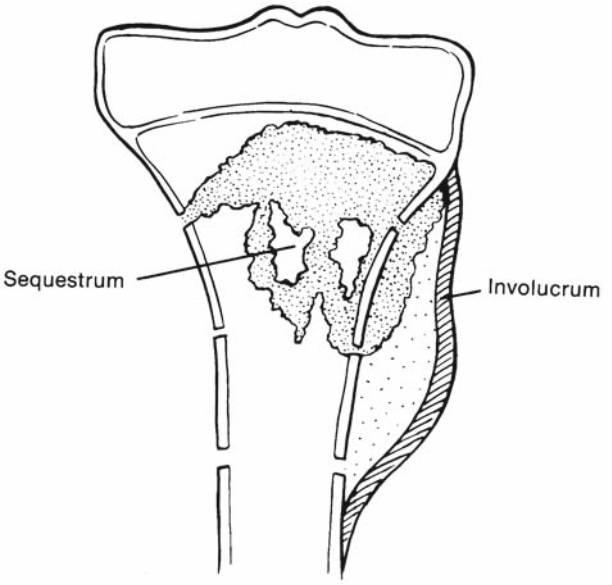


FIGURE 3-6. Sequestered fragments of dead bone and periosteal new bone, or involucrum, may be seen on radiographs.

Diagnosis and Treatment

A careful history and physical examination combined with an index of suspicion is necessary to diagnose osteomyelitis. Invariably, patients present with pain from one to several days in duration, with the typical onset of pain being fairly rapid. The pain is generally severe enough to limit or entirely restrict use of the involved extremity. Older patients may be able to assist in localization of the pain, although the clinician must be capable of identifying potential sites of referred pain (knee pain for hip osteomyelitis). Children are usually irritable and febrile and often give a history of generalized malaise. Uncovering a potential site of a concomitant infection, such as a recent upper respiratory or ear infection, may provide the clinician with an etiology for hematogenous spread. Physical examination is extremely important, with localized swelling and tenderness often characterizing the physical exam. Care must be taken to gain the child's confidence and to proceed in a slow, nonthreatening manner when examining the patient. Examination of an uncooperative child can be extremely frustrating for both the clinician and the patient, making interpretation of physical findings difficult at best.

Laboratory results are extremely important in diagnosing and treating osteomyelitis; however, they do not replace a complete history and physical examination. A complete blood count with differential and an erythrocyte sedimentation rate (ESR) are imperative, as both the white blood cell (WBC) count and ESR are typically elevated. It must be emphasized that not all patients suffering from osteomyelitis present with a classic clinical history, physical findings, and laboratory values. Presentation at early onset may preclude a large amount of soft tissue swelling and pain or an elevated sedimentation rate or WBC count. Notably, a normal WBC count in the presence of an osteomyelitis is not unusual and therefore must be interpreted in the context of the entire clinical setting. Diagnosis in neonates may be especially problematic because of the immaturity of their immune system, which may not be able to mount an identifiable host response.

Plain radiographs should be obtained of all involved areas and include adjacent joints to accommodate for referred pain. Unfortunately, initial radiographs may be negative, except for soft tissue swelling, because the characteristic changes of osteomyelitis require 10 to 14 days to be appreciated. After 2 weeks, increasing radiolucency and a periosteal reaction are generally visible, with bone sclerosis and sequestra and involucrum formation occurring much later (6 weeks or more).

Bone scanning can serve as a valuable tool in the identification of osteomyelitis. Technetium (^{99}Tc), coupled with methylene diphosphonate, is attracted to areas of rapid bone turnover. Although nonspecific, it exhibits a sensitivity for identifying areas of accelerated bone formation or destruction. Unfortunately, it is less than 80% accurate when used to evaluate acute hematogenous osteomyelitis. This limitation may result, in part, from

local thrombosis of vascular channels or devascularization of bone cortices, thereby preventing delivery of the isotope to these surfaces. In fact, a cold scan, in the face of an aggressive bone infection, is indicative of a high degree of bone necrosis and is a poor prognostic indicator for recovery. Bone scanning may be helpful in cases of multifocal infection found in neonates or when the exact site is not readily identifiable, such as seen in the pelvis. It must be remembered that bone scanning does not obviate a good clinical and physical examination. In addition, a bone aspiration should be performed in identifiable sites before embarking on a lengthy and possibly unproductive battery of radiographic examinations. The role for magnetic resonance imaging (MRI) scanning in osteomyelitis continues to evolve. This modality is an excellent means of diagnosing osteomyelitis even in its early phases. It does, however, have the distinct drawback that many children will require IV sedation or anesthesia to obtain an adequate study.

Bone aspiration is the best means of clinically identifying the presence of a bone or joint infection as well as any organisms associated with it. Aspiration should be performed immediately following acquisition of plain radiographs and directed toward the area of maximal swelling and tenderness. A large-bore stylet needle (18- or 16-gauge spinal needle) should be used to prevent plugging of soft tissue, bone, or thickened purulent material in the tip. Both subperiosteal and intramedullary sites must be aspirated. In addition, using a second needle, one should consider aspirating the adjacent joint if clinically indicated. Local anesthesia is given, with the needle being easily drilled through the soft metaphyseal cortex. If purulent material is obtained, the fluid is sent for immediate Gram stain and culture. The presence of pus necessitates that the patient undergo an operative irrigation and debridement. However, antibiotics should be started immediately following aspiration with these initial cultures, serving to direct later modifications to organism-specific antibiotic coverage. The initial antibiotic choice is often based upon the "best guess" of the infecting organism. In patients who are not allergic to penicillin, a semisynthetic penicillin that is beta-lactamase resistant should be chosen. Good initial choices include oxacillin or nafcillin, with penicillin-allergic patients often being treated with cefazolin. The optimal length of therapy is still under debate, with a regimen of 3 weeks of IV antibiotics, followed by 3 weeks of oral therapy, often being acceptable. In the event that purulent material is not aspirated, sterile saline should be injected, aspirated, and sent for culture in the hopes of identifying an organism. Bacteriostatic saline should not be used as this may inhibit bacterial growth. In cases in which no frank purulent material is aspirated, surgery is usually not indicated, as there is no pus to decompress or necrotic bone to debride. In this setting, the administration of antibiotics is the mainstay of treatment. In the face of a negative aspirate, bone scans may provide more useful information in delineating the cause for bone pain.

Chronic infections are uncommon in children, as patients usually present early in the course of the disease. These patients almost invariably require surgical intervention to debride sequestrated tissues. Complications are high in this setting from both the disease process and the surgical procedure, including pathologic fracture and physeal arrest.

Pediatric Septic Arthritis

Acute septic arthritis may develop from hematogenous sources or, more commonly, from extension of an adjacent foci of osteomyelitis into the joint. Susceptible joints are those in which the metaphysis is intraarticular, such as seen in the hip and shoulder where bacteria are afforded an avenue for dissemination (Fig. 3-7). Although relatively uncommon, septic arthritis can rapidly destroy articular surfaces and, therefore, must be definitively excluded at symptom onset. Depending upon the age of the patient, different organisms prevail as likely pathogens (Table 3-1).

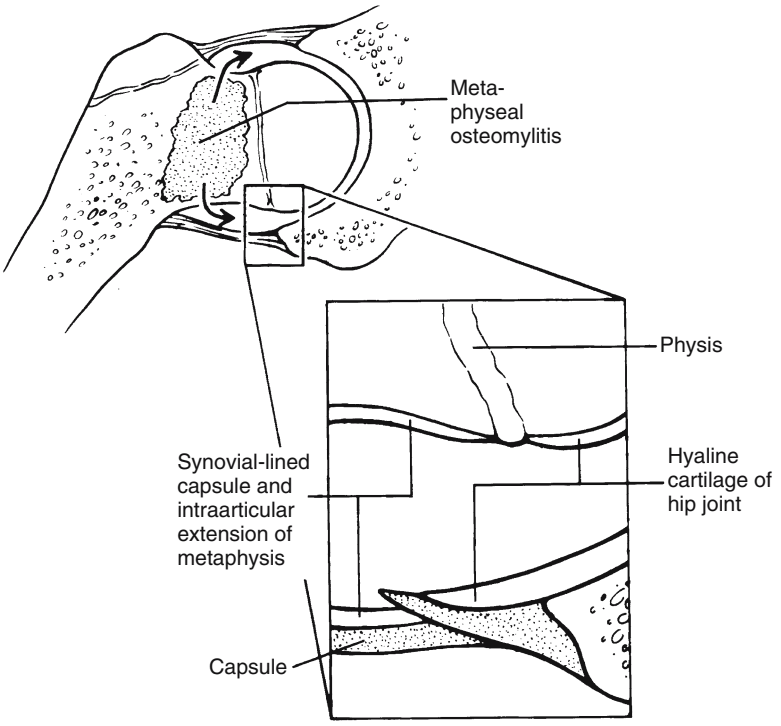


FIGURE 3-7. Schematic representation of the immature hip. Metaphyseal osteomyelitis spreads by direct extension into the hip joint.

TABLE 3-1. Common Pathogens and Recommended Treatment for Septic Arthritis.

Age Group	Probable Organisms	Initial Antibiotic Choice
Neonate	Group B strep, *S. aureus*, Gram-negative coliforms	Penicillin, oxacillin, and gentamicin
Infants and children (4wks to 4yrs)	*S. aureus, H. influenzae*, Group B strep, Group A strep	Cefuroxime
Children (>4yrs)	*S. aureus*	Oxacillin or Cefazolin
Adolescent	N. gonorrhoeae	

Diagnosis and Treatment

Clinical presentation and physical findings are often similar to those seen with acute osteomyelitis (Fig. 3-8). However, patients tend to be sicker with higher temperatures, more pain, and an extremely high ESR. Patients are

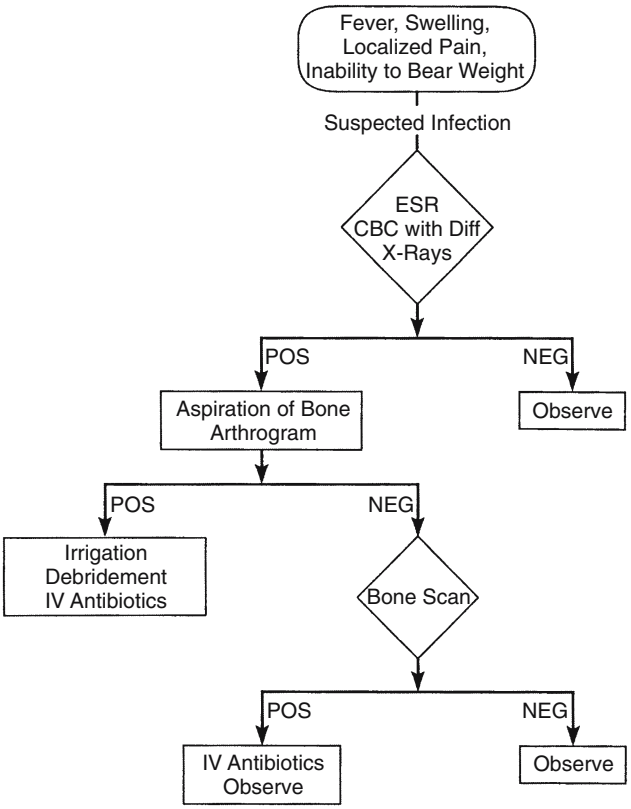


FIGURE 3-8. Acute osteomyelitis and septic arthritis management algorithm.

extremely reluctant to move the involved extremity or infected joint, often positioning the joint so as to maximally relax the surrounding joint capsule. For the hip, this is usually flexion abduction and external rotation. For the knee, this tends to be roughly 30 degrees of flexion. Radiographs demonstrate a joint effusion and associated soft tissue swelling. Occasionally, adjacent bone involvement may be appreciable.

Joint aspiration is mandatory for diagnosis, with immediate Gram stains and cultures being obtained of the joint fluid. The fluid should be analyzed for cell count and differential, for protein and glucose levels, and for the presence of crystals. In addition, the adjacent metaphysis and subperiosteum should also undergo aspiration, as these are often sites of contiguous spread to the joint. In the majority of cases the joint aspiration will demonstrate a WBC count in excess of 50,000; this may often exceed 100,000 in severe cases. The white blood cell population is usually composed of polymorphonuclear leukocytes, comprising as much as 90% to 95% of the cells in fulminant cases. On occasion, circumstances may require the clinician to inform the laboratory of the possible organism as special techniques may be necessary to obtain bacterial growth. *Haemophilus influenzae* is difficult to culture and must be incubated in a CO_2 environment. Because the percentage of organism retrieval has been reported by some series to be between 70% and 85%, blood cultures should also be obtained. Additional clues to possible infection include an elevated protein or a decreased glucose level in the joint aspirate.

Aspiration of accessible joints, such as the knee and ankle, can usually be performed at the bedside using appropriate analgesia and sterile techniques. However, inaccessible sites, such as the hip, may require that the patient undergo fluoroscopically directed aspiration. Requiring the patient to be sedated, this procedure is performed either in the radiology suite or operating room setting. If a septic arthritis is suspected, the initial aspiration can be performed in the operating room under general anesthesia, to be followed by immediate open debridement and irrigation upon confirmation of the presence of pus or organisms. It is important to be assured that joint fluid has been sampled, with an arthrogram being necessary in the case of hip aspiration to confirm needle position. As with osteomyelitis, a negative aspiration should be followed by sterile saline flushing to obtain an adequate sample for culture.

As a joint is considered a closed cavity and a joint infection an abscess, drainage of the joint is mandatory. Some controversy still persists as to whether septic arthritis can be adequately decompressed with serial aspirations, thus avoiding surgery. Despite the controversy, open surgical drainage is favored in most instances, given the disadvantages of serial joint aspiration including: repeated trauma to the joint, higher risk for inadequate decompression, and repeated exposure of the surrounding bony structures. In addition, the joint must be readily accessible, which precludes the hip and shoulder from being treated with serial aspirations. An

infected hip joint is considered an operative emergency. The risk of avascular necrosis is especially high in the hip, as the blood supply is intracapsular and can be disrupted by intraarticular fluid secondary to a high intracapsular pressure. Reexamination of the joint is necessary following surgery or aspiration to be assured a purulent material has not reaccumulated.

Another more recent trend has been the use of arthroscopic debridement techniques. The minimal soft tissue trauma with arthroscopic debridements has led to widespread use in acute infections. The role of these techniques in subacute or chronic infections in which a more-aggressive synovectomy may be necessary is less clear. Regardless of the method employed, the goals of treatment still hold true, namely, adequate decompression of all purulent material, irrigation of both bacteria and host lysozymes from the joint, and debridement of nonviable tissues.

Intravenous antibiotics are initiated immediately following acquisition of joint fluid. Again, antibiotic choice is based upon the suspected pathogens. Compared to treatment of osteomyelitis, the antibiotic course for septic arthritis is usually shorter (4 weeks), with 2 weeks of IV antibiotics followed by an additional 2 weeks of oral therapy.

Adult Osteomyelitis

Management of osteomyelitis involves consideration of several patient variables: physiologic, anatomic, and psychosocial. It is important to weigh all these variables to assess and classify the patient's level of infection and thereby formulate a treatment plan with reasonable goals. At the initiation of treatment it must be determined whether the infection is simple or complex, whether the goal of therapy is palliative or curative, and whether the patient would be better served by an amputation as opposed to a limb-sparing procedure. Host factors may adversely affect wound healing in cases of malnutrition, immune deficiency, malignancy, and diabetes, among others. Local factors, such as chronic lymphedema, venous stasis, major vessel disease, or extensive scarring, may also play a role. The Cierny–Mader classification has been developed to assist surgeons in classifying and selecting various modalities of treatment and to assist in predicting outcomes (Fig. 3-9). Local extent of disease is classified as medullary, superficial, localized, or diffuse osteomyelitis. Medullary involvement is entirely endosteal and does not require bone stabilization following debridement. Superficial osteomyelitis only involves the outer cortex and again does not require bone reconstruction following local excision of infected material. Localized osteomyelitis combines types I and II, thereby necessitating full-thickness cortical resection to effectively debride the bone. Although segmental instability is avoided, bone grafting techniques may need to be employed to reestablish bone continuity and subsequent

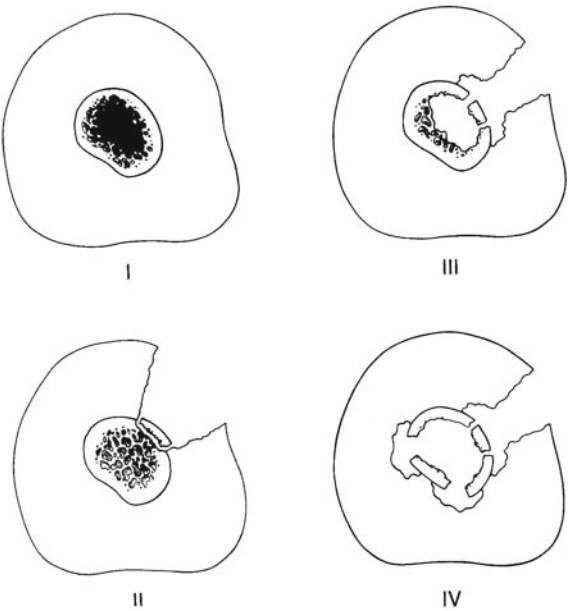


FIGURE 3-9. The Cierny classification of chronic osteomyelitis: type I, medullary; type II, superficial; type III, localized full thickness; type IV, diffuse.

stability. Type IV osteomyelitis results in widespread cortical and endosteal infection, with segmental resection being necessary to eradicate the osteomyelitis. Diffuse osteomyelitis is mechanically unstable both before and after debridement and requires bone reconstruction to attain stability.

Host variables are stratified with regard to physiologic capacity to withstand infection, treatment, and disease morbidity. A-hosts are normal healthy patients. The B-host has a local (B^L), a systemic (B^S), or a combined local and systemic ($B^{L/S}$) compromise. The C-host, because of severe systemic problems, is not a treatment candidate. Treatment of C-hosts may potentially result in greater patient morbidity following treatment than it would before intervention.

Surgical treatment of osteomyelitis involves three main facets: (1) extensive debridement, (2) vascular soft tissue coverage, and (3) bone stabilization. An aggressive debridement is crucial to achieving successful eradication of osteomyelitis. All nonviable tissue must be removed to prevent residual bacteria from persistently reinfecting the bone. Removal of all adherent scar tissue and skin grafts should be undertaken. In addition, a high-speed burr should be used to debride the cortical bone edges

until punctate bleeding can be appreciated. Continuous irrigation is necessary to prevent bone necrosis with the burr. Multiple cultures of all debrided material should be obtained before the initiation of antibiotic therapy. The patient may require several debridements until the wound is considered to be clean enough to accept soft tissue coverage. Soft tissue reconstitution may involve a simple skin graft, but it often requires a local transposition of muscular tissue or vascularized free tissue transfers to effectively cover the debrided bone segment. These muscle flaps provide a fresh bed of vascularized tissue to assist in bone healing and antibiotic delivery. Finally, bone stability must be achieved with bone grafting being undertaken when necessary to bridge osseous gaps. Cancellous and cortical autografts are commonly used, with vascularized bone transfer (vascularized free fibular, iliac, and rib grafts) being occasionally necessary. Although technically demanding, vascularized bone grafts provide a fresh source of blood flow into previously devascularized areas of bone.

The recent advent of bone distraction has been used in lieu of bone grafting or complex soft tissue procedures. Altough technically demanding, application of a small pin (Ilizarov) or half-pin external fixator with bone distraction following a cortical osteotomy can produce columns of bone that fill segmental defects. As distraction is carried out, the soft tissues regenerate along with the bone to cover the newly generated tissue. Recent results seem encouraging, as these patients appear to achieve greater success rates for limb-sparing methods as compared to patients undergoing more conventional bone replacement techniques.

Septic Arthritis

As with children, septic arthritis in adults can develop from hematogenous sources, direct inoculation, contiguous soft tissue infection, or periarticular osteomyelitis. Several factors happen implicating and predisposing patients to septic arthritis, with systemic corticosteroid use, preexisting arthritis, and joint aspiration being the three most common factors reported. As with children, *Staphylococcus aureus* is the most common pathogen isolated from infected adult joints (44%). *Neisseria gonorrhoeae* is another common adult pathogen, with a reported incidence of 11%. The joints most commonly involved are the knee (40%–50%), hip (20%–25%), and shoulder and ankle (10%–15%). In IV drug abusers, the sternoclavicular, sacroiliac, and manubriosternal joints are common sites, with *Pseudomonas aeruginosa* often being isolated.

Adult patients present in a manner similar to children in that pain, swelling, and a decreased range of motion are frequent complaints. Workup involves routine laboratory tests, blood cultures, and joint aspirations. The appearance of the synovial fluid, as well as the WBC count and the percentage of polymorphonuclear cells, can assist in the diagnosis, with cultures of the fluid being mandatory (Table 3-2). In adults, it is even more

TABLE 3-2 Synovial Fluid.

Examination	Normal	Noninflammatory	Inflammatory	Septic
Appearance	Transparent	Transparent	Opaque Translucent	Opaque Yellow to green
Viscosity	High	High	Low	Variable
White cells/mm^3	<200	<200	5000–75,000	>50,000
Polymorphonuclear cells (%)	<25%	<25%	>50%	>75%
Culture	—	—	—	Often positive
Associated conditions	—	Degenerative joint disease Trauma Neuropathic Pigmented villonodular synovitis Systemic lupus erythematosus Acute rheumatic fever	Rheumatoid arthritis Crystal-induced arthritis Seronegative arthritis Systemic lupus erythematosus Acute rheumatic fever	Bacterial infections Compromised immunity

Esterhai JL, Gelb I: Adult septic arthritis. Orthop Clin North Am 18:503–514, 1991; reprinted with permission.

important to carefully evaluate the joint aspirate for crystals because a crystal-induced arthropathy can appear quite similar to a septic arthritis.

Treatment of an adult with a septic arthritis requires aggressive irrigation and debridement utilizing either arthroscopic techniques or an open arthrotomy. Antibiotics are often delivered initially via parenteral routes, with patients being switched to oral therapy when demonstrating clinical improvement in conjunction with maintaining high bactericidal titers of at least 1:8.

Open Fractures

By definition, an open fracture involves exposure of fractured bone to the extracorporeal environment, thus increasing the risk of bone contamination from foreign debris and bacteria. In addition, open fractures are often associated with severe soft tissue damage, devascularization, and devitalization of bone fragments, further increasing the susceptibility of the bone to infection. Open fractures are often graded on the degree of fracture comminution and the degree of soft tissue disruption. Although not universally accepted, the Gustilo–Anderson classification is widely used because of its ease of application and prognostic ability. It is divided into three grades based upon the size of the soft tissue wound, with grade III fractures being further subdivided. Other factors that place fractures

into the grade III category include severe contamination, such as farm or barnyard injuries or shotgun wounds. The three grades are defined as follows:

Grade I: Less than 1-cm soft tissue wound
Grade II: Between 1-cm and 10-cm soft tissue wound
Grade III: Greater than 10-cm soft tissue wound; further subdivided into A (soft tissue wound with sufficient remaining tissues to provide bony coverage), B (severe soft tissue compromise such that either a rotational or free flap will be necessary to provide for bony coverage), and C (arterial laceration requiring surgical repair)

Open fractures are considered operative emergencies and need to be taken to the operating room as soon as the patient is considered medically stable enough to tolerate surgical intervention. With rare exceptions, patients should be taken to the operating room within 6 hours of injury. Wounds should not be explored in the emergency room as further soft tissue damage may be incurred. Active bleeding can almost always be controlled with local compression before surgical exploration. Cultures taken in the emergency room setting or in the operating room before debridement have proven to be of little value in dictating treatment. Cultures are, therefore, taken at the index surgical procedure only in rare instances. Wounds should be assessed, gently irrigated with sterile saline, and dressed with a sterile dressing in the emergency department. Reduction of severely contaminated fractures should be avoided in the emergency room to prevent the drawing of foreign debris into the wound. In addition, IV antibiotics should be given immediately upon admittance to the emergency room. A general rule with regard to antibiotic therapy is that first-generation cephalosporins are given for grade I and grade II fractures. For patients with grade III fractures, a first-generation cephalosporin is given in conjunction with an aminoglycoside. If the fracture is grossly contaminated, such as in a barnyard injury, then a penicillin is added to this regimen (Fig. 3-10).

Assessment of the extent of injury and aggressive debridement should be undertaken in the operating room in an emergent manner. Wounds should be addressed sequentially, with removal of devitalized skin and subcutaneous fat followed by debridement of necrotic muscle, fascia, and bone, to prevent external contamination from being carried beyond the skin to the deeper tissues.

Another important concept is “the zone of injury,” which refers to the area around the wound that has been traumatized but can recover with appropriate management of the soft tissues and bone. Although an initial debridement should aggressively remove necrotic or devitalized tissues, marginal tissue may be preserved to permit potential recovery. If this decision is made at the initial procedure, then a second assessment and debride-

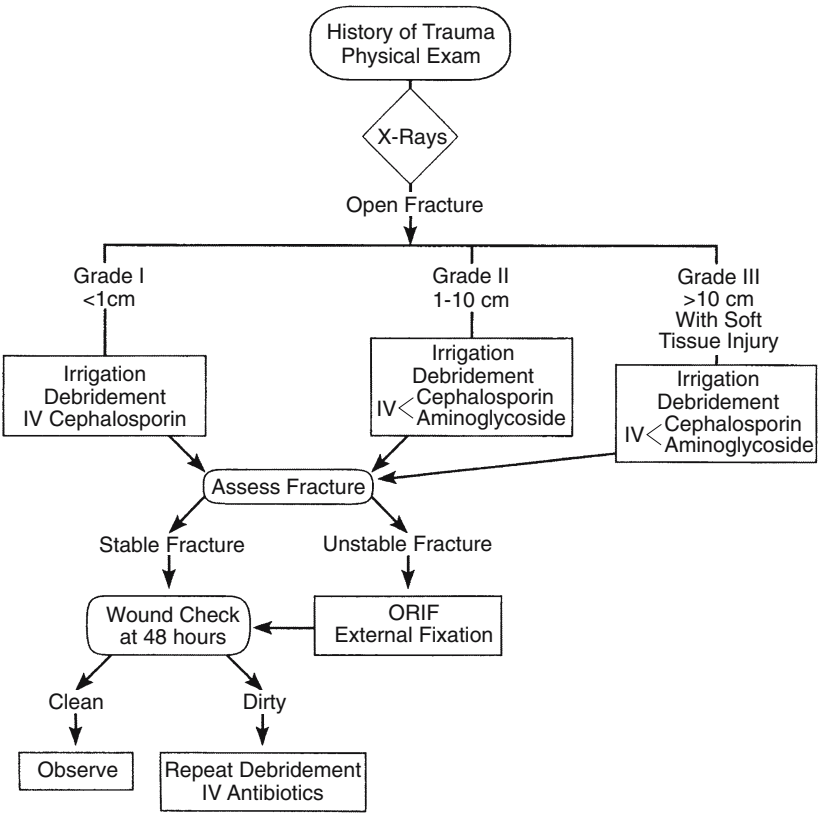


FIGURE 3-10. Algorithm for management of open fractures.

ment should be carried out 48 to 72 hours later. Tissues that have demonstrated local recovery can be preserved, whereas other tissues that have continued to remain ischemic and demonstrate evidence of necrosis should be widely excised. One cardinal rule is to never close the soft tissue laceration of an open fracture. This procedure is potentially disastrous in that an open drainage system is converted to a closed cavity, with a greater susceptibility to develop an abscess or, in the worst case scenario, frank gangrene. All open fractures should be covered with moist sterile dressings that prevent bone and soft tissue desiccation.

The principles of wound management are undisputed when dealing with open fractures, with the majority of controversies surrounding when and what to use for bone stabilization. Suffice it to say that early bone stabilization via intramedullary nailing, plate and screw fixation, or external fixation optimizes soft tissue healing and access to the extremity for examination

and treatment. By preventing continued soft tissue shearing forces, with a resultant further devascularization of soft tissue, further extension of the zone of injury can be minimized. Soft tissue coverage of the fracture should be achieved within the first 5 to 7 days of injury. A delayed primary closure may be all that is required in grade I and grade II fractures, whereas skin grafting or soft tissue transfers may be necessary for grade III fractures. Options for soft tissue coverage should be individualized for the patient and the degree of injury.

Systemic factors play a pivotal role in promoting wound healing. It has been estimated that 50% of metropolitan medical and surgical patients have overt or subclinical protein and calorie malnutrition. Multiple injuries or even isolated fractures result in a large increase in a patient's metabolic demand needed to assist in healing. Systemic parameters that have been shown to impede soft tissue healing include a serum albumin less than 3.5 mg/dL or a total lymphocyte count less than 1500 cells/mL. Patients presenting with or developing malnutrition following multiple traumatic injuries are at increased risk of infection, delayed union, or nonunion of open fractures. Aggressive nutritional resuscitation is necessary with either oral or feeding tube supplementation or, in extreme cases, parenteral nutrition.

If osteomyelitis develops following an open fracture, then the principles of treatment for adult osteomyelitis apply with one important exception; namely, the retention of implants for fixation of the fracture. In patients who present with an infection surrounding an intramedullary nail or plate, the wound should be aggressively debrided and the implant maintained if fracture stability is being achieved. Loose implants should be removed and either replaced or substituted by another implant type (i.e., an external fixator replacing a loose plate and screws). Intravenous antibiotics should be administered and directed toward isolated organisms for at least 6 weeks. Once a fracture has healed, the implant can be removed and further debridement performed as necessary. This approach reduces the complexity of treatment from an infected nonunion to an infected united bone with a better prognosis for successful healing and eradication of the infection.

Infections Associated with Joint Arthroplasty

As previously discussed, the presence of a foreign substrate (e.g., joint surface) can provide bacteria with an excellent opportunity for binding and colonization. Unfortunately, the diagnosis of an infected joint arthroplasty can be extremely difficult. Radiographs can demonstrate subtle or even profound bone resorption surrounding implants suspected of being infected. However, similar changes can be seen with aseptic loosening without an associated infection. Laboratory values, although often abnormal, are also not specific for infection. The WBC count is rarely elevated

except in a fulminant infection. The ESR is generally elevated and has been estimated to be approximately 80% accurate in suggesting the presence of an infection. Aspiration still remains the best single test to identify a subclinical infection, with a sensitivity of 90%, specificity of 80%, and an accuracy of 78%. Fluoroscopy or ultrasound should be used to confirm needle localization within the joint. The use of radionuclide scanning has been utilized to diagnose joint arthroplasty infections. Studies have varied in reporting the accuracy of indium-labeled WBC and gallium scanning. At best, the accuracy of either an indium-labeled WBC scan or a combined gallium-technetium scan is approximately 80 percent for identifying an infected arthroplasty. It has been recommended that all three methods—ESR, joint aspiration, and indium scanning—be used to determine whether an infection is present. If two of the three studies point toward an infection, appropriate treatment should be employed. Further evaluation may be necessary when only a single study is indicative for infection.

Treatment of infected arthroplasties involves removal of the old implant, including all the cement mantle, aggressive irrigation and debridement, and at least 6 weeks of antibiotics followed by reaspiration once the patient has been off antibiotics for at least 2 weeks. A cement spacer impregnated with antibiotics is usually implanted at the time of initial debridement. Patients with cultures negative for bacteria may undergo reimplantation at a later date. Positive cultures necessitate redebridement and another course of antibiotics. In the case of gram-negative bacterial infections, reimplantation may be delayed for as long as 1 year. Antibiotics specific for the infecting organism are generally added to the bone cement at the time of reimplantation.

Summary and Conclusions

The timely diagnosis of a musculoskeletal infection is the most critical aspect in the appropriate management of these conditions. Though the diagnosis may at times prove difficult due to poor historical data from infants and children, or an unreliable exam from an adult with multiple medical comorbidities, the judicious use of laboratory data, imaging studies and sound clinical judgement should render a delayed or missed diagnosis to a sparing few. It can not be overstated that the treatment of a musculoskeletal infection in the acute stages is orders of magnitude more simple than that of the management of a chronic condition.

In general, infections that do not involve a joint or the formation of a frank abscess may be effectively treated with a proper bacteriological diagnosis and antibiotic therapy. In instances in which there is an intraarticular infection or the formation of a abscess, then prompt surgical debridement and subsequent antibiotic therapy are typically necessary. In

the proper host with early and effective therapy, the long-term sequelae of an infection will most typically be modest to unrecognizable. It is for this reason that all clinicians should be able to recognize and initiate management, even if only to make appropriate referral, for all patients suspected of having an orthopaedic infection.

Suggested Readings

Cierny G. Chronic osteomyelitis: results of treatment. Instructional Course Lectures 1990;39:495–508.

Esterhai JL Jr (ed) Orthopaedic infections. Orthop Clin North Am 1991;22:3.

Evarts CM (ed) Surgery of the Musculoskeletal System, 2nd ed. New York: Churchill Livingstone, 1990.

Green NE, Edwards K. Bone and joint infections in children. Orthop Clin North Am 1987;18:555–576.

Gristina AG. Biomaterial-centered infection: microbial adhesion vs. tissue integration. Science 1987;237:1588–1595.

Questions

Note: Answers are provided at the end of the book before the index.

3-1. The involucrum is best described as:
   a. Necrotic bone within a bed of osteomyelitis
   b. Rim of soft tissue enhancement surrounding an infection
   c. Reactive new bone formation around a sequestrum
   d. Thickened joint capsule following a septic arthritis

3-2. Which of the following organism is the most common pathogen in pediatric age group osteomyelitis?
   a. *Streptococcus pneumoniae*
   b. *Streptococcus veridans*
   c. Group-B streptococci
   d. *Staphylococcus aureus*

3-3. Plain radiographs begin to demonstrate changes within the bone consistent with osteomyelitis after?
   a. 2 days
   b. 10 days to 2 weeks
   c. 4 weeks
   d. 3 months

3-4. Which of the following organism(s) is the most common pathogen found in an adult with a septic arthritis?
   a. Gram-negative rods
   b. *Staphylococcus aureus*
   c. *Mycobacterium*
   d. *Streptococcus pyogenes*

3-5. Bacterial growth in a biofilm or "slime layer" around an implant may be resistant to antibiotic therapy because of:
   a. Alterations in the local pH
   b. van der Waals forces between the bacteria
   c. Phenotypic changes in surface-adherent bacteria altering their antibiotic susceptibility
   d. Insufficient vascular supply

3-6. The most common etiology for acute osteomyelitis in children is?
   a. Hematogenous inoculation
   b. Poor immune defense mechanisms
   c. Direct inoculation
   d. Poor hygiene

3-7. Which of the following factor(s) predispose an adult to the development of a septic arthritis?
   a. Systemic steroid use
   b. Preexistent arthritis
   c. Intraarticular injection/aspiration
   d. All of the above

3-8. What is the earliest identifiable change consistent with osteomyelitis that may be evident on plain radiographs?
   a. Bone destruction
   b. Soft tissue swelling
   c. Joint effusion
   d. Bony sclerosis

3-9. The initial treatment of a patient presenting to the emergency room with an open fracture includes all the following except?
   a. Gentle wound inspection
   b. Administration of intravenous antibiotics
   c. Provisional fracture stabilization with splint or traction
   d. Deep wound probing with the purpose of obtaining cultures

3-10. Appropriate antibiotic therapy for a patient presenting to the emergency room with a puncture wound (measuring less than 5 mm) through the forearm and an associated both bone forearm fracture includes?
   a. No antibiotics are appropriate in this setting
   b. An aminoglycoside along with penicillin
   c. First-generation cephalosporin
   d. First-generation cephalosporin with an aminoglycoside

4
Tumors of the Musculoskeletal System

Martin Malawer and Kristen Kellar-Graney

Both benign and malignant tumors (neoplasms) may arise from any mesenchymal soft tissue or bony tissue of the extremities, pelvis, shoulder girdle, or the axial skeleton. All tumors arise from one of the different histologic types of tissue that comprise the musculoskeletal system: bone (osteoid-forming tumors), cartilage (chondroid-forming tumors), and muscle and the fibrous connective tissue (soft tissue tumors). Only rarely do tumors arise from the arteries or nerves.

In general, most tumors are benign, but malignant tumors may also occur. Malignant mesenchymal tumors are termed sarcomas. Sarcomas rank among the least common malignant diagnoses. There are only 8,000 new cases (6,000 soft tissue and 2,000 bone) of sarcoma of the 1.2 million new patients who will be diagnosed with cancer each year in the United States.

Most bone sarcomas (osteosarcoma and Ewing's sarcoma) occur during childhood or adolescence, in contrast to most malignancies (carcinomas), which occur in the later decades of life (more than 40 years of age). Soft tissue sarcomas tend to occur in young adults, and the risk of development increases with each decade of life. Bone tumors usually present with pain, in contrast to soft tissue tumors, which often present as a painless mass (usually greater than 5 cm in size).

Orthopedic surgeons are often the first physician to see these patients and are called upon to make a correct diagnosis and/or to determine if an individual should be referred to a specialist (orthopedic oncologist). To emphasize the rarity of these entities, the average orthopedic surgeon will see only one or two tumors every 5 to 10 years of practice.

A high degree of clinical suspicion, necessary for early diagnosis, is ever more important as fundamental changes in healthcare delivery alter patient access to specialists and to expensive imaging studies. Early detection, combined with proper techniques of diagnosis and treatment, can dramatically improve the chances of achieving functional limb salvage and survival. Continued progress in radiographic imaging, chemotherapy, radiation therapy, and biotechnology, coupled with a better understanding of the

biologic behavior of mesenchymal neoplasms, have led to a rational basis of diagnosis, staging, and surgical treatment.

This chapter reviews the common benign as well as malignant tumors arising from bone and soft tissues of the extremities, shoulder girdle, and pelvis. The biologic and radiographic characteristics are emphasized, evaluation with the use of staging studies such as computed tomography (CT) and magnetic resonance imaging (MRI) is described, and the basic surgical procedures are presented. The biologic basis of tumor growth, staging, and radiographic determination are emphasized.

Natural History of Bone and Soft Tissue Tumors

Mesenchymal neoplasms have characteristic patterns of behavior and growth that distinguish them from other malignancies. These patterns form the basis of a staging system and provide a focus for current treatment strategies.

Biology and Growth

Spindle cell sarcomas form solid lesions through circumferential growth in which the periphery of each lesion is composed of the least mature cells. In contradistinction to benign lesions, which are surrounded by a true capsule composed of compressed normal cells, malignant tumors are generally enclosed by a pseudocapsule consisting of viable tumor cells and a fibrovascular zone of reactive tissue with a variable inflammatory component that interdigitates with the normal tissue adjacent and beyond the lesion. The thickness of the reactive zone varies with the degree of malignancy and histogenetic type.

High-grade sarcomas characteristically have a poorly defined reactive zone that may be locally invaded and destroyed by the tumor. In addition, tumor nodules not in continuity with the main tumor may be present in tissue that appears to be normal. Low-grade sarcomas rarely form tumor nodules beyond the reactive zone (Fig. 4-1).

Local anatomy influences the growth of sarcomas by setting natural barriers to extension. In general, bone sarcomas take the path of least resistance. The three mechanisms of growth and extension of bone tumors are compression of normal tissue, resorption of bone by reactive osteoclasts, and direct destruction of normal tissue. Benign tumors grow and expand by the first two mechanisms; direct tissue destruction is characteristic of malignant bone tumors. Most benign bone tumors are unicompartmental; they remain confined and may expand the bone in which they arise. Most malignant bone tumors are bicompartmental; they destroy the overlying cortex and push directly into the adjacent soft tissue. Soft tissue tumors may start in one compartment (intracompartmental) or between

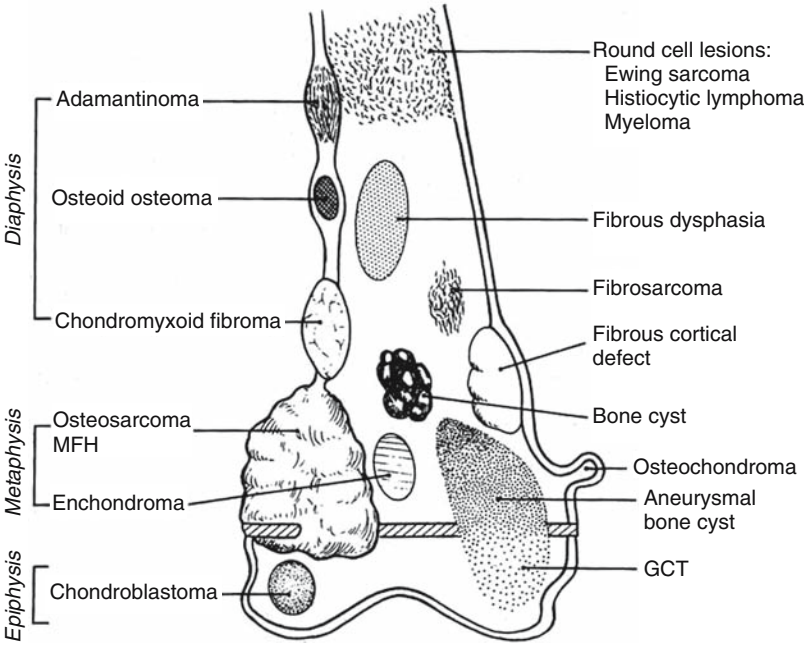


FIGURE 4-1. Schematic of typical locations of common bone tumors. The anatomic location, whether diaphyseal, metaphyseal, or epiphyseal, is one of the most important determinants of tumor type. Cortical, medullary, or eccentric location is also important. One should always pay special attention to the presence of matrix formation. (Source: Devita VT, Hellman S, Rosenberg SA. Cancer: Principles and Practice of Oncology, Fourth Edition. Lippincott Williams & Wilkins, 1993.)

compartments (extracompartmental). The determination of anatomic compartment involvement has become more important with the advent of limb preservation surgery. In general, most benign and malignant bone and soft tissue tumors grow like a ball, pushing normal tissue away as they expand.

The Five Basic Patterns of Sarcoma Behavior

On the basis of biologic considerations and natural history, all bone and soft tissue tumors, benign and malignant, may be classified into five categories, each of which shares certain clinical characteristics and radiographic patterns and requires similar surgical procedures. These five categories and the associated tumor behavior are as follows (Table 4-1):

1. *Benign/latent:* Lesions whose natural history is to grow slowly during normal growth of the individual and then to stop, with a tendency to heal

spontaneously. They never become malignant and heal rapidly if treated by curettage (e.g., lipomas and unicameral bone cysts).

2. *Benign/active:* Lesions whose natural history is progressive growth. Excision leaves a reactive zone with some tumor (e.g., chondroblastoma of bone).

3. *Benign/aggressive:* Lesions that are locally aggressive but do not metastasize. Tumor extends through the capsule into the reactive zone. Local control can be obtained only by removing the lesion with a margin of normal tissue beyond the reactive zone (i.e., giant cell tumors of bone or fibromatosis of soft tissues).

4. *Malignant, low-grade:* Lesions that have a low potential to metastasize. Histologically, there is no true capsule but rather a pseudocapsule. Tumor nodules exist within the reactive zone but rarely beyond. Local control can be accomplished only by removal of all tumor and reactive tissue with a margin of normal bone. These lesions can be treated successfully by surgery alone; systemic therapy is not required (i.e., myxoid chondrosarcoma of bone and low-grade soft tissue sarcomas).

5. *Malignant, high-grade:* Lesions whose natural history is to grow rapidly and to metastasize early. Tumor nodules are usually found within and beyond the reactive zone and at some distance in the normal tissue. Surgery is necessary for local control, and systemic therapy is warranted to prevent metastasis (i.e., osteosarcoma, Ewing's sarcoma of bone. and high-grade malignant fibrous histiocytoma of soft tissues).

Examples of bone and soft tissue tumors in each of these categories are described following and in Table 4.2.

Mechanism of Tumor Spread

In contrast to carcinomas, bone and soft tissue sarcomas disseminate almost exclusively through the blood (i.e., to the lungs and other bones). About 5% to 10% of soft tissue tumors spread through the lymphatic system to regional nodes. Hematogenous spread is manifested by pulmonary involvement in the early stages and by bony involvement in later stages. Bone metastasis occasionally is the first sign of dissemination.

TABLE 4-1. Behavioral classification of bone and soft tissue tumors.

Classification	Bone	Soft tissue
Benign/latent	Nonossifying fibroma	Lipoma
Benign/active	Aneurysmal bone cyst	Angiolipoma
Benign/aggressive	Giant cell tumor	Aggressive fibromatosis
Malignant/low grade	Parosteal osteosarcoma	Myxoid liposarcoma
Malignant/high grade	Classic osteosarcoma	Malignant fibrous histiocytoma

(Adapted from Enneking WF. Staging of musculoskeletal tumors. In: Enneking WF, Musculoskeletal Tumor Surgery, vol.1, New York: Churchill Livingstone; 1983:87–88.)

Table 4-2. General classification of bone and soft-tissue tumors.

Histologic type	Benign	Malignant
Hematopoietic (41.4%)		Myeloma
		Reticulum cell sarcoma
Chondrogenic (20.9%)	Osteochondroma	Primary chondrosarcoma
	Chondroma	Secondary chondrosarcoma
	Chondroblastoma	Dedifferentiated chondrosarcoma
	Chondromyxoid fibroma	Mesenchymal chondrosarcoma
Osteogenic (19.3%)	Osteoid osteomas	Osteosarcoma
	Benign osteoblastoma	Parosteal osteosarcoma
Unknown origin (9.8%)	Giant cell tumor	Ewing's sarcoma
		Malignant giant cell tumor
		Adamantinoma
Fibrogenic (3.8%)	Fibrous histiocytoma	Malignant fibrous histiocytoma
	Fibroma	Fibrosarcoma
	Desmoplastic fibroma	
Notochordal (3.1%)		Chordoma
Vascular (1.6%)	Hemangioma	Hemangioendothelioma
		Hemangiopericytoma
Lipogenic (0.5%)	Lipoma	Liposarcoma
Neurogenic (0.5%)	Neurilemmoma	

Source: From Sim FH, Bowman W, Chao E. Limb salvage surgery and reconstructive techniques. In: Sim FH (ed) Diagnosis and Treatment of Bone Tumors: A Team Approach. A Mayo Clinic Monograph. Thorofare, NJ: Slack, 1983.[5]

The histologic hallmark of malignant sarcomas is their potential to break through the pseudocapsule to form satellite lesions called skip metastases. A skip metastasis is a tumor nodule that is located within the same bone as the main tumor but is not contiguous to it. Transarticular skip metastases are located in the joint adjacent to the main tumor. Although relatively uncommon, skip metastases occur most frequently with high-grade sarcomas.

Sarcoma Tumor Staging

Selection and use of a prognostically significant staging system are fundamental both for the selection of appropriate treatment protocols and for the development of tumor registries necessary for basic research analysis. In 1980, the Musculoskeletal Tumor Society adopted a surgical staging system (SSS), proposed by Dr. William F. Enneking, for both bone and soft tissue sarcomas. This system is based upon the fact that mesenchymal sarcomas of bone and soft tissue behave alike, irrespective of histogenetic type. The SSS is encompasses the "GTM" classification: grade (G), location (T), and lymph node involvement and metastases (M).

1. *Surgical grade.* The letter G incorporates both the histologic grade of a lesion and clinical factors related to aggressiveness, such as growth rate. A low-grade tumor is rated G1 whereas a high-grade tumor is rated G2. Low-grade lesions are malignancies with small potential to metastasize.
2. *Surgical site.* The letter T represents anatomic site, either intracompartmental (T1) or extracompartmental (T2). A compartment is defined as "an anatomic structure of space bounded by natural barriers of tumor extension." T1 lesions are easier to delineate clinically, surgically, and radiographically than T2 lesions and have a correspondingly higher chance of adequate removal without amputative procedures.
3. *Lymph nodes and metastases.* Local disease without evidence of metastasis is designated M0. When a bone or soft tissue sarcoma has metastasized (M1), the prognosis is extremely poor. Lymphatic spread is a sign of extensive dissemination. Regional lymphatic involvement is equated with distal metastases.

The SSS developed for surgical planning and assessment of bone sarcomas is summarized as follows:

Stage IA (GI, T1, M0) Low-grade intracompartmental lesion without metastasis.
Stage IB (GI, T2P, M0) Low-grade extracompartmental lesion without metastasis.
Stage IIA (G2, TI, M0) High-grade intracompartmental lesion without metastasis.
Stage IIB (G2, T2, M0) High-grade extracompartmental lesion without metastasis.
Stage IIIA (GI or G2, M1) Intracompartmental lesion, any grade, with metastasis.
Stage IIIB (GI or G2, T2, MI) Extracompartmental lesion, any grade, with metastasis.

Decision-Making Process

In order to accurately assess the diagnosis, stage, and grade of a suspected bone tumor, rigid protocol should be followed to facilitate the decision-making process as to what staging studies are required and when a biopsy should be performed. Figure 4-2 entitled Evaluation of Suspected Bone Tumor succinctly describes the steps any clinician should follow for patients presenting with a bone tumor.

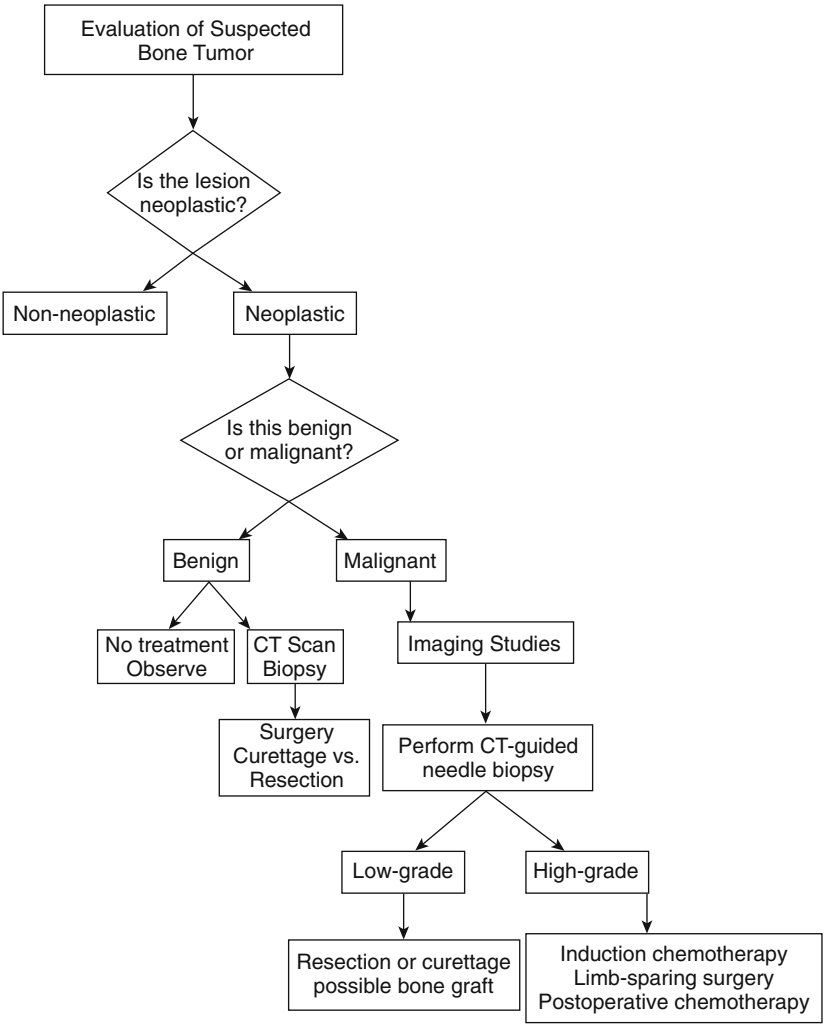


FIGURE 4-2. Process taken when evaluating abnormal bone radiographs.

Clinical and Radiographic Evaluation, Staging, and Biopsy

Staging of a bone or soft tissue tumor mass means determining the local extension (anatomy) of the tumor and any possible sites of distal dissemination. If the clinical examination or plain radiographs suggest an aggressive or malignant tumor, staging studies should be performed before biopsy (see Fig. 4.1). All radiographic studies are influenced by surgical manipula-

tion of the lesion, making interpretation more difficult. Bone scintigraphy, computed tomography or magnetic resonance imaging, and angiography are required to delineate local tumor extent, vascular displacement, and compartmental localization. Figure 4-3 demonstrates the distal femoral anatomic compartment as viewed by various radiographic modalities.

Radiographic Evaluation

X-Rays

Plain radiographs taken in perpendicular planes [anteroposterior (AP) and lateral] remain essential to the characterization and diagnosis of lesions involving the skeleton. Selection and interpretation of other imaging techniques is often guided by the radiographic properties of the lesion. Proper interpretation of a lesion seen on a radiograph can be summarized by answering "four questions" as proposed by Dr. William F. Enneking:

1. What are the anatomic location and extent of the lesion?
2. What is the lesion doing to the bone?

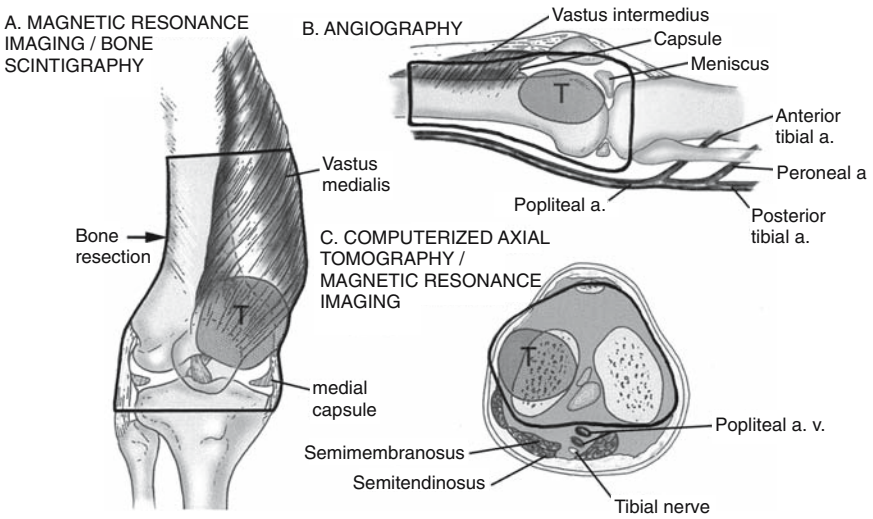


FIGURE 4-3. Surgical schematic illustrations demonstrating the distal femoral anatomic compartment as viewed by various radiographic modalities. In this illustration, a tumor arising in the lateral femoral condyle is noted. The *black outlines* demonstrate the planned region of resection in relation to the critical anatomy. This type of preoperative surgical mapping is critical for a successful limb-sparing surgery. Preoperative imaging studies usually include CT, MRI, and bone scans. (Source: Devita VT, Hellman S, Rosenberg SA. Cancer, Principles and Practice of Oncology, 5th Edition. Lippincott, Williams & Wilkins, 1997.)

3. What is the bone doing to the lesion?
4. Are there any radiographic peculiarities of the lesion that give a hint as to its tissue type?

Distinction between benign, aggressive, and frankly malignant lesions can be made on the basis of this analysis. In general, the plain radiograph is the single most important study in determining the type of bone tumor.

Bone Scans

Bone scintigraphy is useful for evaluation of both bony and soft tissue tumors. Bone scans determine whether other bones are involved by tumor. The scans assist in determining metastatic disease, polyostotic involvement, intraosseous extension of tumor, and the relationship of the underlying bone to a primary soft tissue sarcoma. Malignant bone tumors may present with skeletal metastasis (1.6%). The initial flow phase correlates to the vascularity of the tumor. Recent studies using quantitative techniques and the isotope thallium-201 have shown that the histologic tumor response to chemotherapy can be predicted based upon comparison of pre- and posttreatment studies.

Computed Tomography

Computed tomography (CT) allows accurate determination of intra- and extraosseous extension of skeletal neoplasms. CT accurately depicts the transverse anatomic relationship of a tumor to the surrounding structures. By varying window settings, one can study cortical bone, intramedullary space, adjacent muscles, and extraosseous soft tissue extension. The anatomic compartmental involvement by soft tissue sarcomas is easily determined. High-resolution CT scans (1-mm cuts) and two-dimensional or three-dimensional reconstruction can be extremely valuable in preoperative planning, particularly in the pelvis or spine. CT evaluation must be individualized to obtain the maximum benefit of image reconstruction. Close interaction between the surgeon and the radiologist facilitates accurate and effective imaging. CT is most useful for bony lesions.

Magnetic Resonance Imaging

Magnetic Resonance Imaging (MRI) provides valuable imaging of both bone and soft tissues in multiple planes. Excellent visualization of anatomic compartments, neurovascular bundles, and areas of reactive tissue allow for detailed preoperative planning. Although signal characteristics of any given mass on the traditional T_1- or T_2-weighted images (or on the more-recent fat-suppressed and gradient-echo images) can be diagnostic, distinction between benign or low-grade malignant lesions (such as lipomas

versus well-differentiated liposarcomas) cannot be reliably made on the basis of MRI images alone.

Angiography

The arteriographic technique for bone and soft tissue lesions differs from that used for arterial disease. A minimum of two views (biplane) is necessary to determine the relation of the major vessels to the tumor. Extraosseous extension is easily demonstrated by angiography. As experience with limb-sparing procedures has increased, surgeons have become more aware of the need to determine the individual vascular patterns before resection; this is especially crucial for tumors of the proximal tibia, where vascular anomalies are common. The increasing preoperative use of intraarterial chemotherapy also has increased the need for accurate angiography. Reduction of vascularity following chemotherapy can be correlated to overall histologic response of the tumor. Preoperative embolization of highly vascular tumors before surgical resection can significantly reduce blood loss and intraoperative morbidity.

The combination of plain radiographs, bone scintigraphy, cross-sectional anatomic imaging (via CT or MRI), and longitudinal imaging of vascular supply (via angiography) allows the surgeon to develop a three-dimensional construct of the local tumor area before resection and to formulate a detailed surgical approach for limb salvage.

Biopsy Considerations and Importance

The planning and technique of a biopsy is extremely important. A biopsy should be performed after the staging studies are obtained. If a resection is to be performed, it is crucial that the location of the biopsy be in line with the anticipated incision for the definitive procedure. Extreme care should be taken not to contaminate potential tissue planes or flaps that will compromise the management of the lesion. Improper biopsy technique often eliminates the opportunity for limb salvage. Mankin documented that 60% of referred patients had a major error in diagnosis and 18% had less than optimal treatment secondary to problems related to the biopsy.[6]

Core-Needle Biopsy

To minimize contamination and reduce patient morbidity, needle biopsy of soft tissue masses or of extraosseous components should be attempted before an incisional biopsy whenever possible. Needle or core biopsy of bone tumors often provides adequate specimen for diagnosis (Fig. 4-4). Cooperation between the radiologist and pathologist is vital to ensuring

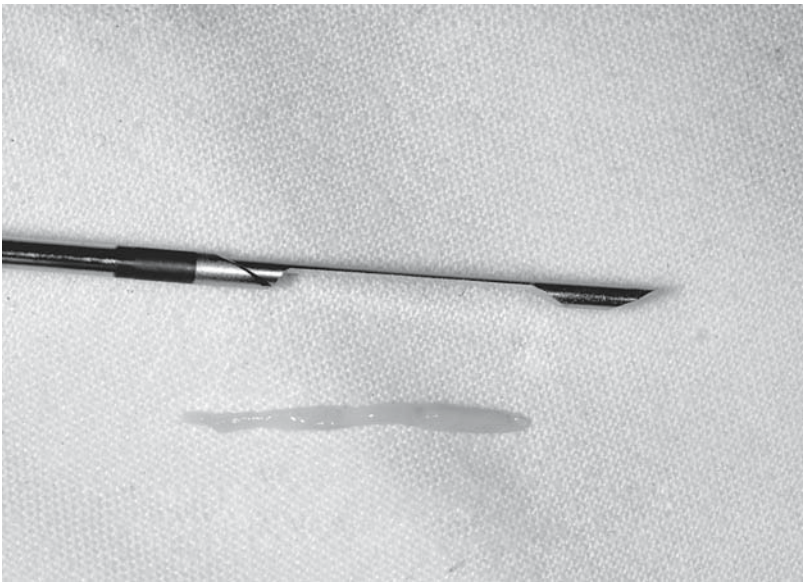


FIGURE 4-4. Biopsy technique. This clinical photograph illustrates a trochar needle utilized for biopsy and frozen-section diagnosis of soft tissue sarcomas. Soft tissue extension of bone tumors may also be sampled using this device. Multiple 'cores' of tissue may be obtained through one puncture site by varying the angle at which the trochar is inserted. Ideally, the orthopedic oncologist should be present during this biopsy to be certain that the biopsy tract is within the plane of dissection for any planned resection in an attempt to prevent contamination of surrounding tissues.

that adequate tissue is obtained to provide a diagnosis. Radiographs should be obtained to document the position of the trocar. Core biopsy is preferable if a limb-sparing option exists because it entails less local contamination than does open biopsy.

Open Incisional Biopsy

Proper techniques for open biopsies are necessary to minimize contamination. A tourniquet is used if feasible to facilitate visualization of the tumor. Transverse incisions are to be avoided at all cost, and consideration of subsequent surgery for limb salvage should guide positioning of the biopsy incision. Because sarcomas are characteristically surrounded by the most immature cells, biopsy of the lesion peripheral tissue is recommended. If a soft tissue component is present, there is no need to biopsy the underlying bone. If it is necessary to biopsy the underlying bone, a small, rounded cortical window should be used, especially for a tumor that requires primary radiotherapy. Large segments do not reossify, leading to fracture and subsequent amputation.

Classification of Surgical Procedures of Bone and Soft Tissue Tumors

Surgical removal—including curettage, resection, and amputation—is the traditional method of managing skeletal neoplasms. The advent of advanced imaging techniques, improved understanding of the biologic behavior of sarcomas, and adoption of effective adjuvant therapy have led to widespread acceptance of limb-sparing techniques. Retrospective analyses of disease-free survival and overall survival have shown no difference between limb salvage and amputation for osteosarcoma (the most common bone sarcoma) of the distal femur.

A classification scheme of surgical procedures based on the surgical plane of dissection (Fig. 4-5) in relation to the tumor and the method of accomplishing the removal has recently been developed. This system, summarized next, permits meaningful comparisons of various operative procedures and gives surgeons a common language.

1. *Intralesional.* An intralesional procedure passes through the pseudocapsule and directly into the lesion. Macroscopic tumor is left, and the entire operative field is potentially contaminated. Biopsies are by definition intralesional.

2. *Marginal.* A marginal procedure is one in which the entire lesion is removed in one piece. The plane of dissection passes through the

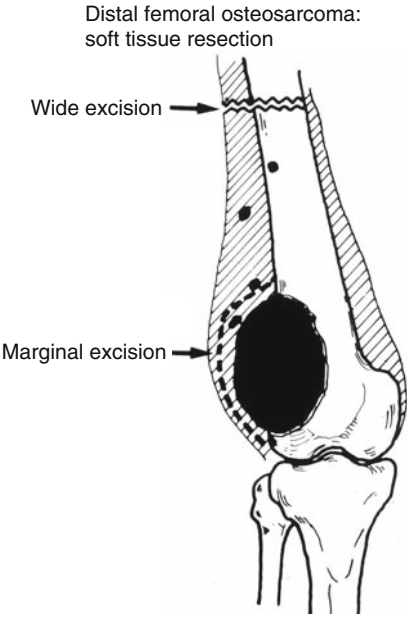


FIGURE 4-5. Schematic diagram of the planes of surgical resection in terms of the biology of the tumor (see text). The distal femur is the most common site of most primary bone sarcomas.

pseudocapsule, or reactive zone, around the lesion. When performed for a sarcoma, it leaves macroscopic disease because of tumor involvement of the pseudocapsule.

3. *Wide (intracompartmental)*. A wide excision is commonly termed en bloc resection. A wide excision includes the entire tumor, the reactive zone, and a marginal cuff of normal tissue. The entire structure of origin of the tumor is not removed. In patients with high-grade sarcomas, this procedure may leave skip nodules.

4. *Radical (extracompartmental)*. The entire tumor and the structure of origin of the lesion are removed. The plane of dissection is beyond the limiting fascial or bony borders.

It is important to note that any of these procedures may be accomplished *either* by local (i.e., limb-sparing) surgery or by amputation. An amputation may entail a marginal, wide, or radical excision, depending upon the plane through which it passes in relationship to the tumor. Therefore, an amputation is not automatically an adequate cancer operation; careful consideration to the desired final margin is required before selection of the amputation level. The local anatomy dictates how a specific margin can be obtained surgically, and proper preoperative staging (as already discussed) is necessary to assess both local tumor extent and relevant local anatomy. In general, benign bone tumors can be adequately treated with either an intralesional procedure (curettage) or a marginal excision. Figure 4-6 demon-

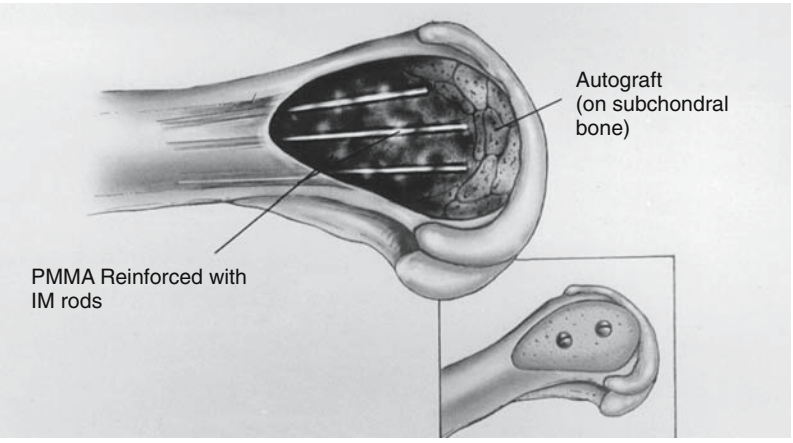


FIGURE 4-6. Surgical reconstruction. Schematic demonstrates reconstruction of a tumor cavity, utilizing subchondral bone graft, intramedullary hardware, and polymethyl acrylate (PMMA). This type of reconstruction is frequently utilized following curettage and cryosurgery to permit early mobilization, and it can be used in all anatomic locations. (Source: Bickels J, Meller I, Shmookler BM, Malawer MM. The role and biology of cryosurgery in the treatment of bone tumors. A review. Acta Orthop Scand. 1999 Jun;70(3):308–15, reprinted by permission of Taylor & Francis AS, http://www.tandf.no/ortho.)

strates reconstruction of a tumor cavity following curettage and cryosurgery. Malignant tumors require a minimum of wide (intracompartmental) excision or radical (extracompartmental) resection, which can be accomplished by amputation or by an en bloc procedure (limb salvage). Similarly, benign soft tissue tumors are treated by marginal excision, aggressive tumors by wide excision, and malignant tumors by wide or radical resection.

Malignant Bone Tumors

Primary malignancies of bone arise from mesenchymal cells (sarcoma) and bone marrow cells (myeloma and lymphoma). Bone is also a common site of metastasis from a variety of carcinomas. Osteosarcoma and Ewing's sarcoma, the most common malignant mesenchymal bone tumors, usually occur during childhood and adolescence. Other mesenchymal tumors [malignant fibrous histiocytoma (MFH), fibrosarcoma, chondrosarcoma], while occasionally seen in childhood, are more common in adults. Multiple myeloma and metastatic carcinoma typically increase in frequency with increasing patient age and are usually seen in patients over 40 years of age. This section describes the clinical, radiographic, and pathologic characteristics and treatment of the primary bone sarcomas.

Osteosarcoma provides the model on which treatment of all other sarcomas is based. The effectiveness of multiagent chemotherapy regimens has been proved by increasing overall survival rates from the bleak picture of 15% to 20% with surgery alone in the 1970s to 55% to 80% by the 1980s. In parallel with improved survival, dramatic advances in reconstructive surgery have made it possible for limb salvage to supplant amputation as the standard method of treatment.[7]

Classic Osteosarcoma

Osteosarcoma (OS) is a high-grade malignant spindle cell tumor arising within a bone. Its distinguishing characteristic is the production of "tumor" osteoid, or immature bone, directly from a malignant spindle cell stroma.

Clinical Characteristics and Physical Examination

OS typically occurs during childhood and adolescence. In patients over the age of 40, it is usually associated with a preexistent disease such as Paget's disease, irradiated bones, multiple hereditary exostosis, or polyostotic fibrous dysplasia. The most common sites are bones of the knee joint (50%) and the proximal humerus (25%). Between 80% and 90% of OS occur in the long tubular bones; the axial skeleton is rarely affected.

With the exception of the level of serum alkaline phosphatase, which is elevated in 45% to 50% of patients, laboratory findings are usually not helpful. Furthermore, an elevated alkaline phosphatase level per se is not

diagnostic because it is also found in association with other skeletal diseases such as hyperparathyroidism (brown tumor), fibrous dysplasia, and Paget's disease. Pain is the most common complaint on presentation, with a firm, soft tissue mass fixed to the underlying bone found on physical examination. Systemic symptoms are rare. Incidence of pathologic fracture is less than 1%.

Radiographic Characteristics

Typical radiographic findings in OS include increased intramedullary sclerosis (caused by tumor bone or calcified cartilage), an area of radiolucency (caused by nonossified tumor), a pattern of permeative destruction with poorly defined borders, cortical destruction, periosteal elevation, and extraosseous extension with soft tissue ossification. This combination of characteristics is not seen with any other lesion. There are three broad categories: sclerotic (Fig. 4-7A) OS (32%), osteolytic OS (22%), and mixed (Fig. 4-7B) (46%). Although there is no statistically significant difference among overall survival rates of these types, it is important to recognize the patterns. The sclerotic and mixed types offer few diagnostic problems. Errors of diagnosis most often occur with pure osteolytic tumors. The differential diagnosis of osteolytic OS includes giant cell tumor, aneurysmal bone cyst, fibrosarcoma, and MFH.

Microscopic Characteristic

The diagnosis of OS is based on the identification of a malignant stroma that produces unequivocal osteoid matrix. The stroma consists of a haphazard arrangement of highly atypical cells. The pleomorphic cells contain hyperchromatic, irregular nuclei. Mitotic figures, often atypical, are usually easy to identify. Between these cells is a delicate, lacelike eosinophilic matrix, assumed to be malignant osteoid. The term *osteoblastic osteosarcoma* is used for those tumors in which the production of malignant osteoid prevails. Calcification of the matrix is variable. Some tumors reveal a predominance of malignant cartilage production; hence, the term *chondroblastic osteosarcoma*. Even though the malignant cartilaginous elements may be overwhelming, the presence of a malignant osteoid matrix warrants the diagnosis of OS. Yet another variant is characterized by large areas of proliferating fibroblasts, arranged in intersecting fascicles. Such areas are indistinguishable from fibrosarcoma, and thorough sampling may be necessary to identify the malignant osteoid component.

Natural History, Prognosis, and Chemotherapy

Before the development of adjuvant chemotherapy, effective treatment was limited to radical margin amputation. Metastasis to the lungs and other

bones generally occurred within 24 months. Overall survival rates 2 years after surgery ranged from 5% to 20%. No significant correlation between overall survival and histologic subtypes, tumor size, patient age, or degree of malignancy was seen. The most significant clinical variable was anatomic site: pelvic and axial lesions had a lower survival rate than extremity tumors, whereas tibial lesions had a better survival rate than femoral lesions.

The dismal outcome associated with osteosarcoma has been dramatically altered by adjuvant chemotherapy as well as by aggressive thoracotomy for pulmonary disease. A recent update of 227 patients showed that 48% remained alive at an average 11 years after surgery. Of critical importance was that no difference in local recurrence or overall survival was seen between patients undergoing amputation versus limb-sparing surgery.

Chemotherapy protocols have typically included various combinations and dosage schedules of high-dose methotrexate (HDMTX), doxorubicin hydrochloride (adriamycin), and cisplatin. Ifosfamide, which is as effective as adriamycin in single-agent studies, recently has supplanted methotrexate in many ongoing protocols. Multiagent chemotherapy, using various dosing schedules, is now considered standard treatment for osteosarcoma. Success with adjuvant chemotherapy led to investigation of treatment in the neoadjuvant (preoperative) setting. When used in that setting, tumor response results in shrinkage of the soft tissue components, facilitating surgical excision and subsequent limb salvage (Fig. 4-8A,B).

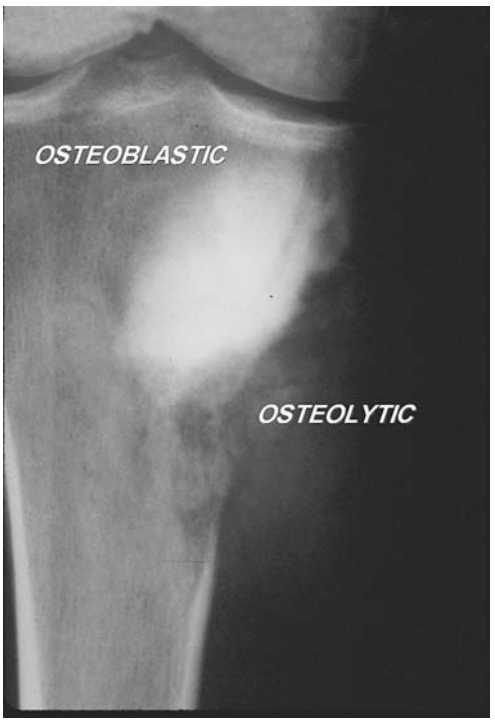
Limb-Sparing Resection

Limb salvage surgery is a safe operation for approximately 85% to 90% of individuals. This technique may be used for all spindle cell sarcomas, regardless of histogenesis. The majority of OS can be treated safely by a limb-sparing resection combined with effective adjuvant treatments.[7] The successful management of localized OS and other sarcomas requires careful coordination and timing of staging studies, biopsy, surgery, and preoperative and postoperative chemotherapy and/or radiation therapy. The site of the lesion is evaluated as previously described. Preoperative studies allow the surgeon to conceptualize the local anatomy and the volume of tissue to be resected and reconstructed.

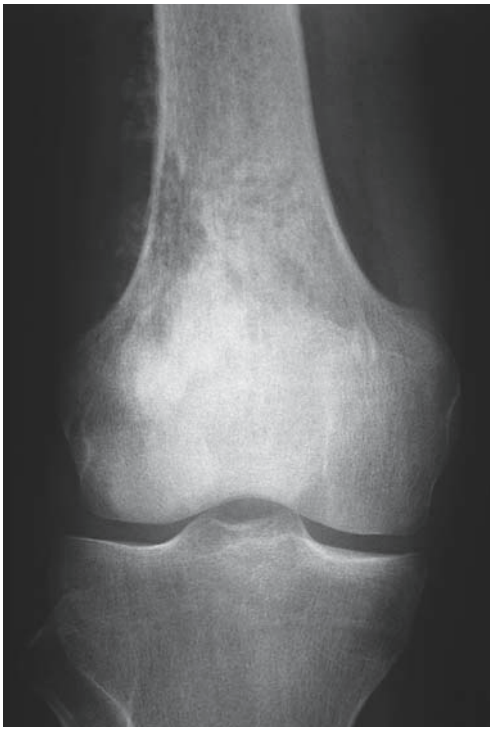
Successful limb-sparing surgery consists of three phases:

1. *Resection of tumor.* Resection strictly follows the principles of oncologic surgery. Avoiding local recurrence is the criterion of success and the main determinant of the amount of bone and soft tissue to be removed.

2. *Skeletal reconstruction.* The average skeletal defect following adequate bone tumor resection measures 15 to 20 cm. Techniques of

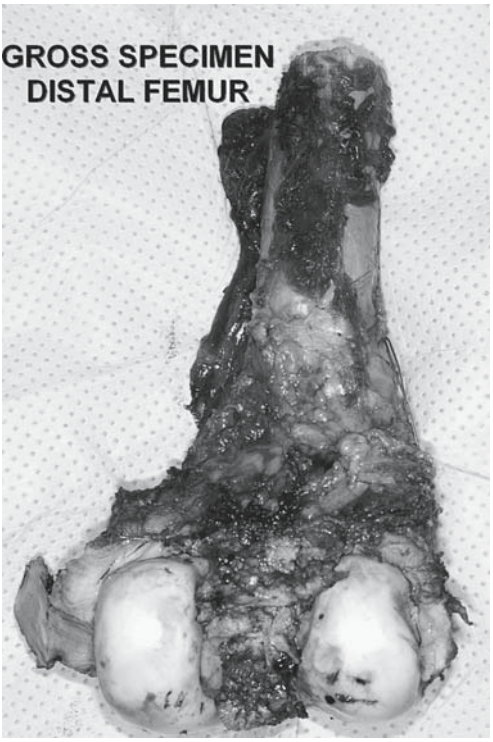


A

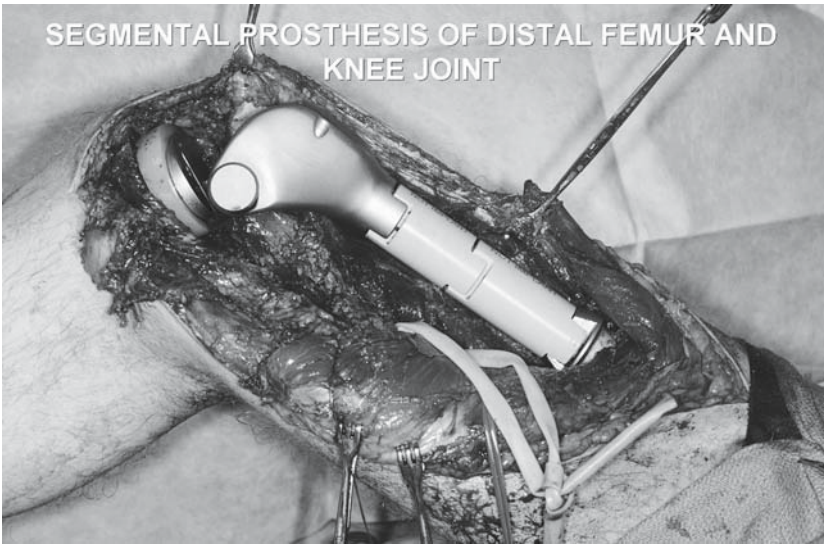


B

FIGURE 4-7. Osteosarcoma. (A) Anteroposterior (AP) radiograph of the right distal femur shows a densely sclerotic (new bone formation) lesion of the lateral condyle. This is a typical radiograph of a bone producing sarcoma (osteosarcoma). (B) AP radiograph of the knee shows an aggressive mixed blastic (new bone formation) and lytic (bone-destroying) lesion of the proximal tibia with soft tissue extension. Osteoid matrix formation is visible in the proximal portion of this tumor. The proximal tibia is the second most common site for osteosarcoma. It is the most difficult region to reconstruct because of the lack of soft tissues to be utilized for endoprosthetic coverage.



C



D

FIGURE 4-7. (*Continued*)

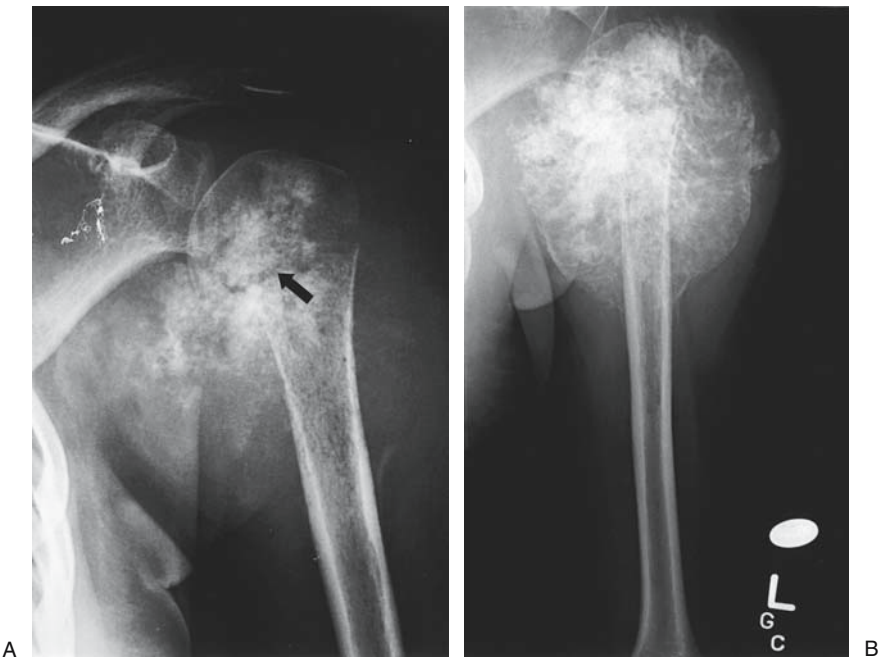


FIGURE 4-8. Osteosarcoma. (A) AP radiograph of the left proximal humerus shows a large expansile, lytic osteosarcoma with marked bony destruction. The *arrow* indicates a pathologic fracture, and there is clear evidence of a soft tissue component in the medial tissues; 95% of bone sarcomas have a soft tissue component. (B) AP radiograph shows a large osteosarcoma of the proximal humerus following induction chemotherapy. Healing of pathologic fractures and ossification of the tumor following use of chemotherapy are good prognostic signs. There is substantial ossification of this lesion.

reconstruction [prosthetic replacement (Fig. 4-9), arthrodesis, allograft, or combination] vary and are independent of the resection, although the degree of resection may favor one technique over the other.

3. *Soft tissue and muscle transfers.* Muscle transfers are performed to cover and close the resection site and to restore lost motor power. Adequate skin and muscle coverage is mandatory to decrease postoperative morbidity.

Guidelines for Surgical Resection

The surgical guidelines and technique of limb-sparing surgery used by the authors and by surgeons at most cancer centers in the United States are summarized as follows:

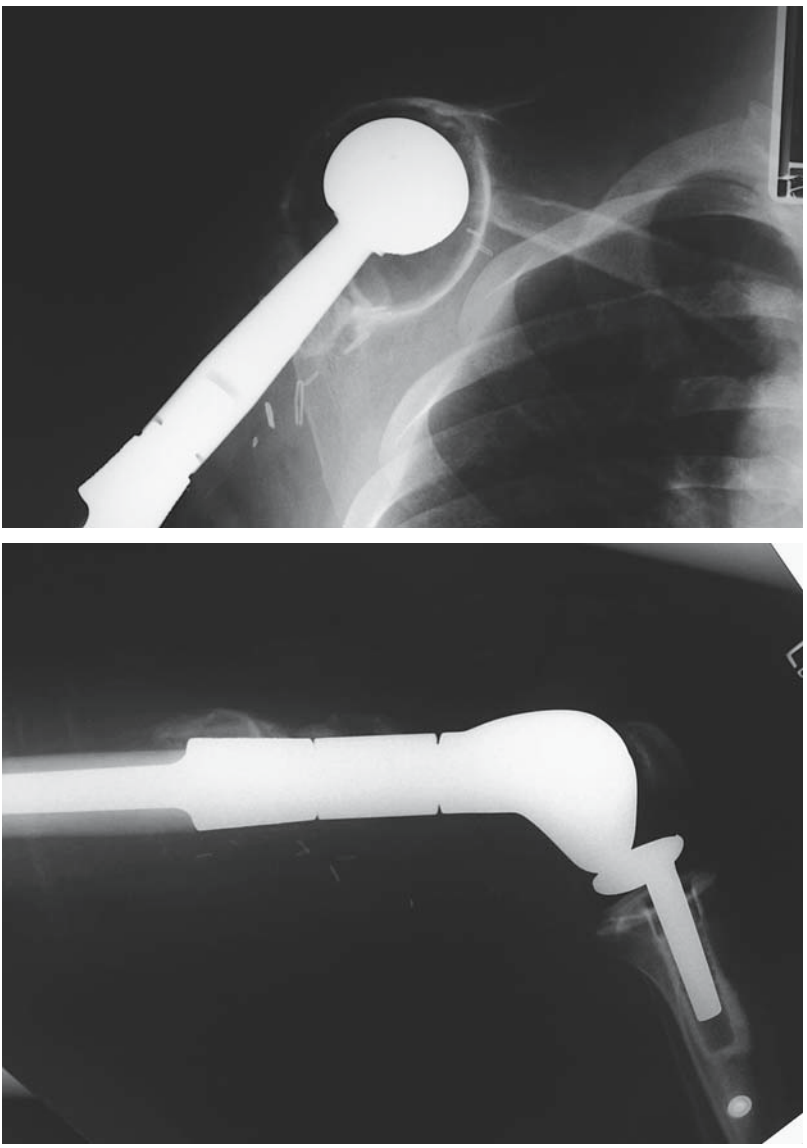


FIGURE 4-9. Segmental prostheses. (A) AP postoperative radiograph of a patient who underwent limb-sparing resection for osteosarcoma of the proximal humerus. A segmental prosthesis was inserted for reconstruction of the bony defect. Reconstruction with a segmental system provides better mobilization and improved function when compared with patients who have no reconstruction and are left with a flail extremity. The shoulder is the third most common site for bone sarcomas. (B) Segmental prosthesis of the distal femur. Lateral radiograph shows flexion of the knee following distal femoral resection and reconstruction with a modular segmental prosthesis. The distal femur is the most common site for bone sarcomas (osteosarcoma) to arise. The technique of reconstruction with a prosthesis is referred to as limb-sparing surgery, in lieu of an amputation.

1. The major neurovascular bundle must be free of tumor.
2. Wide resection of the affected bone with a normal muscle cuff in all directions should be done.
3. All previous biopsy sites and all potentially contaminated tissues should be removed en bloc.
4. Bone should be resected 3 to 4 cm beyond abnormal uptake as determined by bone scan. (This is a safe margin to avoid intraosseous tumor extension.)
5. The adjacent joint and joint capsule should be resected.
6. Adequate motor reconstruction must be accomplished by regional muscle transfers.
7. Adequate soft tissue coverage is needed to decrease the risk of skin flap necrosis and secondary infection.

Overall Treatment Strategy

The patient with a primary tumor of the extremity without evidence of metastases requires surgery to control the primary tumor and chemotherapy to control micrometastatic disease. Eighty percent to 90% of all patients with osteosarcoma fall into this category.

Surgery alone results in a 15% to 20% cure rate at best. The choice between amputation and limb-sparing resection must be made by an experienced orthopedic oncologist taking into account tumor location, size or extramedullary extent, the presence or absence of distant metastatic disease, and patient factors such as age, skeletal development, and lifestyle preference that might dictate the suitability of limb salvage or amputation. Routine amputations are no longer performed; all patients should be evaluated for limb-sparing options. Intensive, multiagent chemotherapeutic regimens have provided the best results to date. Patients who are judged unsuitable for limb-sparing options may be candidates for presurgical chemotherapy; those with a good response may then become suitable candidates for limb-sparing operations. The management of these patients mandates close cooperation between chemotherapist and surgeon.

Variants of Osteosarcoma

There are 11 recognizable variants of the classic OS. OS arising in the jaw bones is the most common of all variants. Parosteal and periosteal OS are the most common variants of the classic OS occurring in the extremities. In contrast to classic OS, which arises within a bone (intramedullary), parosteal and periosteal OS arises on the surface (juxtacortical) of the bone. Parosteal osteosarcoma is the most common of the unusual variants, representing about 4% of all osteosarcomas.

Parosteal Osteosarcoma

Parosteal osteosarcoma (POS) is a distinct variant of conventional osteosarcoma, accounting for 4% of all OS. It arises from the cortex of a bone and generally occurs in older individuals. It has a better prognosis than classical osteosarcoma.

Radiographic Findings

X-rays characteristically show a large, dense, lobulated mass broadly attached to the underlying bone without involvement of the medullary canal. If old enough, the tumor may encircle the bone. The periphery of the lesion is characteristically less mature than the base.

Chondrosarcoma

Chondrosarcoma, the second most-common primary malignant spindle cell tumor of bone, is a heterogeneous group of tumors whose basic neoplastic tissue is cartilaginous without evidence of direct osteoid formation. Bone formation occasionally results from differentiation of cartilage. If there is evidence of direct osteoid or bone production, the lesion is classified as an OS. There are five types of chondrosarcoma: central, peripheral, mesenchymal, differentiated, and clear cell. The classic chondrosarcomas are central (arising within a bone) (Fig. 4-10A) or peripheral (arising from the surface of a bone). The other three are variants and have distinct histologic and clinical characteristics.[10]

Both central and peripheral chondrosarcomas can arise as a primary tumor or secondary to underlying neoplasm. Seventy-six percent of primary chondrosarcomas arise centrally.[10] Secondary chondrosarcomas most often arise from benign cartilage tumors (see Fig. 4-10B). The multiple forms of the benign osteochondromas or enchondromas have a higher rate of malignant transformation than do the corresponding solitary lesions.

Central and Peripheral Chondrosarcomas

Clinical Characteristics and Physical Examination

Half of all chondrosarcomas occur in persons older than 40 years of age. The most common sites are the pelvis, femur, and shoulder girdle. The clinical presentation varies. Peripheral chondrosarcomas may become quite large without causing pain, and local symptoms develop only because of mechanical irritation. Pelvic chondrosarcomas are often large and present with referred pain to the back or thigh, sciatica secondary to sacral plexus irritation, urinary symptoms from bladder neck involvement, unilateral edema resulting from iliac vein obstruction, or as a painless abdominal mass. Conversely, central chondrosarcomas present with dull pain. A mass is rarely present. Pain, which indicates active growth, is an ominous sign of a central cartilage lesion. This sign cannot be overemphasized. An

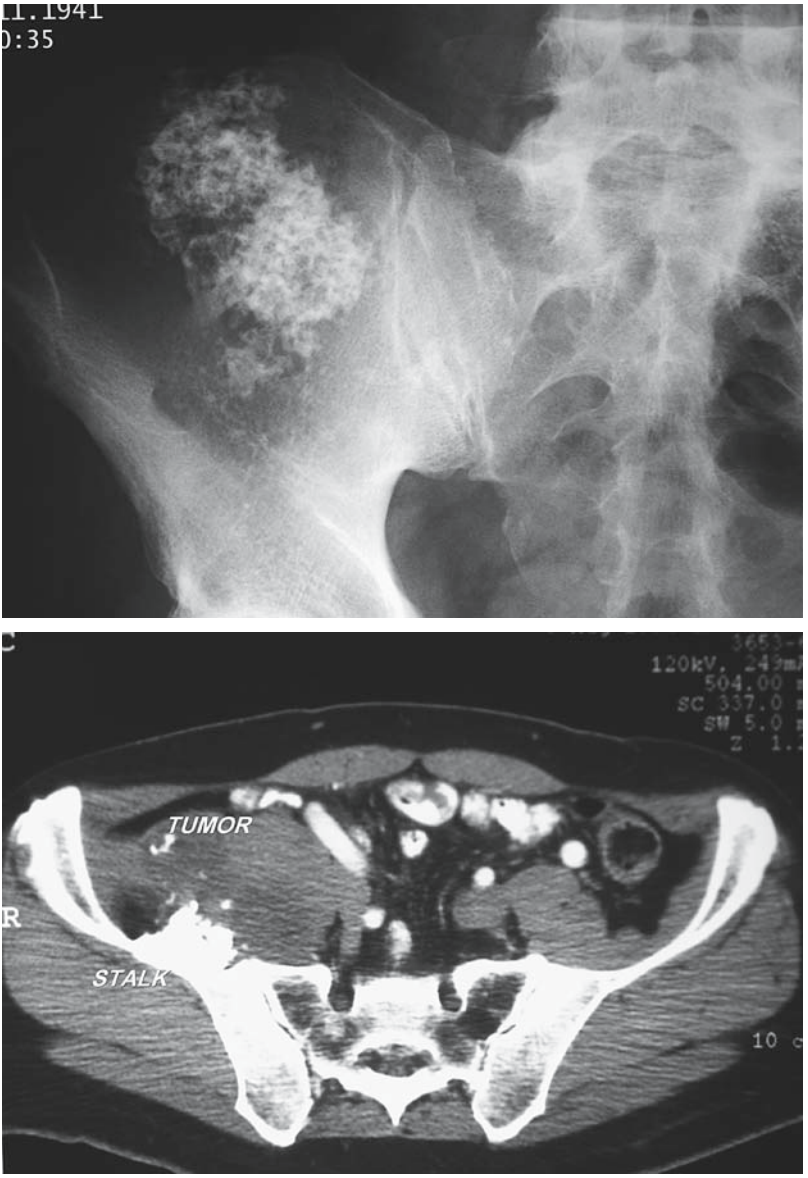


Figure 4-10. Chondrosarcoma. (A) Plain AP radiograph demonstrates a large central calcification of the right ilium, approaching the sacroiliac joint. This patient has a fairly well-defined lytic lesion showing calcification, which is typical of chondrosarcoma. (B) Computed tomography (CT) scan demonstrates secondary chondrosarcoma and a large soft tissue component. Chondrosarcomas are the most common malignancies of the pelvic bones. Large soft tissue components are common. Note the stalk indicating a preexisting exostosis.

adult with a plain radiograph suggestive of a "benign" cartilage tumor but who is experiencing pain most likely has a chondrosarcoma.

Radiographic Findings

Central chondrosarcomas have two distinct radiologic patterns. One is a small, well-defined lytic lesion with a narrow zone of transition and surrounding sclerosis with faint calcification; this is the most common malignant bone tumor that may appear radiographically benign (Fig. 4-11). The second type has no sclerotic border and is difficult to localize. The key sign of malignancy is endosteal scalloping. This type is difficult to diagnose on plain radiographs and may go undetected for a long period of time. In contrast, peripheral chondrosarcoma is easily recognized as a large mass of characteristic calcification protruding from a bone. Correlation of the clinical, radiographic, and histologic data is essential for accurate diagnosis and evaluation of the aggressiveness of cartilage tumor. In general, proximal or axial location, skeletal maturity, and pain point toward malignancy, even though the cartilage may appear benign.

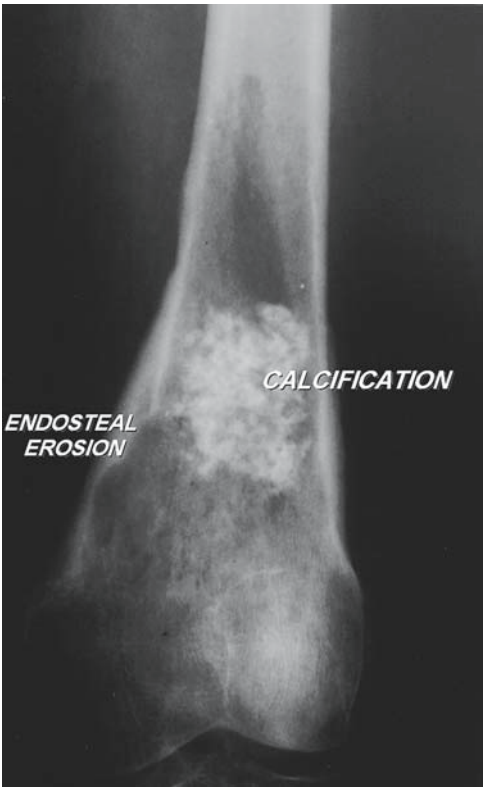


FIGURE 4-11. Low-grade chondrosarcoma of the distal femur. AP radiograph of a small, low-grade, well-defined central chondrosarcoma arising from the distal femur. Some endosteal scalloping is noted in this view, and some cortical thinning has occurred on the lateral side. Endosteal scalloping is typical in low-grade chondrosarcomas.

Grading and Prognosis

Chondrosarcomas are graded I, II, and III; the majority are either grade I or grade II. The metastatic rate of moderate grade versus high grade is 15% to 40% versus 75%.[1] Grade III lesions have the same metastatic potential as osteosarcomas.

In general, peripheral chondrosarcomas are a lower grade than central lesions. Ten-year survival rates among those with peripheral lesions are 77% compared with 32% among those with central lesions. Secondary chondrosarcomas arising from osteochondromas (see Fig. 4-10B) also have a low malignant potential; 85% are grade 1. The multiple forms of benign osteochondromas or enchondromas have a higher rate of malignant transformation than the corresponding solitary lesions.

Microscopic Characteristics

The histologic spectrum of this neoplasm varies tremendously: high-grade examples can be easily identified, whereas certain low-grade tumors are exceedingly difficult to distinguish from chondromas. Correlation of the histologic features with both the clinical setting and the radiographic changes is therefore of utmost importance in avoiding serious diagnostic error. The grade of malignant cartilaginous tumors correlates with clinical behavior. Grade I tumors are characterized by an increased number of chondrocytes set in a matrix that is chondroid to focally myxoid.

Areas of increased cellularity with more marked variation in cell size, significant nuclear atypia, and frequent pleomorphic forms define a grade II lesion. Binuclear forms are more common in this group.

Grade III chondrosarcomas, which are relatively uncommon, show even greater cellularity, often with spindle cell areas, and reveal prominent mitotic activity. Chondrocytes may contain large, bizarre nuclei. Areas of myxoid change are common.

Treatment

The treatment of chondrosarcoma is surgical removal. Guidelines for resection for high-grade chondrosarcomas are similar to those for OS. The sites of origin and the fact that chondrosarcomas tend to be low grade make them amenable to limb-sparing procedures. The four most common sites are the pelvis, proximal femur, shoulder girdle, and diaphyseal portions of long bones.

Variants of Chondrosarcoma

There are three less common variants of classic chondrosarcoma. Each is briefly described next.

Clear Cell Chondrosarcoma

Clear cell chondrosarcoma, the rarest form of chondrosarcoma, is a slow-growing, locally recurrent tumor resembling a chondroblastoma but with some malignant potential that typically occurs in adults. The most difficult clinical problem is early recognition; it is often confused with chondroblastoma. Metastases occur only after multiple local recurrences. Primary treatment is wide excision. Systemic therapy is not required.

Mesenchymal Chondrosarcoma

Mesenchymal chondrosarcoma is a rare, aggressive variant of chondrosarcoma characterized by a biphasic histologic pattern, that is, small, compact cells intermixed with islands of cartilaginous matrix. This tumor has a predilection for flat bones; long tubular bones are rarely affected. It tends to occur in the younger age group and has a high metastatic potential. The 10-year survival rate is 28%. This entity responds favorably to radiotherapy.

Dedifferentiated Chondrosarcoma

Approximately 10% of chondrosarcomas may dedifferentiate into either a fibrosarcoma or an OS.[1,2] They occur in older individuals and are often fatal. Surgical treatment is similar to that described for other high-grade sarcomas. Adjuvant therapy is warranted.

Giant Cell Tumor of Bone

Giant cell tumor of bone (GCT) is an aggressive, locally recurrent tumor with a low metastatic potential (4%–8%). Giant cell sarcoma of bone refers to a de novo, malignant GCT, not to the tumor that arises from the transformation of a GCT previously thought to be benign. These two lesions are separate clinical entities.

Clinical Characteristics and Physical Examination

GCTs occur slightly more often in females than in males. Eighty percent of GCTs in the long bones occur after skeletal maturity; 75% of these develop around the knee joint. A joint effusion or pathologic fracture, uncommon with other sarcomas, is common with GCT. GCTs occasionally occur in the vertebrae (2%–5%) and the sacrum (10%).[1]

Natural History and Potential Malignancy

Although GCTs are rarely malignant de novo (2%–8%), they may undergo transformation and demonstrate malignant potential histologically and clinically after multiple local recurrences. Between 8% and 22% of known

GCTs become malignant following local recurrence.[1] This rate decreases to less than 10% if patients who have undergone radiotherapy are excluded. Approximately 40% of malignant GCTs become malignant at the first recurrence. The remainder typically become malignant by the second or third recurrence; thus, each recurrence increases the risk of malignant transformation. A recurrence after 5 years is extremely suspicious for a malignancy. Primary malignant GCT generally has a better prognosis than secondary malignant transformation of typical GCT does, especially if the transformation occurs after radiation therapy. Local recurrence of a GCT is determined by the adequacy of surgical removal rather than by histologic grade.

Radiographic and Clinical Evaluation

GCTs are eccentric lytic lesions without matrix production occurring at the end of long bones. About 10% are axial. They have poorly defined borders with a wide area of transition. They are juxtaepiphyseal with a metaphyseal component. Although the cortex is expanded and appears destroyed, at surgery it is usually found to be attenuated but intact. Periosteal elevation is rare; soft tissue extension is common (Fig. 4-12). In the skeletally immature patient, aneurysmal bone cyst must be differentiated, although both lesions are closely related. GCTs are classified as type I, II, or III (Enneking staging system).

Microscopic Characteristics

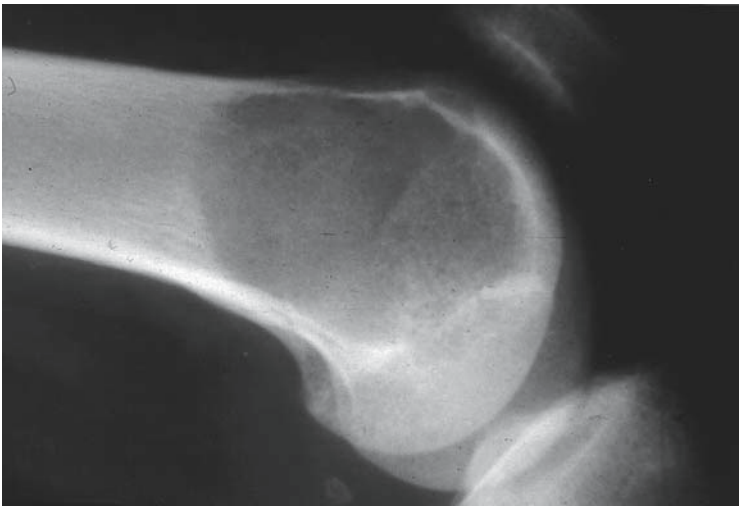
Two basic cell types constitute the typical GCT. The stroma is characterized by polygonal to somewhat spindled cells containing central round nuclei. Scattered diffusely throughout the stroma are benign, multinucleated giant cells. Small foci of osteoid matrix, produced by the benign stroma cells, can be observed; however, chondroid matrix never occurs.

Treatment

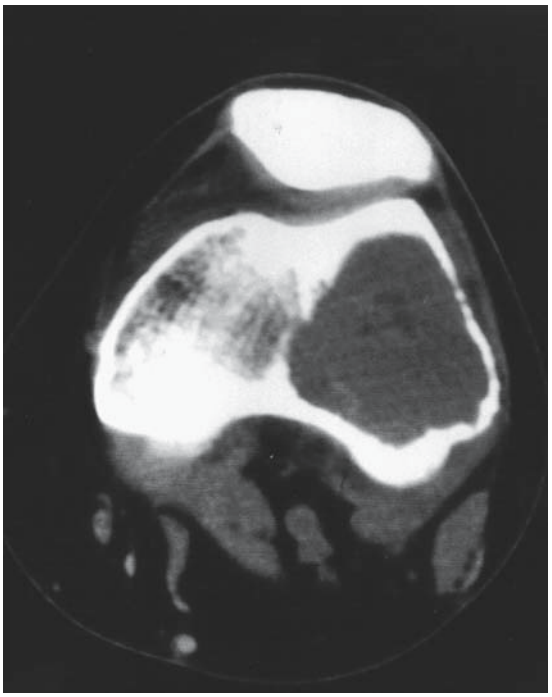
Treatment of GCT of bone is surgical removal. In general, curettage of the bony cavity with "cleaning" of the walls with a high-speed burr drill and the use of a physical adjuvant kills any cells remaining within the cavity wall. The author prefers the combined use of cryosurgery (either liquid nitrogen or a closed system of argon/helium) to obtain temperatures of –40°C. The cavity is then reconstructed with bone graft, polymethyl acrylate (PMMA), and internal fixation devices, which permit early mobilization.

Cryosurgery

Cryosurgery has been used more successfully for GCT than for any other type of bone tumor. Cryosurgery is effective in eradicating the tumor while



A



B

FIGURE 4-12. Giant cell tumor. (A) Plain lateral photograph demonstrates a giant cell tumor (GCT) of the distal femur; this is an aggressive expansile, lytic lesion that has thinned the cortex on the anterior portion of the bone. GCTs typically arise from the metaphyseal–epiphyseal junction in skeletally mature patients. This radiograph shows no evidence of matrix formation, as would be expected for an osteosarcoma, which frequently arises from the same location. The distal femur is the most common site for GCTs. (B) CT scan of the distal femur demonstrates a GCT of the distal femoral condyle. The cortices are thin, although there is no evidence of pathologic fracture or soft tissue extension.

preserving joint motion and avoiding the need for resection or amputation. Liquid nitrogen is a very effective physical adjuvant and is recommended following curettage resection. Curettage alone is not recommended because of the associated high rate of local recurrence.

Malignant Fibrous Histiocytoma

Clinical Characteristics

Malignant Fibrous Histiocytoma (MFH) is a high-grade bone tumor histologically similar to its soft tissue counterpart. Osteoid production is absent. It is a disease of adulthood. The most common sites are the metaphyseal ends of long bones, especially around the knee. Alkaline phosphatase values are normal, helping rule out an osteosarcoma or fibrosarcoma. Pathologic fracture is common. MFH disseminates rapidly. Lymphatic involvement, although rare for other bone sarcomas, has been reported.

Radiographic Characteristics

MFH is an osteolytic lesion associated with marked cortical disruption, minimal cortical or periosteal reaction, and no evidence of matrix formation. The extent of the tumor routinely exceeds plain radiographic signs. MFH may be multicentric (10%) and associated with bone infarcts (10%).

Treatment

Treatment is similar to that of other high-grade sarcomas. Adjuvant chemotherapy has similar results to that seen in the treatment of osteosarcoma.

Fibrosarcoma of Bone

Clinical Characteristics

Fibrosarcoma of bone is a rare entity, accounting for only 1% of bone tumors. It is characterized by interlacing bundles of collagen fibers (herringbone pattern) without any evidence of tumor bone or osteoid formation. Fibrosarcoma occurs in middle age. The long bones are most affected. Fibrosarcomas occasionally arise secondarily in conjunction with an underlying disease such as fibrous dysplasia, Paget's disease, bone infarcts, osteomyelitis, postirradiation bone, and GCT. Fibrosarcoma may be either central or cortical (termed *periosteal*). The histologic grade is a good prognosticator of metastatic potential. Overall survival rate is 27% and 52% for central and peripheral lesions, respectively. Late metastases do occur, and 10- and 15-year survival rates vary. In general, periosteal tumors have a better prognosis than do central lesions.

Radiographic Features

Fibrosarcoma is a radiolucent lesion that shows minimal periosteal and cortical reaction. The radiographic appearance closely correlates with the histologic grade of the tumor. Low-grade tumors are well defined, whereas high-grade lesions demonstrate indistinct margins and bone destruction similar to those of osteolytic OS. Plain radiographs often underestimate the extent of the lesion. Pathologic fracture is common (30%) because of the lack of matrix formation. Differential diagnosis includes GCT, aneurysmal bone cyst, MFH, and osteolytic OS.

Ewing's Sarcoma and Other Small Round Cell Sarcomas of Bone

Round cell sarcomas of bone behave differently and require different therapeutic management than do spindle cell sarcomas. Round cell sarcomas of bone consist of poorly differentiated small cells without matrix production. They present radiographically as osteolytic lesions. These lesions are best treated with radiation and chemotherapy; surgery is reserved for special situations. Non-Hodgkin's lymphoma and Ewing's sarcoma are the most common small cell sarcomas. The differential diagnosis of round cell sarcomas includes metastatic neuroblastoma, metastatic undifferentiated carcinoma, histiocytosis, small cell OS, osteomyelitis, and multiple myeloma.

Ewing's Sarcoma

Ewing's sarcoma is the second most common bone sarcoma of childhood; it is approximately one-half as frequent as OS. The lesion is characterized by poorly differentiated, small, round cells with marked homogeneity. The exact cell of origin is unknown. The clinical and biologic behavior is significantly different from that of spindle cell sarcomas. Within the past two decades, the prognosis of patients with Ewing's sarcomas has dramatically been improved by the combination of adjuvant chemotherapy, improved radiotherapy techniques, and the select use of limited surgical resection.

Clinical Characteristics and Physical Examination

Ewing's sarcomas tend to occur in young children, although rarely in those below the age of 5 years. Characteristically the flat and axial bones (50%–60%) are involved. When a long (tubular) bone is involved, it is most often the proximal or diaphyseal area. In contrast, OS occur in adolescence (average age, 15), most often around the knees, and involve the metaphysis of long bones. Another unique finding with Ewing's sarcomas is systemic signs, such as fever, anorexia, weight loss, leukocytosis, and anemia.[1] All

may be a presenting sign of the disease (20%–30%); this is in contrast to the distinct absence of systemic signs with OS until late in the disease process. The most common complaint is pain and/or a mass. Localized tenderness is often present with associated erythema and induration. These findings, in combination with systemic signs of fever and leukocytosis, closely mimic those of osteomyelitis.

Radiographic Findings

Ewing's sarcoma is a highly destructive radiolucent lesion without evidence of bone formation. The typical pattern consists of a permeative or moth-eaten destruction associated with periosteal elevation. Characteristically there is multilaminated periosteal elevation or a sunburst appearance. When Ewing's sarcoma occurs in flat bones, however, these findings are usually absent. Tumors of flat bones appear as a destructive lesion with a large soft tissue component. The ribs and pelvis are most often involved. Pathologic fractures occur secondary to extensive bony destruction and the absence of tumor matrix. The differential diagnosis is osteomyelitis, osteolytic OS, metastatic neuroblastoma, and histiocytosis.

Natural History

Ewing's sarcoma is highly lethal and rapidly disseminates. Historically, fewer than 10% to 15% of patients remained disease free at 2 years.[1] Many patients present with metastatic disease. The most common sites are the lungs and other bones. Ewing's sarcoma was once thought to be a multicentric disease because of the high incidence of multiple bone involvement. In contrast to other bone sarcomas, Ewing's sarcoma is associated with visceral, lymphatic, and meningeal involvement, and a search must be made for these.

Radiographic Evaluation and Staging

There is no general staging system for Ewing's sarcoma. The musculoskeletal staging system does not apply to the round cell sarcomas of the bone. Because these lesions have a propensity to spread to other bones, bone marrow, the lymphatic system, and the viscera, evaluation is more extensive than that for spindle cell sarcomas. It must include a careful clinical examination of regional and distal lymph nodes and radiographic evaluation for visceral involvement. Liver-spleen scans and bone marrow aspirates are required, in addition to CT of the lungs and the primary site. Angiography is required only if a primary resection is planned.

Biopsy Considerations

Because of the frequent difficulty of accurate pathologic interpretation and potential problems with bone heating, the following are guidelines for the biopsy of suspected round cell tumors:

1. Adequate material must be obtained for histologic evaluation and electron microscopy.
2. Routine cultures should be made to aid in the differentiation from an osteomyelitis.
3. Biopsy of the bony component is not necessary. The soft tissue component generally provides adequate material. Bone biopsy should be through a *small* hole on the compressive side of the bone. Pathologic fracture through an irradiated bone often does not heal.

Microscopic Characteristics

Large nests and sheets of relatively uniform round cells are typical. The sheets are often compartmentalized by intersecting collagenous trabeculae. The cells contain round nuclei with a distinct nuclear envelope. Nucleoli are uncommon, and mitotic activity is minimal. There may be occasional rosette-like structures, although neuroectodermal origin has never been confirmed. In the vicinity of necrotic tumor, small pyknotic cells may be observed. Vessels in these necrotic regions often are encircled by viable tumor cells. The cells often contain cytoplasmic glycogen. This neoplasm belongs to the category of small blue round cell tumors, a designation that also includes neuroblastoma, lymphoma, metastatic OS, and, occasionally, osteomyelitis and histiocytosis. When confronted with this differential diagnosis, the pathologist may turn to electron microscopy or immunohistochemistry for additional information.

Combined Multimodality Treatment

Ewing's sarcomas are generally considered radiosensitive. Radiation therapy to the primary site has been the traditional mode of local control. Within the past decade, surgical resection of selected lesions has become increasingly popular. Although detailed management is beyond the scope of this chapter, the following sections summarize some common aspects of the multimodality approach.

Chemotherapy

Doxorubicin, actinomycin D, cyclophosphamide, and vincristine are the most effective agents. There are a variety of different combinations and schedules. All patients require intensive chemotherapy to prevent dissemination. Overall survival in patients with lesions of the extremities now ranges between 40% and 75%.

Radiation Therapy

Radiation to the entire bone at risk is required. The usual dose ranges between 4,500 and 6,000 cGy delivered in 6 to 8 weeks. To reduce the morbidity of radiation, it is recommended that between 4,000 and 5,000 cGy be delivered to the whole bone, with an additional 1,000 to 1,500 cGy to the tumor site.

Surgical Treatment

The role of surgery in the treatment of Ewing's sarcoma is currently undergoing change. The Intergroup Ewing's Study recommends surgical removal of expendable bones such as the ribs, clavicle, and scapula. In general, surgery is reserved for tumors located in high-risk areas, such as the ribs, ilium, and proximal femur. *Risk* is defined as an increased incidence of local recurrence and metastases. In general, surgery is considered an adjunct to the other treatment modalities.

Recently, there has been increased interest in primary resection of Ewing's sarcoma following induction (neoadjuvant) chemotherapy, similar to the treatment of OS. When this is performed, radiation therapy is not given if the surgical margins are negative (wide resection). The goal of this approach is to increase local control as well as minimize the complications and functional losses that are associated with high-dose radiotherapy.

Multiple Myeloma/Plasmocytoma

Clinical and Physical Examination

Multiple myeloma is often referred to as the most common primary malignancy of bone, with an incidence between 2 and 3 cases per 100,000. It is a disease of older adults, and frequently presents with signs and symptoms related to bone marrow suppression, hypercalcemia, and renal failure. Bone pain and spontaneous vertebral fractures are often present. The radiographic hallmark of this disease is multiple osteolytic (punched-out) lesions involving both the axial and appendicular skeleton. Bone scans are typically less sensitive than plain radiographs because osteoclast activity predominates in the lytic process. Myeloma should be suspected when routine laboratory studies reveal anemia, increased serum creatinine, elevated calcium, and elevated serum protein. Confirmation can be readily made by demonstrating a monoclonal spike on a serum protein electrophoresis (SPEP). Infection and renal failure are the most common causes of death, and the presence of either is a poor prognostic indicator.

Metastatic Bone Disease and Pathologic Fracture

Approximately 100,000 patients a year in the United States develop metastatic bony disease. The orthopedic surgeon is commonly asked to manage patients with skeletal metastases. The operative and nonoperative treatment of metastatic disease is continuously evolving. Approximately 85% of all patients dying of cancer have skeletal involvement, although only 5% will sustain a pathologic fracture.

Diagnosis

Clinical Characteristics and Physical Examination

Metastatic carcinoma is the most common bone tumor in patients more than 40 years of age. Despite the wide variety of carcinomas, the hallmark of skeletal involvement is pain. A patient with a known cancer who develops skeletal pain must be assumed to have a bony metastasis until proved otherwise. Approximately 10% of cancer patients present with bony metastasis as the first sign of the disease. Plain radiographs may appear normal for weeks or months after the onset of pain. Thus, clinical suspicion is the key to accurate diagnosis. The most common primary sources of skeletal metastases are the lungs, breast, prostate, pancreas, and stomach.

Bone Scan and Batson's Plexus

Bone scans are highly accurate and demonstrate increased uptake of contrast medium. The most common sites of involvement are spine (thoracic, then lumbar), pelvis, femur, and ribs. This distribution reflects the pattern of hematogenous spread. Vertebral lesions are thought to be secondary to seeding via Batson's plexus, that is, perivertebral via the valveless venous plexus that permits retrograde flow. The hip and femur are the most common sites of pathologic fracture. Spinal involvement presents with back pain or neurologic deficit secondary to epidural compression. Laboratory data may show hypercalcemia, reflecting accelerated bone resorption. An elevated alkaline phosphatase level is less common and is the result of a secondary osteoblastic attempt to repair the destructive lesion. An elevated acid phosphatase level is pathognomonic of metastatic prostate cancer.

Staging Studies

Staging studies are similar to those used in the evaluation of primary sarcomas. The information obtained is useful in local evaluation and in therapy.

Radiographic Findings

Most metastatic carcinomas tend to be irregularly osteolytic with some osteoblastic response. Characteristically, osteoblastic metastases occur in the breast, prostate, lung, or bladder. In general, most endocrine tumors tend to be osteoblastic, whereas nonendocrine tumors tend to be radiolucent or osteolytic. Between 75% and 90% of patients with metastatic disease have multiple lesions at initial presentation. Soft tissue extension is rare for metastatic disease. Periosteal elevation is rare except with prostate cancer. Radiographic diagnosis of metastatic disease tends to be simple. Factors favoring metastasis are irregular osteolytic and/or mixed osteoblastic lesion, multiple lesions, and age above 40 years. A few meta-

static lesions may mimic a primary sarcoma. Specifically, a metastatic prostate (osteoblastic) lesion may appear as a primary osteosarcoma and a solitary hypernephroma (Fig. 4-13) as an osteolytic sarcoma, for example, MFH of bone.

Bone Scans

Bone scintigraphy is the most helpful study in evaluating metastatic disease. Presence of multiple lesions favors the diagnosis of metastatic carcinoma and often suggests that there is involvement of other anatomic areas not suspected from clinical examination. Intraosseous extension beyond the area indicated by the plain radiographs is not unusual; this is caused by the propensity of carcinoma cells to permeate between the bony trabeculae.

Computed Tomography/Magnetic Resonance Imaging

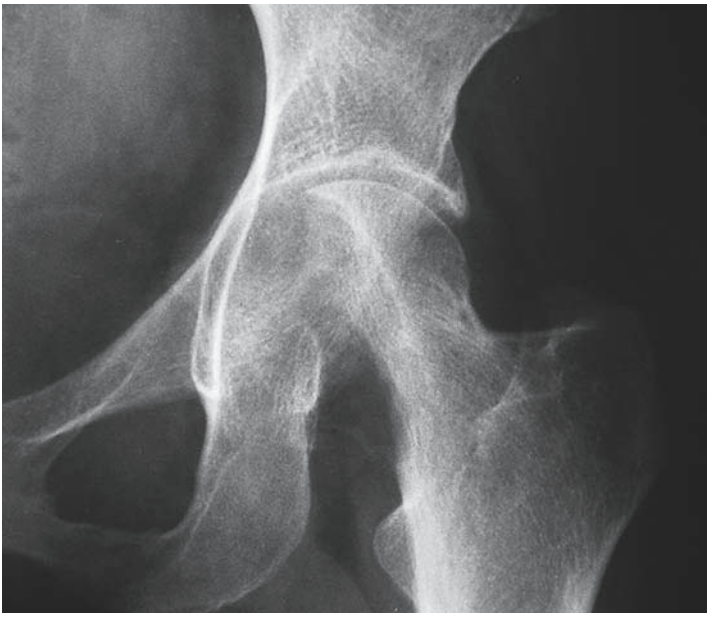
Axial studies of the body are not only helpful in the definition of localized skeletal disease but are of great importance in diagnosing the site of primary disease in patients initially presenting with a bone lesion. CT scans of the chest, and contrast-enhanced CT scans of the abdomen and pelvis, allow for accurate screening for solid tumors of the major organ systems. Despite this, however, approximately 10% of all patients will never have an identifiable site of primary disease. MRI has become increasingly useful in patients with spinal, pelvic, and hip lesions. Thus, both CT and MRI are useful in evaluation of patients with metastatic disease.

Biopsy

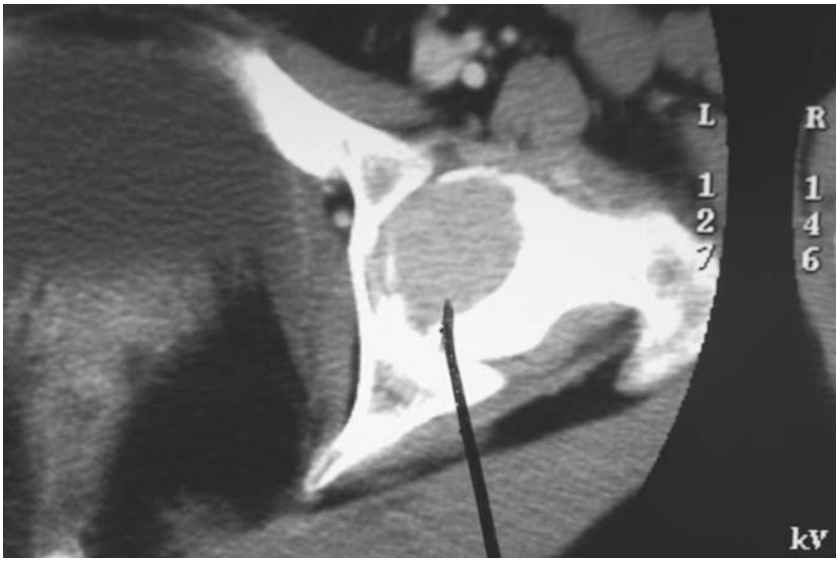
The principles and techniques of biopsy are similar to those described for primary bone tumors. If a metastatic lesion is strongly suspected, a needle biopsy is often sufficient (90%) for a correct diagnosis. Needle biopsies are most useful for confirming metastatic carcinoma in a patient with a known cancer.

Microscopic Characteristics

The primary site determines, to a large degree, the histologic appearance of the metastatic focus. Unequivocal epithelial features such as acinar formation, papillae with epithelial lining, or keratin pearl formation indicate that the lesion is not primary in bone; furthermore, based on both the pattern and certain histochemical properties, a likely primary site can be suggested. For example, the presence of epithelial mucins within tumor cell vacuoles suggests lung, gastrointestinal tract, or pancreas, among others, as possible primary sites. The Fontana stain confirms the presence of



A



B

FIGURE 4-13. Metastatic carcinoma. (A) AP radiograph demonstrates a large lytic metastatic lesion of the head and neck of the left proximal femur. Hypernephroma (i.e., renal cell carcinoma) is an extremely vascular lesion that typically requires preoperative embolization. The hip is one of the most common sites of metastatic carcinoma. (B) CT scan shows metastatic hypernephroma to the left proximal femur and acetabulum. This tumor is associated with cortical destruction, hypervascularization, and a soft tissue component. There is no calcification or ossification. A trochar needle is utilized to obtain cores of tissue for pathologic diagnosis. Metastatic hypernephromas typically require embolization before surgical resection in an attempt to prevent excessive intraoperative bleeding. CT scans accurately depict bony changes and are extremely reliable.

melanin pigment, as would be expected in malignant melanoma. Immunohistochemical studies, as for thyroglobulin or prostate-specific acid phosphatase, offer an additional means of tumor identification.

Treatment

Treatment considerations for patients with metastatic skeletal disease differ from those for patients with primary bone neoplasms. In general, overall survival is less than 1 year. The main goals of treatment are relief of bone pain, prevention of fracture, continued ambulation, and avoidance of cord compression from metastatic vertebral disease. The treatment for each patient must be highly individualized, but there are certain guidelines:

1. Bone pain can be relieved by analgesics and radiation therapy. Lesions of the lower extremity often require prophylactic fixation to avoid fracture. Closed intramedullary rodding reduces the local morbidity of diaphyseal lesions.
2. If multiple sites are involved, the lower extremity (especially the hips) should be treated early to permit ambulation.
3. Early spinal cord compression should be treated aggressively with radiotherapy. If symptoms persist, early decompression is required. Increasing back pain is an early sign of cord compression.
4. Intramedullary fixation (Fig. 4-14) is preferred over screw-and-plate fixation. Endoprosthetic replacement is preferred for the hip in lieu of nail or plate fixation. Polymethyl methacrylate (PMMA) is required to permit immediate stable fixation and to prevent loosening.
5. Perioperative antibiotics are required because of the increased risk of infection.
6. Hematologic parameters should be carefully evaluated before, during, and after surgery because of the increased risk of bleeding in cancer patients (coagulopathy). The platelet count, prothombin time (PT), and partial prothombin time (PTT) are routinely obtained.

Benign Bone Tumors

Benign bone tumors are more common than malignant bone tumors and usually occur during childhood or adolescence. Some can be treated successfully by simple curettage (intralesional procedure), whereas others require extensive resection (marginal or wide). Treatment is based upon the natural history of the specific entity. Treatment must be individualized; preservation of function is important. The important clinical aspects of these tumors are emphasized in this section. In general, the preoperative staging studies are extremely accurate, and the plain radiographs often suggest the correct diagnosis.

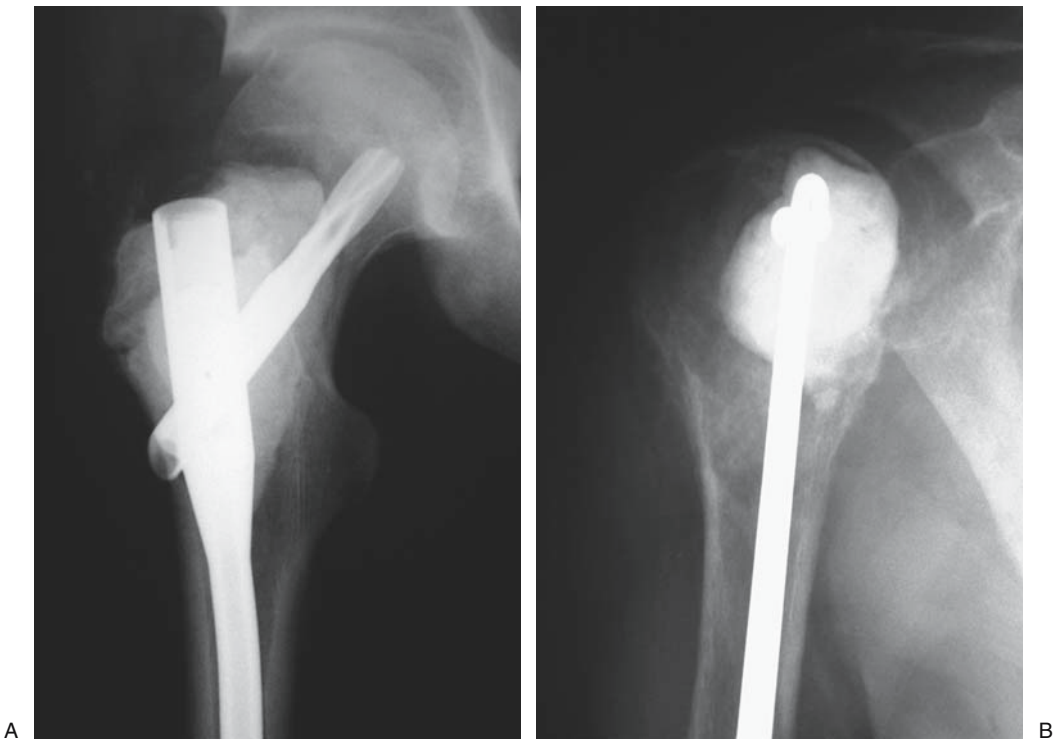
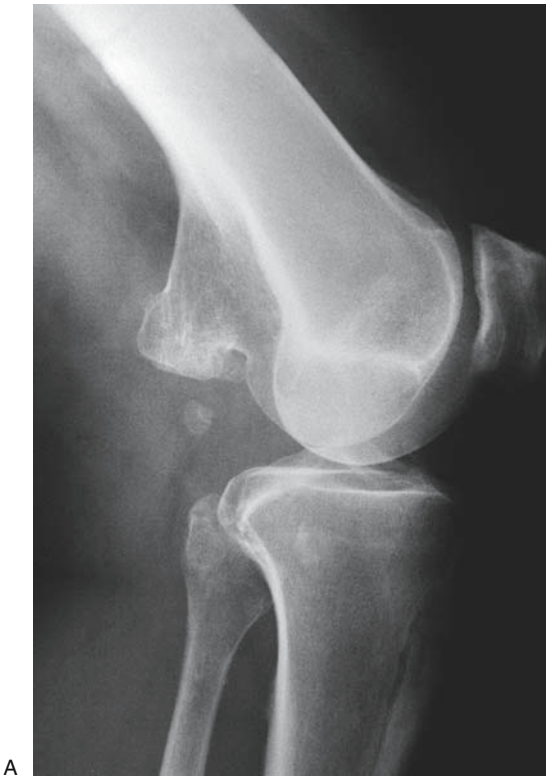


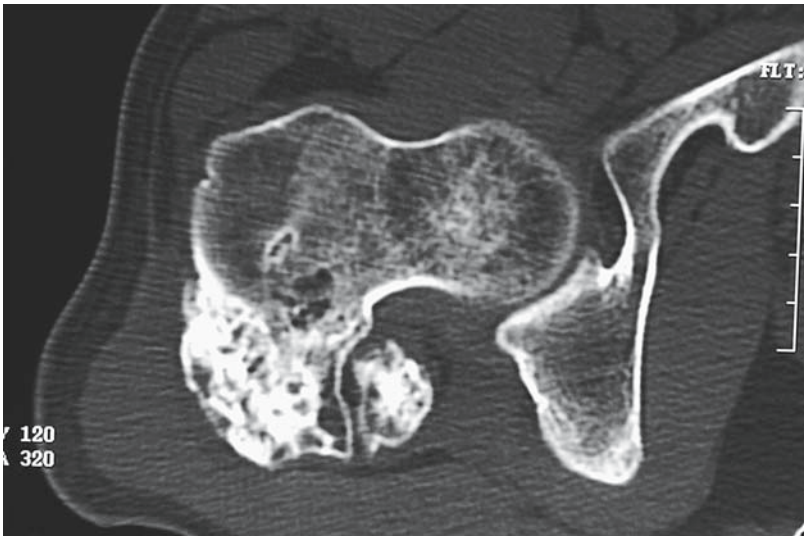
FIGURE 4-14. Metastatic carcinoma. (A) AP postoperative radiograph following curettage, intramedullary rodding, and cementation with polymethyl methacrylate for a metastatic carcinoma to the proximal femur. This reconstruction method enable early weight-bearing and mobilization of the patient. (B) AP postoperative radiograph of the right proximal humerus and shoulder girdle demonstrates cementation and internal fixation with intramedullary rodding for a metastatic lesion.

Solitary and Multiple Osteochondromas (Exostosis)

Osteochondromas are the most common benign bone tumor. They are characteristically sessile or pedunculated, arising from the cortex of a long tubular bone adjacent to the epiphyseal plate. Osteochondromas are usually solitary except in patients with multiple hereditary exostosis. Plain radiographs are usually diagnostic (Fig. 4-15A), and no further tests are required. Sessile osteochondromas present difficulty in diagnosis, especially when found in unusual sites such as the distal posterior femur, in which case they must be differentiated from a parosteal OS. Bone scintigraphy and CT (Fig. 4-15B) are helpful in distinguishing between these two entities.



A



B

FIGURE 4-15. Osteochondroma. (A) Lateral radiograph demonstrates a solitary sessile osteochondroma arising from the lateral portion of the distal femur cortex. As this is a less common location for osteochondroma to arise, differential diagnosis must also include malignant neoplasms. Osteochondromas are the most common benign bone tumors, although approximately 1%–2% will undergo malignant transformation. (B) CT scan shows a large osteochondroma arising from the right proximal femur. Proximal osteochondromas, especially around the pelvis and the hip, are more likely, when compared with distal lesions, to undergo malignant transformation.

Osteochondromas grow along with the individual until skeletal maturity is reached; growth of an osteochondroma during adolescence, therefore, does not signify malignancy. Pain is not a sign of malignancy in children or adolescents, although in an adult it is a significant warning sign. Pain in a child may be caused by a local bursitis, mechanical irritation of adjacent muscles, or a pathologic fracture.

Between 1% and 2% of solitary osteochondromas undergo malignant transformation; patients with multiple hereditary exostosis are at a higher (5%–25%) risk. Malignant tumors arising from a benign osteochondroma are usually low-grade chondrosarcomas. Proximal osteochondromas are at a higher risk to undergo malignant transformation than are distal lesions. In general, surgical removal is recommended only for symptomatic osteochondromas or for those arising along the axial skeleton and pelvic and shoulder girdle.

Enchondromas

Enchondromas may be solitary or multiple (Ollier's disease). They have been reported in most bones. These lesions are often difficult to diagnose radiographically and histologically. The biologic potential is often over- or underestimated. Malignant transformations do occur, but the rate is difficult to determine. In general, lesions of the pelvis, femur, and ribs are at higher risk than are more-distal sites.

Enchondromas are rarely painful unless a pathologic fracture exists. Otherwise, pain is a sign of local aggressiveness and possible malignancy. Enchondromas of the hands and feet, irrespective of pathologic findings, are benign, whereas cartilage tumors of the pelvic or shoulder girdle are often malignant, despite a benign-appearing histologic appearance. Plain radiographs may be helpful in this differentiation. Radiographic scalloping is a sign of local aggressiveness. Bone scintigraphy is not helpful in differentiating a low-grade chondrosarcoma from an active enchondroma. Age is an important indicator of possible malignancy; enchondromas rarely undergo malignant transformation before skeletal maturity. Painful, benign-appearing, proximal enchondromas in an adult are often malignant, despite the histologic findings. The correlation of symptoms, plain radiographs, and histologic findings is crucial in assessing an individual cartilage tumor.

Curettage of enchondromas, with or without bone graft, in a child is usually curative. Pathologic fracture may require internal fixation in addition to curettage. In an adult, curettage has a significant rate of local recurrence; resection or curettage combined with cryosurgery has a high success rate.

Microscopic Characteristics

When chondroid lesions are under evaluation, histologic features must be correlated with both radiographic changes and the clinical setting. There

may be variable cellularity, but the chondrocytes tend to remain small and uniform. Nuclear atypia is minimal, and occasional binucleate forms are not inconsistent with the diagnosis of a benign lesion. As a rule, the chondrocytes are situated in individual lacunae. Correlating with the gross findings, foci of calcification, and endochondral ossification can be observed. Features such as marked nuclear atypia, mitotic activity, myxoid degeneration of matrix, and multiple cells in individual lacunae should raise a strong suspicion of chondrosarcoma.

Chondroblastoma, Osteoblastoma, and Osteoid Osteoma

Chondroblastoma and osteoblastoma are characterized by immature but benign chondroid and osteoid production, respectively. Both may undergo malignant transformation in rare cases, and osteoblastoma can metastasize. Osteoid osteomas are small (less than 1 cm), painful, bone-forming tumors that are always benign. Chondroblastomas typically occur in the epiphysis of a skeletally immature child. Although osteoblastomas may be found in any bone, the spine and skull account for 50% of all reported cases. The differential diagnosis of chondroblastoma includes GCT, aneurysmal bone cyst, and clear cell chondrosarcoma. Osteoblastoma must be differentiated from osteosarcoma and osteoid osteoma. Clinical correlation of age, site, and histologic findings often points to the correct diagnosis.

Chondroblastomas and osteoblastomas are aggressive benign lesions with a high recurrence rate following simple curettage. Local control can be obtained by primary resection; however, routine resection cannot be recommended for tumors adjacent to a joint. Cryosurgery has avoided the need for resection and extensive reconstruction in select patients.

Osteoid Osteoma

Clinical Characteristics and Physical Examination

This lesion has classic symptoms and CT scan appearance in 80% of patients (Fig. 4-16). Osteoid osteomas are extremely painful (equivalent to a severe toothache) and well localized. Pain is often worse at night. The pain is relieved by salicylates; narcotics often are not helpful. The response to salicylates is dramatic, occurring in 20 to 30 minutes with a minimal dose of one or two tablets of regular-strength aspirin. This pain pattern may exist for 6 to 9 months before the appropriate diagnosis is considered. Occasionally, the pain precedes the appearance of radiographic abnormalities and therefore leads to multiple incorrect diagnoses, including neuroses. The most common anatomic sites are the femur and tibia, although any bone, including the skull, spine, and small bones of the hands

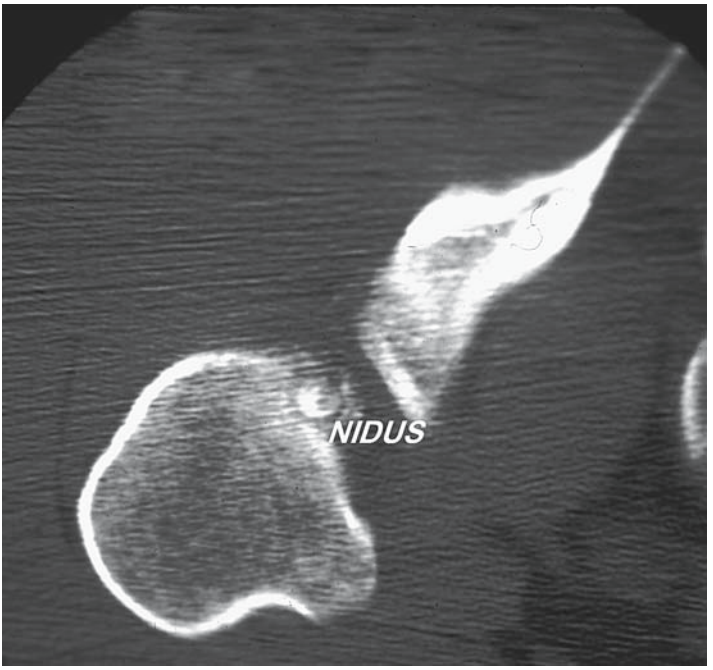


FIGURE 4-16. Osteoid osteoma. CT scan demonstrating an intracortical (nidus) osteoid osteomas of the proximal humerus. Osteoid osteomas are small (less than 1 cm), characteristically painful, and usually found in young patients.

and feet, may be involved. When the lesion is located near a joint, symptoms may mimic those of monoarticular arthritis. Osteoid osteomas of the spine often present as a painful scoliosis mimicking a vertebral osteomyelitis, spinal cord tumor, or abdominal disease. There is an interfacing network of irregular partially calcified bony trabeculae that resembles that seen in osteoblastoma.

Radiographic Appearance and Evaluation

The tumor can be found in any portion of a bone. The position relative to the cortex, periosteum, and spongiosa determines the radiographic appearance. The most common site is intracortical. Plain radiographs may show the nidus (lesion), which is radiolucent but often obscured by a large amount of dense, white, reactive bone that is stimulated in response to the tumor. When the lesion is intramedullary, there is less sclerotic response. Detection and localization of the lesion are difficult. Bone scintigraphy is the most useful staging study and demonstrates markedly increased uptake of contrast medium.

Treatment

Surgical removal of the nidus is required; the sclerotic, reactive bone need not be removed. Pain is dramatically resolved if the nidus has been excised. Incomplete removal routinely results in a clinical recurrence. Recently, nonsurgical removal by CT-guided radiofrequency ablation has been recommended.

Aneurysmal Bone Cysts

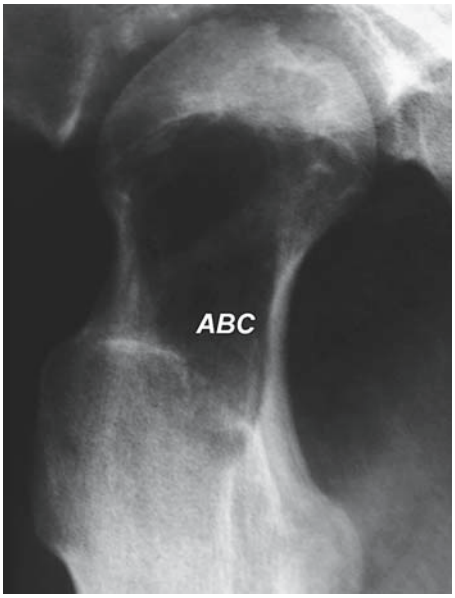
Aneurysmal bone cysts (ABC) are benign tumors of childhood, occurring typically before skeletal maturity. They never become malignant. ABC often involve the metaphyseal regions of the long bones or the vertebrae. Radiographically, ABC are eccentric, lytic, and expansile, characterized by cortical destruction and periosteal elevation (Fig. 4-17). They can grow rapidly and appear extremely aggressive, and distinguishing them from a primary malignancy may be difficult. Differential diagnosis includes GCT and telangiectatic osteosarcoma. ABC contain some osteoid; however, careful examination reveals this to be reactive and not neoplastic. Approximately one-third arise in conjunction with another bony neoplasm.

Unicameral (Simple) Bone Cysts

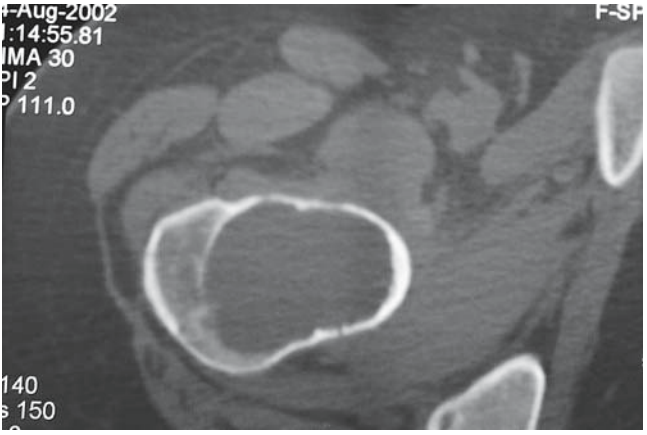
Unicameral bone cysts (UBC) are benign lesions that occur during growth. They involve the metaphysis and/or the diaphysis of a long bone. They are not believed to be true neoplasms.

The most common sites are the proximal humerus (67%) and proximal femur (15%). UBC are usually asymptomatic until a fracture occurs. Radiographically, UBC are radiolucent and slightly expansile, with well-defined margins (Fig. 4-18). UBC are rarely confused with other benign or malignant tumors. Plain radiograph is the primary imaging study utilized for diagnosis when these tumors arise in common locations. Other preoperative staging studies usually are not required. Bone scintigraphy is

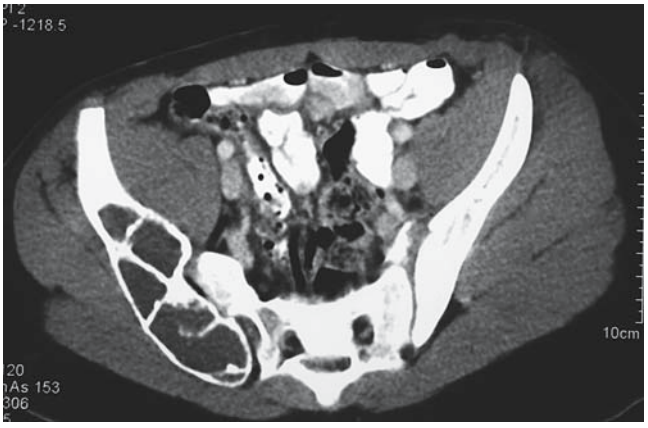
FIGURE 4-17. Aneurysmal bone cyst (ABC). (A) Plain radiograph demonstrates an ABC and fibrous dysplasia of the proximal third of the femur. ABCs are expansile and lytic lesions arising in skeletally immature patients with cortical thinning, as seen both medially and laterally in this patient. Approximately one-third of all ABCs arise in conjunction with another bony neoplasm, as seen here. The hip is a common site of fibrous dysplasia. (B) CT scan of the same patient demonstrates marked cortical thinning and periosteal elevation. CT scans are very good in determining bony changes. (C) CT scan shows marked involvement of the distal portion of the right ilium and entire ischium and acetabulum. This ABC shows a classic eccentric, lytic, expansile lesion with periosteal elevation and cortical thinning. This patient was treated with curettage and bone grafting. ABCs often occur in the skeletal flat bones.


ABC

A


-Aug-2002
:14:55.81
MA 30
PI 2
111.0
140
s 150

B


-1218.5
10cm
20
As 153
306

C

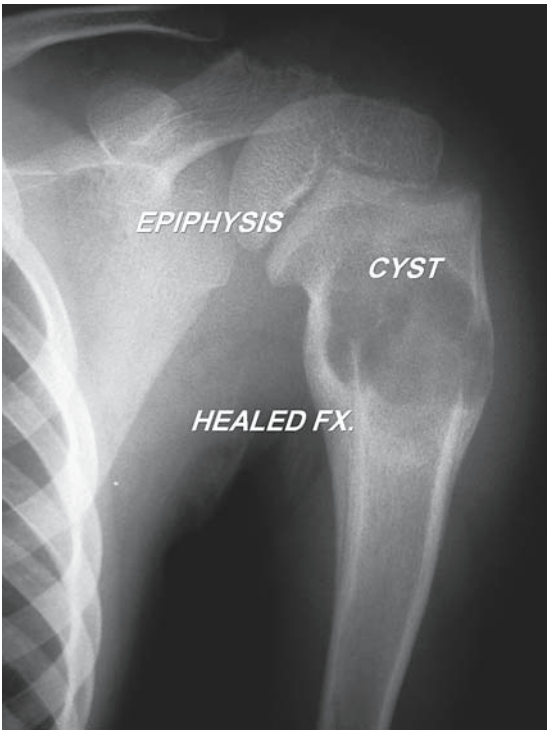


FIGURE 4-18. Unicameral bone cyst (UBC). AP radiograph demonstrates a UBC in the proximal humerus of a skeletally immature patient. This lesion has a well-defined border and a narrow transition area that is often associated with a reactive sclerosis. The lateral cortex is thin but appears intact; this is the most common site for UBCs to arise.

the most useful study when the diagnosis is in doubt. The bone scan typically shows a photon-deficient area corresponding to detail on the plain radiograph. A small area of increased uptake of contrast reflects a typical hairline crack that initiates pain and radiographic investigation.

Treatment

The traditional treatment has been curettage. Recently, aspiration, flushing, and injection with methylprednisolone acetate have successfully treated UBC.

UBCs are treated by aspiration, high-pressure Renografin injection, and intracavitary methylprednisolone. Pathologic fractures should be allowed to heal *before* injection is performed. If the diagnosis is in doubt, a Craig needle procedure or small incisional biopsy should be performed. There may be radiographic recurrence; this can be successfully treated with repeat injections. UBCs should not be left untreated in the hope that they

will spontaneously regress. Less than 1% of UBC do so; the remainders often become large before the appropriate treatment is undertaken, making definitive treatment more difficult. Alternatively, UBC are treated by curettage and bone grafting.

Eosinophilic Granuloma (Histiocytosis X)

Langerhans' cell histiocytosis is a more descriptive and recently accepted term to describe the disease commonly referred to as histiocytosis X. Eosinophilic granuloma (EG) is a solitary destructive lesion arising presumably from the reticuloendothelial system during the first decade of life. There is slight male predominance. Any bone may be involved, but the most common sites are the long bones and commonly the periacetabular region. The skull, mandible, ribs, and vertebrae are frequent sites. Multiple bony involvement is common; between 10% and 20% of patients develop multiple lesions. Plain radiographs characteristically show a lytic, punched-out lesion with some evidence of cortical destruction. Approximately 50% of patients have periosteal elevation. The differential diagnosis includes osteomyelitis, Ewing's sarcoma, and lymphoma. The diaphysis and the metaphysis are equally affected. Primary epiphyseal involvement or extension is rare.

Good results have been achieved with the use of steroids to treat localized bony EG. The natural history of EG of bone is to spontaneously heal. Curettage or intralesional steroid is recommended for documented lesions, especially in a weight-bearing bone.

Tumors of the Joint

Specific Diagnoses

Pigmented Villonodular Synovitis (Aggressive Synovitis)

Pigmented villonodular synovitis (PVNS) is a rare primary disease of the synovium characterized by exuberant proliferation with the formation of villi and nodules. It presents with localized pain, joint swelling, a thickened synovium, and an effusion that on aspiration shows either a brownish or a serosanguineous discoloration. PVNS commonly occurs between the second and the fifth decades of life. The knee is most commonly involved (75%–90%), followed by the hip and ankle joints (Fig. 4-19). Treatment is often delayed because PVNS is not considered in the differential diagnosis. Clinical suspicion is the key to early diagnosis. PVNS should be considered in the differential diagnosis of a monoarticular arthritis of the knee or hip joint. Simple aspiration is often suggestive, and synovial biopsy is definitive. Plain radiographs demonstrate juxtacortical erosions of both sides of an affected joint and may show marked joint or bone destruction if the

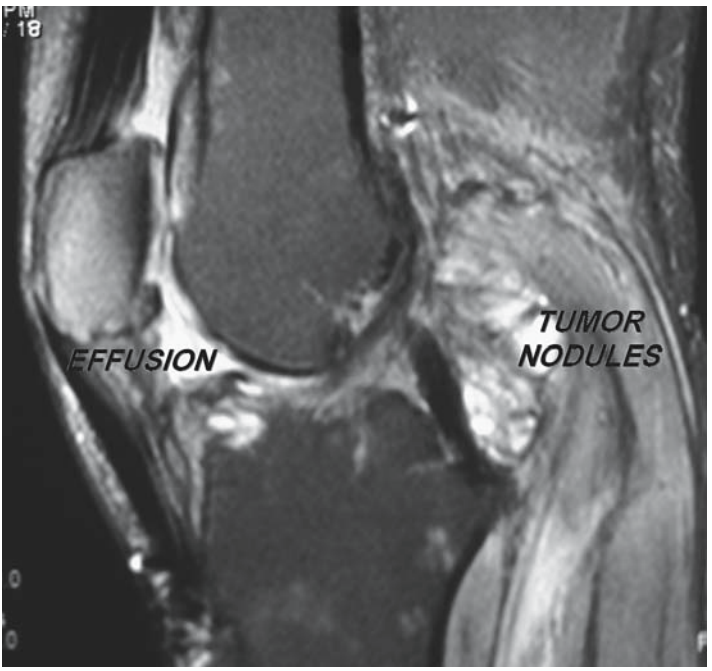


FIGURE 4-19. Pigmented villonodular synovitis. Magnetic resonance imaging (MRI) demonstrates pigmented villonodular synovitis (PVNS) of the knee. PVNS is the most common neoplastic lesion of the synovium. Note the fullness and effusion within the joint.

disease has been present for a long time. Arthrography and arthroscopy are helpful in establishing the correct diagnosis. Arthrography shows diffuse nodular masses, whereas arthroscopy shows a brownish, discolored synovium with large, flattened nodules and villous proliferation. Rarely, PVNS may present as a primary bony or soft tissue tumor because of marked proliferation of the synovium with destruction of the adjacent joint or a soft tissue mass. The histologic findings in this situation may incorrectly suggest a MFH.

PVNS is treated by surgical excision. Localized lesions require simple excision, whereas extensive involvement requires a synovectomy. If the anterior or posterior compartments of the knee may be extensively involved, a staged approach is required. The anterior joint is treated through a standard midline incision and arthrotomy. The posterior knee is best approached by a popliteal incision with complete exposure of the posterior capsule. The author's preference is to begin by performing an anterior synovectomy, which should enable the patient to regain knee motion, and then to perform a posterior synovectomy. Recurrent disease should be treated by surgical excision. If there is extensive bony destruction, arthrodesis or prosthetic

replacement, combined with an extraarticular joint resection, is required. Low-dose radiation treatment may be beneficial in improving local control, particularly in high-risk patients.

Microscopic Characteristics

The typical lesion consists of heterogeneous population of cells. The villi are lined by several layers of plump synovial cells. Beneath the synovium are sheets of histiocytes, xanthoma cells, hemosiderin-laden macrophages, and multinucleated giant cells, all in variable proportions. Occasionally, slitlike spaces are present within the more cellular areas.

Ganglia

Ganglia are among the most common soft tissue lesions. The wrist is the most common location; other sites include the metatarsophalangeal joints and the ankle and knee joints. When the lesions are located in unusual sites, the diagnosis is often less obvious. Ganglia represent benign myxoid degeneration. It must be emphasized that all masses are not ganglia and should be critically evaluated. All too often, a sarcoma of the hand or ankle is assumed to be a ganglion. Excision is undertaken, and the correct diagnosis is made only after extensive soft tissue contamination has occurred. This unfortunate circumstance leads to many lost limbs. Treatment of ganglia is simple excision or aspiration.

Soft Tissue Sarcomas

Soft tissue sarcomas (STS) are malignant tumors arising from or within the soft tissues of the extremities or the shoulder and/or the pelvic girdle. These heterogeneous groups of tumors arise specifically from the supporting extraskeletal mesenchymal tissues of the body, that is, muscle, fascia, connective tissues, fibrous tissues, and fat. They are rare lesions, constituting less than 1% of all cancers. There are wide morphologic differences among these tumors, probably resulting from the different cells of origin; however, all STS, similar to bone sarcomas, share certain biologic and behavioral characteristics.

The clinical, radiographic, and surgical management of most STS is identical, regardless of histogenesis. The surgical grading system developed by the Musculoskeletal Tumor Society applies to both bone sarcomas and soft tissue sarcomas.

Clinical Findings and Physical Examination

Soft tissue sarcomas are a disease of adulthood, occurring in persons between 30 and 60 years of age. The sole exception is rhabdomyosarcoma,

which occurs in young children. Approximately one-half of STS are found in the extremities; the remainders arise in the head/neck and trunk. The lower extremity is the most common anatomic site; 40% of all STS occur in this location. The anterior thigh (quadriceps) is the most common compartment, followed by the adductors and hamstrings.

Most STS present as a painless mass. Systemic signs such as fever, weight loss, or anemia are rare. There are no useful laboratory screening examinations. Clinical suspicion is therefore crucial to diagnosis. Any adult presenting with an extremity mass must be presumed to have a sarcoma until proved otherwise and should be further evaluated. History of coincident trauma often can be especially misleading. Unfortunately, a presumptive diagnosis of lipoma, ganglion, hematoma, or muscle tear is often made, thereby delaying definitive evaluation and treatment. Local examination reveals a well-localized, nontender mass that may be movable. The lesion may be firm or, rarely, cystic (Fig. 4-20).

Biologic Behavior and Natural History

The pattern of growth, metastasis, and recurrence of STS is similar to that of spindle cell sarcomas arising in bone. The major distinctions are

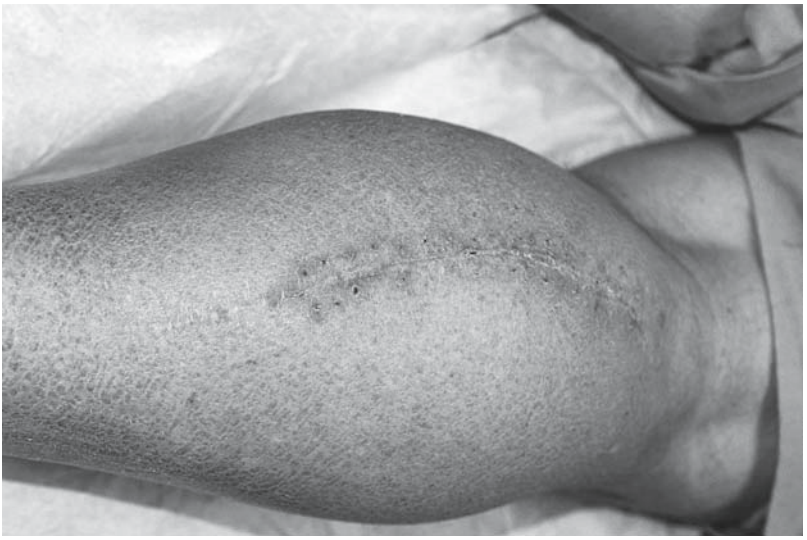


FIGURE 4-20. Soft tissue sarcoma. Clinical photograph demonstrates a large soft tissue sarcoma of the posterior leg (soleus muscle). This patient underwent an open biopsy (not recommended) before referral for definitive diagnosis. Resection of this tumor will require complete excision of the biopsy tract and scar in addition to en bloc removal of the tumor. Malignant fibrous histiocytoma (MFH) is the most common type of soft tissue sarcoma.

the tendency of STS to remain intracompartmental and a significant incidence of lymphatic involvement in a few of the less common entities, such as the epithelioid, synovial, and alveolar soft-part sarcomas. The prognosis of an STS is most closely related to its histologic grade and the presence or absence of metastases. Historically, high-grade STS have an overall survival rate of 40% to 60%. In half of all cases, wide local excision is followed by local recurrence within 12 to 24 months, followed by pulmonary metastases resulting from hematogenous dissemination to the lungs. Visceral and lymphatic involvement are rare. Pulmonary and local recurrence are the most common sites of relapse. Aggressive surgical resection of local recurrences should be considered. If distant metastases have not occurred, a 5-year salvage rate of 50% to 80% can be achieved.

Decision-Making Process

In order to accurately assess the diagnosis, stage, and grade of a suspected soft tissue tumor, rigid protocol should be followed to facilitate the decision-making process as to what staging studies are required and when a biopsy should be performed. Figure 4-21 entitled Evaluation of Patient with a Soft-Tissue Mass succinctly describes the steps any clinician should follow for patients presenting with any type of soft tissue tumor.

Pathology and Staging

STS are classified on the basis of histologic cell of origin. Individual grading is often difficult; in general, however, the extent of pleomorphism, atypia, mitosis, and necrosis correlates with the degree of malignancy. Notable exceptions are synovial sarcomas, which tend to behave like high-grade lesions even in the absence of these findings. The exact histogenesis of some soft tissue sarcomas often cannot be accurately defined, although grading can still be adequately performed. The surgical stage is determined by grade, location, and the presence or absence of pulmonary or lymphatic metastases, similar to other malignancies. Staging studies must be done before treatment.

Radiographic Evaluation

Magnetic Resonance Imaging

Because of better visual contrast and the ability to image in coronal and sagittal planes, MRI has surpassed CT as the most useful study for evaluating STS of the extremities. CT remains valuable for retroperitoneal tumors and for assessment of lung metastases. Either imaging method can delin-

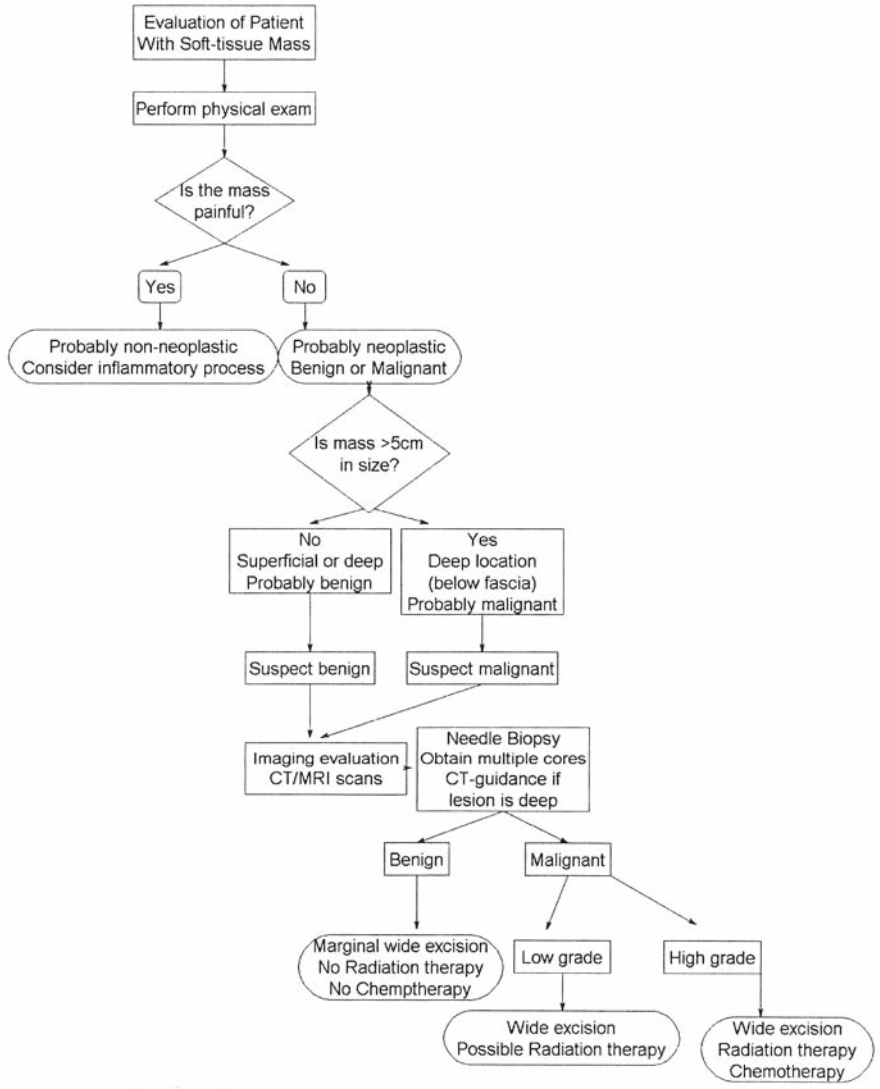


FIGURE 4-21. Process taken when evaluating a patient presenting with a soft-tissue mass.

eate the cross-sectional anatomic extent and compartmentalization of the lesion. Unique features of modern MRI, including use of gadolinium contrast, mixed spin-echo images, and fat-suppression images, appear to facilitate visualization of tumor extent and may prove crucial to longitudinal study of postoperative patients to allow for early detection of local recurrences (Fig. 4-22).

Angiography

Biplane angiography remains the standard technique for demonstrating the position of the major vessels. Although MRI and contrast-enhanced CT often show the vessels, angiography is helpful in planning an operative approach, especially if displacement is noted on the CT scan (Fig. 4-23).

Bone Scans

Bone scintigraphy is used to determine the relation of adjacent bony structures to the tumor. Increased contrast-medium uptake by a bone in close proximity to a STS usually indicates a reactive rim of tumor near the periosteum, rather than direct intraosseous tumor extension.

Treatment

The treatment of high-grade STS has undergone fundamental changes within the past decade. Treatment of these patients requires a multimodality approach, and successful management requires cooperation of the surgeon, chemotherapist, and radiation oncologist. The appropriate role of each modality is continuously changing but can be described in general as follows.

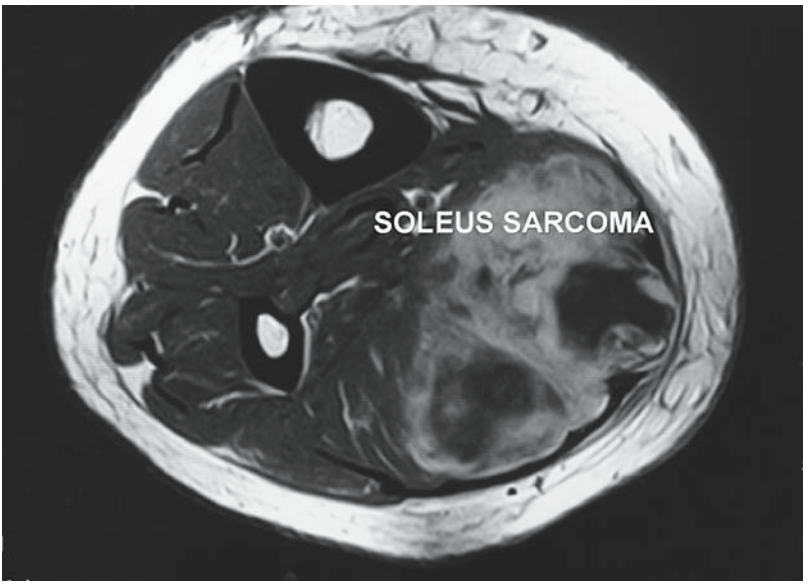


FIGURE 4-22. Sarcoma of leg. MRI scan demonstrates a large soft tissue mass of the posterior leg (soleus muscle). This lesion has compressed the surrounding anatomical structures and has a heterogeneous appearance.

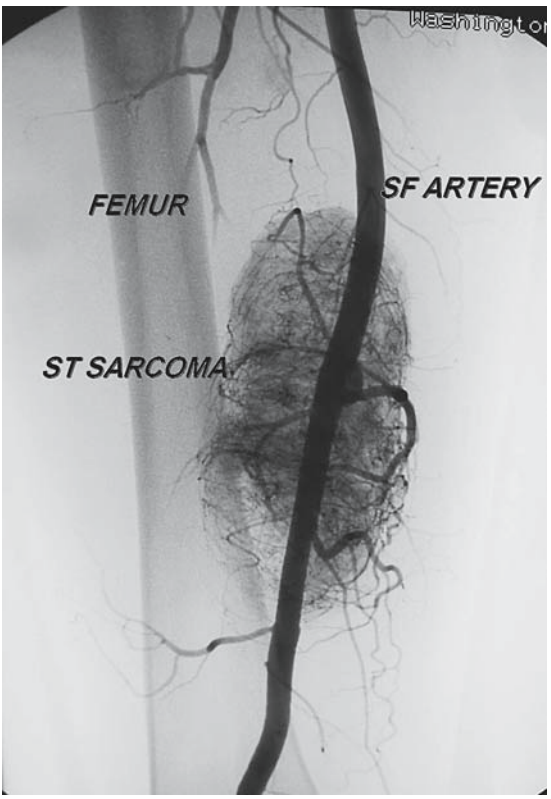


FIGURE 4-23. Angiogram demonstrates an incredibly vascular soft tissue tumor arising in the thigh. The superficial femoral artery serves as the main blood supply for this sarcoma.

Chemotherapy

Combination chemotherapy has been shown to be more effective in preventing pulmonary dissemination from high-grade sarcomas than single-agent therapy. The most effective drugs in use today are doxorubicin hydrochloride (Adriamycin) and ifosfamide. Dacarazine (DTIC), methotrexate, and cisplatin also have activity and are included in many current protocols. The various combinations are traditionally given in an adjuvant (postoperative) setting and are presumed effective against clinically undetectable micrometastases. Neoadjuvant (preoperative) chemotherapy is being evaluated in several institutions. Early results have indicated that significant reduction in tumor size can occur, thereby facilitating attempts at limb salvage.

Radiation Therapy

Radiation typically consists of 5,000 to 6,500 cGy over many fractions. This modality is effective in an adjuvant setting in decreasing local recurrence following nonablative resection. The degree to which the initial surgical volume should be decreased in these circumstances is controversial, although the local recurrence following a wide excision and postoperative radiotherapy is 5% to 10%. The technique of radiation therapy includes irradiating all the tissues at risk, shrinking fields, preserving a strip of unirradiated skin, and using filters and radiosensitizers. Local morbidity has been greatly decreased within the past decade. Preoperative radiation is effective in reducing tumor volume but is associated with increased morbidity resulting from significant wound-healing complications.

Surgery

Removal of the tumor is necessary to achieve local control; this may be accomplished either by a nonablative resection (limb salvage) or by an amputation. The procedure chosen depends on results of the preoperative staging studies. A prospective randomized National Cancer Institute (NCI) trial established that a multimodality approach employing limb salvage surgery combined with adjuvant radiation and chemotherapy offered local control and survival rates comparable to those of amputation plus chemotherapy while simultaneously preserving a functional extremity.

The use of adjuvant therapy (chemotherapy or radiation) permits limb-sparing procedures for the majority of extremity soft tissue sarcomas. Enneking has shown that a radical resection for an STS has about a 5% local recurrence rate with surgery alone.[3,4] Wide excision (without adjuvant radiation or chemotherapy) has a 50% rate of local failure. Results from the NCI showed that the rate of local recurrence decreased to 5% following local excision (either a marginal or wide excision) when combined with postoperative radiation therapy and chemotherapy. Others have reported similar good results from preoperative radiation, with or without preoperative chemotherapy. Contraindications to limb-sparing surgery are similar to those for the bony sarcomas. In general, nerve or major vascular involvement is a contraindication.

Studies of referred patients show that approximately half of all patients with soft tissue sarcomas treated with attempted excisional biopsy by the referring surgeon have remaining microscopic or gross tumor. As a result, referred patients undergo routine reresection of the surgical site to ensure adequate local control before institution of adjuvant treatment.

General Surgical Technique and Considerations

The general surgical and oncologic principles are as follows:

1. All tissue at risk should be removed with a wide, en bloc excision that includes the tumor, a cuff of normal muscle, and all potentially contaminated tissues. The 1entire muscle group need not be removed. The biopsy site should be removed with 3 cm of normal skin and subcutaneous tissue en bloc with the tumor.
2. The tumor or pseudocapsule should never be visualized during the procedure. Contamination of the wound with tumor greatly increases the risk of local recurrence.
3. Distant flaps should not be developed at the time of resection, as this may contaminate a noninvolved area.
4. The margin surrounding the surgical wound should be marked with metallic staples. The staples help the radiotherapist determine the high-risk area, should radiation treatment be needed later.
5. Reconstruction of the defect should include local muscle transfers to protect exposed neurovascular bundles and bone cortex.
6. All dead space should be closed, and there should be adequate drainage to prevent hematoma.

Perioperative antibiotics should be given. These procedures have a low but significant rate of postoperative infection. The risk of infection following preoperative adjuvant therapy is particularly high.

Specific Soft Tissue Sarcomas

The five most common soft tissue sarcomas are briefly described next.

Malignant Fibrous Histiocytoma

Malignant fibrous histiocytoma (MFH), first described as a specific entity in 1963, is the most common STS in older adults. MFH occurs in primarily in adults and is most prevalent in the lower extremity, followed in frequency by the upper extremity and retroperitoneum. The histologic grade (usually intermediate to high grade) is a good prognosticator of metastatic potential. The myxoid variant, particularly when located in the superficial soft tissues, tends to have a more favorable prognosis than the other subtypes. In fact, the pure myxoid tumors with bland spindle cells are considered to be low-grade neoplasms with minimal metastatic potential. It has been suggested that high-grade pleomorphic MFH are a heterogeneous collection of poorly differentiated sarcomas, many of which can be specifically classified with the application of immunohistochemical and electron microscopic techniques.

Liposarcoma

Liposarcoma is the second most common STS. It has a wide range of malignant potential dependent upon the grade of the individual tumor.

Determination of subtype and grade is essential to appropriate management. Well-differentiated (grade I) liposarcomas rarely metastasize. Unlike other sarcomas, liposarcomas may be multiple and may occur in unusual sites within the same individual. Careful evaluation of other masses in a patient with a liposarcoma is mandatory. Occasionally, these lesions occur in children. Liposarcomas very rarely arise from preexisting benign lipomas.

Fibrosarcoma

Fibrosarcoma used to be considered the most common STS. Following the identification of MFH as a distinct entity and the establishment of reproducible criteria for the recognition of other definitive spindle cell sarcomas, fibrosarcoma is less commonly diagnosed. Clinical and histologic difficulty occasionally arise in differentiating low-grade fibrosarcoma from fibromatosis and its variants. The anatomic site, age, and histologic findings must be carefully evaluated. This is a neoplasm of midadulthood and most commonly affects the lower extremity.

Synovial Sarcoma

Synovial sarcomas are the fourth most common STS. They characteristically have a biphasic pattern that gives the impression of glandular formation, which was originally thought to be indicative of synovial origin. These tumors, however, rarely arise within a joint, but rather have a distribution similar to those of other STS. Uncommon primary sites include the retropharynx, orofacial area, and retroperitoneum. Synovial sarcomas occur in a younger age group than other sarcomas; 72% of patients in one large study were below the age of 40 years. There is a propensity for the distal portions of extremities: hand (5%), ankle (9%), or foot (13%). The plain radiograph often shows small calcifications within a soft tissue mass; this should alert the physician to the diagnosis. Lymphatic spread occurs occasionally (5%–7%). Virtually all synovial sarcomas are high grade.

Epithelioid Sarcoma

Epithelioid sarcoma was first described in 1970. It is an unusually small tumor that is often misdiagnosed as a benign lesion. Half these lesions occur in the forearm and wrist, and it is the most common sarcoma of the hand. This lesion has a propensity for eventual lymph node involvement. Rarely, it presents as a metastasis to the epitrochlear lymph node. In contrast to other sarcomas, it occurs predominantly in adolescents and young adults (average age, 26 years). When it arises in the dermis, in which case it presents as a nodular or ulcerative process, it often clinically simulates benign cutaneous diseases, such as granulomatous dermatitis.

Benign Soft Tissue Tumors

All mesenchymal tissue can give rise to benign lesions. They may occasionally be confused with malignant lesions, or they may become symptomatic because of their size, anatomic location, or both. Although these tumors are benign, local recurrence or difficult anatomic location can cause significant morbidity. Some, such as lipomas, are easily cured by simple removal, while others, most notably fibromatoses, require extensive resection. Thus, it is important to differentiate these lesions from their malignant counterparts, establish a correct diagnosis, and remove them surgically.

There are a large number of benign lesions. The more-common lesions and their unique characteristics are described.

Benign Adipose Tumors

Simple Lipoma

Lipomas, the most common mesenchymal neoplasms, arise from normal fat and appear during adulthood. They may be single or multiple; the latter occur in only 5% of all patients. They are found either subcutaneously or deeply embedded. Eighty percent of all lipomas are of the simple type. The shoulder girdle and proximal thigh are the two most common sites. Simple surgical excision is curative (Fig. 4-24).

Microscopic Characteristics

Both types of lipomas consist of monotonous sheets of mature fat cells that are ovoid to round and usually contain a single fat droplet that compresses the nucleus along the cell membrane. Capillary-like vessels occasionally appear between the fat lobules. Areas of myxoid change or dense fibrous trabeculae are sometimes seen.

Spindle Cell Lipoma

This is a variant of lipoma consisting of benign spindle cells in addition to mature fat. The tumor has a predilection for males (90%) and most commonly occurs in the neck and shoulder. Spindle cell lipomas are encapsulated and are easily removed by simple excision. It is essential to distinguish this lesion clinically from a well-differentiated liposarcoma.

Pleomorphic lipomas also consist of mature fat cells, but they are more variable in size. They contain both pleomorphic and distinctive multinucleated giant cells instead of spindle cells. These giant cells contain multiple overlapping nuclei at their peripheries. Occasionally, lipoblast-like cells occur.

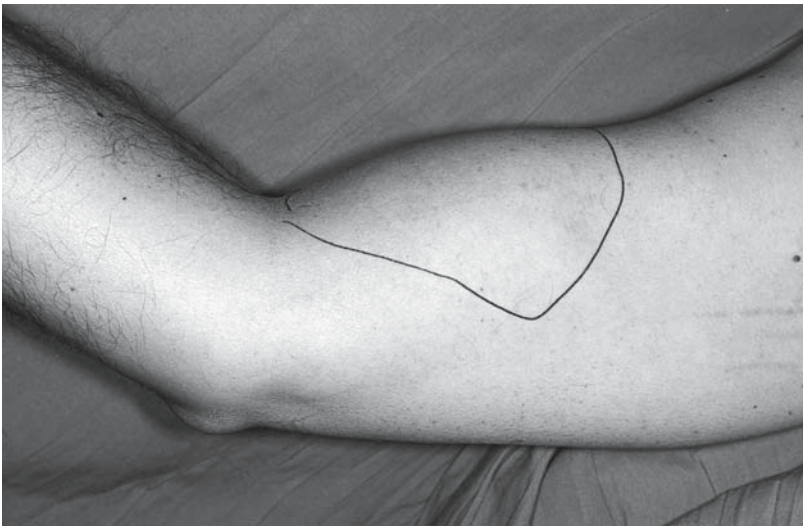


FIGURE 4-24. Lipoma. Clinical photograph of a large lipoma of the distal portion of the biceps muscle of the arm. Lipomas tend to be slow growing and are frequently asymptomatic to the patient. Lipomas are the most common soft tissue tumors of the extremities. Lipomas never become malignant.

Intramuscular and Intermuscular Lipomas

Lipomas occurring within (intramuscular) and between (intermuscular) muscle groups often become large, produce few symptoms, and present as a mass mimicking an STS. Clinical evaluation and staging are similar to those of any suspected sarcoma. The pathologist must be aware of the clinical setting, and an adequate sample must be obtained to differentiate a low-grade liposarcoma from a true benign lipoma. In contrast to superficial lipomas, these lesions often do not have a capsule and tend to infiltrate the surrounding muscle. A marginal or wide resection is required to obtain local control. These lesions never become malignant (Fig. 4-25).

Benign Tumors of Peripheral Nerves

The two most common nerve tumors are neurilemmoma and neurofibroma.

Neurilemmoma (Schwannoma)

These benign growths arise within a nerve and are surrounded by a true capsule composed of the epineurium. They are composed of Antoni A (cellular) and Antoni B (loose myxoid) components. These lesions generally are not associated with von Recklinghausen's disease (multiple

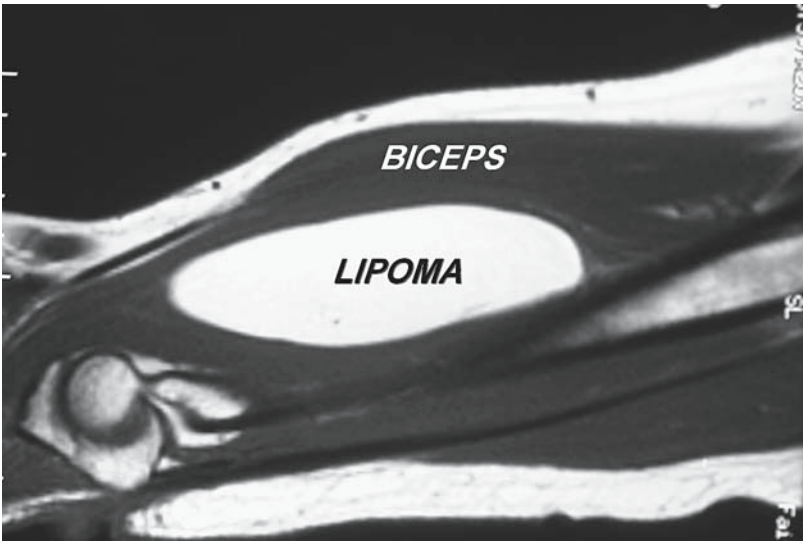


FIGURE 4-25. Lipoma. MRI demonstrates an intramuscular lipoma. Note that the tumor has approximately the same level of enhancement as the normal subcutaneous fat, with no heterogeneosity noted, as is characteristic of all lipomas.

neurofibromatosis). Surgical treatment entails opening the capsule and enucleating the growth from the nerve. "Ancient" neurilemmoma is cystic degeneration of a neurilemmoma. These lesions clinically present as a large mass with some cellular atypia. They must be differentiated from malignant lesions. Simple excision, done for diagnostic purposes or if the lesion is symptomatic, is curative.

Neurofibroma

Neurofibromas may be solitary or multiple. In contrast to neurilemmomas, they are not encapsulated. They often enlarge the nerves and may undergo malignant degeneration. Histologically, they consist of Schwann cells associated with collagen fibrils and myxoid material. Multiple neurofibromas are found in patients with von Recklinghausen's disease. These lesions cannot be surgically detached from the underlying nerve. Surgery is indicated only if malignant degeneration is suspected. Between 20% and 65% of patients with neurofibromatosis ultimately develop a sarcoma.

Benign Fibrous Tumors

There are a large variety of benign fibrous tumors. Most are treated by simple excision. Aggressive fibromatosis is a benign but locally aggressive lesion deserving special consideration.

Aggressive Fibromatosis

This tumor, which appears bland microscopically, is the most serious of all the benign soft tissue tumors. It does not have a capsule and tends to infiltrate far beyond its clinically recognized boundaries. This lesion does not respect fascial borders and thus can attain a large size and involve multiple anatomic compartments if left untreated. The most common locations are the neck, shoulder, and pelvic girdle. Death results from intrathoracic or retroperitoneal extension. The clinical history often reveals multiple recurrences despite supposedly adequate surgical removal. The appropriate surgical procedure is wide excision. Local recurrence uniformly follows excision with positive margins. Surgical staging studies should be performed before resection. Amputation is occasionally required. Radiation and chemotherapy have recently been used for unresectable fibromatosis.

Benign Vascular Tumors

Hemangioma

Benign tumors of the blood vessels consist of a variety of hemangiomas. It is not certain whether these are true neoplasms, hamartomas, or vascular malformations. There are two types of hemangiomas, generalized and localized; the latter are more common. Hemangiomas are classified on the basis of their pathologic appearance—capillary, cavernous, venous, or arteriovenous. Capillary hemangiomas are the most common type. Most hemangiomas occur during childhood. Venous hemangiomas occur during adulthood and are often deeply situated. Intramuscular hemangiomas are rare and are occasionally difficult to differentiate from angiosarcomas. Evaluation requires angiography and venography. Surgery is indicated if symptoms develop. Hemangiomas rarely become malignant.

Angiomatosis is a benign condition characterized by involvement of multiple types of mesenchymal tissues. Large anatomic regions, even an entire limb, may be affected. These extensive vascular lesions, which are probably hamartomatous, can involve the skin, subcutaneous fat, skeletal muscle, fascia, and bone. Involvement of an entire extremity can cause hypertrophy of the limb.

Suggested Readings

1. Malawer M, Sugarbaker PH (eds) Musculoskeletal Cancer Surgery: Treatment of Sarcomas and Allied Diseases, 1st ed. Dordrecht: Kluwer, 2001.
2. Enneking WF, Spanier SS, Malawer MM. The effect of the anatomic setting on the results of surgical procedures for soft parts sarcoma of the thigh. Cancer (Phila) 1981;47(5):1005–1022.

3. Dahlin DC. Bone Tumors: General Aspects and Data on 6221 Cases, 3rd ed. Springfield: Thomas, 1978.
4. Enneking WF, Spanier SS, Goodman MA. A system for the surgical staging of musculoskeletal sarcoma. Clin Orthop 1980;153:106–120.
5. Sim FH, Bowman W, Chao E. Limb salvage surgery and reconstructive techniques. In: Sim FH (ed) Diagnosis and Treatment of Bone Tumors: A Team Approach. A Mayo Clinic Monograph. Thorofare, NJ: Slack, 1983.
6. Mankin HJ, Lange TA, Spanier SS. The hazards of biopsy in patients with malignant primary bone and soft tissue tumors. J Bone Joint Surg [Am] 1982;64(8):1121–1127.
7. Marcove RC, Mike V, Hajek JV, Levin AG, Hutter RV. Osteogenic sarcoma under the age of twenty-one. A review of one hundred and forty-five operative cases. J Bone Joint Surg [Am] 1970;52(3):411–423.
8. Rougraff BT, Simon MA, Kneisl JS, Greenberg DB, Mankin HJ. Limb salvage compared with amputation for osteosarcoma of the distal end of the femur. A long-term oncological, functional, and quality-of-life study. J Bone Joint Surg [Am] 1994;76(5):649–656.
9. Edeiken J. Bone tumors and tumor-like conditions. In: Edeiken J (ed) Roentgen Diagnosis and Disease of Bone, 3rd ed. Baltimore: Williams & Wilkins, 1981:30–414.
10. Marcove RC. Chondrosarcoma: diagnosis and treatment. Orthop Clin North Am 1977;8(4):811–820.

Review Questions

1. ____and ____ are the two most commonly diagnosed primary malignant bone tumors in children and adolescents.
   a. Osteoid osteoma and osteoblastoma
   b. Giant cell tumor and osteochondroma
   c. Liposarcoma and angiosarcoma
   d. Osteosarcoma and Ewing's sarcoma
2. Carcinomas tend to grow in an invasive manner, infiltrating surrounding soft tissues. Sarcomas ____
   a. Grow in a ball-like manner and typically compress surrounding tissues
   b. Behave exactly like carcinomas and always grow invasively
   c. Immediately spread to the lymph nodes and metastasize through the lymphatic system
   d. None of the above
3. When performing a biopsy, the preferred approach would include:
   a. An open or incisional biopsy to obtain a large amount of tumor
   b. A fine-needle aspirate of the fluid surrounding the tumor
   c. Biopsy is typically not indicated for sarcomas because typically radiographs and staging studies are conclusive
   d. A core-needle biopsy in the same anatomic planes as any planned surgical resection

4. When evaluating a plain radiograph of a patient with a suspected osteosarcoma, the following characteristics may be seen with regard to the affected bone:
   a. Intramedullary sclerosis and/or cortical destruction
   b. Periosteal elevation
   c. Extraosseous extension with ossification
   d. a, b, and c
5. The most common location of origin of an osteosarcoma is:
   a. The distal femur
   b. The acetabulum
   c. The spine
   d. The ribs
6. Which of the following diagnoses should be included in a differential diagnosis for a 61-year-old patient with pain and a pathologic fracture of the pelvis?
   a. Chondrosarcoma
   b. Multiple myeloma
   c. Metastatic carcinoma to bone
   d. All of the above
7. Batson's plexus refers to:
   a. The neurovascular bundle located in the axilla
   b. The valveless venous plexus that permits retrograde blood flow to the spine, pelvis, and shoulder-girdle
   c. A condition wherein the patient describes a 'pins and needles' sensation
   d. None of the above
8. Benign bone tumors should be surgically removed under which of the following circumstances?
   a. There is a pathologic fracture
   b. They are painful
   c. They have the potential to undergo malignant transformation or have recurred
   d. All of the above
9. Which of the following modalities is utilized in the treatment of high-grade soft tissue sarcomas?
   a. Surgery
   b. Chemotherapy (pre- and/or postoperative)
   c. Radiation therapy
   d. All of the above
10. The appearance of an intramuscular lipoma, when viewed on aT_1-weighted MRI, would be described as:
    a. Heterogeneous and bright on T_1 sequence
    b. Homogeneous and bright on T_1 sequence
    c. Cystic and dark on T_2 sequence
    d. Hemorrhagic and both bright and dark on T_1 as well as T_2 sequence

Suggested Readings

1. Malawer M, Sugarbaker PH (eds) Musculoskeletal Cancer Surgery: Treatment of Sarcomas and Allied Diseases, 1st ed. Dordrecht: Kluwer, 2001. (Note: The best general overview of musculoskeletal cancer imaging, pathology, radiology and surgery.)
2. Enneking WF, Spanier SS, Malawer MM. The effect of the anatomic setting on the results of surgical procedures for soft parts sarcoma of the thigh. Cancer (Phila) 1981;47(5):1005–1022. (Classic article of surgical anatomy and soft tissue muscle resections in lieu of amputations.)
3. Dahlin DC. Bone Tumors: General Aspects and Data on 6221 Cases, 3rd ed. Springfield: Thomas, 1978. (Classic text reviewing pathology and radiology of bone tumors.)
4. Enneking WF, Spanier SS, Goodman MA. A system for the surgical staging of musculoskeletal sarcoma. Clin Orthop 1980;153:106–120. (The classic article describing the system of musculoskeletal cancer staging.)
5. Sim FH, Bowman W, Chao E. Limb salvage surgery and reconstructive techniques. In: Sim FH (ed) Diagnosis and Treatment of Bone Tumors: A Team Approach. A Mayo Clinic Monograph. Thorofare, NJ: Slack, 1983. (A general review of limb-salvage techniques.)
6. Mankin HJ, Lange TA, Spanier SS. The hazards of biopsy in patients with malignant primary bone and soft-tissue tumors. J Bone Joint Surg [Am] 1982;64(8):1121–1127. (The classic article describing the importance and risks of the initial biopsy in the overall treatment of musculoskeletal tumors.)
7. Marcove RC, et al. Osteogenic sarcoma under the age of twenty-one. A review of one hundred and forty-five operative cases. J Bone Joint Surg [Am] 1970;52(3):411–423. (The original article describing the high risk and survival of osteosarcoma.)
8. Rougraff BT, et al. Limb salvage compared with amputation for osteosarcoma of the distal end of the femur. A long-term oncological, functional, and quality-of-life study. J Bone Joint Surg [Am] 1994;76(5):649–656. (This article compares the clinical differences of an amputation versus an endoprosthetic limb-sparing procedure.)
9. Edeiken J. Bone tumors and tumor-like conditions. In: Edeiken J (ed) Roentgen Diagnosis and Disease of Bone. Baltimore: Williams & Wilkins, 1981. (Textbook and review of all bone tumors.)
10. Marcove RC. Chondrosarcoma: diagnosis and treatment. Orthop Clin North Am 1977;8(4):811–820. (The classic article on the treatment of chondrosarcoma; the second most common primary bony sarcoma.)

5
Children's Orthopedics

John N. Delahay and William C. Lauerman

Children are different! This statement has been presented in many different ways; but it is critically important that this central fact be recognized if one is to successfully diagnose and treat disease in this age group. Even within this rather broad range of ages there are dramatic differences among specific subsets: neonate, child, and adolescent.

These differences are not only biologic, but psychologic, social, and emotional. It is likewise inappropriate to focus only on one aspect of these differences. For example, it would be unwise to ignore a young child's activity level when treating a fracture: inadequate immobilization or cast removal too early will have disastrous end results.

Recognition of this special group actually gave orthopedics its name. The word means "straight child" and alludes to the interest and time spent correcting deformities in children. These deformities can result not only from injury but also from systemic and local disease states, both congenital and acquired. Because the child is *growing*, these diseases produce anatomic and physiologic effects not expected in the adult. Before discussing specific entities, it would, therefore, be appropriate to review some of the biologic differences of the child's musculoskeletal system and the influences that act on the immature skeleton.

Biologic Differences

Growth

As mentioned, the fact that the child's skeleton is growing, both longitudinally and latitudinally, positions it uniquely for damage resulting from the adverse effects of trauma and disease. The extent of this damage is a reflection of the rate of growth and the immaturity of the skeleton. Hence, an insult will have a greater impact if applied at the time of more rapid growth (a growth spurt) or when the skeleton is very young (neonate).

Remodeling

The immature skeleton can remodel to a much greater degree than that of the adult. Because of the presence and activity of multiple cell populations, damage to the skeleton can be repaired more extensively than one should anticipate in the adult. The challenge for the physician is to be able to recognize the limitations of this remodeling process and work within the boundaries of this potential.

Specific Anatomic Structures

Bone

Although a child's bone is historically lamellar in pattern, there remains enough flexibility in the skeleton to permit what has been called "biological plasticity," a phenomena not nearly as extensive in adult bone. Essentially, this allows a bone to "bend without breaking"; in point of fact, it is responsible for some of the unique types of fractures seen in the pediatric age groups, specifically, torus and greenstick fractures.

In addition, the mechanical properties of a child's bone vary from those of the adult. Such characteristics as modulus of elasticity, ultimate tensile strength, and yield point all reflect the elasticity and plasticity unique in this age group. However, the overall "strength" tends to be less than that of the adult in certain modes of loading, such as tension and shear.

Ligament

As a tissue, ligament is one of the most age-resistant tissues in the human body. The tensile strength of the ligaments in the child and the adult is virtually the same. Therefore, these structures remain as a constant in the musculoskeletal system. Although the strength of bone, cartilage, and muscle tends to change, the ligamentous structures remain unchanged with growth and development.

Periosteum

The outer covering of the bone is a dense fibrous layer, which in the child is significantly thicker than that of the adult. The periosteum of the child actually has an outer fibrous layer and an inner cambial or osteogenic layer. Hence, the child's periosteum confers both mechanical strength as well as biologic activity. The effect of these biologic differences are far reaching when one discusses fractures in children. Because of this thickened periosteum, fractures do not tend to displace to the degree seen in adults, and the intact periosteum can be used as an aid in fracture reduction and maintenance. In addition, fractures will heal significantly faster than

similar injuries in adults because all the cellular precursors are already present. The osteogenic layer supplies active osteoblasts, ready to make bone for the fracture callus. The generation of these precursor elements in adults takes a period of time not required in the child.

Cartilage

As one will recall, the skeleton is developed embryologically within a cartilage model. At birth, large portions of any given bone remain largely cartilaginous. Unfortunately, cartilage is *not* seen on standard X-rays. The cartilage anlage is very labile and is dramatically affected by external influences such as mechanical loading. It is important to realize, when examining an X-ray, that one should not be lulled into a false sense of security if all appears well; what you do not see (i.e., the cartilage) is more important than what you do! Aberrant cartilaginous growth will drastically affect the ultimate shape of bones and, more importantly, joints. The best example is the proximal femur, where most of the upper end is cartilaginous. Adverse influences caused by eccentric loading seen in developmental dysplasia of the hip can have far-reaching effects when applied to the immature cartilage of the neonatal hip.

The Growth Plate

By far and away the most exceptional characteristic of the immature skeleton—indeed, the defining component of the immature skeleton—is the growth plate, or the "physis." The physis is a cartilage plate interposed between the epiphysis (the secondary ossification center) and the metaphysis (Fig. 5-1). It is essential for long bone growth to occur. The downside is that this anatomic structure creates a "normal flaw" in the overall skeletal structure and thus a point of mechanical weakness. The physis historically has four zones (Fig. 5-2), each with its own physiologic role:

a. Resting zone: The top layer of flattened cells are germinal and metabolically store materials for later use, because they will ultimately "move their way" down the plate toward the metaphysis. The chondrocytes in this zone also are synthetic, as they fabricate the matrix within which they lie.
b. Proliferating zone: The cells in this region are actively replicating and extending the plate. They have been described as looking like a "stack of plates." In this region, the cells are using the materials that they have previously stored for their "trip to the metaphysis."
c. Hypertrophic zone: Having extended the plate in the former zone, the cells now tend to swell and switch over to a more-catabolic state. They prepare the matrix for calcification and ultimately for conversion to bone. Because of its large swollen cells and the disorganized matrix,

this zone has been cited as being the weakest mechanically; hence, it is here that failure tends to occur. Most, however, would agree that crack propagation can be seen throughout all zones in the case of trauma.

d. Calcified zone: Metabolically, the matrix has been readied for the deposition of calcium salts, and the task of forming the osteoid is left for this lowest region of the plate. In the adjacent metaphysis, small vascular twigs can be seen arborizing toward the basal layers of the plate.

Peripheral Structures of the Plate

Two defined histologic regions have been identified with specific functional roles to play in skeletal development.

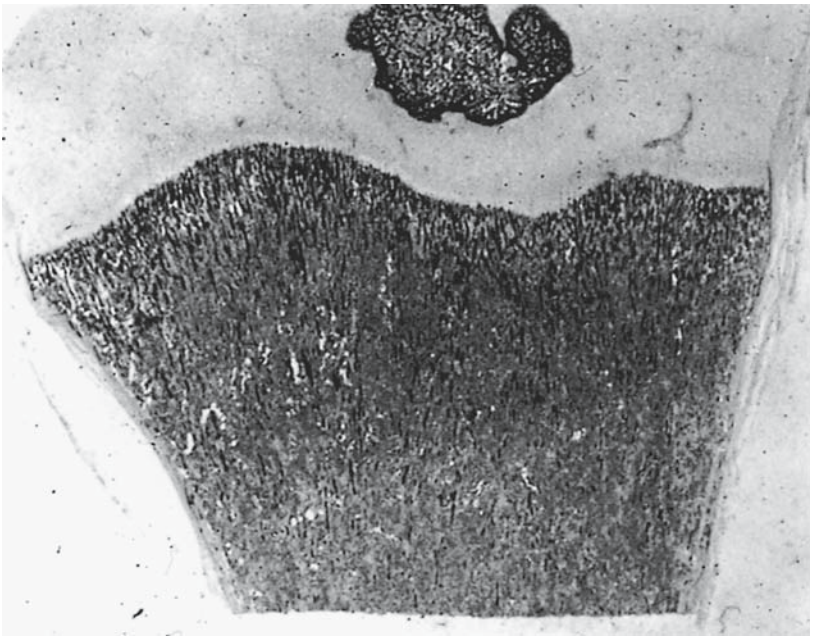


FIGURE 5-1. Early secondary ossification center of mature fetus. The formation of the secondary ossification centers in the lower tibia and upper femur coincide with fetal maturity. The secondary center begins not in the center of the epiphysis, but nearer the growth plate. Expansion, therefore, is eccentric. (From Bogumill GP. Orthopaedic Pathology: A Synopsis with Clinical Radiographic Correlation. Philadelphia: Saunders, 1984. Reprinted by permission.)

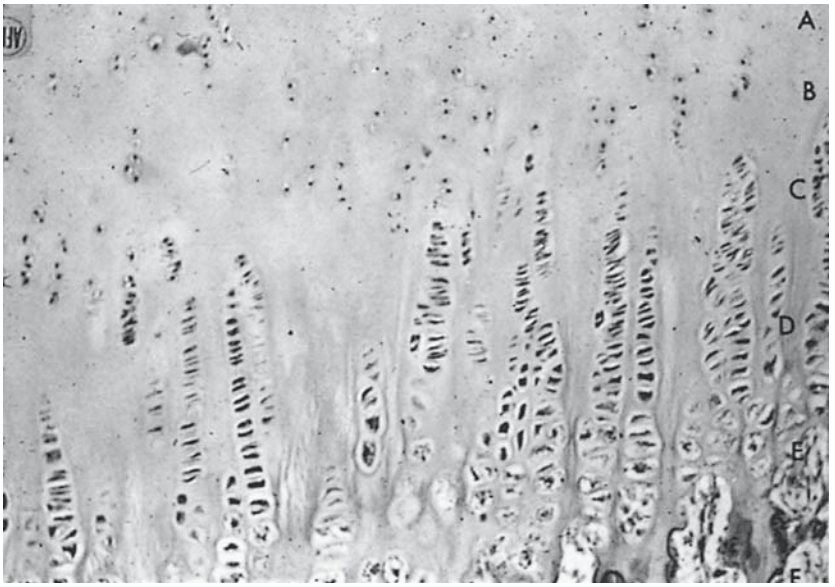


FIGURE 5-2. Growth plate. Low-power view showing entire plate. (A) Resting zone has isolated cartilage cells in the upper portion together with empty lacunae. (B) Cell reproduction produces cloning of cells that "stack up" longitudinally. Successive generations occupy more space than each single progenitor cell and thus increase the length of the cartilage model. Secretion of new matrix (C) is followed by dehydration with accompanying fibrillation of the territorial cartilage matrix between the "dinner plates" at (D). Hypertrophy of cartilage cells at (E) is caused by imbibition of water. Calcification of matrix is followed by vascular invasion at (F). (From Bogumill GP. Orthopaedic Pathology: A Synopsis with Clinical Radiographic Correlation. Philadelphia: Saunders, 1984. Reprinted by permission.)

a. Zone of Ranvier: Around the circumference of the plate is an identifiable clustering of cells that are responsible for latitudinal growth of the plate.
b. Perichondral ring of Lacroix: As the periosteum is continuous around the margins of the plate, this fibrous structure is apparent. Its function arguably has been to serve as a "girdle" for the plate and give mechanical support against translational movement.

Factors Affecting Skeletal Growth

Numerous factors, both intrinsic and extrinsic, affect the way in which the skeleton develops. Some examples are noteworthy, as indicated next.

Genetic Impact

Inborn errors of metabolism (renal rickets) as well as chromosomal alterations (Down syndrome) can cause phenotypic variations in the development of the skeleton. Abnormal histology, aberrational growth, and variational development all affect the ultimate shape and behavior of the skeleton.

Nutrition

Vitamins and proteins are required for normal skeletal development, and without appropriate levels of these, abnormalities are seen. Rickets, for example, will alter the shape of the metaphysis in addition to disrupting normal physeal development.

Endocrine

Hormonal influences play a significant trophic or permissive role in the development of the skeleton. Shortages or excesses, therefore, disrupt the way in which the skeleton matures. Thyroid hormone is a good example. Disrupted epiphyseal development is a hallmark of cretinism.

Environmental Factors

Mechanical effects as well as environmental toxins and drugs can adversely affect the development of the skeleton. Fetal alcohol syndrome and the use of illicit narcotics by the mother are just two examples of the growing compendium of skeletal aberrations caused by externally applied toxins.

Coexistent Disease

Neuromuscular diseases of children, such as cerebral palsy, polio, and muscular dystrophy, provide good examples of the secondary effects seen in the skeleton as a result of extrinsic disease. In these examples, the final common pathway in the pathophysiology of the deformities is muscle imbalance; hence, eccentric and aberrational mechanical loading of the immature skeleton produces changes such as joint dislocations and deformities (e.g., scoliosis).

Developmental Variations in Skeletal Growth

It seems axiomatic to say that children grow and develop at different rates and in different ways. Yet, one of the most common reasons that children are brought to a physician is to evaluate the position of their lower

extremities and the way in which they stand and walk. Toeing in and toeing out, as well as knock-knees and bowlegs, are a major preoccupation of parents and especially grandparents—and a major source of orthopedic referrals. The simple fact is that most of these children, well over 90%, are normal children who are simply reflecting variational growth and development. Dr. Mercer Rang, a preeminent pediatric orthopedist, has tried to emphasize this important fact by referring to these conditions as "non-disease."

Rang further goes on to suggest that the appropriate management for "non-disease" is "non-treatment." It is important to recognize the difference between doing nothing and "non-treatment." As the physician seeing the child, one must be able to recognize the variational patterns and differentiate them from pathologic states. Once that has been accomplished, the physician may embark on a program of aggressive "non-treatment," which might include such steps as these:

1. Careful examination of the normal child
2. Reassurance of parents and grandparents
3. Supply educational information to strengthen one's diagnosis and approach
4. Consider use of benign shoe adjustment (scaphoid pad) for the "terminally skeptical"
5. Offer the option of yearly follow-up "to be sure that the non-disease is getting better"

Torsional Variations

The newborn typically reflect the intrauterine position and environment. Therefore, a certain amount of "molding" is to be anticipated. This usually, but not always, results in an internally rotated position of the lower extremities and the ultimate manifestation of this rotation is toeing-in when the child begins to walk. The two most typical variations leading to intoeing follow:

1. *Internal tibial torsion:* Axial rotation of the tibias can best be identified by examining the child supine with hips and knees flexed and evaluating the transmalleolar axis at the ankle for its relation to the knee axis. Normally, it should lie 10 to 30 degrees externally rotated from that of the knee. Neonates typically have an internally rotated axis that causes intoeing with the initiation of walking and spontaneously corrects after about 1 year of walking. Tibial external rotation can occasionally be seen but is far less common. Neither requires any specific treatment other than those recommended for "non-treatment" (Fig. 5-3).

2. *Internal femoral torsion (femoral anteversion):* The plane of the femoral head and neck in the normal adult lies 15 degrees externally

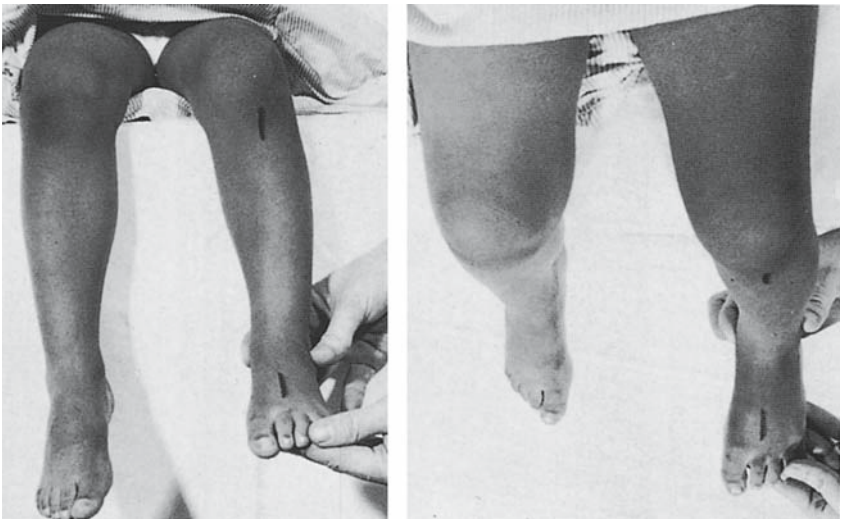


FIGURE 5-3. Practical clinical method of measuring tibial torsion (see text for explanation). (From Tachdjian MO. Pediatric Orthopedics, 2nd ed, vol 1. Philadelphia: Saunders, 1990. Reprinted by permission.)

rotated from that of the transcondylar plane of the distal femur. In the newborn, this relationship is more extreme: the head–neck plane is about 45 degrees external to that of the transcondylar plate, and it corrects spontaneously at a rate of about 2 degrees per year (Fig. 5-4). Persistence of this infantile pattern beyond the age of walking will cause intoeing as the leg internally rotates at the hip so that the femoral head sits properly in the acetabulum. The rate of correction varies widely, and non-treatment is usually all that is required. Additionally, two other recommendations might be made: first, the child should be discouraged from sitting in the so-called W position or TV position, because it seems to delay spontaneous correction; and second, lightweight footwear should be encouraged, because the child will toe-in less because of the weight of shoes.

External femoral torsion is described, but most believe this actually represents the persistence of an infantile external rotational contracture of the soft tissues posterior to the hip; despite its etiology, spontaneous correction of this variation can similarly be anticipated.

Examining the child for femoral rotational patterns is best accomplished with the child prone, hips extended, and knees flexed 90 degrees (Fig 5-5). Internal and external rotation of the hips can then be easily estimated using the leg as an angle guide.

Angular Variations

Knock-knees (genu valgum) and bowlegs (genu varum) are another common source of physician referrals. Recognition of the normal allows relatively easy determination of pathologic states.

Salenius examined thousands of "normal" children and has provided us with standard expectations for this group (Fig. 5-6). Newborns demonstrate 4 to 10 degrees of genu varus, which tends to spontaneously correct by 18 months of age. Thus, a child who presents with bowlegs would be diagnosed as "physiologic genu varum." After 18 months of age, a child develops knock-knees, which increases until about age 4 or 5 and then begins to improve. By age 7 or 8, most children have assumed more of an adult pattern: 5 to 7 degrees of valgus in males and 7 to 9 degrees of valgus in females.

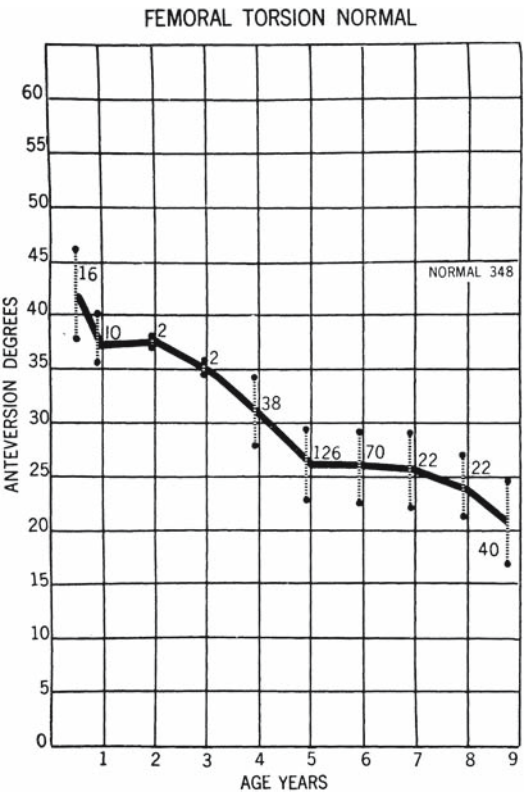


FIGURE 5-4. The degree of normal femoral torsion in relation to age. The *solid lines* represent the mean; the *vertical lines* represent standard deviation. (From Tachdjian MO. Pediatric Orthopedics, 2nd ed, vol 1. Philadelphia: Saunders, 1990. Reprinted by permission.)

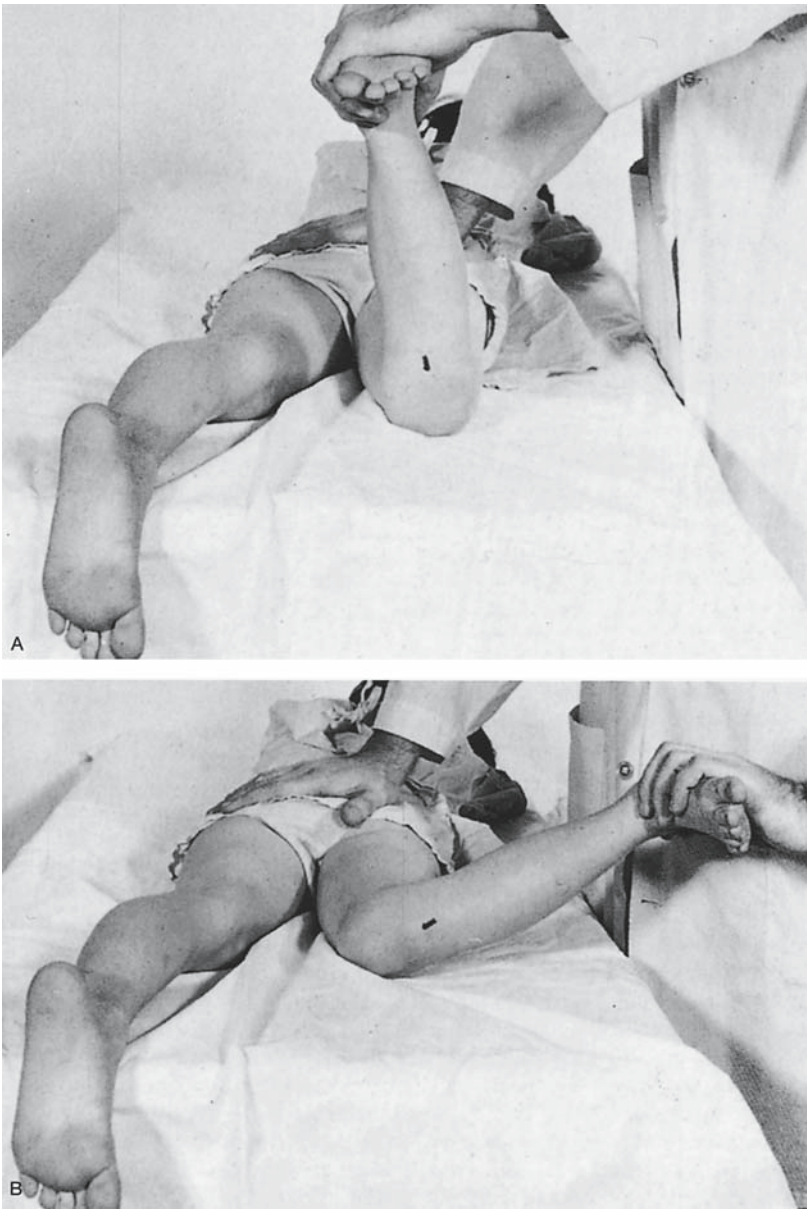


FIGURE 5-5. Range of rotation of the hip in excessive femoral antetorsion. (A) Lateral rotation of the hip in extension is exaggerated. (B) Medial rotation of the hip in extension is limited to neutral. (From Tachdjian MO. Pediatric Orthopedics, 2nd ed, vol 1. Philadelphia: Saunders, 1990. Reprinted by permission.)

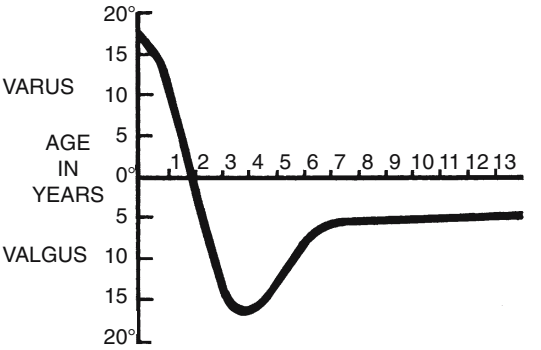


FIGURE 5-6. Development of the tibiofemoral angle during growth. (From Tachdjian MO. Pediatric Orthopedics, 2nd ed, vol 1. Philadelphia: Saunders, 1990. Reprinted by permission.)

It is best to record the degree of varus by measuring the number of fingerbreadths accommodated between the child's knees and the degree of valgus by recording the number of fingerbreadths accommodated between the medial malleoli.

Differential Diagnosis

Recognizing that the vast majority of children with angular patterns are normal and require nontreatment, it is nonetheless important to realize that angular deformities can be a manifestation of pathologic states.

A. *Knock-knees (genu valgum)* (Fig. 5-7)
   1. Physiologic
   2. Renal rickets
   3. Skeletal dysplasias
   4. Trauma

B. *Bowlegs (genu varum)* (Fig. 5-8)
   1. Physiologic
   2. Blounts' disease
   3. Rickets (nutritional)
   4. Skeletal dysplasias (achondroplasia)
   5. Trauma

As one can appreciate from these lists, symmetry is important. Physiologic angular deformity is virtually always symmetrical; the finding of asymmetry should, therefore, suggest a pathologic state and trigger an appropriate workup.

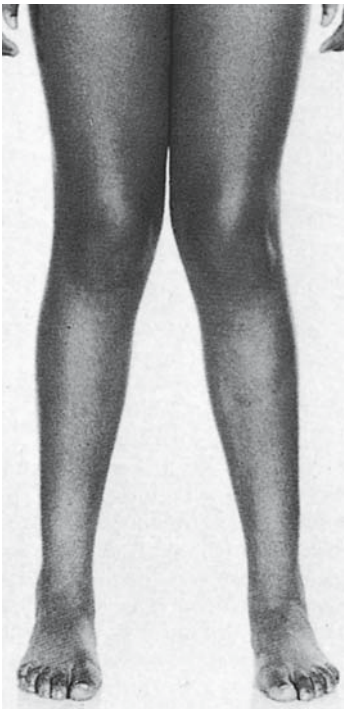


FIGURE 5-7. Bilateral genu valgum in an adolescent. (From Tachdjian MO. Pediatric Orthopedics, 2nd ed, vol 1. Philadelphia: Saunders, 1990. Reprinted by permission.)

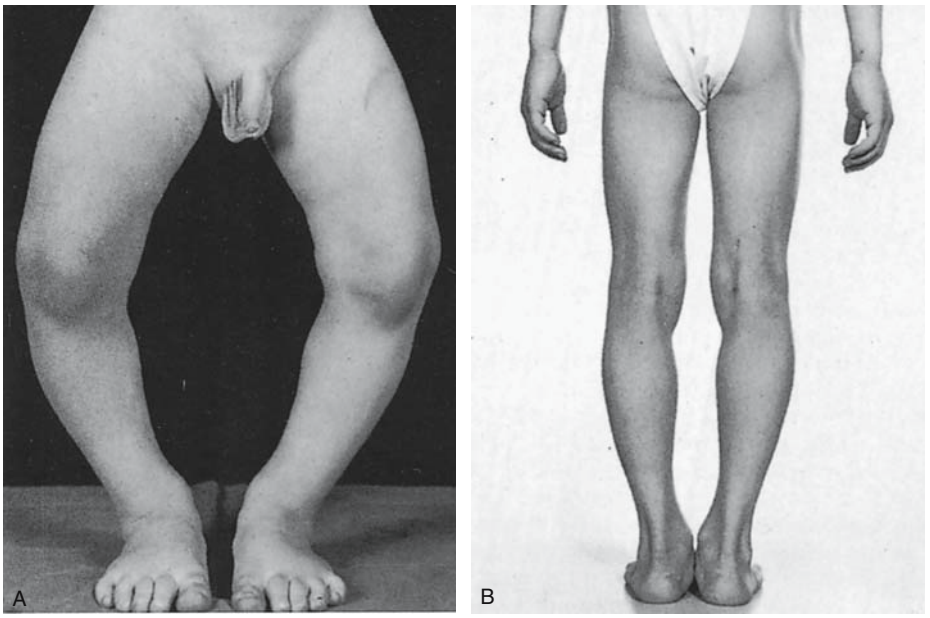


FIGURE 5-8. Bilateral genu varum. (A) At age 1.5 years. (B) At 7 years, showing spontaneous correction without treatment. (From Tachdjian MO. Pediatric Orthopedics, 2nd ed, vol 1. Philadelphia: Saunders, 1990. Reprinted by permission.)

General Affectations of the Pediatric Skeleton

Many diseases have skeletal manifestations, which makes it impossible in one short chapter to fully discuss the vast array of pathologic states that have an impact on the musculoskeletal system. Rather, by being introduced to several specific examples in each disease category, one can appreciate some of the general ways in which the skeleton reacts to various insults. Recalling the VITAMIN acronym introduced earlier in the text, we now focus on some of the vascular, infectious, arthritic, metabolic, and neurodevelopmental diseases that produce skeletal manifestations. An entire chapter of this book is devoted to a discussion of tumor and another one to injury; therefore, these concerns are mentioned only insofar as their effects are unique to the growing skeleton.

Infection

Osteomyelitis

The pediatric skeleton is a prime location for bone and joint infections. In part, this is the result of the many bacterial infections that small children seem to have, hence providing organisms capable of hematogenously spreading from the skin, ear, and nasopharynx. In addition, the unique metaphyseal blood supply (Fig. 5-9) in the child establishes the battlefield for the host–organism interaction. Because the physis creates a barrier to the vessels, they must double back on themselves, thereby forming end-loop capillaries and creating an area of stasis in the bony metaphysis. This area of stasis "catches" bacteria as they are showered hematogenously from distant sites. Once entrenched, the bacteria establish a focus of infection, and the classic case of osteomyelitis develops. It is important to recognize that the changes are not simply the result of the damage the bacteria do to the bone, but also the reparative changes initiated by the bone in an effort to localize the infection.

The result of this activity is a mixture of bony destruction by the organisms and new bone formed to wall off the infection and shore up the areas of damage. The dead and dying bony fragments are referred to as "sequestra," and the new viable bone being formed is called "involucrum" (Fig. 5-10; see also Chapter 3).

Clinical Features

One should inquire about a past history of trauma, as well as infections elsewhere, that may have provided a source for the organism. Occasionally, no such history is available and one is evaluating a child who presents with pain in a limb and fever. The combination of these two findings—pain in an extremity and fever—should be presumed to be osteomyelitis until proven otherwise.

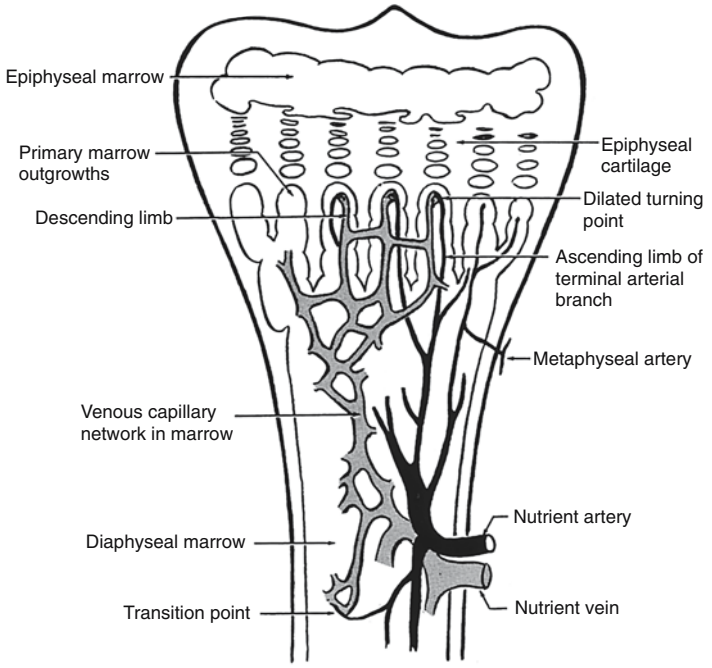


FIGURE 5-9. Localization of osteomyelitis caused by structure of metaphyseal sinusoids. Diagram of blood supply of long bones in children showing the structure of metaphyseal sinusoids to be the cause for localization of pathogenic bacteria in the metaphysis. (From Tachdjian MO. Pediatric Orthopedics, 2nd ed, vol 1. Philadelphia: Saunders, 1990. Reprinted by permission.)

In children under 1 year of age, the findings may be more nonspecific and poorly localized, for example, irritability, changes in feeding habits, and few signs of sepsis. Pseudoparalysis (failure to use the limb) may be the only localized finding.

Localized physical findings such as swelling, heat, localized tenderness, erythema, and signs of systemic sepsis are frequently seen in the older child.

Diagnosis

Standard laboratory studies usually show an elevated white blood cell (WBC) count and sedimentation rate (ESR). The C-reactive protein (CRP) is similarly elevated. The ESR and CRP are both acute-phase reactants; however, the latter responds more rapidly to the presence of infection and, therefore, tends to be a more sensitive measure of skeletal involvement. X-rays initially may be negative, because it takes 10 days for the pathology to become demonstrable radiographically. Bone resorption and new peri-

osteal bone formation are the characteristic changes. However, neither of these may be seen initially. A standard total body bone scan is often quite helpful in the evaluation of these children. The bone scan is particularly useful in the localization of pathology (Fig. 5-11).

Appropriate cultures are essential. Blood cultures are reportedly positive in approximately 50% of cases of acute hematogenous osteomyelitis. Source cultures from the throat, ear, skin, etc. should also be obtained. Bony aspiration is essential in the complete evaluation of these children. It is axiomatic that to diagnose a bone infection one must culture the bone. To that end, and using a large-bore needle, one should aspirate at the point of maximal tenderness in an effort to retrieve organisms. Reportedly, aspiration will be positive in approximately 60% of cases. The organisms vary slightly with age, but ordinarily either *Staphylococcus aureus* or *Streptococcus* species should be anticipated. In neonates, one needs to consider the possibility of gram-negative organisms.

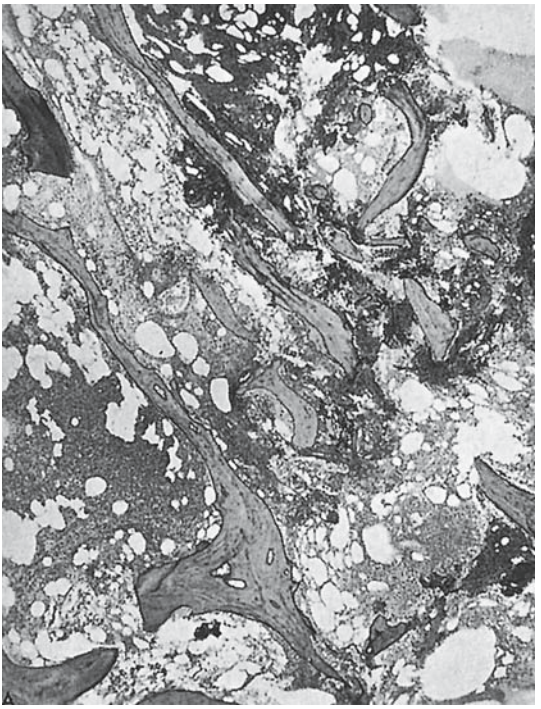


FIGURE 5-10. Histologic findings in acute osteomyelitis. (A) Necrotic trabeculae of bone surrounded by inflammatory cells (×25). (From Tachdjian MO. Pediatric Orthopedics, 2nd ed, vol 1. Philadelphia: Saunders, 1990. Reprinted by permission.)

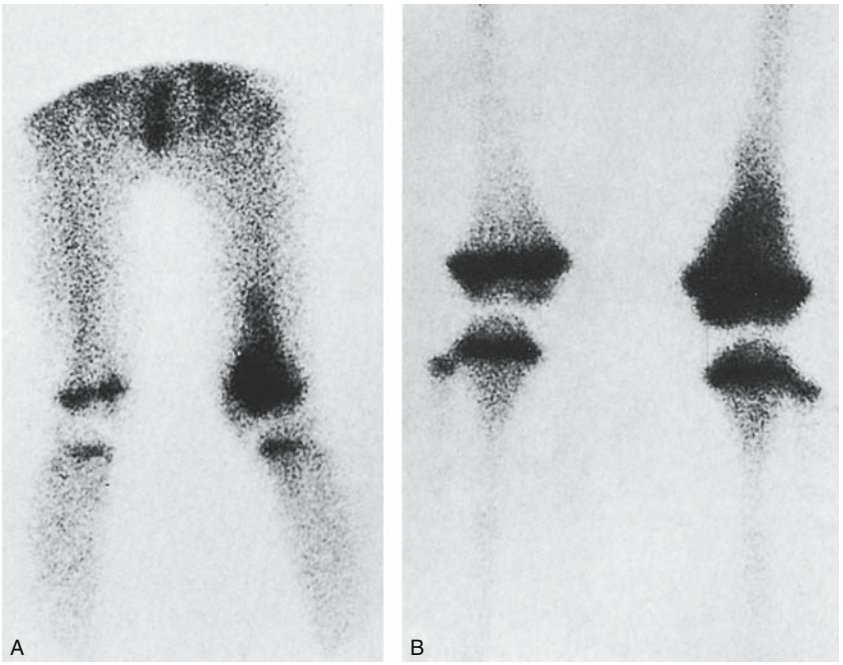


FIGURE 5-11. Scintigraphic findings with technetium-99m in acute diphosphonate of the left distal femoral metaphysis. Note the increased localized uptake. (A) Early vascular flush. (B) Two hours later. (From Tachdjian MO. Pediatric Orthopedics, 2nd ed, vol 1. Philadelphia: Saunders, 1990. Reprinted by permission.)

Treatment

Diagnosis is critical before initiating antimicrobial treatment. All too often broad-spectrum antibiotics are given before a bacteriologic diagnosis is made. The result is a "partially treated osteomyelitis." These children present a challenging problem because the classical physical findings tend to be damped or eradicated completely. The problem, however, is that the organisms are frequently not killed; they only await antibiotic withdrawal before initiating a new wave of bony destruction. The principles of management have been established for many years and are best summarized as follows: (1) complete bacteriologic diagnosis; (2) appropriate antibiotic selection; (3) antibiotic delivery by the appropriate route and for the appropriate duration; (4) immobilization to decrease the risk of pathologic fracture; and (5) surgical drainage of abscesses. For many years, the tradition of intravenous antibiotic delivery has been accepted as essential. Although some would argue that the oral route is adequate, the IV route is still considered by most to be the standard mode of delivery despite the inconve-

nience caused to child, family, and physician. The traditional duration of 6 weeks has been altered in some protocols to 3 weeks intravenous and 3 weeks oral based on clinical response.

The indication for surgical drainage is the presence of loculated pus. Typically, this is seen within the metaphysis and/or under the periosteum (Fig. 5-12). These subperiosteal abscesses typically follow breakthrough of the thin cortical bone in the metaphyseal region. As these subperiosteal collections strip the periosteum from the underlying cortex, the cortex is devascularized and segments become avascular. In severe cases of acute hematogenous osteomyelitis, it is not uncommon to see sequestration of the entire bony diaphysis.

Septic Arthritis

Infection of a child's joint typically results from one of three pathologic mechanisms:

1. Hematogenous spread: just as in osteomyelitis, organisms can localize in the joint, finding the highly vascular synovium a favorable location for replication.

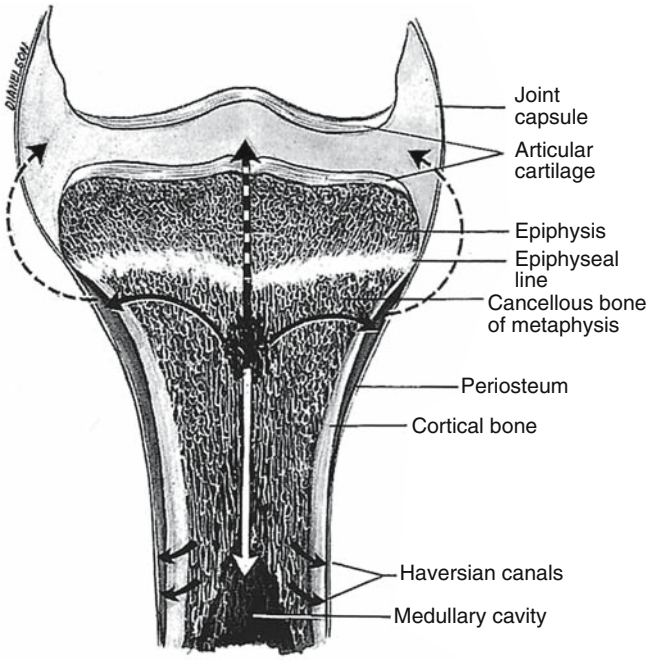


FIGURE 5-12. Diagram showing spread of acute hematogenous osteomyelitis. The *interrupted lines* are rare routes. (From Tachdjian MO. Pediatric Orthopedics, 2nd ed, vol 1. Philadelphia: Saunders, 1990. Reprinted by permission.)

2. Breakthrough from a metaphyseal osteomyelitis: this occurs in specific joints where a portion of the metaphysis is intraarticular. Anatomically, the synovial reflection extends below the physis and includes a portion of metaphyseal cortical bone. The transverse Volkmann's canals provide a conduit for pus in the metaphysis to access the joint. In doing so, a secondary septic arthritis results. This phenomenon of breakthrough is most typical in the hip (Fig. 5-13), but it can also occur in the elbow, where the radial head is intraarticular, the shoulder, and the ankle.

3. Penetrating trauma: this results in joint sepsis when organisms are directly injected into the joint.

Clinical Feature

Joint swelling and redness are the typical physical findings that one would expect. Systemic signs of sepsis are also usually readily apparent. In contradistinction to acute hematogenous osteomyelitis, children affected with septic arthritis tend to be more toxic, exhibiting high fevers, listlessness, and poor feeding. In addition, these children resist any attempt to move the involved joint.

Diagnosis

A workup similar to that for osteomyelitis should be carried out and, at the risk of appearing repetitious, one cannot seriously consider this diag-

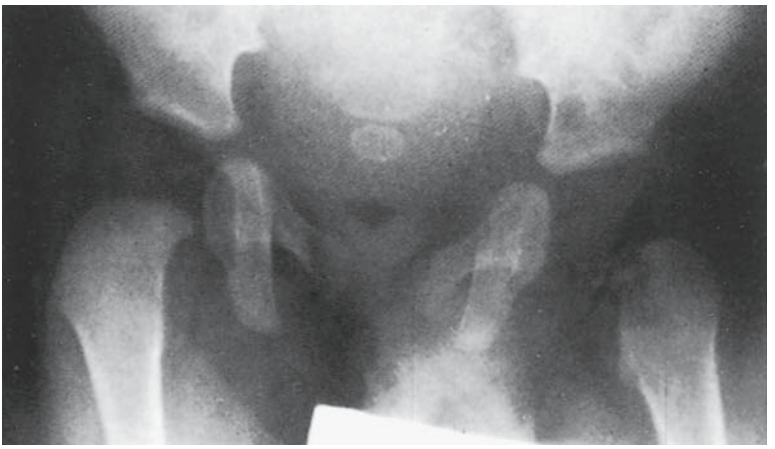


FIGURE 5-13. Septic arthritis of left hip. Lateral subluxation and area of rarefaction in the femoral neck are evident. (From Tachdjian MO. Pediatric Orthopedics, 2nd ed, vol 1. Philadelphia: Saunders, 1990. Reprinted by permission.)

nosis in the differential without having made an attempt to retrieve organisms from the joint. It is important to be sure that the joint is, indeed, being aspirated, and this frequently requires fluoroscopic control, especially if the joint in question is the hip. The pediatric hip is often difficult to enter under the best of circumstances, and radiographic control using an arthrogram is recommended.

Microbiogically, the most common organism retrieved in the child is *Staphylococcus aureus*. As is the case with osteomyelitis, neonates should be suspected of having unusual organisms including gram negatives. In the adolescent patient, one must never forget the most common cause of septic arthritis: *Neisseria gonorrhoeae*.

Treatment

Septic arthritis, in contrast to acute hematogenous osteomyelitis, is a surgical emergency. It is imperative that the pus be removed from the joint as soon as possible. The articular cartilage is extremely vulnerable and easily damaged by enzymes, those produced by the microorganisms as well as those produced by the white cells. It is, therefore, NOT enough to simply kill the organisms in the joint. The joint must be rid of all WBCs, bacterial by-products, and enzymes. In most young children, this requires an arthrotomy. Occasionally, in the older child, arthroscopy is an appropriate technique for cleaning out a more-accessible joint such as the knee. Repeated needle aspirations are rarely effective in cleaning the inflamed joint. In addition, repetitive aspiration in the child is yet another example of "man's inhumanity to man."

Antibiotic management is similar to that for osteomyelitis. The choice of antibiotic and the route of delivery are usually identical. The duration of administration, however, is frequently shortened. The prognosis for septic arthritis in a child depends on early diagnosis, aggressive drainage, and appropriate antibiotic management. Delay in diagnosis or delay in adequate surgical drainage can have disastrous long-term effects on the joint, typically producing irreversible changes.

Complications of Bone and Joint Infections

Long-term sequelae can result from bacterial damage to these relatively vulnerable tissues (Fig. 5-14). In addition to the bone and articular cartilage, the child has a physis, which is likewise exposed to the insult.

Septic Joint Destruction

Loss of articular cartilage and arthrofibrosis ultimately result in joint contracture, deformity, and occasionally bony ankylosis (fusion). Salvage of the irreparably damaged articulations is difficult at best and frequently impossible.

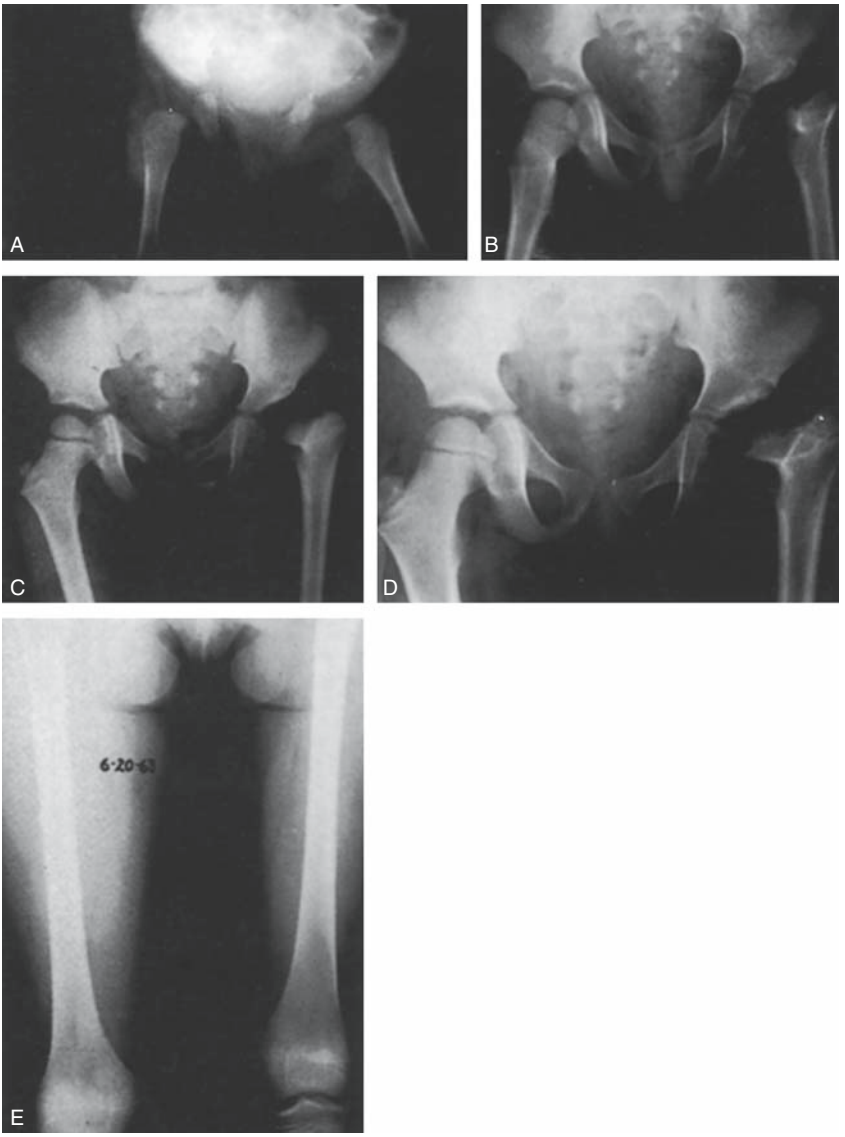


FIGURE 5-14. Suppurative arthritis of the left hip in a 3-month-old infant. Onset was at 4 weeks of age. Erroneous diagnosis of fibrocystic disease and thrombophlebitis resulted in a 2-month delay in diagnosis. (A) Radiograms of hips show marked effusion of left hip with lateral subluxation. (B–D) Serial radiograms of hips show failure of ossification of the femoral head (due to avascular necrosis) and the development of coax vara. (E) Teleoradiograms taken 9.5 years after onset of sepsis in left hip. There is a 3.9-cm shortening of the left femur. A subtrochanteric abduction osteotomy was performed 4 years earlier. The left hip has functional range of motion. Skeletal growth of lower limbs is being followed, and the plan is to perform distal femoral epiphyseodesis on the right at the appropriate age. (From Tachdjian MO. Pediatric Orthopedics, 2nd ed, vol 1. Philadelphia: Saunders, 1990. Reprinted by permission.)

Physeal Damage

Injury to the plate can have long-term effects, especially when it occurs in a very young child with significant growth remaining. Complete arrest and subsequent limb-length inequality or partial arrest and the resultant angular deformity are the two standard patterns of postinjury deformity.

Pathologic Fracture

Although infected bone frequently looks more dense (i.e., sclerotic) on an X-ray, it should not be assumed that it is mechanically stronger. In point of fact, the dense bone is disorganized, its lamellar pattern is disrupted, and therefore it is mechanically less sound. Pathologic fracture can occur even in the immobilized limb, although the risk is less.

Chronic Infection

Despite aggressive treatment, some infections are not completely eradicated, and a "stalemate" is established between the host and the organism. Occasionally, at times of psychologic or environmental stress, the infection will reactivate and produce additional damage (see Chapter 3).

Arthritis in Childhood

Juvenile Rheumatoid Disease

Frequently referred to as Still's disease, juvenile rheumatoid disease (JRA) is the most common connective tissue disease in children. In fact, George Still specifically described the systemic form of the illness. Children have systemic symptoms—fever, rash, hepatosplenomegaly—and develop a polyarticular arthritis. This is the most destructive form of the disease and leaves multiple destroyed joints in its wake.

The other two forms of the disease are definitely less virulent. Polyarticular disease, as the name implies, takes its toll on the joints, but is not associated with systemic findings. Pauciarticular JRA is the most common and the most benign form of the disease. Typically, it is a monarticular arthritis, with the knee, elbow, and ankle being the joints most commonly involved. Frequently, children suffering from the pauciarticular form of the disease present with an isolated chronically swollen joint. This finding should trigger a diagnostic workup. Diagnostic blood studies are usually negative (rheumatoid factor is positive in only 10% of cases). X-rays usually only show juxtaarticular osteopenia, and frequently a synovial biopsy may be needed (Fig. 5-15). The histology of the synovium is similar to that of the adult disease; namely, hyperplasia and villous hypertrophy of the synovium. It is imperative to recognize that JRA is the leading cause of blindness in children because of the destructive iridocyclitis that can

accompany the joint disease. All children with JRA should be under the care of an ophthalmologist because eye involvement does NOT parallel the degree of joint involvement; those with minimal joint disease can have the most severe eye changes.

Treatment should be directed toward control of the synovitis with medications, physical therapy to maintain joint motion, psychologic support for those chronically impaired children, and ultimately arthroplasties or fusions for those joints most severely involved.

Hemophilia

Children with bleeding dyscrasias frequently have repeated hemarthroses. Initially, the blood in the joint simply distends the capsular structures and causes a mild synovitis. With repeated bleeds, the synovium becomes hyperplastic and ultimately pannus formation is seen. At this point, the joint changes appear very similar to those seen in rheumatoid disease, such as osteopenia, enzymatic cartilage degradation, bony erosions, and lysis (Fig. 5-16).

Lyme Disease

In the endemic regions of the Northeast and Middle Atlantic states, the child who presents with a swollen knee needs to be considered as a poten-

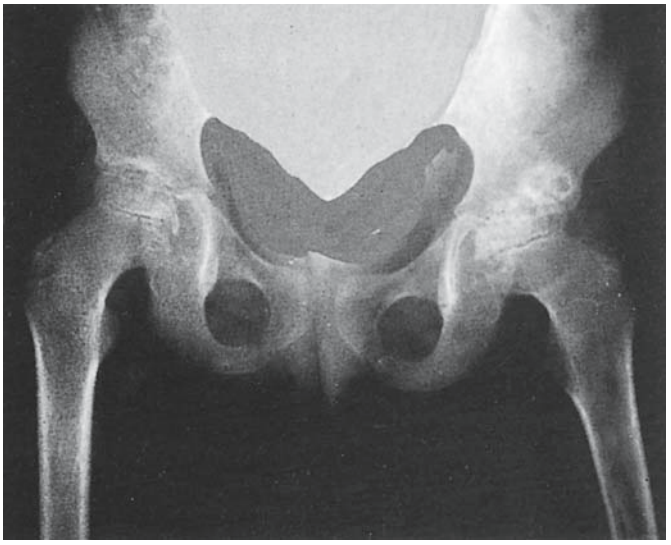


FIGURE 5-15. Rheumatoid arthritis of both hips. Radiogram of hips taken 3 years later. The child was allowed to be ambulatory without protection of the hips. Note the destructive changes with fibrous ankylosis on the right and bony ankylosis on the left. (From Tachdjian MO. Pediatric Orthopedics, 2nd ed, vol 1. Philadelphia: Saunders, 1990. Reprinted by permission.)

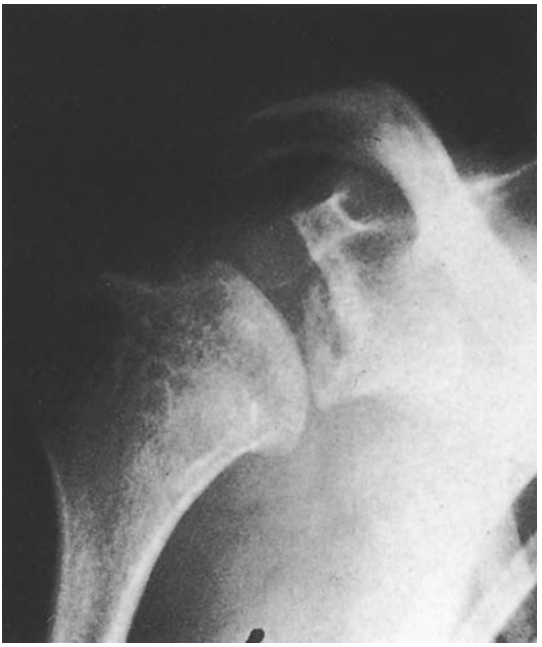


FIGURE 5-16. Hemophilic arthropathy of shoulder. (From Tachdjian MO. Pediatric Orthopedics, 2nd ed, vol 1. Philadelphia: Saunders, 1990. Reprinted by permission.)

tial victim of Lyme disease. This infectious arthritis is caused by a specific spirochete, *Borrelia burgdorferi*. The organism is transmitted to the human host by the bite of a deer tick. These ticks are significantly smaller than the common wood tick, and they are barely visible with the naked eye. Unfortunately, a history of a bite is rare and usually the diagnosis is reached by a high index of suspicion in a susceptible host. The combination of endemic region, erythematous annular skin lesions, and monarticular arthritis should lead the physician to order a Lyme titer.

Treatment is generally successful if begun early. Occasionally, despite adequate treatment, the arthritis can progress to chronic joint destruction, mandating further care.

Metabolic Disease

Perhaps the classic metabolic disease to affect the pediatric skeleton is rickets. The etiologies of rickets are multiple (Table 5-1), but the important pathophysiologic step is a relative paucity of vitamin D. It will be remembered that vitamin D is essential for normal progression of physeal bone

TABLE 5-1. Etiologies of rickets.

1. Vitamin D dietary deficiency
2. Malabsorption states
3. Renal rickets
   a. Tubular defects (generally congenital)
   b. Glomerular disease (generally acquired)
4. Miscellaneous causes
   a. Associated with neurofibromatosis
   b. Complication of Dilantin therapy

development, and without it provisional calcification will not occur in the deepest layer of the growth plate.

As a result, physeal disorganization (Fig. 5-17) can be anticipated with subsequent physeal widening, trumpeting of the metaphysis, and aber-

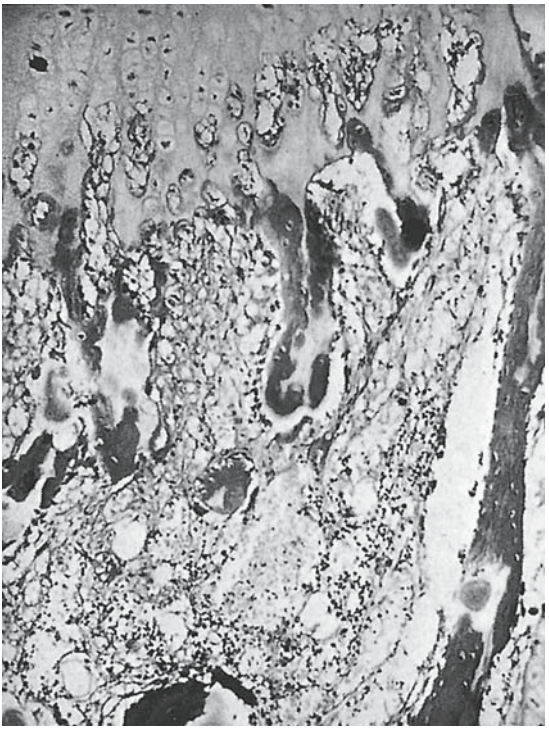


FIGURE 5-17. Histologic appearance of rickets. Micrograph through the epiphyseal–metaphyseal junction. Note the uncalcified osteoid tissue, failure of deposition of calcium along the mature cartilage cell columns, and disorderly invasion of cartilage by blood vessels (×25). (From Tachdjian MO. Pediatric Orthopedics, 2nd ed, vol 1. Philadelphia: Saunders, 1990. Reprinted by permission.)

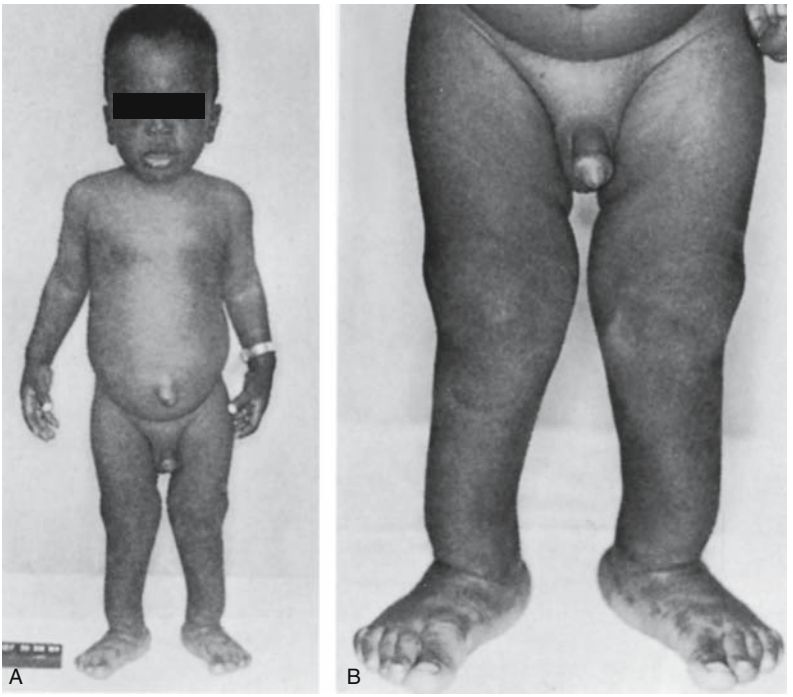


FIGURE 5-18. Simple vitamin D deficiency rickets. (A, B) Clinical appearance of patient. The legs are bowed anterolaterally. Note the protuberant abdomen with the umbilical hernia. (From Tachdjian MO. Pediatric Orthopedics, 2nd ed, vol 1. Philadelphia: Saunders, 1990. Reprinted by permission.)

rant enchondral bone growth. The clinically apparent changes of knobby joints, beading of the costochondral joints, and genu varum are all phenotypic reflections of the underlying histologic disruption of bone formation (Fig. 5-18).

Depending on the etiology of the rickets, the histologic pattern varies slightly, but the overall skeletal changes remain relatively constant.

Vascular and Hematologic Disease

Vascular diseases of the pediatric skeleton are typified by osteochondroses such as Perthes' disease of the hip and Osgood-Schlatter's disease of the knee. These are considered regionally, leaving the hematologic diseases to be discussed here.

Sickle Cell Disease

The red cell deformation that occurs in sickle cell patients caused by the abnormal hemoglobin is responsible for the skeletal changes. The abnormally shaped cells cause stasis and sludging in small arterioles and capillaries. The effect, as expected, is disrupted flow and bony necrosis. The bony infarcts seen in sickle cell disease can occur anywhere in the bone but are more typical in the metaphysis (Fig. 5-19).

These children are also predisposed to osteomyelitis, probably because of the already sludged vessels in the metaphysis, making bacterial trapping even easier. Even though *Staphylococcus* is the most common organism retrieved, this patient population is also susceptible to infection with *Salmonella*. This organism gains access to the circulatory system through small infarcts in the intestinal wall and then enters the bone hematogenously. The incidence of *Salmonella* osteomyelitis is approaching that of *Staphylococcus* in this population.

The treatment for the infarcts is appropriate hematologic care, such as hydration and analgesics. Antibiotic selection for osteomyelitis should take into consideration the incidence of *Salmonella*.

Leukemia

Leukemia is the most common malignancy of childhood, and the skeleton is not spared its ravages. The bones by X-ray show nondescript lytic changes, most characteristically seen in the metaphyseal region and referred to as

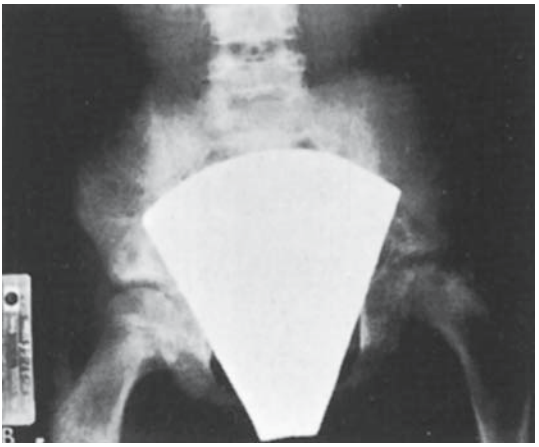


FIGURE 5-19. Sickle cell disease in an 11-year-old girl. Anteroposterior radiogram of the hips. Note the avascular changes in the left femoral head. (From Tachdjian MO. Pediatric Orthopedics, 2nd ed, vol 1. Philadelphia: Saunders, 1990. Reprinted by permission.)

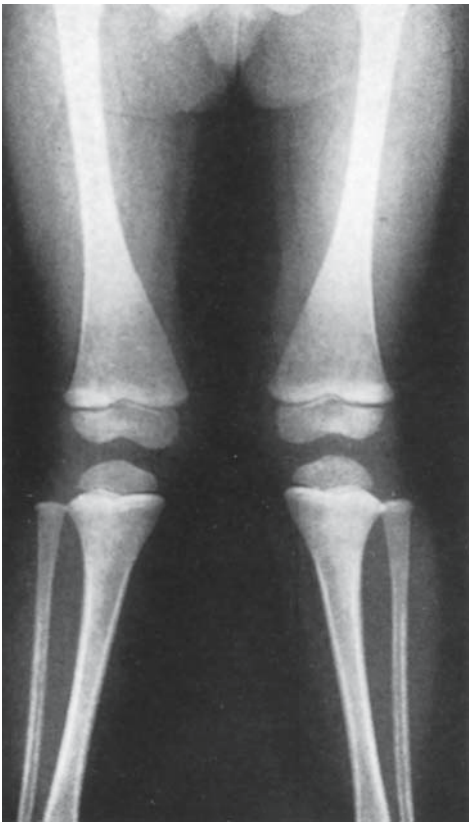


FIGURE 5-20. Bone manifestations of acute leukemia. (From Tachdjian MO. Pediatric Orthopedics, 2nd ed, vol 1. Philadelphia: Saunders, 1990. Reprinted by permission.)

metaphyseal banding (Fig. 5-20). The areas of osteopenia parallel and are adjacent to the physis; although suggestive of leukemia, they are NOT pathognomonic of it.

Although usually the diagnosis has been made well before skeletal complications develop, occasionally a child will present for the evaluation of "growing pains" only to have a workup reveal this disease. Ordinarily "growing pains" occur in children 2 to 7 years of age, affect primarily the legs, are symmetrical (although not simultaneous), occur in early evening or just after going to bed, and are NOT associated with any systemic complaints. Any variation from the usual pattern should suggest a basic workup to include X-rays and a white count with differential.

Congenital and Neurodevelopmental

This group is the largest and most nondescript "wastebasket" of pathologic states, many of which have severe impact on the pediatric skeleton. Included here are congenital birth defects of no known etiology, such as proximal

femoral focal deficiency, as well as genetic diseases transmitted in classic Mendelian fashion (e.g., hemophilia) or caused by chromosomal defects (e.g., Down syndrome).

In addition, the neuromuscular diseases frequently have an immense impact on the skeleton, as aberrant and eccentric muscular forces are created. Unfortunately, it is difficult to find many common themes that make an appreciation of the skeletal impact easier to understand.

Osteogenesis Imperfecta

This disease is transmitted in a classic autosomal dominant pattern with only rare exception. The basic defect is one of abnormal collagen synthesis caused by impotent osteoblasts. For this reason, it has been grouped with other "sick" cell syndromes. Certainly, the osteoblasts are normal in number but are incapable of normal synthetic activity. The collagenous product of their incompetence is poorly formed and poorly cross linked, making it weak. The subsequent bone that is made is similarly architecturally thin and mechanically weak.

The severity of the disease is as expected, a function of the dose of abnormal genetic material. Some of the severe homozygotes are stillborn as a result of intracranial bleeds occurring in the perinatal period. As with most genetic diseases, penetrance varies such that some children have multiple fractures and severe shortening and others, less involved, have only the occasional fracture.

Typically, the bones are osteopenic (Fig. 5-21), with thinned cortices and decreased diameter. Multiple fractures with resulting deformities are the norm. These fractures respond to appropriate treatment, and healing is only slightly prolonged. Occasionally, it is necessary to correct long bone deformities, which is best accomplished operatively by performing multiple osteotomies in a single bone (Fig. 5-22) and lining the resultant fragments up on an intramedullary rod (Sofield "shish kabob").

Scoliosis can also complicate this disease, and its management can be very challenging, especially if surgical management is required to correct the deformity. It is very difficult to use spinal instrumentation in the face of this osteopenic, softened bone.

Down Syndrome

First described in England by Langdon Down in the 1800s, this syndrome has been shown to result from a trisomy of the number 21 chromosome. It is the most common chromosomal abnormality that we see today, and it occurs in approximately 1 in 500 to 800 live births based on the age of the mother. Because of its frequency, it is the prototype for the other chromosomal abnormalities, and the orthopedic manifestations tend to be somewhat common to all.

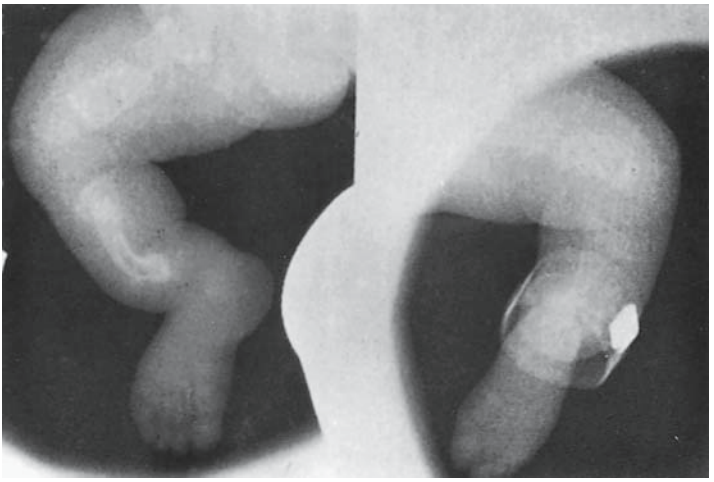


FIGURE 5-21. Osteogenesis imperfecta congenita in a newborn. Radiogram of lower limbs, showing multiple fractures. (From Tachdjian MO. Pediatric Orthopedics, 2nd ed, vol 1. Philadelphia: Saunders, 1990. Reprinted by permission.)

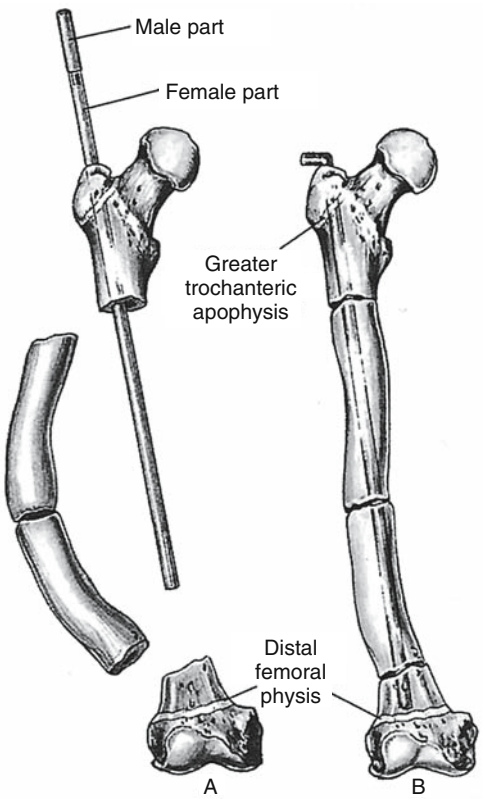


FIGURE 5-22. Williams modification of Sofield–Millar intramedullary rod fixation. (From Tachdjian MO. Pediatric Orthopedics, 2nd ed, vol 1. Philadelphia: Saunders, 1990. Reprinted by permission.)

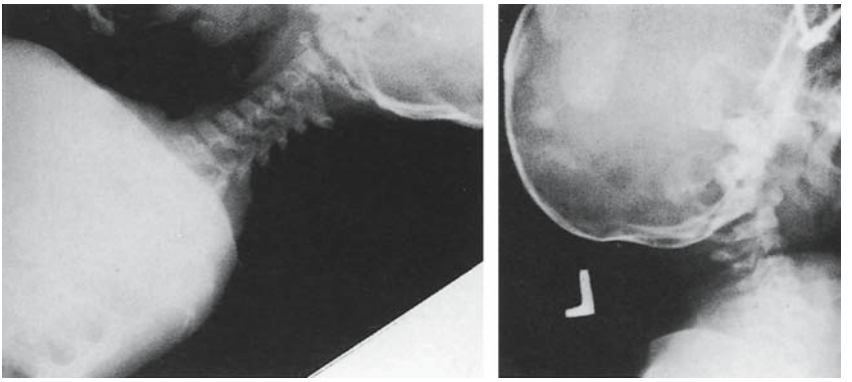


FIGURE 5-23. Atlantoaxial instability in Down's syndrome. (From Tachdjian MO. Pediatric Orthopedics, 2nd ed, vol 1. Philadelphia: Saunders, 1990. Reprinted by permission.)

Hypotonia and ligamentous laxity typify the group. The ligamentous laxity results from an inordinate number of elastic fibers relative to the number of collagen fibers in ligament and joint capsule. The joint changes typical of this disease and other chromosomal diseases can be traced directly to this ligamentous laxity. Specific manifestations include the following:

1. C1–C2 instability (Fig. 5-23): Because of laxity of the transverse ligament of the odontoid process, anterior translation of C1 on C2 occurs, frequently to alarming degrees. Routine lateral cervical spine radiographs in flexion and extension should be regularly obtained in these children to evaluate them for this problem.
2. Hip subluxation and dislocation can occur insidiously over time, again resulting from the capsular laxity about the joint.
3. Patellar subluxation is the cause of the typical gait seen in the older child with Down syndrome. These children often walk with a stiff-legged gait in an effort to preclude patellar subluxation.
4. Hypermobile flat feet and bunions.

The management of these orthopedic problems is primarily directed at controlling the deformity, if possible, and minimizing the pain, which is rarely a significant problem. Despite fixed deformities, it is frequently surprising how well these children are able to compensate.

Skeletal Dysplasias

There are several hundred recognized skeletal dysplasias, each with its own unique clinical characteristics and specific skeletal abnormalities. It

is impossible to recall all the features that define a given dysplastic condition, especially in light of the fact that each is usually quite rare. At best, generalizations can be employed to assist in the diagnosis of a specific patient and thereby guide the appropriate workup and referral to an individual skilled in definitive diagnosis. The anticipated orthopedic problems, treatment, and prognosis will hinge on the diagnosis.

When presented with an individual displaying dysplastic findings, especially short stature, chromosomal evaluation and standard X-rays are good starting points once appropriate history (especially family history) and a careful physical examination have been carried out. The X-rays should include a lateral of the cervical and thoracolumbar spine, an anteroposterior view of the pelvis, and anteroposterior views of the wrists and the knees. These views allow one to evaluate epiphyseal, physeal, metaphyseal, and diaphyseal growth and their aberrations.

Most of the dysplasias tend to affect a specific region of the bone; by assessing each region, clues can be obtained regarding the specific type of dysplasia. For example, spondyloepiphyseal dysplasia affects primarily epiphyseal growth, as the name implies. One should expect to see deformities of the epiphyseal nuclei and disordered apophyseal growth. On the other hand, achondroplasia is a defect in physeal growth and will, therefore, produce significant dwarfing; in fact, it is the most common cause of pathologic short stature.

Most of the skeletal dysplasias are genetically transmitted, and a careful family history will define the pattern. Many, however, are spontaneous mutations or without a defined etiology. It is important to keep in mind that by definition a skeletal dysplasia is a GENERALIZED affectation of the skeleton with all bones showing some changes. Obviously, the end of the bone growing more rapidly demonstrates the defect to a greater degree; thus, the knee and wrist films are more likely to show changes than the hip or elbow views.

Achondroplasia

As an example of how a dysplasia affects the skeleton, one should consider the most common, achondroplasia. Transmitted as an autosomal dominant in most cases, it is usually apparent at birth. The infant is rhizomelically shortened; that is, the proximal segment of the limbs is relatively shorter than the middle or distal segments (Fig. 5-24). In addition, the child is disproportionately built because the limbs are preferentially involved and, therefore, are very short relative to the spine and trunk.

These children follow the growth curve, but several standard deviations below normal, achieving a mature height between 3 to 4 feet. As with all the true dysplasias, intelligence is not impaired and life expectancy is virtually normal.

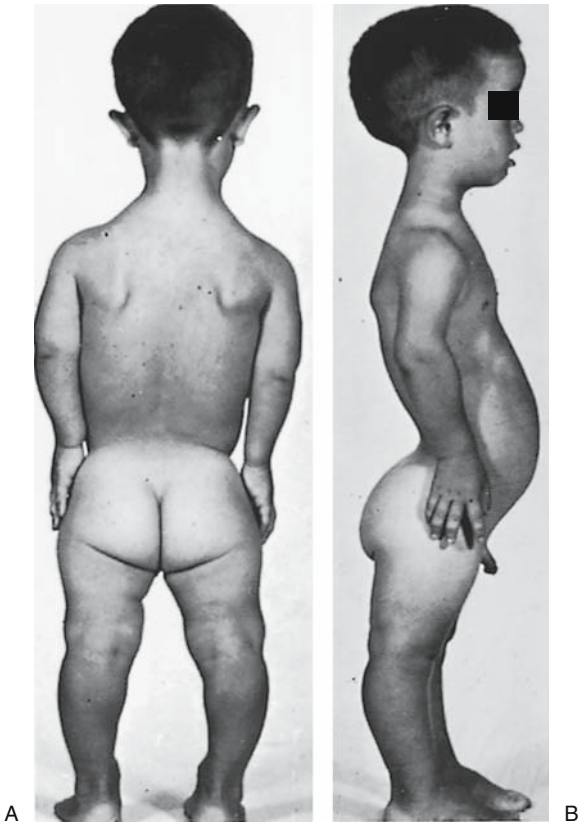


FIGURE 5-24. (A) Posterior photograph of achondroplastic dwarf showing distorted growth of long bones. The proximal limb segments are proportionately shorter than the distal, with the hands reaching only to the hip region. The legs are bowed, and the scapulae and pelvis are smaller than normal. Scoliosis is uncommon. (B) Lateral photograph of child with achondroplasia. Note marked lumbar lordosis with prominent buttocks as a result of pelvic tilt. The lordosis is caused in part by differential growth of vertebral body versus posterior elements. (From Bogumill GP. Orthopaedic Pathology: A Synopsis with Clinical Radiographic Correlation. Philadelphia: Saunders, 1984. Reprinted by permission.)

Clinical Features

The child's head shows flattening of the nasal bridge and prominent frontal bones. Both findings result from the disparity between the normal intramembranous calvarial growth and the retarded enchondral growth of the basilar portions of the skull.

The extremities are short, with each of the bones being short in length, but relatively normal in girth, because periosteal bone formation remains relatively unaffected. The spine and pelvis also show some decrease in height, but of greater significance is the decrease in the interpedicular distance, which effectively creates a spinal stenotic syndrome; this, coupled with a hyperlordotic lumbar spine, creates many achondroplasts to develop disk symptoms at an early age.

The major problem of the older adolescent is obesity, which complicates many of the other abnormalities. As adults, multiple tendonitis and bursitis problems are commonplace.

Neuromuscular Disease

In contrast to the skeletal dysplasias, which are intrinsic abnormalities of the skeleton, this group of diseases is extrinsic, but drastically alter the normal skeleton, primarily by the muscle imbalance they create.

Common themes can be seen that emphasize the fact that the problem is disparity in the agonist–antagonist relationship. Major joints tend to dislocate, with the hip being a prime example. The flexor pattern tends to become dominant, causing the femoral head to dislocate posteriorly. Scoliosis should be expected as asymmetry of spinal muscle action alters normal balance. If the neurologic defect is asymmetrical, as in polio, then the growth plates in one leg will "feel" a different muscle pull than those of the other, and a leg-length discrepancy can be anticipated.

Cerebral Palsy

Cerebral palsy is a static neurologic disease of children caused by an insult to the immature brain during the perinatal period. The defect is, therefore, central, damaging the normal inhibitory influences on the peripheral gamma efferent system. Without central damping, the peripheral reflex arc functions autonomously, and the result is increased tone or spasticity.

Cerebral palsy is classified in one of two ways:

1. Physiologic classification
   a. Spastic: Hypertonia, hyperflexia, and contractures are seen. This is the most common form of the syndrome.
   b. Athetoid: This is far less common today than it was in years past. Rh incompatibility and erythroblastosis fetalis were a common etiology of this form.
   c. Rigid
   d. Ballismic
   e. Mixed

FIGURE 5-25. Spastic quadriplegia with total body involvement. At 4 years of age. The marked scissoring of the hips and equinus deformity of the ankles provide a poor base upon which balance can develop. Note the pes valgus. (From Tachdjian MO. Pediatric Orthopedics, 2nd ed, vol 1. Philadelphia: Saunders, 1990. Reprinted by permission.)

2. Geographic classification
   a. Hemiplegia: The most common form, it is frequently associated with seizures.
   b. Diplegia: Both lower extremities predominate the pattern.
   c. Quadriplegia: The most severe cases involve children, many of whom are retarded and few of whom will ever walk.

Cerebral palsy is really a syndrome rather than a disease (Fig. 5-25), and no two children are the same, which makes comparison of procedures and other treatments extremely difficult if not impossible. The muscles all tend to be spastic; however, the muscle imbalance is created between spastic and more spastic muscles. Contractures, joint dislocations, limb deformities, and scoliosis should all be anticipated.

Polio

With the introduction of the Salk vaccine in 1954, this disease has become rare in the United States; however, it is certainly not eradicated in the Third World. Because immigrants are seen in our larger cities on an increasingly frequent basis with the sequelae of this disease, some familiarity with it seems appropriate.

The polio virus has unique predilection for the anterior horn cells of the cord and the bulbar portion of the brain. In most cases, the involvement is spotty and the degree of paralysis is variable. The victim is left with a mix of normal muscle, weak muscle, and absent muscle, thus creating a broad spectrum of muscle imbalance but in an asymmetrical distribution. It is important to remember that the sensory fibers are NOT affected, which gives these children a clear and distinct benefit over the children with spina bifida.

Spina Bifida

Despite the improvement in antenatal testing, many children with myelodysplasia are born in the United States each year. Because of open cord defects at a certain level (Fig. 5-26), these children are essentially congenital paraplegics; they are without motor and sensory modalities below the level of the defect. Needless to say, the higher their level of defect, the poorer their function and, hence, the prognosis (Fig. 5-27). For example, a child with a T12 level (the spinal roots that are the last to function are

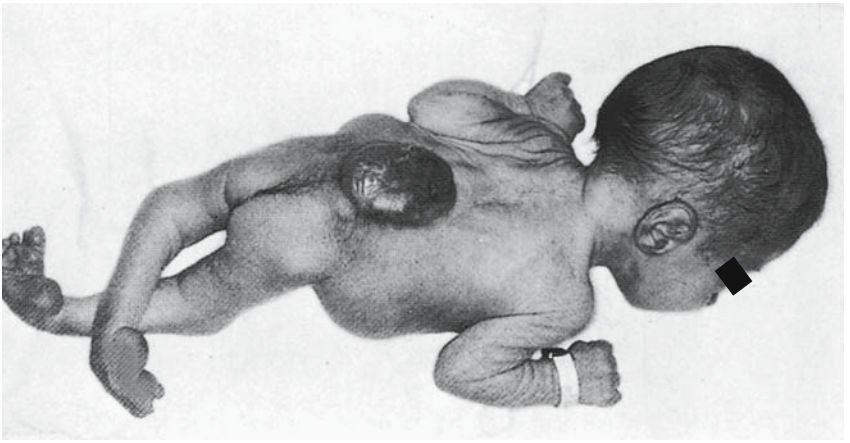


FIGURE 5-26. Newborn infant with lumbosacral myelomeningocele. Note the severe equinovarus deformity of both feet. (From Tachdjian MO. Pediatric Orthopedics, 2nd ed, vol 1. Philadelphia: Saunders, 1990. Reprinted by permission.)

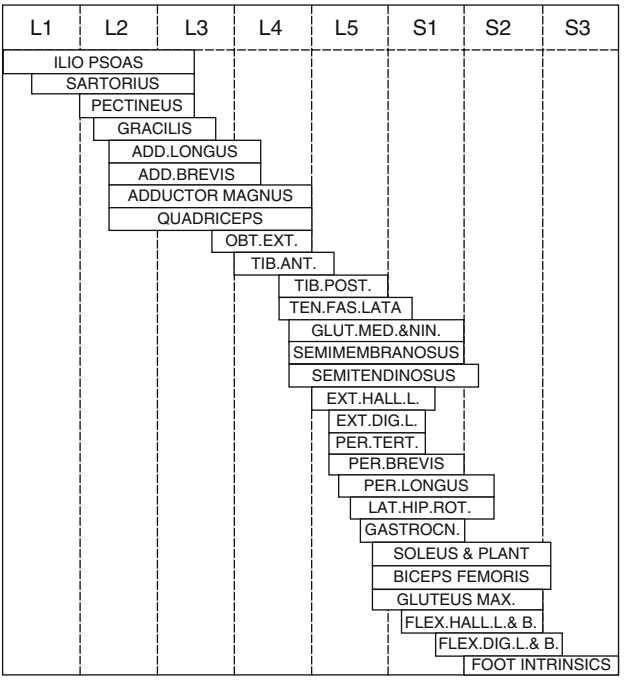


FIGURE 5-27. Neurosegmental innervation of muscles of lower limb. (From Tachdjian MO. Pediatric Orthopedics, 2nd ed, vol 1. Philadelphia: Saunders, 1990. Reprinted by permission.)

T12) has no motor power and no sensation below the waist. These children will be wheelchair confined and have bowel and bladder compromise. On the other hand, children with an S1 level (the last functioning spinal level is S1) have only minimal motor involvement and usually walk without braces. Their major problems are bowel and bladder malfunction.

The absence of sensation below the level of the lesion creates many additional problems for these children. Not unlike a diabetic patient with severe neuropathy, children with spina bifida are prone to foot ulceration, infection, and the development of neuropathic joints.

One recently identified problem in this group is latex allergy. Perhaps as a result of repeated catheterization with latex rubber catheters, these patients can become severely sensitized to all latex contact, to the point of anaphylaxis. Specific protocols are now used at the time of surgical procedures to avoid contact with any latex products, including gloves, catheters, and IV tubing.

Last, it is important to realize that these children, as well as many of those with cerebral palsy, are multiply handicapped. They have learning difficulties, perceptual problems, and hearing and visual impairments, not

to mention emotional issues, all of which require a coordinated effort by multiple specialists to provide optimal care.

Regional Orthopedic Problems

The Pediatric Hip

Most of the showcase pediatric orthopedic maladies affect the hip. Developmental dysplasias, Perthes' disease, and slipped capital epiphysis have established the hip as the preeminent joint of a child's musculoskeletal system. Several unique anatomic features predispose this joint to long-term problems following septic, vascular, developmental, and traumatic insults.

In the newborn, the upper end of the femur (Fig. 5-28) is entirely cartilaginous, representing the secondary ossification centers of both the greater trochanter and the femoral head (capital femoral epiphysis) as a composite chondroepiphysis. The two bony ossification centers develop within this one cartilage mass and grow differentially to their ultimate adult size and shape. Implicit in this fact is that the growth of one is in part dependent on the growth of the other. Normally, the bony centrum of the capital femoral epiphysis is radiographically visible by 3 to 6 months of age.

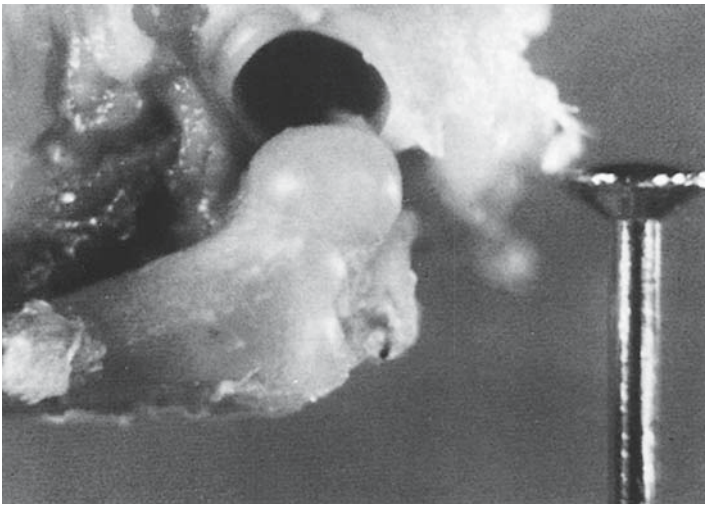


FIGURE 5-28. Embryology of the hip joint. Note the spherical configuration of the femoral head and acetabulum. The limbus and transverse acetabular ligament are well-formed structures. (From Tachdjian MO. Pediatric Orthopedics, 2nd ed, vol 1. Philadelphia: Saunders, 1990. Reprinted by permission.)

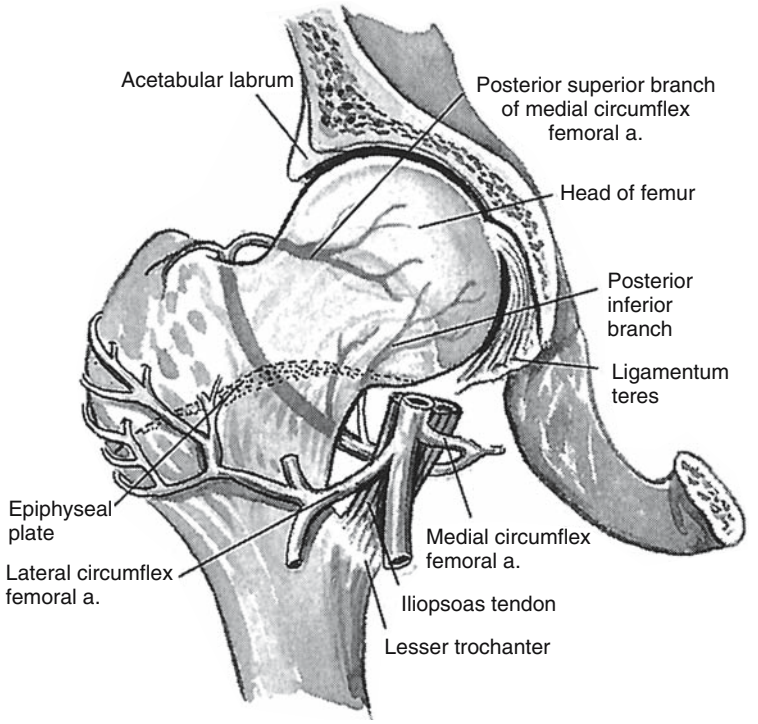


FIGURE 5-29. Posterior view of the normal blood supply of the upper end of the femur in an infant. (From Tachdjian MO. Pediatric Orthopedics, 2nd ed, vol 1. Philadelphia: Saunders, 1990. Reprinted by permission.)

The growth of this epiphysis is dependent primarily on the blood supply of the upper end of the femur (Fig. 5-29). It is essential to recognize that up until 1 year of age there is communication between the metaphyseal and epiphyseal circulations, and this connection protects the capital femoral epiphysis from isolation in the event of an insult to the epiphyseal side. Unfortunately, as the physis thickens and matures by 18 months of age, it becomes an impenetrable barrier between the two circulations, leaving the epiphysis of the head totally dependent on the epiphyseal vessels for its viability. Less than 10% of the femoral head is supplied by the branch of the obturator artery through the ligamentum teres. The epiphyseal vessels are supplied by the medial and lateral circumflex branches of the femoral artery. This vascular isolation of the upper end of the femur is largely responsible for the disastrous complications of developmental dislocation of the hip (DDH), Perthes' disease, and slipped capital femoral epiphysis (SCFE).

The acetabulum develops from two cartilage segments. The first is the triradiate cartilage, which a bilaminar physis forms at the junction of the

ilium, ischium, and pubis. Integrity of this growth plate is essential for acetabular *height* to be normal. The *depth* of the acetabulum is a function of the cartilaginous labrum that circumferentially surrounds the developing acetabulum.

Developmental Dislocation of the Hip

The previous nomenclature, "congenital dislocation," was recently changed to "developmental dislocation" in recognition of the fact that some of these hips are located at birth and go on to dislocate in the postnatal period. The incidence of this condition is about 1 per 1,000 live births and is more common in females. Although it is fair to say that the etiology is unknown, it is important to recognize that there are both genetic and environmental factors; hence, it is considered a multifactorial trait. It is also critical to recognize that this is a true dysplasia (i.e., aberrant growth), and NOT simply a femoral head that is not located in the acetabulum (Fig. 5-30). It

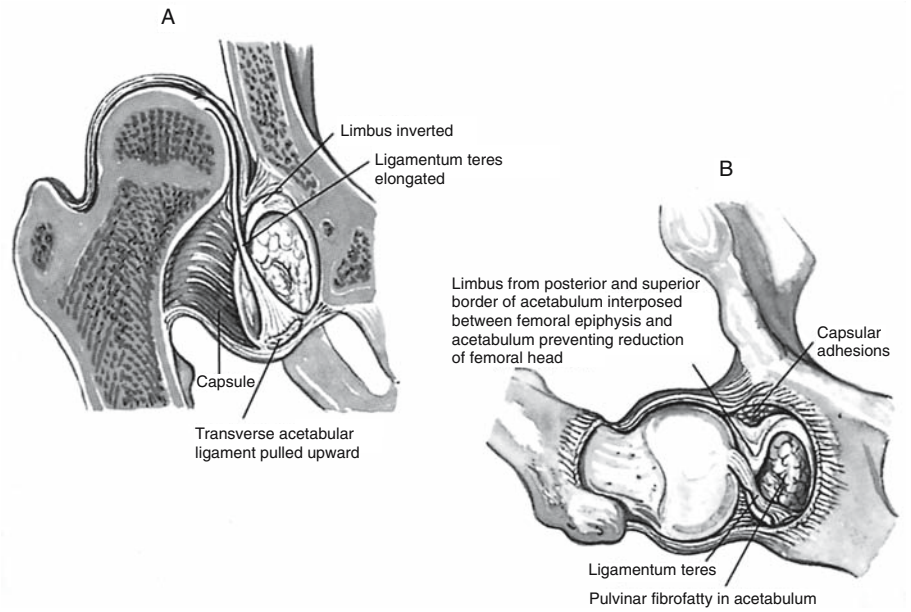


FIGURE 5-30. Pathology of the dislocated hip that is irreducible owing to intraarticular obstacles. (A) The hip is dislocated. (B) The hip cannot be reduced on flexion, abduction, or lateral rotation. Obstacles to reduction are inverted limbus, ligamentum teres, and fibrofatty pulvinar in the acetabulum. The transverse acetabular ligament is pulled upward with the ligamentum teres. (From Tachdjian MO. Pediatric Orthopedics, 2nd ed, vol 1. Philadelphia: Saunders, 1990. Reprinted by permission.)

is important to stress this fact to the parents in an effort to assist them in understanding the pathology.

Early diagnosis is the key to optimal treatment and the best prognosis. First, consider the risk factors:

1. First-born female
2. Breech presentation
3. Positive family history
4. Hip "click"
5. Presence of a muscular torticollis

With these in mind, a careful physical examination of the hips is the logical next step. In the newborn, one should attempt to demonstrate laxity and instability (Fig. 5-31). The Barlow test is performed with the infant supine and the hips flexed. As the hips are brought from the abducted to adducted position, a positive test is noted as the femoral head subluxes posteriorly over the posterior rim of the acetabulum; this indicates instability. The Barlow is a provocative test: the hip is located and the maneuver dislocates it. Conversely, the Ortolani test is a reduction maneuver; the hip is dislocated and the test reduces it; this is accomplished by abducting the adducted hip and noting a palpable (but rarely audible) "clunk" as the femoral head reduces over the posterior acetabular rim.

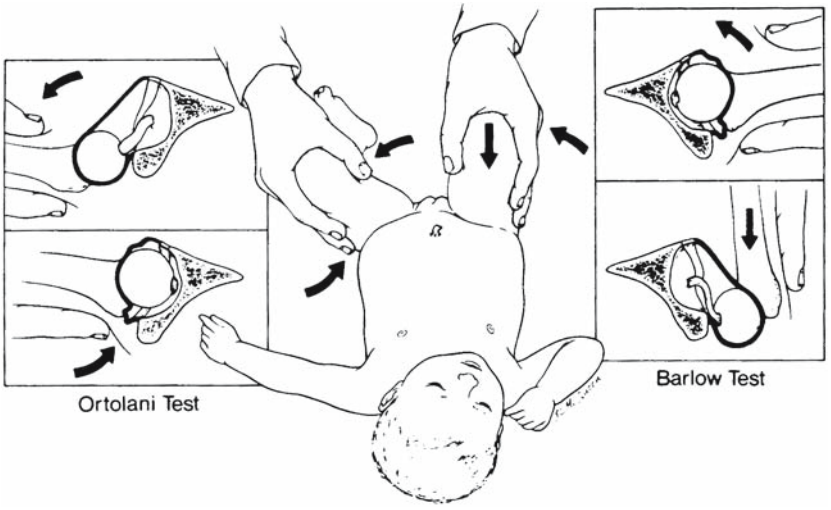


FIGURE 5-31. On the *left*, the Ortolani (reduction) test is demonstrated. The Barlow (provocation dislocation) test is shown on the *right*. These tests must be performed on a relaxed infant. (From Sabiston DC Jr. Essentials of Surgery. Philadelphia: Saunders, 1987. Reprinted by permission.)

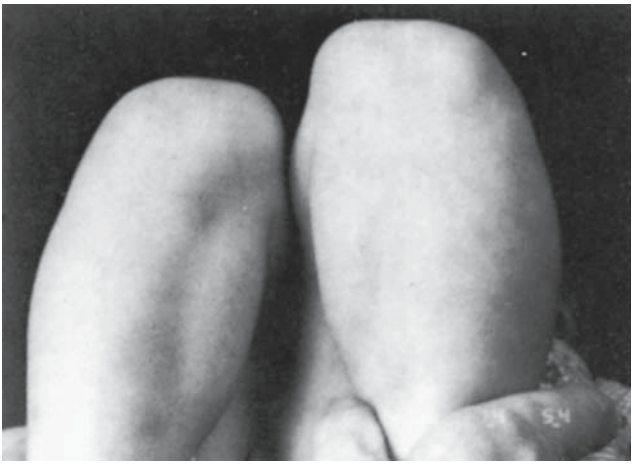


FIGURE 5-32. The Galeazzi test is performed by comparison of the relative height of the femoral condyles by holding the hips in flexion. The right femur appears shorter because of a right hip dislocation. This test is usually not helpful in the case of bilateral hip dislocations. (From Sabiston DC Jr. Essentials of Surgery. Philadelphia: Saunders, 1987. Reprinted by permission.)

As the child becomes older (by 3 months of age), the dislocated hip tends to become fixed in that position, and the classic signs of instability disappear in favor of those indicating a fixed dislocation deformity. Limited abduction is perhaps the most important finding to note. While examining the child on a firm surface, subtle differences in the degrees of hip abduction may herald a dislocated hip on the restricted side. Similarly, viewing knee height with the child supine and the hips and knees flexed may reveal a positive Allis sign (Fig. 5-32); one knee higher than the other, again indicating a dislocation on the low side.

Imaging studies are important in both diagnosis and treatment. The current popularity of ultrasound is based on the fact that under 3 months of age much of the proximal femur is cartilaginous. Ultrasound has been helpful in the diagnosis of DDH (Fig. 5-33), as well as in defining relatively subtle degrees of acetabular dysplasia. The value of ultrasound decreases after the child is 3 months old, and standard X-rays assume a more central role. Many still believe that a standard anteroposterior (AP) view of the pelvis with the hips in neutral is the "gold standard" to which all other studies should be compared (Fig. 5-34). Historically, many classic measurements are made on this X-ray that allow one to determine the location of the femoral head as well as the degree of acetabular dysplasia. In addition, subsequent X-rays are important to monitor the progress of treatment, despite the enthusiasm in some centers for using ultrasound for therapeutic monitoring.

Treatment

Simply stated, the goals of treatment are these:

1. Reduce the femoral head concentrically into the acetabulum.
2. Maintain this reduction.
3. Avoid the complications of doing both.

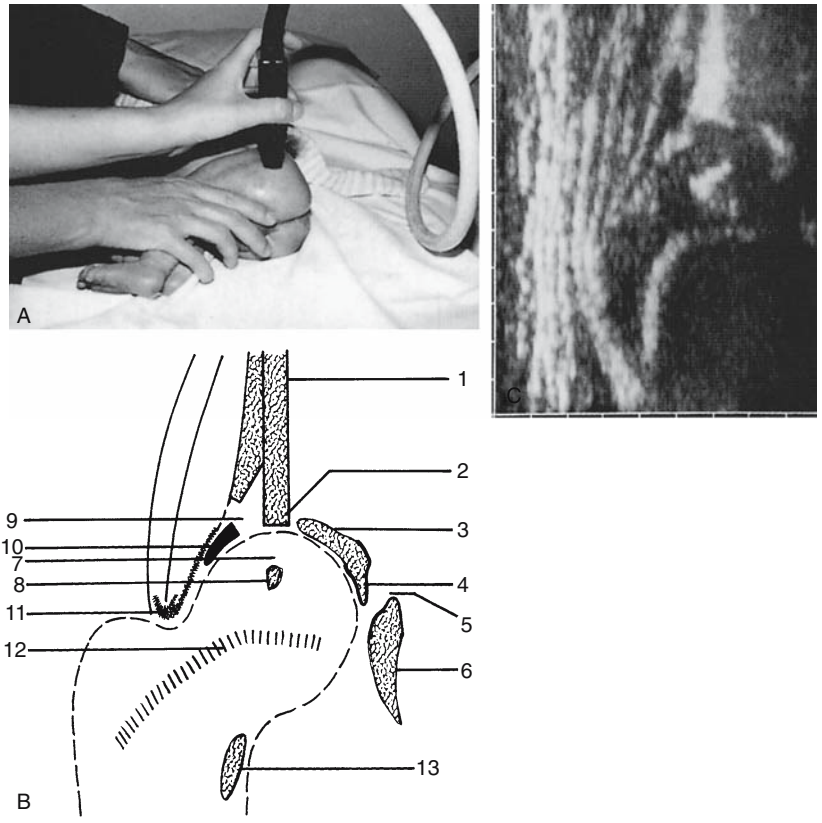


FIGURE 5-33. Ultrasonography of the hip in congenital hip dislocation. (A) Lateral decubitus position of the infant for ultrasonographic examination of the hip. (B) Diagram of structures identified during static nonstress ultrasonography of the hip: *1*, iliac bone; *2*, the most distal point of the ilium in the roof of the acetabulum; *3*, ossified medial wall of the acetabulum; *4*, the inferior end of the iliac bone at the triradiate cartilage; *5*, triradiate cartilage; *6*, ossified ischium; *7*, the cartilaginous femoral head; *8*, ossific nucleus of the femoral head; *9*, cartilaginous roof of the acetabulum; *10*, labrum; *11*, intertrochanteric fossa; *12*, cartilaginous growth plate of the femoral head; *13*, ossified metaphysis of the femoral neck. (C) Ultrasonogram showing structures. (From Tachdjian MO. Pediatric Orthopedics, 2nd ed, vol 1. Philadelphia: Saunders, 1990. Reprinted by permission.)

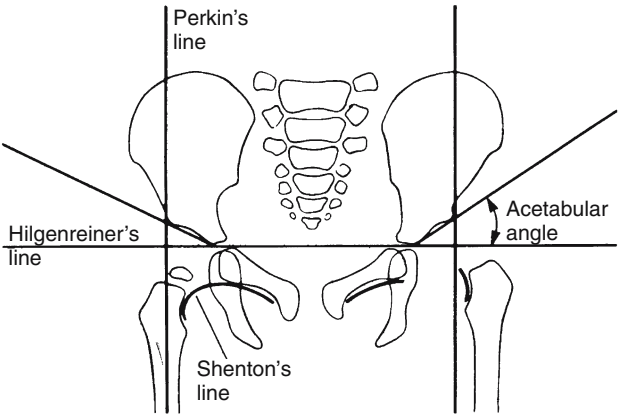


FIGURE 5-34. Radiographic features of congenital dislocation of the hip (left hip dislocated, right hip normal). There is a delay in ossification of the capital femoral epiphysis. Shenton's line, a smooth continuation of an imaginary line drawn along the femoral neck and superior margin of the obturator foramen, is disrupted. The acetabular angle is increased, usually greater than 30 degrees. The proximal medial I margin of the femoral metaphysis is displaced lateral to Perkin's line, a line drawn from the lateral margin of the acetabulum perpendicular to Hilgenreiner's line. (From Sabiston DC Jr. Essentials of Surgery. Philadelphia: Saunders, 1987. Reprinted by permission.)

There is probably no other pediatric orthopedic malady in which there is a greater understatement of treatment. The pitfalls in accomplishing these apparently simple goals qualify more as "landmines." The adage "The first physician to treat DDH is the last physician with the opportunity to achieve a normal hip" emphasizes the difficulties frequently encountered in the management of this problem. Also implied is the fact that the younger the child is when treatment is initiated, the better the prognosis will be. Indeed, it is generally believed that if treatment is delayed until after the age of walking, it will not be possible to produce a normal hip.

The use of a Pavlik harness (Fig. 5-35) as initial treatment in the infant has become the international standard. For the child under 3 months of age with a frank dislocation or with persistent instability (as documented, for example, by a positive Barlow test in a 3-week-old), appropriate application and use of a Pavlik harness assures a normal hip in about 80% of cases. The device, however, is not foolproof, with avascular necrosis, inferior dislocation, and femoral nerve palsy reported as complications, not to mention failure to achieve a reduction. One should be familiar with the appropriate use of this device and NOT randomly apply it as a panacea to all children with hip clicks.

If diagnosis for some reason is delayed and the child presents after 6 months for treatment, more-aggressive modalities are generally required

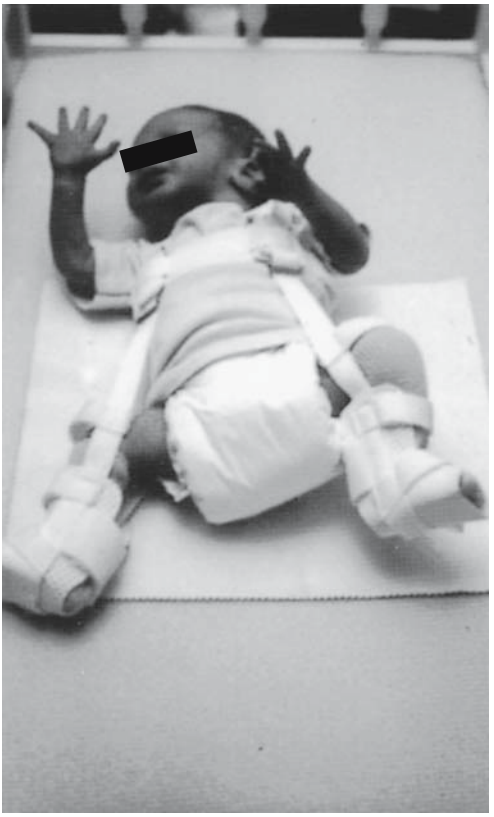


FIGURE 5-35. The Pavlik harness. (From Tachdjian MO. Pediatric Orthopedics, 2nd ed, vol 1. Philadelphia: Saunders, 1990. Reprinted by permission.)

to achieve a reduction. Closed reduction under anesthesia, adductor tenotomy, and occasionally prereduction traction are generally employed at this point, with open reduction indicated for those who cannot undergo closed reduction. Immobilization in a spica cast is essential to maintain the reduction.

After 18 months of age, operative approaches are required to reduce the hip and also to reconform the acetabulum. Pelvic osteotomies and proximal femoral osteotomies are utilized in the older age groups. Keep in mind that it is rarely possible to produce a normal hip when treatment is initiated after the age of walking.

The prognosis for DDH is generally very good, when the diagnosis is made early and treatment initiated in infancy. With delay in diagnosis and, therefore, in treatment, the prognosis worsens. The complication most dreaded, avascular necrosis, can occur at many points in the treatment algorithm. Despite earlier diagnosis and advances in treatment, many

reported series still record about a 10% incidence of avascular necrosis. If it occurs, the prognosis is fair at best.

Perthes' Disease

Idiopathic avascular necrosis of the femoral head in the child was originally described in 1909 by multiple authors: Legg in Boston, Calvé in France, and Perthes in Germany. Unfortunately, all authors interpreted that the observed changes were caused by nontuberculous sepsis. Slowly, it was recognized that the cause was, in fact, an avascular event. It has more recently been shown that the changes cannot be produced by a single period of avascularity. Rather, multiple episodes are needed to cause the characteristic pathologic changes. The exact trigger for this vascular disruption has remained elusive.

The affected children are typically male, from a lower socioeconomic status, aged 4 to 9 years, and slightly delayed in skeletal growth. Generally, the child presents with a limp and absence of any systemic symptoms. Clinically, the child usually has restricted hip motion, especially rotational, and some adductor muscle spasm. Local findings of tenderness and erythema are not seen. Because standard laboratory studies are usually normal, imaging studies are paramount in the diagnosis and treatment of the disease.

Pathologically, the disease progresses through four stages (Fig. 5-36), and these are reflected by the X-rays and magnetic resonance imaging (MRI) scans. Initially, the stage of synovitis, which lasts 2 to 3 weeks, produces an irritable hip syndrome easily confused with toxic synovitis. The X-rays are negative at this time. Subsequently, the stage of avascularity onsets, lasting 2 to 3 months, during which time the femoral head necrosis occurs. Fragmentation changes of the capital femoral epiphysis herald this stage. Once the avascular event has occurred, the femoral head revascularizes and the process will "heal," resulting in the stage of revascularization. The critical issue is the degree of deformation of the normally spherical femoral head before complete healing occurs. Eccentric mechanical loads applied to the softened, diseased head frequently alter its sphericity. Ultimately, the process burns itself out, leaving the hip in the stage of residua. The healing phase lasts approximately 2 years, at which time only the residual deformity remains as the permanent marker of the disease.

The treatment principles for this disease are really no more advanced than they were 30 years ago. Nevertheless, certain facts seem generally accepted. The prognosis seems to hinge on two basic features. First is the patient's age at onset of the disease. Children under age 5 will do well left untreated, which is the current recommendation. Those over age 8 do poorly despite treatment. The other factor is the extent of head involvement. Obviously, the head that is completely necrotic is more likely to sustain permanent deformation than a head only partially involved. For

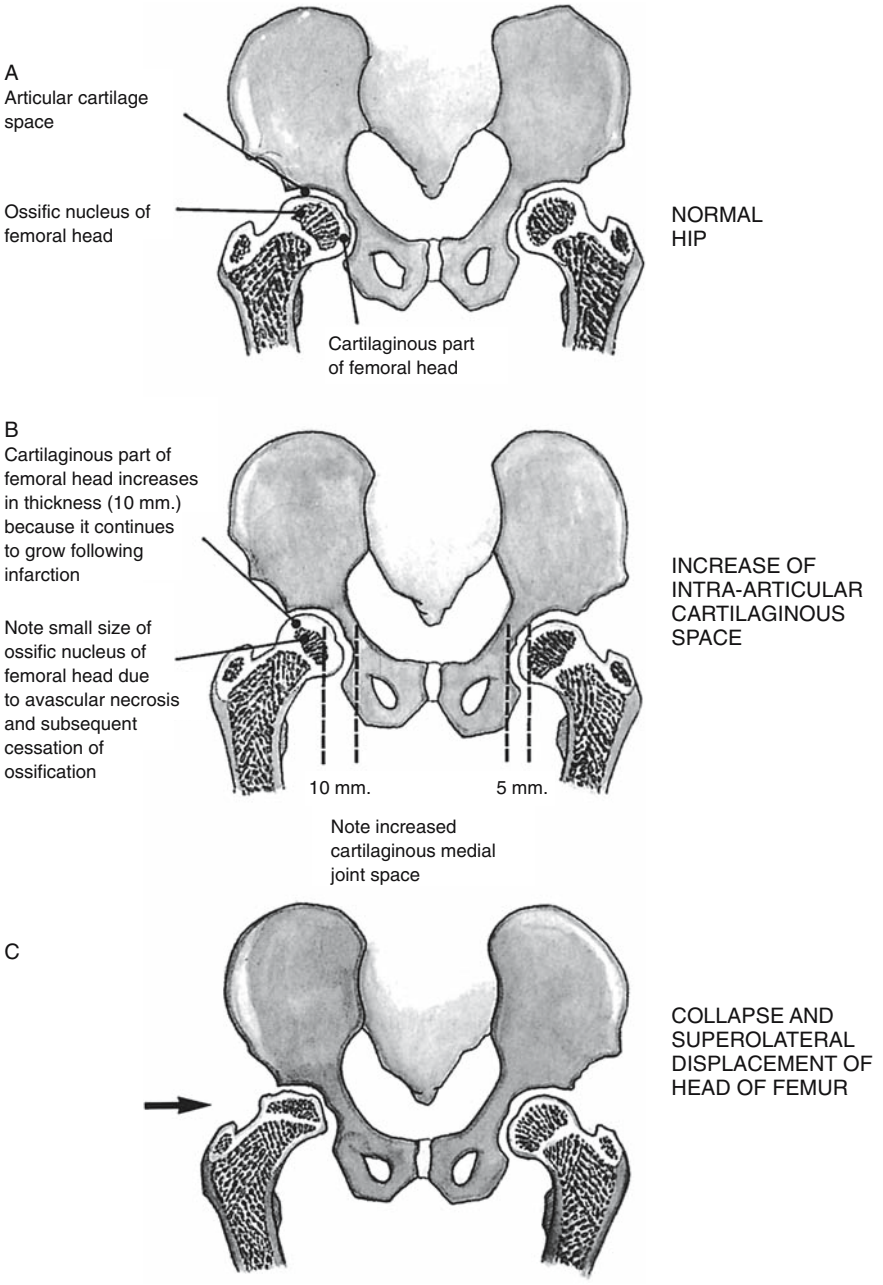


FIGURE 5-36. Pathogenesis of deformity of the femoral head in Legg–Calve–Perthes' disease. (A) Normal hips. (B) Widening of the medial cartilaginous joint space caused by hypertrophy of the cartilage covering of the femoral head. Note the smaller ossific nucleus caused by cessation of bone growth as a result of avascular necrosis. (C) Collapse of the femoral head with superolateral displacement.

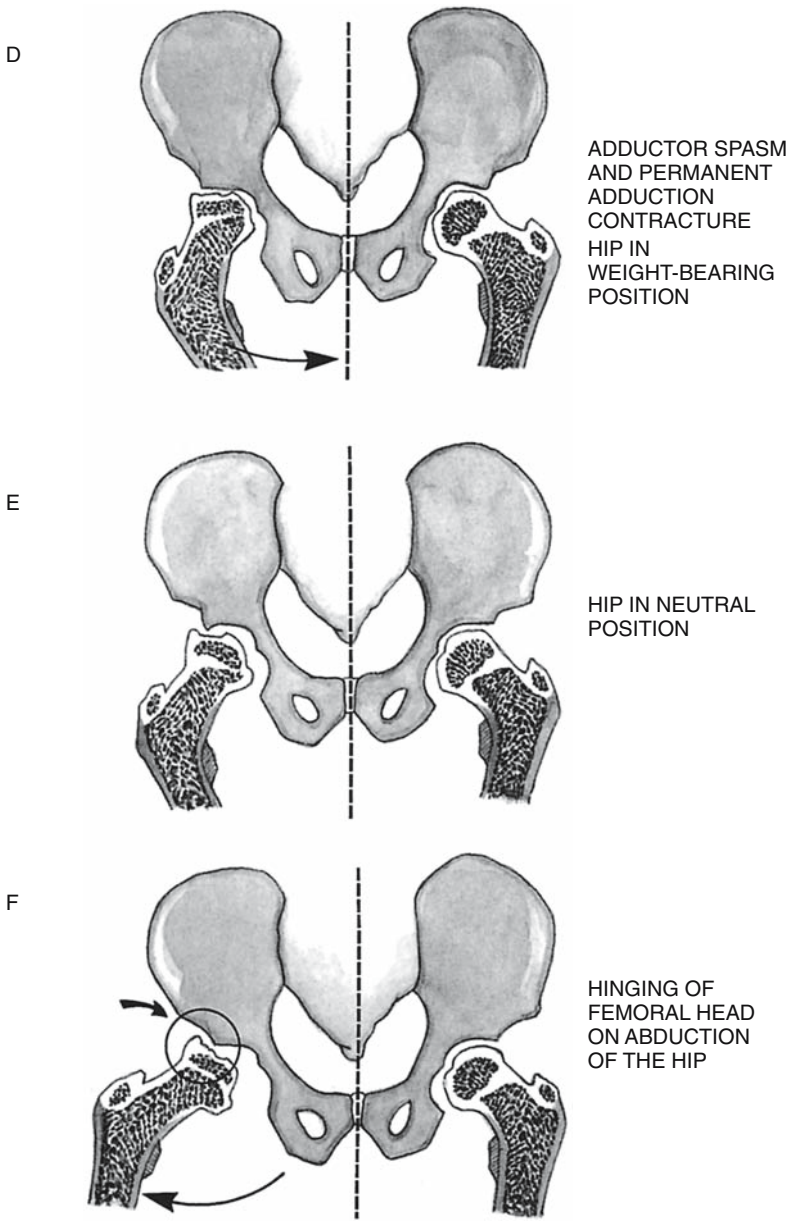


FIGURE 5-36. (D) The hip is adducted in weight-bearing position. Note in (E) the dent in the lateral part of the femoral head that is blocking concentric reduction of the hip. (E, F) Hinged abduction. On abduction of the hip (F), the femoral head is displaced further laterally, with increase in the medial joint space. (From Tachdjian MO. Pediatric Orthopedics, 2nd ed, vol 1. Philadelphia: Saunders, 1990. Reprinted by permission.)

children of intermediate age, 5 to 8 years, the principle of "containment" continues to be accepted. Conceptually, the thought is to place the softened femoral head concentrically into the acetabulum, which will in turn act as a mold or template as the head revascularizes. This alteration can be accomplished in the smaller child by using an abduction orthosis (Fig. 5-37) and in the larger child by using either a femoral or acetabular osteotomy to improve congruity before deformation. The treatment for the older child with an already deformed hip is highly controversial.

In general, the prognosis is good for the younger children, whereas many of those diagnosed after age 9 require total hip replacement in their forties or fifties.

Slipped Capital Femoral Epiphysis

Hip pain in the adolescent should always raise suspicion of this entity. In fact, many of these patient's present with pain along the medial side of the thigh radiating to the knee. This referred pain in the obturator distribution is quite typical. These children also share a common body habitus: they tend to be quite obese, with delayed secondary sexual characteristics. Many of these children have been limping for several months before they present for evaluation.

FIGURE 5-37. Scottish-Rite hip orthosis. (A) Anteroposterior view of the orthosis. (B) Anteroposterior view of a patient wearing the orthosis. (From Tachdjian MO. Pediatric Orthopedics, 2nd ed, vol 1. Philadelphia: Saunders, 1990. Reprinted by permission.)

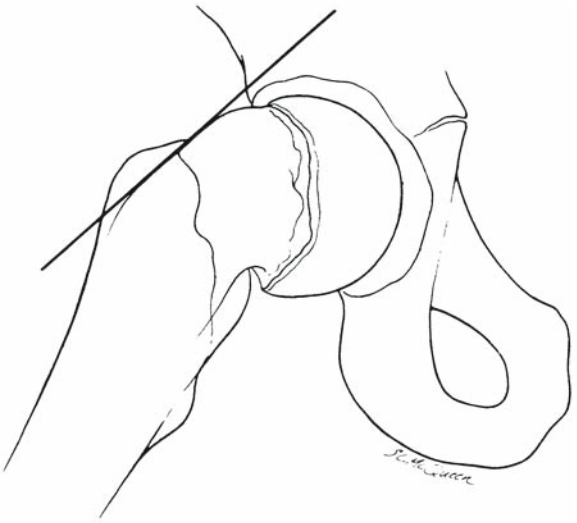


FIGURE 5-38. Slipped capital femoral epiphysis is most reliably seen on the lateral radiograph. Posterior migration of the femoral head relative to the neck is seen. A line drawn up the anterior or lateral margin of the femoral neck does not intersect the epiphysis. (From Sabiston DC Jr. Essentials of Surgery. Philadelphia: Saunders, 1987. Reprinted by permission.)

Pathologically, the capital femoral epiphysis has "slipped" or translated posteriorly and inferiorly relative to the femoral neck (Fig. 5-38). There are those who prefer to emphasize the fact that the neck is actually moving anteriorly and superiorly relative to the head. This displacement ultimately results in an irritated hip, which is manifested by a limp, pain, and external rotational deformity of the leg. This deformity is usually readily apparent on physical examination. As the hip is flexed, the leg obligately externally rotates.

There have been multiple suggestions as to the etiology of the slipped capital femoral epiphysis. Many authors believe that these children are hormonally predisposed and with the superimposed stress of obesity, the perichondral ring is no longer able to "girdle" the physis. Hence, the slip occurs. Typically, the slip is said to occur through the hypertrophic zone of the plate. Recent studies suggest that the displacement may actually transcend the entire physis. There have been several different attempts to group these patients clinically. Historically, children were said to have chronic slips, implying that they had symptoms for more than 3 weeks. Acute slipped capital femoral epiphysis was often considered the result of an acute injury and, therefore, frequently considered by some authors to be a fracture through the physis. When the child had a history of limping and then a superimposed acute injury, the resultant slip was often referred to as an acute on chronic slip.

At the present time, most simply classify slips into stable versus unstable groups. The defining characteristic is the ability of the child to walk. Children with unstable slips are unable to bear weight on the extremity.

Treatment for slipped capital femoral epiphysis (SCFE) is very straight forward: stop the slipping and avoid the complications of doing so. To stop the slipping, an "in situ" pinning with a centrally placed compression screw crossing the physis is employed (Fig. 5-39). It is currently important to note that any attempt to reduce the slipped epiphysis is rarely recommended. To do so would subject the head to a high risk of avascular necrosis.

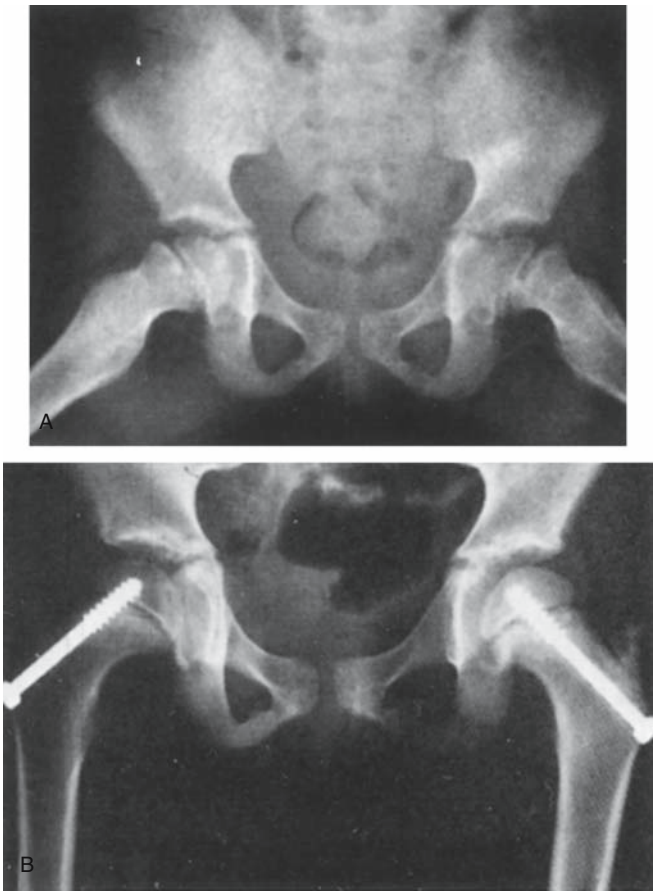


FIGURE 5-39. Slipped capital femoral epiphysis of both hips in a 10-year-old girl with hypothyroidism. (A, B) Anteroposterior and lateral views of both hips. (From Tachdjian MO. Pediatric Orthopedics, 2nd ed, vol 1. Philadelphia: Saunders, 1990. Reprinted by permission.)

Slips are typically graded based on the degree of displacement, and should severe slipping have occurred, resulting in excessive deformity, most authors would recommend that this deformity be corrected as a second stage once the physis has fused.

The complications of the disease and its treatment can be devastating. Avascular necrosis is primarily a complication of the treatment rather than the disease itself. Aggressive reduction maneuvers and femoral neck osteotomies have both been implicated in the etiology of avascular necrosis. There is literature to suggest, however, that avascular necrosis may be a complication of high-grade slips.

The other concern is chondrolysis. Most consider that this phenomenon is a complication of the disease rather than the treatment. Chondrolysis appears to be a particular concern in Afro-Americans, leading some to suggest an immunologic link. Slowly, one observes degradation of the articular cartilage with resultant joint space narrowing and severe hip stiffness.

It should be recognized that this condition primarily affects adolescents. Therefore, when it is diagnosed in a younger child, one should consider specific endocrine abnormalities or metabolic diseases such as hypothyroidism or chronic renal failure. With early and adequate treatment, specifically pinning "in situ," excellent long-term results can be anticipated.

Transient Synovitis of the Hip

By far and away the MOST COMMON cause of limp and hip pain in a child is the "irritable hip syndrome," also called "transient" or "toxic" synovitis. Frequently, these children have a history of an upper respiratory infection (URI) or ear infection in the recent past, leading many to believe that this condition is a postinfectious inflammation of the hip.

Clinically, such children are not sick; they remain active, feed well, and are afebrile. Their laboratory studies, including X-rays, are usually normal. On a typical examination, the hip is irritable, with additional findings of an antalgic limp, decreased range of motion, and pain with log rolling of the leg. The treatment is supportive and includes nonsteroidal antiinflammatory drugs (NSAIDs) and activity reduction, the latter being key. Normally, the process is self-limited, with the limp disappearing in 5 to 7 days. If it persists longer, one should suspect that the child has remained too active.

The Pediatric Knee

In contrast to the hip, the affectations that one sees about the knee in a child are, for the most part, all benign and generally respond to simple treatment measures.

Osgood–Schlatter's Disease

Osteochondritis of the tibial tuberosity (Fig. 5-40) is one of the more-common causes of knee pain, especially of the preadolescent age group. Although the name implies inflammation, there generally is relatively little present. Essentially, this is a "traction apophysitis"; that is, a powerful muscle group pulls on an open growth plate, producing an overload strain and resulting irritation of the local tissues.

These children have local swelling and tenderness over the tibial tuberosity without other findings. The key to successful treatment is activity restriction observed acutely at first, followed by activity modification until the plate closes. It is important for the children to accept responsibility for their knee care: decreasing activity, using ice after activity, and occasionally using a lightweight knee sleeve, primarily for psychologic support. It is equally important to reassure the parents that, no matter how much pain their child has, he or she is not damaging the knee in any permanent way.

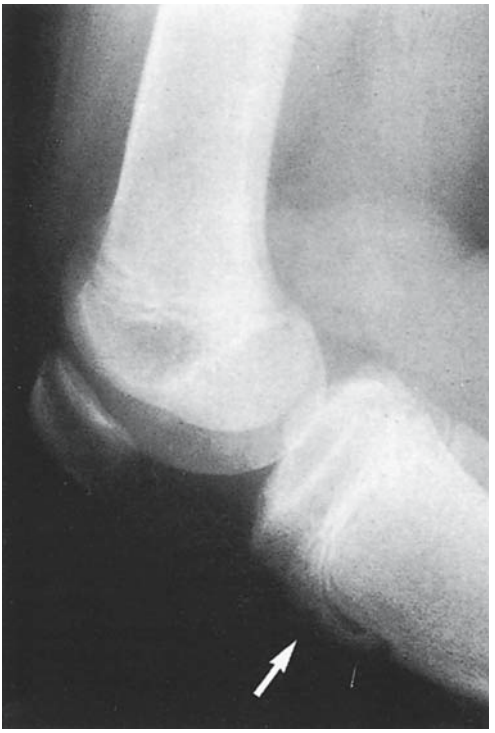


FIGURE 5-40. Osgood–Schlatter disease of the left proximal tibia with free ossicle lying anterior to the proximal tibial tubercle. (From Tachdjian MO. Pediatric Orthopedics, 2nd ed, vol 1. Philadelphia: Saunders, 1990. Reprinted by permission.)

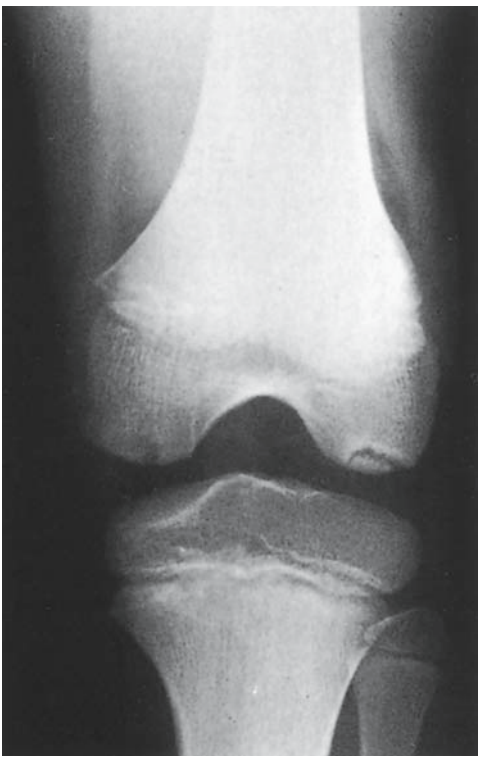


FIGURE 5-41. Osteochondritis dissecans of the knee. (From Tachdjian MO. Pediatric Orthopedics, 2nd ed, vol 1. Philadelphia: Saunders, 1990. Reprinted by permission.)

Osteochondritis Dissecans

Another osteochondrosis, osteochondritis dissecans, is believed to be an avascular necrosis of a portion of the subchondral bone (Fig. 5-41). Typically, it most commonly affects the medial side of the lateral femoral condyle, adjacent to the intercondylar notch. However, it can occur on any of the condylar surfaces.

Clinically, the child presents with vague knee pain, which is poorly localized. Occasionally, an effusion is present. The diagnosis is usually made radiographically, especially if an intercondylar notch view is obtained. Generally, short-term activity restriction, ice, and NSAIDs are adequate to relieve acute symptoms. Many can then return to sports. If symptoms continue unabated or recur, arthroscopy should be considered; should a loose fragment be identified, it can be removed or pinned into place.

The Discoid Meniscus

The menisci develop embryologically from a cartilaginous plate referred to as the interzone. The cartilage plates normally thin out to become shaped like the letter "C" on the medial side and the letter "O" on the

lateral side of the knee. Should this hollowing-out NOT occur on the lateral side, a thick cartilage plate persists as a discoid meniscus (Fig. 5-42). This structure causes the child to have knee pain and occasional effusion beginning about age 3 to 5 years. Most dramatic is a prominent audible and palpable "clunk" seen when the knee is flexed and extended with some rotation applied. If symptoms warrant, arthroscopic removal of the central portion of the disk is required, contouring it to the normal shape. Complete excision is NOT desirable.

Popliteal Cysts

A localized mass in the popliteal space (Fig. 5-43) occurs more than infrequently in small children. Typically, this is a cyst containing gelatinous fluid. As with any mass, these cysts are a source of great concern to the parents, who can benefit a great deal from reassurance as to the correct diagnosis.

These cysts can be seen at a young age, frequently just after the child begins to walk. Typically, the cyst presents between the tendon of the semitendinosus and the medial head of the gastrocnemius; thus, it lies medial in the popliteal space. An X-ray should be negative, and an ultrasound confirms a cystic structure. A more extensive workup should be considered if the mass is atypical, that is, on the lateral side, painful, and enlarging. Because most of these cysts disappear in time, surgical excision should be reserved for the ones that cause symptoms. It is important to

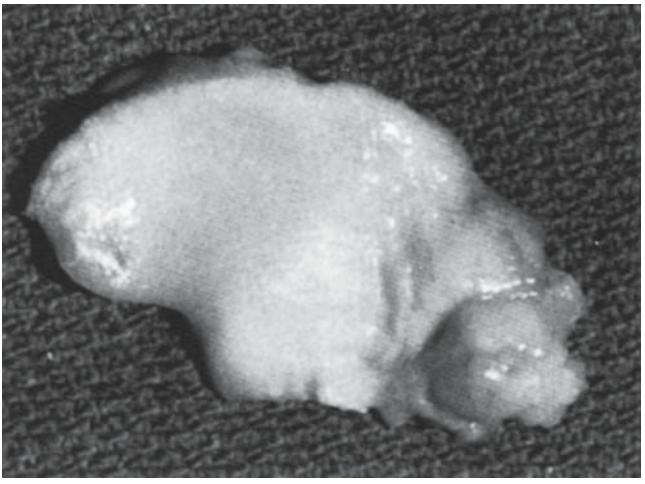


FIGURE 5-42. Discoid lateral meniscus. (From Tachdjian MO. Pediatric Orthopedics, 2nd ed, vol 1. Philadelphia: Saunders, 1990. Reprinted by permission.)

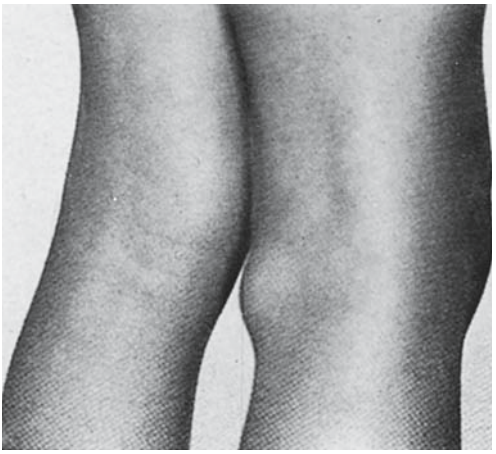


FIGURE 5-43. Popliteal cyst. Clinical appearance. (From Tachdjian MO. Pediatric Orthopedics, 2nd ed, vol 1. Philadelphia: Saunders, 1990. Reprinted by permission.)

note that in children these are rarely associated with intraarticular pathology whereas in the adult that association is the norm.

The Pediatric Foot

There are as many developmental variations in foot configuration as there are children who have feet. It seems that no two pairs of feet are exactly alike. The challenge then for the physician is to determine which of these feet are pathologic and which are essentially normal. Although a number of guidelines have been suggested, none is as helpful as the axiom, "Feel the foot." The pathologically deformed foot cannot be positioned normally by manual manipulation; hence, it is rigid. Conversely, if the abnormally positioned foot can be reduced to a normal configuration with only modest manual pressure, the foot should be considered flexible and the result of excessive intrauterine molding. It is generally true that most flexible "deformities" are considered "non-disease" and as such require no specific treatment. On the other hand, rigid deformities usually present a definite therapeutic challenge. Foot deformities in children are common and a frequent cause for orthopedic referrals.

The Flatfoot

As the name implies, the longitudinal arch is low to nonexistent. Officially, the foot is pronated, and the heel is typically in valgus or everted. Flatfeet can be flexible or rigid, and the difference is critical. Besides feeling the foot, the other technique that is helpful in differentiating the two is simply to examine the child sitting, standing, and standing on the toes. The rigid flatfoot will remain flat in all three positions, whereas the flexible foot is

only flat when standing. When seated (not weight-bearing) and when toe-standing, the arch reconstitutes itself and the foot appears to normalize.

Congenital Hypermobile Flatfoot

This condition is no longer considered an abnormality and is not a cause for exclusion from military service as it once was. Rather, this genetic trait currently is viewed as a normal variant, and the mere finding of it is not an indication for treatment as in years past.

Three pain syndromes do occasionally occur that generally respond to simple therapeutic measures:

1. Arch pain: The child with flatfoot occasionally develops a strain pattern in the arch, which is easily treated with simple, inexpensive, commercially available supports.
2. Calf pain: Typically, this is caused by tight heel cords and can be treated simply with stretching exercises and arch supports.
3. Accessory navicular syndrome: A modest percentage of children have a separate ossicle in the posterior tibial tendon adjacent to the tarsal navicular. The prominence of this bone may cause symptoms, which generally respond to padding or occasionally excision of the accessory navicular.

The Rigid Flatfoot

The pronated foot that does not correct on toe-standing should be studied for the presence of a tarsal coalition. These bony, cartilaginous, or fibrous bridges are genetically determined and usually can be diagnosed by appropriate X-rays and a computed tomography (CT) scan. Treatment is based on location and severity of symptoms.

Another cause of a rigid flatfoot when seen in a newborn is congenital vertical talus. This germ plasm defect results in abnormal positioning of the talus, with the navicular dorsally dislocated onto the talar neck. As a result, the foot is beyond flat: the arch actually is convex (rather than concave) and frequently referred to as a "rocker-bottom deformity." This uncommon pathologic foot requires surgical correction.

Congenital Clubfoot

Similar to DDH, congenital clubfoot is multifactorial in origin. Environmental factors applied to a genetically predisposed individual result in this pathologic deformity. As with DDH, it is important to make it clear to the parents that this is NOT a postural deformity. Rather, there is an anatomic abnormality of the talus. Because of the abnormal medial and plantar deviation of the talar neck, there are a number of secondary deformities. The tarsal navicular is dislocated dorsally onto the talar neck; soft tissue

contractures develop, and the resultant configuration is characteristic. The forefoot is adducted, the hindfoot is in varus (inverted), and the entire foot is in equinus.

A clubfoot, as is the case with most pathologic feet, is rigid on clinical exam (Fig. 5-44). X-rays can be used to confirm the diagnosis. As clubfeet are frequently seen in association with other abnormalities, every effort should be made to evaluate the whole child. Syndromes often associated with the presence of clubfeet include myelodysplasia, arthrogryposis, and diastrophic dwarfism, to mention just a few. The treatment of these deformed feet in these syndromic children is usually exceedingly difficult. It is probably fair to say that surgery will be required in virtually all cases.

In the case of the "standard" congenital clubfoot, occurring in an otherwise normal child, the recommended initial treatment is stretching and serial casting. The Ponseti method has regained significant popularity. Using this method of manipulation in conjunction with serial casting, many authors are reporting successful correction by closed treatment in 80% of cases. Should closed treatment fail or should recurrent deformity be observed, surgical correction is the usual next step. Most authors recommend surgical correction between 6 and 9 months of age if closed treatment has been unsuccessful. The overall success of various treatment protocols is largely dependent on the initial severity of the deformity. In addition, the need for late procedures to correct residual deformity is similarly a function of initial severity as well as the success of initial correction tech-

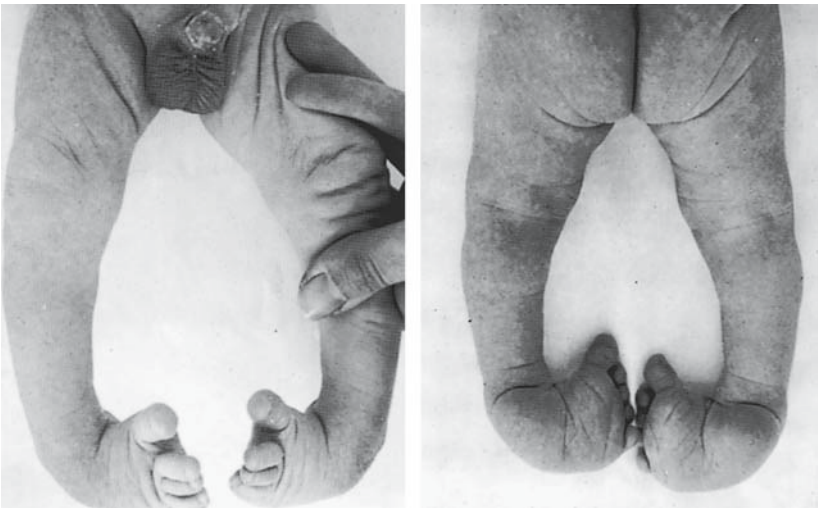


FIGURE 5-44. Bilateral talipes equinovarus in a newborn infant. (From Tachdjian MO. Pediatric Orthopedics, 2nd ed, vol 1. Philadelphia: Saunders, 1990. Reprinted by permission.)

niques. In general, if correction is complete and achieved before the age of walking, an excellent prognosis can be anticipated. It is, however, important to point out to the family that congenital clubfoot involves not only the foot but the soft tissues of the leg itself. Therefore, an overall decrease in the girth of the calf should be expected.

Metatarsus Adductus

One of the more-common problems seen in the child's foot is metatarsus adductus. Many cases are simply the result of excessive uterine cramming and, therefore, are best considered as "non-disease." The supple postural deformities are essentially normal variants and will correct without specific treatment. The clinical problem, however, is that some of these feet are, in fact, pathologic rather than postural and, therefore, do need appropriate care.

Typically, metatarsus adductus presents with forefoot adduction (Fig. 5-45) and supination. When viewed from the plantar surface, the foot with

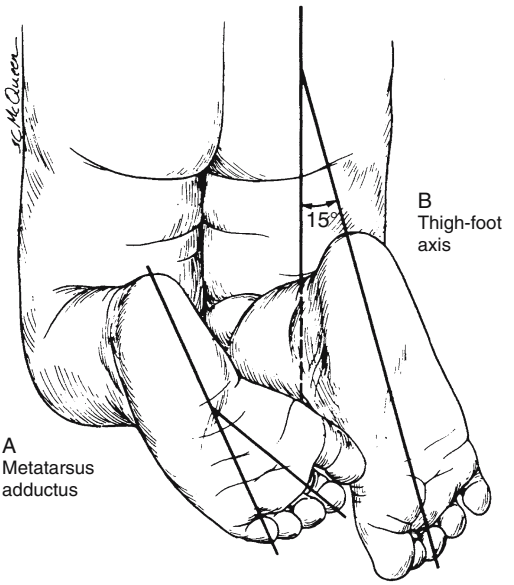


FIGURE 5-45. The heel bisector line is utilized in determining the severity of metatarsus (A). Deviation of the forefoot causes this line to extend lateral to the second toe. The deviation of the forefoot causes the lateral border of the foot to be convex and the medial border to be concave. The thigh–foot axis (B) is used to determine tibial version. The normal thigh–foot axis is external 15 degrees, as demonstrated. (From Sabiston DC Jr. Essentials of Surgery. Philadelphia: Saunders Company, 1987. Reprinted by permission.)

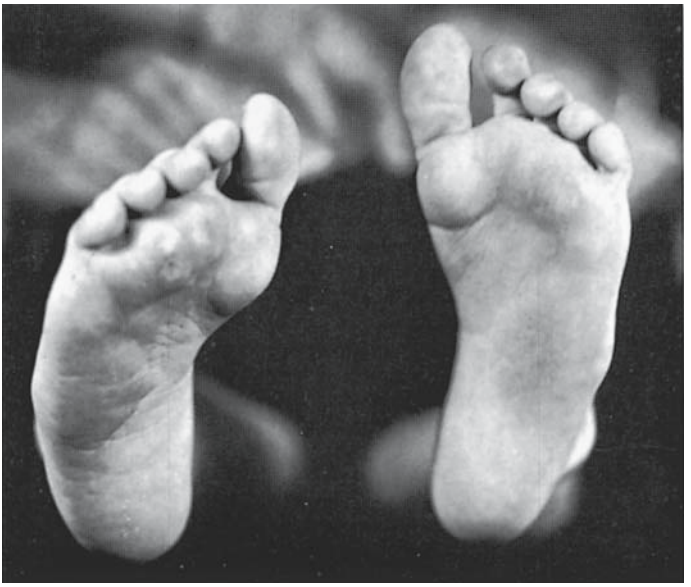


FIGURE 5-46. Untreated metatarsus deformity in a young boy. (From Gartland JJ. Fundamentals of Orthopaedics, 4th ed. Philadelphia: Saunders, 1987. Reprinted by permission.)

metatarsus adductus has a typical "kidney bean" appearance. Again, on examination it is critical to "feel the foot." By doing so, these feet can be grouped into three clinical types. First, type I (mild): foot is supple and easily corrects with digital stroking of the lateral side of the foot. Type II (moderate): gentle, manual pressure is required on the medial forefoot for correction. Type III (severe): moderate force is required for correction; even so, some cases may not be correctable.

The mild and moderate deformities frequently correct spontaneously and do not require aggressive treatment. Simple shoeing or occasionally serial casts are used in these children to gain initial improvement. A simple way to monitor this improvement is to stand the child on a copying machine at each follow-up visit and reproduce a copy of the plantar surface of the feet. The severe feet and some of the tighter moderate feet clearly deserve serial casting at the very least. Certainly in some cases, when serial casting fails, surgical intervention may be required.

For most cases, the prognosis is excellent. Even those children with mild persistent deformity have virtually no functional or cosmetic problems with their feet. Unfortunately, persistent severe metatarsus adductus (Fig. 5-46) can cause problems such as shoe fitting, pain, and cosmetic deformity. Late reconstruction of these feet usually requires osteotomies through the midfoot.

The Pediatric Upper Extremity and Neck

In general, most upper extremity problems in children that require orthopedic evaluation are traumatic in origin. Fractures of the elbow and forearm are relatively common and represent some of the most challenging problems in orthopedics. Nontraumatic conditions of the upper extremity are far less common, and those worthy of note are primarily congenital in nature.

Sprengel's Deformity

Congenital elevation of the scapula (Fig. 5-47) is generally the result a fibrous cartilaginous or bony bar that persists between the spine and the superior medial border of the scapula, that is, an omovertebral bar. This structure prevents the scapula from migrating inferiorly from its embryonic position adjacent to the cervical spine to the normal adult position.

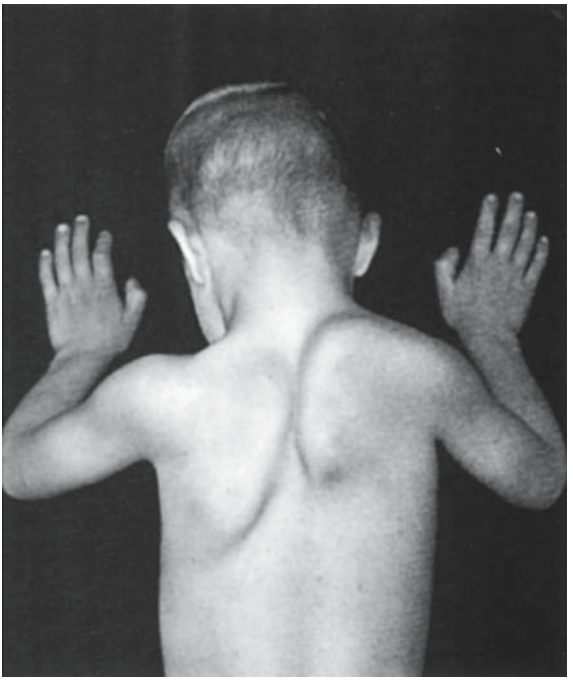


FIGURE 5-47. Sprengel's deformity of the right shoulder. The scapula is elevated and hypoplastic, its horizontal diameter being greater than the vertical. (From Tachdjian MO. Pediatric Orthopedics, 2nd ed, vol 1. Philadelphia: Saunders, 1990. Reprinted by permission.)

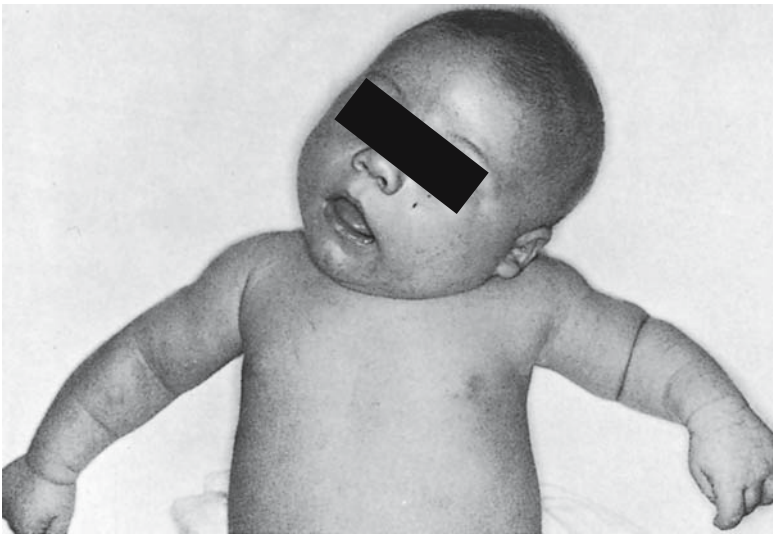


FIGURE 5-48. Congenital muscular torticollis on the left. The head is tilted to the left and the chin rotated to the right. (From Tachdjian MO. Pediatric Orthopedics, 2nd ed, vol 1. Philadelphia: Saunders, 1990. Reprinted by permission.)

Sprengel's deformity usually presents as asymmetry of the neck or shoulder and physical examination is generally adequate for diagnosis. Because most children have no significant functional deficits, surgical treatment is usually not recommended. Cosmesis is an occasional complaint and can be managed by simple excision of the upper portion of the scapula. If a functional deficit does exist, several operative procedures have been developed to reduce the scapula to its normal position.

Congenital Muscular Torticollis

Although it is not truly an upper extremity problem, children with this condition present with a wry neck and asymmetry. Physical examination is usually adequate to make the diagnosis and differentiate it from some of the other causes of asymmetry in this region: Klippel–Feil anomaly, congenital scoliosis, and Sprengel's deformity (Fig. 5-48).

Essentially, the problem is a contracture within the sternocleidomastoid muscle. The exact etiology of this contracture has been the subject of some controversy. Intrauterine hemorrhage within the muscle, local compartment syndrome, and fibrotic bands have all been proposed. Despite the etiology, the net result is a newborn presenting with a torticollis and facial asymmetry. Typically, the head is tilted TO the side of the lesion and the face and chin are turned AWAY from the side of the lesion.

The deformity usually responds to simple physical therapy, stretching by the parents, and positioning the crib to encourage the infant to look TO the side of the lesion, thereby stretching the tight sternocleidomastoid. Occasionally, nonsurgical treatment is not adequate and operative release is required; this should be done before the child is 18 months to 2 years of age, most importantly, to level the eyes.

Worthy of note is the coincidence of this condition and developmental hip dysplasia. Because 20% of these children have abnormal hips, careful screening in this group is strongly recommended.

Radial Anomalies

The most common long bone deficiencies in the upper extremity involve the radius (Fig. 6-49). Partial or complete absence of this bone, with or without adjacent hand deficiencies, can be seen as an isolated finding or in association with several syndromes. Franconi's and Vater syndromes should be considered when the radial dysplasia is bilateral. Further workup will usually reveal the renal defect or the thrombocytopenia.

The hand tends to deviate to the radial side and is referred to as radial clubhand. Early treatment is nonoperative and based on stretching and bracing. Later surgical reconstruction of the extremity to improve wrist function is appropriate.

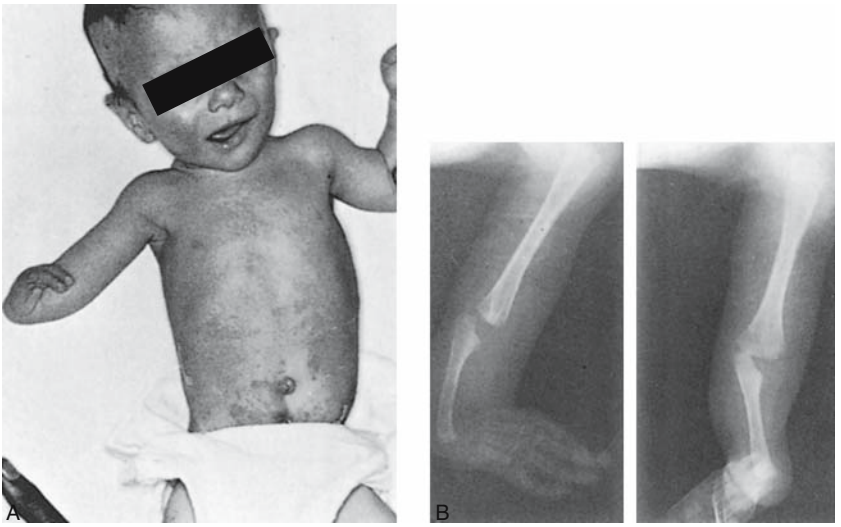


FIGURE 5-49. Congenital absence of the radius in an infant. (A) Clinical appearance. (B) Preoperative radiograms. (From Tachdjian MO. Pediatric Orthopedics, 2nd ed, vol 1. Philadelphia: Saunders, 1990. Reprinted by permission.)

Congenital Trigger Thumb

Perhaps it is best not to use the term congenital for trigger thumb because the defect is rarely noticed at birth or, for that matter, in the first 6 months. It is usually appreciated when the child begins using the hand for grasping. At this point, the flexed attitude of the interphalangeal joint is noticed by the parents. Initially, stretching will straighten the digit, but as the tendinous nodule of the flexor pollicis longus enlarges, it will no longer slide under the flexor pulley. The thumb is then "stuck" in flexion.

Some thumbs respond to simple stretching, but most require surgical tenolysis after 6 to 9 months of age. Most of those treated in this way have an excellent result and no recurrence.

Pediatric Trauma

The basic principles of injury to the immature skeleton have been discussed in part elsewhere. The unique features of pediatric fractures are primarily the results of the biologic differences between child and adult. Specifically, the presence of an open growth plate, the periosteum, the ability of pediatric bone to plastically deform, and the ability to remodel this deformity are the bases for the fracture patterns typically seen.

The physis is clearly an internal "flaw" in the bone and, thus, a point of mechanical weakness. Many loading modes are capable of causing failure through the physis. These fractures were classified many years ago by Salter and Harris (Fig. 5-50). Their classification was based on the direction that the fracture line took through the physis and adjacent osseous structures. Purportedly, this classification correlates with prognosis: the higher the number of fracture type, the poorer the prognosis. Although true within certain limits, this is not always the case. For example, a Salter II fracture of the distal radius is a common, benign injury whereas a Salter II fracture of the distal femur is complicated by a partial physeal arrest in more than 50% of cases. Fractures of the physis heal rapidly in 3 to 4 weeks, but parents should be warned about potential growth plate arrest. Physeal fractures that cross the plate and/or enter the joint require operative restoration of normal anatomy in an effort to minimize the risk of this complication.

The periosteum (Fig. 5-51), as previously noted, is thicker, more vascular, and more osteogenic than that of an adult. The mechanical benefits provided by the periosteum tend to minimize fracture displacement, act as an aid in reduction, and assist in maintenance of reduction. Biologically, the active osteogenic potential allows fractures to heal in half the time required for a similar bone in the adult.

The biologic plasticity of pediatric bone is responsible for the typical fracture patterns seen in the pediatric diaphysis. The incomplete

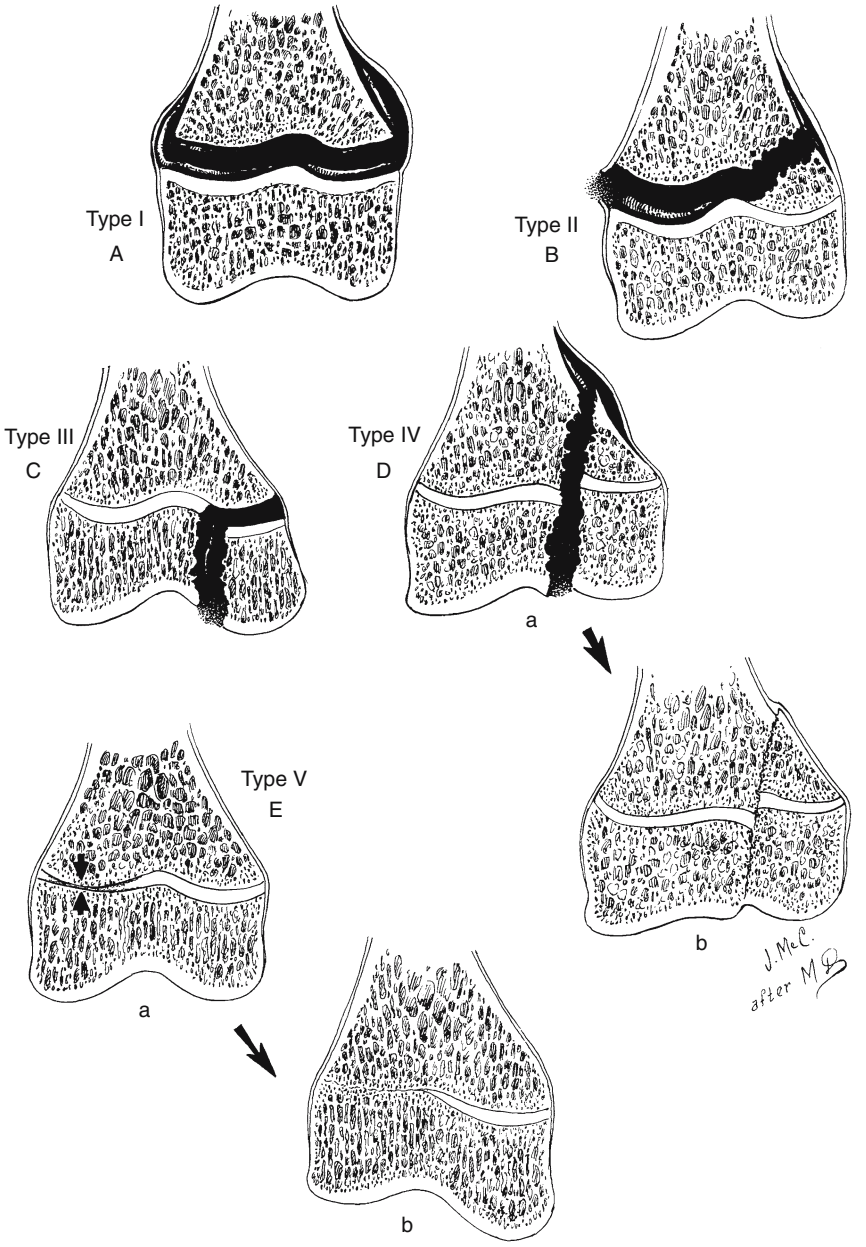


FIGURE 5-50. Classification of epiphyseal plate injuries according to Salter and Harris. (Redrawn after Salter RB, Harris WR. Injuries involving the epiphyseal plate. J Bone Joint Surg 1963;45A:587. In: Tachdjian MO. Pediatric Orthopedics, 2nd ed, vol 4. Philadelphia: Saunders, 1990. Reprinted by permission.)

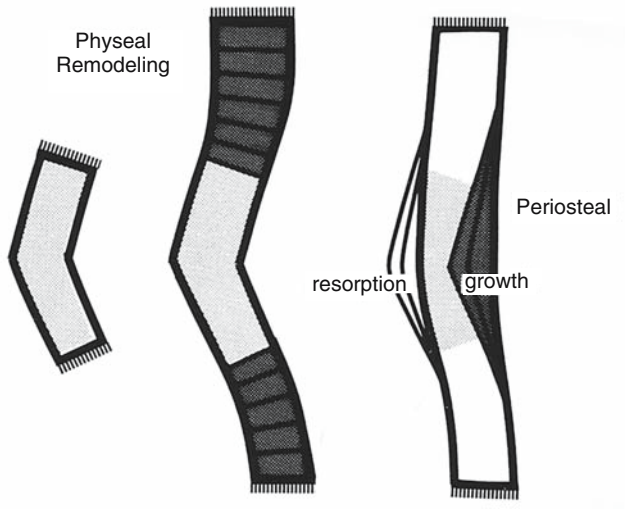


FIGURE 5-51. The basis of remodeling. (From Rang M. In: Rang M (ed) Children's Fractures, 2nd ed. Philadelphia: Lippincott, 1983. Reprinted by permission.)

fractures—greenstick and torus—represent the ability of these bones to bend but not break all the way through. In general, this phenomena is not seen in the adult bone as a result of the progressive stiffening of cortical bone that occurs with aging. Occasionally, this feature presents a therapeutic dilemma. In the forearm, a plastically deformed ulna acts as a spring to redeform the already fractured radius. The solution is to complete the fracture of the ulna by osteoclasis; this will allow one to align the forearm acceptably and prevent redeformation.

Finally, the extensive remodeling ability of pediatric bone has corrected many seemingly unacceptable reductions without the need for multiple closed reductions. There are limits to the amount of correction that can be anticipated (Fig. 5-52). One should not be overly secure, expecting "Mother Nature" to correct all malposition. In general, angular deformity will remodel to variable degrees. Greater correction can be expected if the deformity is in the plane of motion of the joint. Similarly, the closer the fracture to the joint, the more complete will be the correction. Translational deformity (i.e., displacement) at all levels tends to completely remodel. Rotational malalignment does NOT remodel; therefore, it is important to correct all rotatory deformity. Complications of pediatric fractures are uncommon with adequate treatment; however, when they do occur, management is frequently problematic. The reason for this is the growth remaining in the skeleton. Any injury compromising the growth mechanics of a long bone will only compound itself over time as the

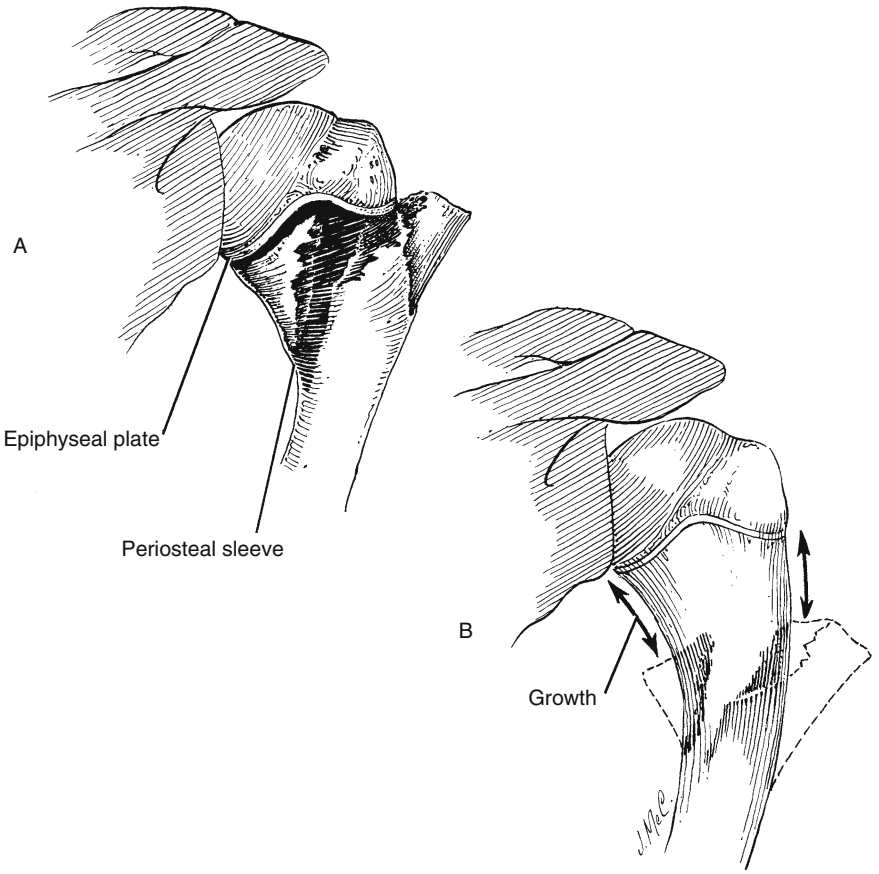


FIGURE 5-52. Diagram showing remodeling process of a malunited fracture involving the proximal humeral physis. (From Tachdjian MO. Pediatric Orthopedics, 2nd ed, vol 1. Philadelphia: Saunders, 1990. Reprinted by permission.)

deformity appears to worsen. Periarticular fractures and physeal fractures tend to present more problems in this regard than do those in the diaphysis.

The treatment principles, then, are directed toward fracture reduction and maintenance while avoiding complications, goals similar to those in the adult. Operative treatment of certain physeal injuries is common, and there is now current interest in operative treatment of more diaphyseal fractures, especially of the femur, in an effort to decrease length of hospital stay. Regardless of the reduction approach, the need for immobilization is undisputed. Children by definition are noncompliant; premature removal of immobilizing devices usually has disastrous results. One need *not* be concerned about joint stiffness or a cast-induced atrophy in children. It is

far more important to continue the immobilization until the fracture is healed. Physical therapy following cast removal is rarely needed because the activity level of a normal child, unhampered by a cast, is more than adequate to mobilize the extremity. It is especially important NOT to subject the child with an elbow injury to a well-meaning but overaggressive physical therapist as this will only aggravate the joint stiffness and retard resolution.

In summary, children's fractures mandate management goals similar to the adult: reduction, maintenance, and avoidance of complications. However, due to generally permissive biologic mechanisms, the tolerances in treatment are much greater. Successful results require adequate recognition of the unique qualities of the pediatric skeleton and the special problems that may follow skeletal trauma.

Battered Child Syndrome

No discussion of pediatric skeletal trauma would be complete without mention of this syndrome. The sociologic implications are extensive for the patient, the family, and the physician. Child abuse rarely occurs as an isolated event, and the result of returning the child to the home may be disastrous. It then becomes important to recognize the signs and symptoms of "nonaccidental" trauma. Failure to recognize or suspect this syndrome has often resulted in continued abuse.

As the name implies, this is a "syndrome," meaning the diagnosis is usually based on finding a constellation of manifestations. The diagnosis rarely can be made on the basis of an isolated fracture; rather, several fractures in multiple stages of healing will more reliably indicate abuse over time. The syndrome typically presents with findings in multiple areas, including the following:

1. *General neglect*. Beware the child who fails to make eye contact with parents or physician. The child who is dirty and uncared for and who exhibits evidence of psychologic and nutritional neglect should raise one's suspicions.
2. *Skin and soft tissue injury*. "Imprinting" of the skin from blows with specific objects, such as belt buckles, coat hangars, ropes, etc., should be searched out. Evidence of cigarette and radiator burns can commonly be found. Eye-ground hemorrhages and forehead hematomas indicate "shaken baby syndrome."
3. *Craniocerebral injury*. Subdural or epidural hematomas with or without nonparietal skull fractures are highly suggestive of abuse.
4. *Skeletal injury* (Fig. 5-53).
    a. Rib fractures: Multiple fractures especially in a line typically indicate a kicking injury.

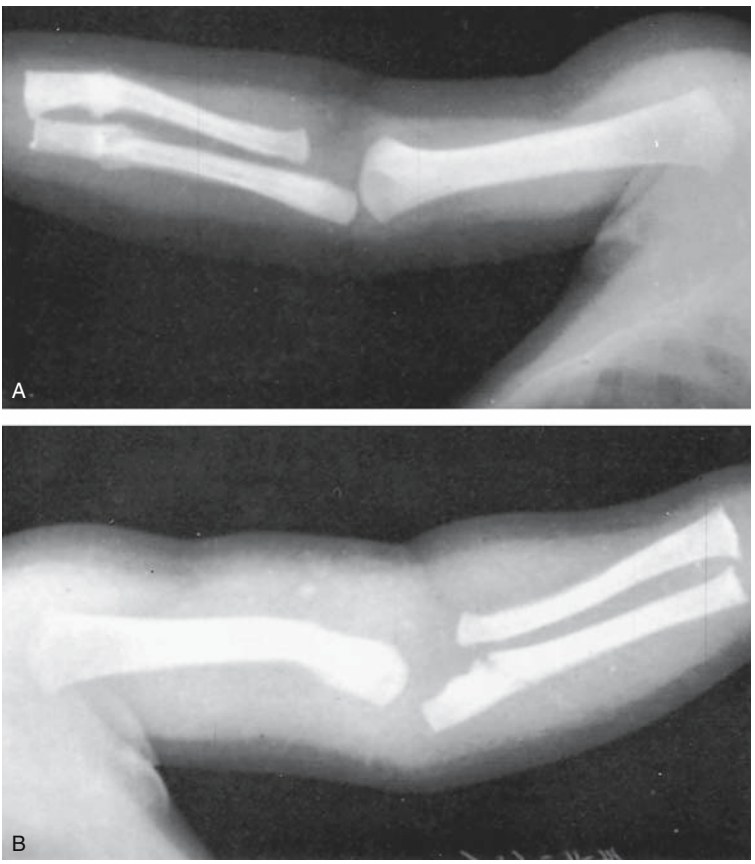


FIGURE 5-53. Multiple fractures in different stages of healing. (A) Fractures of the distal end of the right radius and ulna with callus at the fracture site and smooth periosteal new bone formation along the shaft. (B) Fracture of the left humerus and proximal end of the ulna with minimal reaction. There is also a metaphyseal avulsion of the distal end of the radius. (From Akbarnia BA, Adbarnia NO. The role of (the) orthopedist in child abuse and neglect. Orthop Clin North Am 1976;7(3):739. Reprinted by permission.)

b. Metaphyseal-epiphyseal fractures: "Bucket-handle" and "teardrop" fractures of the metaphyseal region generally suggest shaking the child while holding the limb.
c. Diaphyseal fractures: Spiral fractures of the distal humerus and fractures of the femoral shaft in a nonambulatory child are the most typical of abuse. Other long bone injuries occurring as an isolated finding should not generate a referral to child protective services.

This tragic problem is becoming more commonly diagnosed in recent years, primarily because of heightened societal awareness of the problem. Physicians need to be vigilant and knowledgeable of the hallmarks of the syndrome; only then can they meet their legal reporting requirements, thereby saving a child from return to an abusive environment.

Evaluation of a Limp

The limping child is a relatively common problem, and yet one that is difficult to evaluate. Multiple etiologies, the child's difficulty in localizing pain, and a vague history make it essential that the physician has a systematic approach to this problem. Rather than order multiple unpleasant and expensive diagnostic studies, it is usually more valuable to carefully observe and examine the child, especially in a sequential fashion.

Generically, a limp is any uneven or laborious gait or, for that matter, any alteration in normal gait sequence. Normal gait classically occurs in two phases for each extremity: stance and swing. The stance phase is initiated at heel strike for a given limb and terminated with toe-off of that extremity. Stance accounts for 60% normally, leaving 40% of the cycle for swing, when the foot is off the ground. Three classic aberrations of the gait cycle have been described in children:

1. Antalgic limp: Pain is the etiology of this gait aberration. Because of pain in the limb with ground contact, the stance phase is shortened and the patient unloads the extremity more quickly. Many etiologies will cause an antalgic limp, such as a fracture in the foot or toxic synovitis of the hip.
2. Trendelenburg limp (gluteus medius lurch): Frequently referred to as an abductor lurch, this pattern is due to the incompetence of the abductor lever arm to stabilize the pelvis (Fig. 5-54). If one remembers that a movement is created by a force acting over a distance, it can be appreciated that altering either factor will cause a Trendelenburg limp:
    a. Force alteration: Muscle weakness, as seen in polio
    b. Distance alteration: Shortened lever arm, as seen in DDH or malunited femoral neck fracture
3. Short leg limp: Leg-length discrepancy of significance will be manifested as an apparent limp with the pelvis dropping on the short side (Fig. 5-55).

A careful history should investigate a past traumatic event, systemic symptoms, and the effect on activity. Physical findings such as fever, focal findings of swelling, limitation of motion, and muscle spasm should be sought. Age itself may be a clue to the etiology as each group seems particularly prone to certain ailments.

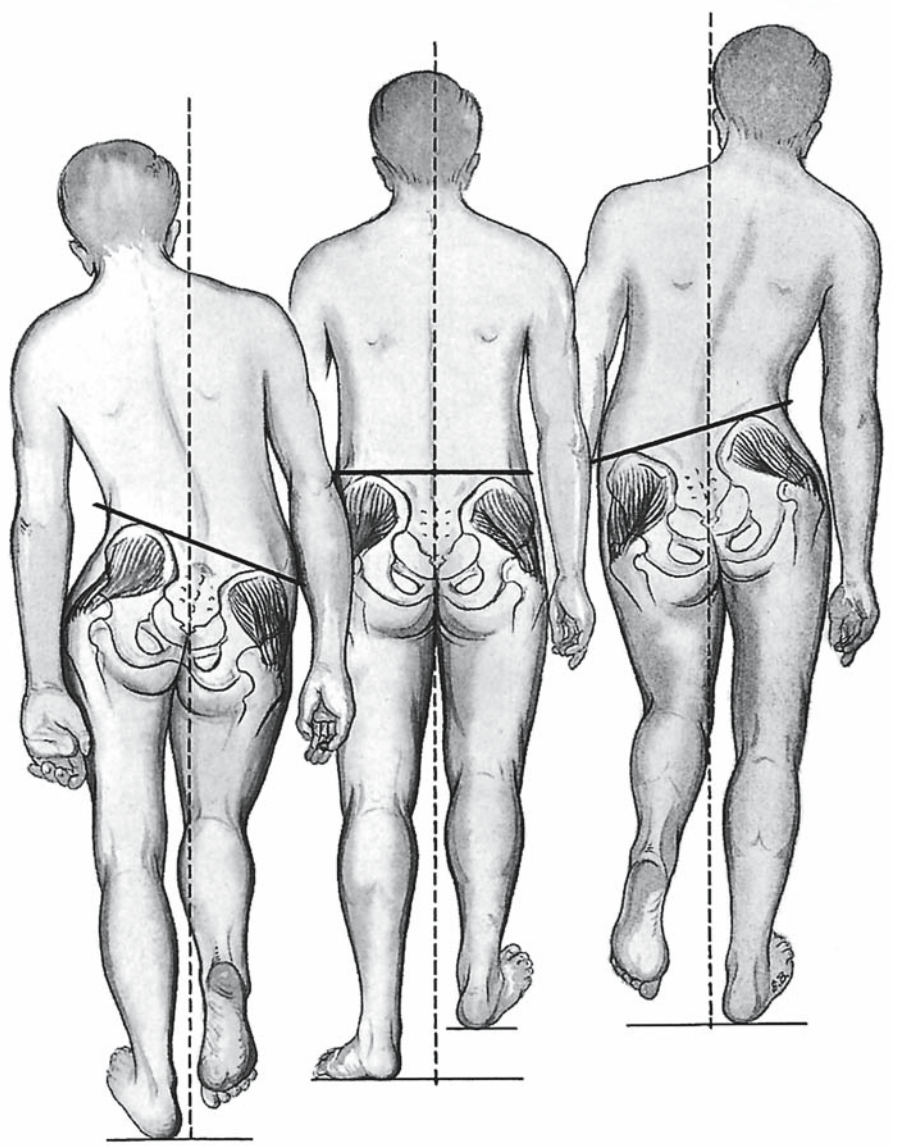


FIGURE 5-54. Gluteus medius lurch. (From Tachdjian MO. Pediatric Orthopedics, 2nd ed, vol 1. Philadelphia: Saunders, 1990. Reprinted by permission.)

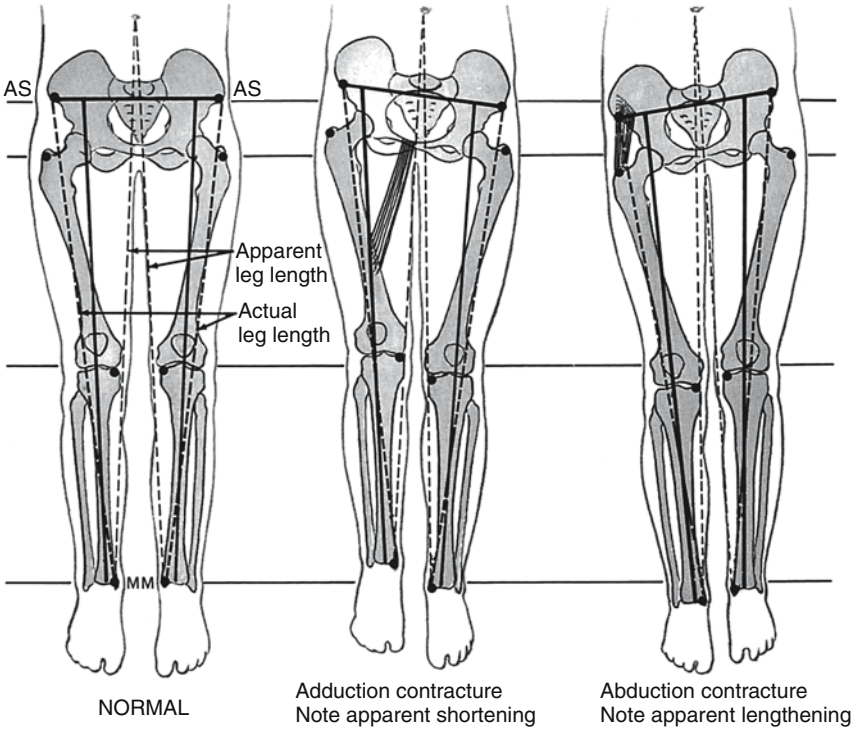


FIGURE 5-55. Measurement of actual and apparent leg lengths. *AS*, anterior iliac spine; *MM*, medial malleolus. (From Tachdjian MO. Pediatric Orthopedics, 2nd ed, vol 1. Philadelphia: Saunders, 1990. Reprinted by permission.)

1 to 3 years old: trauma, infection, DDH, new shoes
5 to 9 years old: transient synovitis, Perthes' disease, JRA, Lyme disease
Over 12 years: SCFE

Extending the diagnostic workup, one should first consider standard X-rays, especially of the hips. A routine hemogram is frequently beneficial. A three-phase bone scan is a reasonable second-line study, especially if localization is necessary. Unfortunately, it is not possible to specifically outline the studies to be routinely obtained. Reaching the correct diagnosis is all too often the result of coinciding historical data, physical findings, laboratory data, and a "gut" sense. Several diagnostic algorithms have been proposed that emphasize the basic factors in evaluating pediatric limp:

Is there a history of trauma?
Are there systemic symptoms?
Are there focal findings?

By answering there questions, a workup can be fashioned that should ultimately reveal the etiology.

Conclusions

Children are different. They are not small adults. Biologically and mechanically their musculoskeletal system predisposes them to patterns of injury and disease unique to their age group. By understanding these differences, one can anticipate some of the patterns, thereby permitting appropriate treatment and minimizing complications.

The seven categories of disease—vascular, infections, tumor, arthritis, metabolic, injury, and neurodevelopmental—all produce changes in the skeleton that reflect the unique feature of childhood: *growth*. Simple insults can be made worse over time as a result of aberrational growth and, conversely, potentially disastrous insults can be palliated by the innate remodeling potential of the pediatric skeleton.

Pediatric Spine: William Lauerman

Scoliosis

Scoliosis refers to abnormal curvature of the spine when viewed in the coronal plane. The human spine is normally straight when viewed from behind, but, because of the potential implications of unnecessarily labeling a child as "having" scoliosis, minor deviations from normal (less than 10 degrees) may be considered within normal limits. Scoliosis has been discussed in the medical and orthopedic literature since antiquity, and it is widely believed by the lay population and medical professionals to be a debilitating or disabling condition, resistant to treatment, and with a grave prognosis. Advances in both operative and nonoperative treatment in the past 40 years, as well as a better understanding of the natural history of scoliosis, have removed much of the stigma from this condition.

A variety of conditions may cause or be associated with scoliosis (Table 5-2). The most common type of scoliosis is referred to as idiopathic, meaning that the cause of the disorder is unknown. Hereditary factors have been implicated, and research is ongoing as to other possible causes of idiopathic scoliosis. Although it is likely that the development of idiopathic scoliosis is multifactorial, genetic, hormonal, biochemical, biomechanical, and neuromuscular abnormalities continue to be investigated. Idiopathic scoliosis can be categorized by age at diagnosis: curvature of the spine diagnosed up to age 3 years is defined as infantile idiopathic scoliosis, a diagnosis between the ages of 4 and 10 is juvenile idiopathic scoliosis, and a curve diagnosed after the age of 10, or the onset of adolescence, is

Table 5-2. Etiology of scoliosis.

Idiopathic
Congenital
Neuromuscular
Polio
Cerebral palsy
Posttraumatic (spinal cord injury)
Spinal muscular atrophy
Muscular dystrophy
Friedreich's ataxia
Charcot-Marie-Tooth disease
Syringomyelia
Myelomeningocele
Arthrogryposis
Neurofibromatosis
Marfan's syndrome
Ehlers-Danlos syndrome
Juvenile rheumatoid arthritis
Spine or spinal cord tumor
Postlaminectomy
Thoracic cage defect/deficiency
Osteochondrodystrophy (dwarfism)
Osteogenesis imperfecta

referred to as adolescent idiopathic scoliosis. Most cases of idiopathic scoliosis are identified during the adolescent growth spurt and are therefore considered adolescent curves.

Numerous other conditions either cause or are associated with scoliosis and must be considered when evaluating an individual for scoliosis. Congenital abnormalities of the vertebrae, resulting in congenital scoliosis or congenital kyphosis, represent some of the more common etiologies of spinal deformity. Neuromuscular disorders such as polio, cerebral palsy, muscular dystrophy, spinal muscular atrophy, or myelomeningocele are frequently associated with spinal deformity. Other conditions such as neurofibromatosis or Marfan's syndrome may result in spinal deformity, and scoliosis is also seen secondary to intraspinal anomalies such as syringomyelia (cystic degeneration of the central aspect of the spinal canal) or a tethered spinal cord. There is also a known association between scoliosis and certain congenital conditions such as congenital heart disease.

Estimates of the prevalence of scoliosis depend on the threshold for definition. Although 1.5% to 3% of the population is believed to have curves greater than 10 degrees, only 0.2% to 0.3% of the normal population have curves greater than 30 degrees, a magnitude where treatment is typically instituted. The natural history of idiopathic scoliosis has been well established. Most curves are identified in early adolescence. Progression is variable and is more likely in younger patients, in skeletally immature patients (in particular, premenarchal girls), and in larger curves.

Finally, although mild curves are as common in boys as in girls, progressive curves, and curves requiring treatment, are far more common in girls.

The implication of scoliosis in adulthood entails consideration of curve progression, pain, disability, and mortality. It has been established that an idiopathic curve greater than 50 degrees, in particular a right thoracic curve (which is the most common type of idiopathic curve), is at significant risk for progression even in adulthood. Although curve progression is a possibility, the presence of scoliosis does not necessarily place the patient at risk for back pain. Some patients with scoliosis appear to have pain related to the curve, but it has been demonstrated that patients with idiopathic scoliosis are not at any increased risk, when compared to the general population, for the development of disabling low back symptoms. Similarly, pulmonary dysfunction and significant functional disability are relatively rare occurrences.

The mortality rate of individuals with idiopathic scoliosis does not differ significantly, with the possible exception of severe (greater than 100 degrees) curves present since childhood, from that of the general population. Finally, scoliosis does not have an adverse impact on a woman's ability to bear children, nor is the curve more likely to progress during pregnancy than at other times.

Management

The management of a child with documented or suspected scoliosis begins with a thorough evaluation. Most cases are picked up during school screening or by the patient's primary care physician. The Adam's forward bend test is the key to checking a child for possible scoliosis. Asymmetry of the spine and trunk is identified by asking the child to bend forward at the waist with the knees straight and the hands hanging towards the floor (Fig. 5-56). The observer is seated behind the patient. Asymmetry of the ribs from right to left is considered a positive test and merits further evaluation by an orthopedist. Other possible signs of scoliosis include pelvic or shoulder asymmetry or asymmetry of the waist creases. Evaluation for scoliosis, including the Adam's forward bend test, should be a routine part of a pediatrician's well-child physical examination and is very sensitive for picking up most cases of scoliosis.

In evaluating the patient with possible scoliosis, important historical points include a family history of spinal deformity, any abnormality or delay in reaching developmental milestones, and associated neurologic symptoms involving the lower extremities or urogenital system, including gait abnormalities, paresthesias, recent onset of enuresis, etc. Physical examination includes the above evaluation as well as a thorough inspection of the skin, looking for café au lait spots, palpation of the spine, looking for an occult spina bifida, and examination of the lower extremities, looking for calf or foot atrophy or asymmetry. Neurologic examination should also

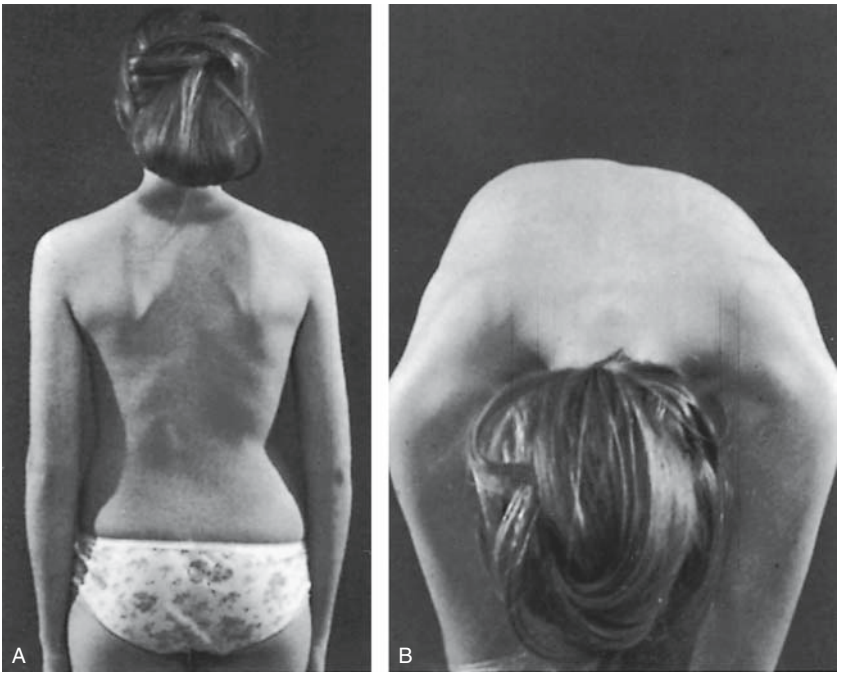


FIGURE 5-56. Careful examination by a school nurse resulted in early diagnosis of this curvature (10 degrees). Note the spine asymmetry in the flexed position (B).

be carried out, including assessment of deep tendon reflexes, superficial skin reflexes, and testing for Babinski's sign. Any sign or symptom suggestive of central nervous system abnormality merits a more detailed workup, possibly including imaging of the brainstem, spinal cord, or cauda equina.

Radiographic evaluation is carried out on any patient suspected of having significant scoliosis. A standing posteroanterior (PA) view of the full spine, including the pelvis, will demonstrate the presence or absence of significant deformity. The pelvis is inspected for evidence of skeletal maturity, manifested by closure of the iliac apophysis. In some cases obtaining a wrist film for bone age may be helpful. Because there is a known association between scoliosis and spondylolisthesis (see following), a lateral X-ray of the spine should be obtained, including visualization down to the sacrum.

Treatment options available for the growing child with scoliosis include observation, bracing, and surgery. Previous attempts at curve control utilizing physical therapy, chiropractic, exercises, or electrical stimulation have

proven ineffectual and are not to be recommended. Observation, with repeat radiographs every 4 to 6 months, is appropriate in the child with scoliosis less than 25 to 30 degrees. Curves that have been documented to progress beyond 25 degrees or curves measuring beyond 30 degrees at first presentation, in a child with significant growth remaining, are commonly treated with a brace.

For many years the standard orthosis for the treatment of scoliosis was the Milwaukee brace, which had documented effectiveness in controlling curves measuring between 25 and 40 degrees. Patient resistance to the use of the Milwaukee brace, including the neck and chin ring, has resulted in the now-widespread use of underarm orthoses such as the Boston or Wilmington brace. These braces have proven equally effective at controlling most thoracic and thoracolumbar idiopathic curves, avoiding the need for surgery in approximately 80% of cases, and have become the current standard for the management of curves of moderate magnitude in skeletally immature patients. Unfortunately, successful bracing means preventing any further progression of the scoliosis but does not usually result in permanent improvement in the curve.

When a curve exceeds 40 or 45 degrees, it becomes increasingly difficult to control with an external orthosis. Because of this, as well as the increasing risk of progression into adulthood with curves greater than 50 degrees, surgery is generally recommended for curves that progress into the range of 40 to 50 degrees. The commonly accepted indications for surgical treatment of scoliosis include adolescents with curves documented to have progressed beyond 40 to 45 degrees, adolescents with curves at presentation exceeding 45 to 50 degrees, and on occasion adults with either documented curve progression, disabling pain, or both. The goals of the surgical treatment of scoliosis include the arrest of progression, achievement of a solidly fused, balanced spine, and improvement in the curve with associated improvement in cosmetic appearance. Although upward of 50% curve correction can routinely be obtained in the adolescent, the more important goals of surgery are achieving a solid fusion, well balanced over the sacrum, and extending from the top to the bottom of the curve.

The surgical treatment of scoliosis constitutes, first and foremost, a spinal fusion. The most common approach to this fusion is posterior, although certain curves are amenable to anterior fusion. Since the introduction of the Harrington rod in the 1950s, instrumentation of the spine at the time of fusion has become well accepted. Improved rates of correction and fusion, as well as a diminished need for postoperative immobilization, have more than offset the risks incurred. Spinal instrumentation has evolved over the last quarter of a century and newer implants, utilizing multiple points of fixation along the spine, are more easily contoured to help the surgeon restore physiologic alignment in three planes. Postoperative immobilization is rarely needed when these newer implants are utilized (Fig. 5-57).

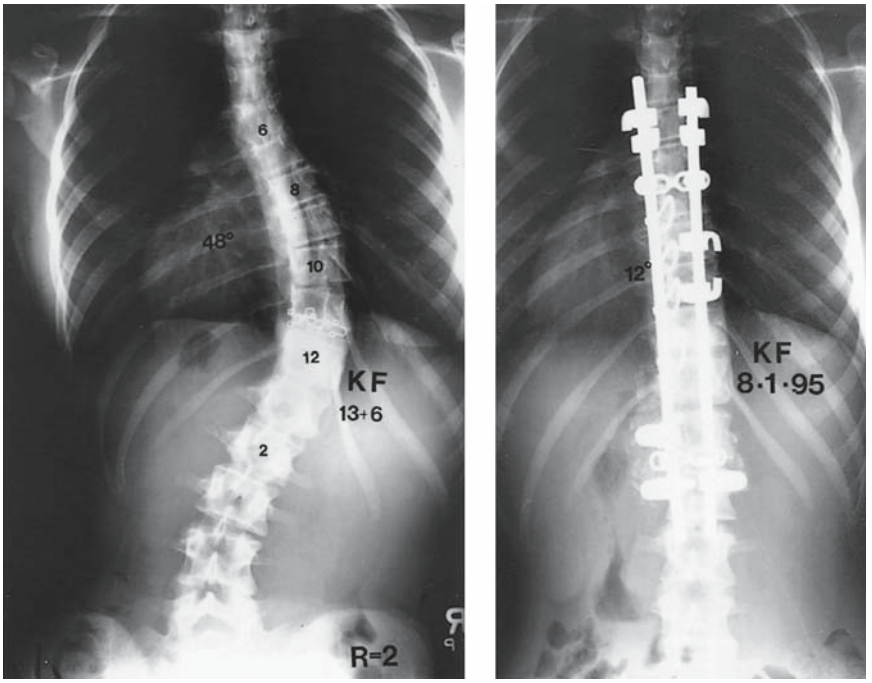


FIGURE 5-57. A 13-year-old girl with progressive idiopathic scoliosis measuring 48 degrees. Following surgery, a posterior spinal fusion with segmental instrumentation and iliac crest bone graft, her curve corrected to 12 degrees. She went on to a solid fusion with no loss of correction.

In the adolescent with idiopathic scoliosis, curve correction using modern techniques averages 50% to 70%. Ninety-five percent to 98% of patients go on to solid fusion with less than 10% loss of correction. Infection and thromboembolic disease are occasional complications of spinal instrumentation and fusion, although they are seen more commonly in adults than in adolescents. The most feared complication of surgery for scoliosis, paraplegia, is rare in the absence of a known risk factor such as kyphosis, congenital scoliosis, or a preoperative neurologic deficit, but it is a recognized occurrence.

Congenital Scoliosis

Individuals with congenital abnormality of the spine represent an unusual, but well-defined, subset of patients with spinal deformity. Failure of forma-

tion (hemivertebrae), failure of segmentation (bars), and mixed deformities are seen. The prognosis varies depending upon the type of anomaly present, but the patient with congenital scoliosis, in particular with a failure of segmentation, is certainly at higher risk for progression than the patient with an idiopathic curve. There is a known association between congenital spine deformity and congenital anomalies of the urogenital system, and all patients with congenital scoliosis or kyphosis should be referred for imaging of the genitourinary (GU) system. Congenital heart disease is also more common in this population, although a normal history and physical examination of the heart is considered sufficient to rule out a significant cardiac abnormality.

In addition to the increased risk of progression, which approaches 100% in curves involving a unilateral unsegmented bar, congenital curves have proven to be resistant to bracing. While progressive congenital scoliosis in a growing child is still routinely treated with an orthosis, the orthopedic surgeon, the pediatrician, and the patient and family need to be aware that there is a high risk for further progression necessitating surgical intervention. Congenital deformities can, on occasion, result in quite severe curves in very young children, but postponing surgery in this setting only results in a more difficult reconstructive problem at a later date.

Neuromuscular Deformity

Neuromuscular or paralytic causes of scoliosis include polio, cerebral palsy, muscular dystrophy, posttraumatic paraplegia, and myelomeningocele. At one time polio was the most common cause of scoliosis in this country, and it continues to be so in much of the Third World. Neuromuscular curves have a characteristic long, C-shaped appearance. Extension of the curve into the pelvis, with pelvic obliquity on sitting or standing, is common and complicates both surgical and nonsurgical treatment. The risk of scoliosis varies among these conditions but may be as high as 60% to 70%. All neuromuscular curves have a propensity, once progression ensues, for rapid collapse of the spine into a severe curve. Because of the respiratory difficulty associated with many of these conditions, it is imperative to screen patients carefully for scoliosis, to monitor them closely for progression, and to institute early and aggressive treatment when indicated.

Brace treatment with a well-molded, total-contact TLSO (thoracolumbosacral orthosis) is instituted for curves measuring beyond 30 degrees in the growing patient. Progression despite adequate bracing, resulting in progressive loss of function, is believed in most cases to be an indication for surgery in this patient population. In these patients, surgical treatment is fraught with a high rate of complications including instrumentation failure secondary to osteoporosis, increased rates of infection, and postoperative respiratory failure.

Kyphosis

Kyphosis refers to forward curvature, or rounding, of the spine when viewed from the side. Kyphosis is normal in the mid- and upper thoracic spine, with a normal range of thoracic kyphosis from 20 to 45 degrees in children and adolescents. Excessive kyphosis, as measured on a standard lateral radiograph exceeding 45 to 50 degrees, has several possible etiologies.

The child or adolescent presenting with hyperkyphosis of the thoracic spine is frequently accompanied by a parent giving a long history of "poor posture." Although postural kyphosis is not uncommon, other causes of the deformity should be considered. The most prominent among these is juvenile kyphosis, known as Scheuermann's disease. Although the etiology of Scheuermann's disease remains unknown, several theories have been proposed, including avascular necrosis of the cartilaginous ring apophysis of the vertebral body, the presence of Schmorl's node (herniation of intravertebral disk material through the end plate), endocrine or nutritional abnormalities, and metabolic bone disease. Congenital kyphosis is a rare condition that must be ruled out because of the possibility of severe progression and subsequent neurologic abnormality. As in congenital scoliosis, congenital kyphosis can result from failure of formation or failure of segmentation. In contrast to congenital scoliosis, however, congenital kyphosis secondary to failure of formation (congenital hemivertebrae) is the more-malignant type, with an exceedingly high rate of progression. Congenital kyphosis in association with a hemivertebra has the highest rate of neurologic impairment of any of the spinal deformities. Tuberculosis should also be considered in the child or adolescent with excessive kyphosis, particularly if there is a history of travel outside the United States or a positive family history.

Scheuermann's kyphosis is the most common form of nonpostural kyphosis. The criteria for diagnosis in the thoracic spine include excessive thoracic kyphosis with associated radiographic abnormalities including vertebral wedging of greater than 5 degrees at three consecutive vertebrae, end-plate irregularity, and the presence of Schmorl's nodes (Fig. 5-58). The reported prevalence of this disorder varies among authors but is approximately 1%. The female-to-male ratio varies from 1.4:1 to 2:1. Although the postural abnormality may be identified earlier, radiographic changes are usually not seen until 11 to 12 years of age.

Most cases of thoracic hyperkyphosis represent primarily cosmetic abnormalities. Mild postural kyphosis will frequently resolve spontaneously or following a thoracic extension exercise program. The natural history of Scheuermann's disease has only recently been elucidated. Most patients with Scheuermann's kyphosis lead normal lives, with no functional limitations and an incidence of disabling back pain that is not increased

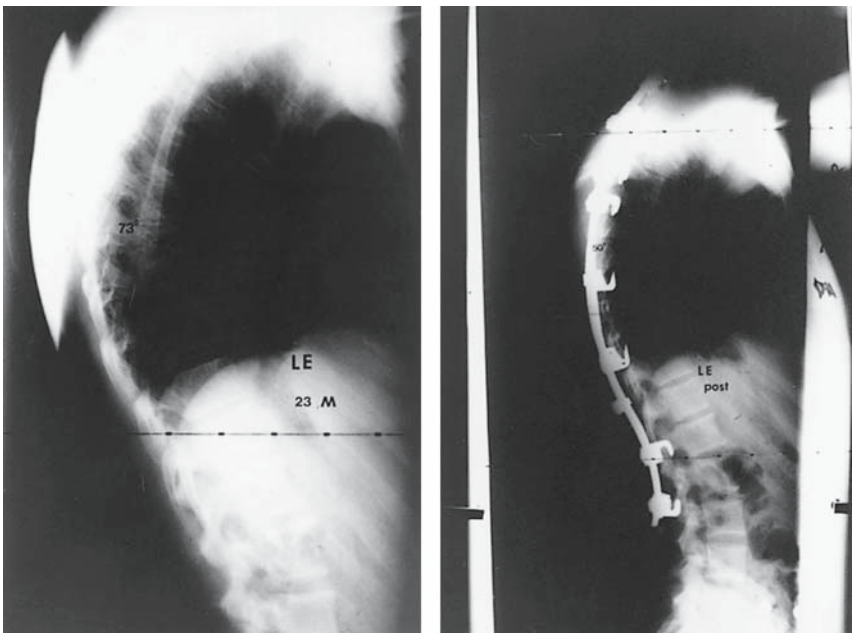


FIGURE 5-58. A 23-year-old man with persistent thoracic back pain secondary to Scheuermann's kyphosis. Because of failure to improve after a 1-year course of exercises and NSAIDs, he underwent a posterior fusion with segmental instrumentation and bone grafting, which resulted in excellent pain relief.

over the normal population. There is some evidence, however, that adults with kyphosis in excess of 65 to 70 degrees may have an increased incidence of thoracic back pain and mild to moderate functional limitations. Neurologic complications secondary to Scheuermann's disease are rare but have been reported. There is no evidence that cardiopulmonary dysfunction is a complication of this condition.

Management of the patient with hyperkyphosis begins with a thorough physical examination. The increase in normal thoracic kyphosis is best appreciated when viewed from the side and frequently coexists with increased lumbar lordosis. Differentiation between Scheuermann's disease and postural kyphosis is facilitated by viewing the patient, in the forward flexed position, from the side. Patients with postural kyphosis have a smooth, round curve that reverses on voluntary extension. The typical deformity in Scheuermann's kyphosis involves a sharp, angular gibbus that does not correct on extension of the spine. A minimal scoliosis of the spine may also be noticed on forward bending and is a common finding in

patients with juvenile kyphosis. A thorough neurologic examination is mandatory to rule out spastic paraparesis, which would suggest other possible diagnoses including congenital kyphosis, intraspinal anomaly, or thoracic disk herniation. Standing PA and lateral radiographs of the entire spine are obtained. Kyphosis is measured using the Cobb technique, and the lateral X-ray is scrutinized for findings of Scheuermann's disease, as already described. A mild scoliosis is frequently seen radiographically. In addition, it is important to check for the presence of lumbosacral spondylolisthesis, which has been reported to be increased in prevalence in patients with Scheuermann's disease.

Patients with hyperkyphosis can be treated with observation, bracing, or surgery. Observation, frequently accompanied by a program of thoracic extension exercises, is utilized in patients with postural kyphosis or without evidence of clear-cut progression in cases of Scheuermann's disease. Bracing is indicated for patients with structural kyphosis who have clear-cut evidence of progression of the curve and have at least 18 months of growth remaining. Because underarm orthoses are ineffective in this condition, Milwaukee brace treatment is required in most cases. In contrast to scoliosis, Scheuermann's kyphosis responds in many cases with long-lasting curve improvement following successful brace treatment. It should be noted, however, that patients with larger curves, in excess of 70 to 75 degrees, frequently lose correction following cessation of bracing.

Because of the usually benign natural history of Scheuermann's kyphosis, surgery is rarely indicated. Bracing should be attempted in most patients with adequate growth remaining because long-lasting curve improvement may result. Surgery is usually reserved for individuals who do not respond to brace treatment, who have curve progression in the brace, or who have severe curves, usually in excess of 80 to 90 degrees, that are not likely to respond to bracing and represent a potentially significant functional and cosmetic deformity. Surgery is also undertaken, on occasion, in adults with intractable thoracic back pain that does not respond to a nonoperative program of exercise and NSAIDs. These individuals usually have curves in excess of 65 to 70 degrees.

Surgery for the patient with Scheuermann's kyphosis consists of a spinal fusion with instrumentation. The fusion extends from just above to just below the area of kyphosis, typically over 10 to 12 levels. Flexible curves, which can be reversed to 55 degrees or less on hyperextension, may be treated with a posterior spinal fusion with compression instrumentation. More-severe or more-rigid curves are treated with anterior diskectomies and release of the hypertrophied anterior longitudinal ligament, followed by posterior fusion with instrumentation. Surgery typically results in excellent curve correction, ranging from 30% to 50% in most series of combined anterior and posterior surgery, which usually reduces the kyphosis into the normal range. Cosmetic improvement is significant, but when the surgery is undertaken for pain relief the results are uncertain. Complications of

surgery include infection, implant failure, and neurologic injury. Junctional kyphosis, the development of kyphosis above or below the end of the fusion, may be seen as well. It should be stressed that the surgical treatment of Scheuermann's kyphosis is rarely employed, and the surgeon, the patient, and the patient's parents need to view the natural history of this disorder in the context of the magnitude of the surgery required, usually a combined anterior and posterior approach.

Spondylolisthesis

"Spondylolisthesis" refers to the forward slippage of one vertebra on that below it. First described by Herbiniaux, a Belgian obstetrician, this condition has been extensively studied and reported. Spondylolisthesis is most common in the lower lumbar spine, particularly at L5–S1, and is a common cause of back pain in children and adolescents (Fig. 5-59).

Spondylolisthesis has been classified by Newman (Table 5-3). The most common types are type II, isthmic, and type III, degenerative. Degenerative spondylolisthesis occurs in middle-aged and older adults as a result of

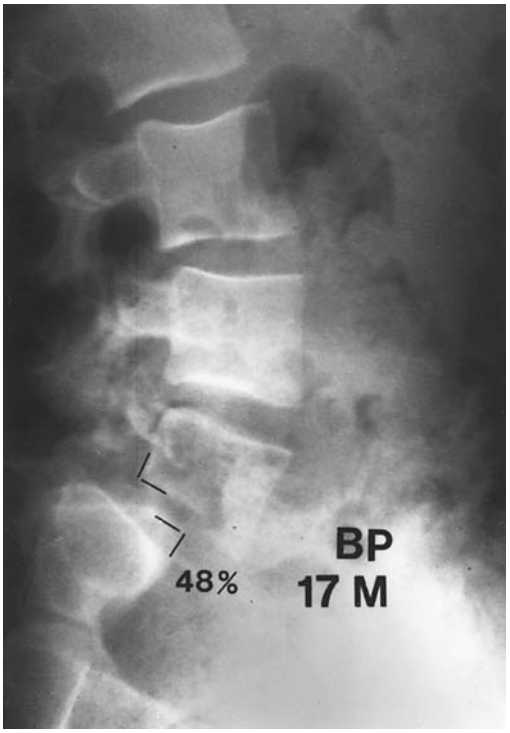


FIGURE 5-59. A 17-year-old boy with a 48% (grade II) isthmic L5–S1 spondylolisthesis.

Table 5-3. Classification of spondylolisthesis.

Type I:	Dysplastic—congenital dysplasia of the S1 superior articular facet, or L5 inferior facet.
Type II:	Isthmic—a defect in the pars interarticularis a. stressor fatigue fracture b. elongated but intact pars c. acute traumatic pars fracture
Type III:	Degenerative—degenerative changes in the disc and facet joints allowing subluxation.
Type IV:	Traumatic—acute fracture, other than in the pars (e.g. facet, pedicle, etc.), allowing anterolisthesis.
Type V:	Pathologic—attenuation of the posterior elements, with subluxation, secondary to abnormal bone quality (e.g. osteogenesis imperfecta, neurofibromatosis, etc.).
Type VI:	Postsurgical—anterolisthesis that occurs or worsens following compressive laminectomy.

degenerative changes in the disks and facet joints, allowing subluxation. It most commonly occurs at L4–L5 and is often associated with spinal stenosis. The most common type of spondylolisthesis is type II or isthmic spondylolisthesis; this is caused by a defect in the pars interarticularis at L5, resulting in slippage at L5–S1. The pars defect, referred to as spondylolysis, is believed to be a stress or fatigue fracture and occurs in most affected individuals when they are between the ages of 4 and 7. Spondylolysis is present in 5% to 6% of the normal adult population; 75% to 80% of these individuals also demonstrate spondylolisthesis. Spondylolisthesis is twice as common in males as in female and is more common in whites than in blacks. It is also seen more commonly in athletes who participate in sports demanding frequent hyperextension, such as gymnasts or football lineman.

In children and adolescents, spondylolysis or spondylolisthesis may present as back pain, frequently associated with hamstring spasm. Other less common causes of back pain in the pediatric population include disk space infection, benign tumors such as osteoid osteoma, or lumbar disk herniation. Isthmic spondylolisthesis can also be, and more commonly is, a cause of back pain in the adult. Patients with isthmic spondylolisthesis are reported to have an increased prevalence of disk degeneration, back pain, and sciatica, with the onset of symptoms occurring at any time during adulthood. Because back pain is such a ubiquitous complaint, the relationship between a patient's complaint of back or leg pain and the presence of spondylolisthesis is often difficult to determine.

Evaluation of the patient with spondylolisthesis begins with a thorough history and physical. In the adult, a history of back pain during adolescence may be helpful. Although acute pars fractures are occasionally seen, there is usually no distinct history of trauma given. The patient typically presents

with low back pain, which radiates into the buttock, and on occasion, down the leg in a dermatomal distribution. Physical examination may demonstrate tenderness in the area of the L5–S1 facet joint. Often a characteristic, painful "catch" in extension is elicited. The most telltale sign in the adolescent is hamstring spasm, which can be quite severe. In patients with a high-grade slip, flattening of the buttocks and a transverse abdominal crease may be seen. Neurologic findings are rare, although in more advanced cases L5 findings may be seen.

Plain radiographs should be obtained in the standing position. Most pars defects are visible on the lateral radiograph. If the diagnosis is uncertain, oblique views increase the sensitivity of plain radiography. The posterior arch has been described as a "Scotty dog" on the oblique view, and a pars defect appears as a "collar" on the neck of the Scotty dog (Fig. 5-60). Radionuclide bone scanning [single photon emission computed tomography (SPECT) scan] or fine-cut CT scanning may be used to diagnose occult defects in the pars interarticularis, and MRI imaging is useful to identify nerve root compression in the L5–S1 foramen in patients with significant leg pain.

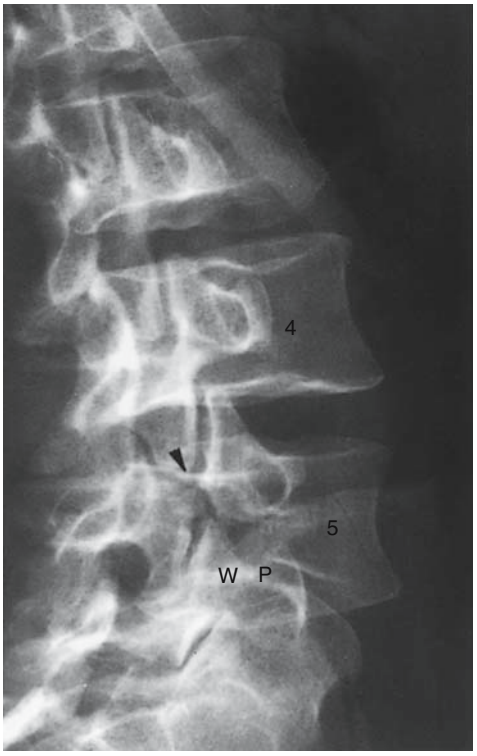


FIGURE 5-60. A pars defect (spondylolysis) at L4, seen on this oblique radiograph as a "collar" on the neck of the "Scotty dog."

The treatment of patients with spondylolysis or spondylolisthesis depends on the degree of slippage as well as the patient's symptoms. The percent slip ranges from 0% to 100% and has been broken down as grades I (0%–25%), II (25%–50%), III (50%–75%), and IV (75%–100%). It is not uncommon for pediatric patients to be diagnosed with spondylolisthesis following an episode of minor trauma and then to become asymptomatic. In the skeletally immature patient who is asymptomatic, activity guidelines are based on the degree of slippage. In patients with a grade I slip, full activity is allowed with annual radiographic follow-up. Skeletally immature individuals with grade II spondylolisthesis are advised to avoid contact sports or repetitive hyperextension activities such as are seen in gymnastics. Operative treatment is usually recommended for skeletally immature patients with progressive slippage or with grades III or IV spondylolisthesis.

Symptomatic patients are initially treated with activity modification and NSAIDs. Because many of these patients are athletes, temporarily holding them out of their sport frequently results in improvement in symptoms. The patient is then begun on a program of Williams' flexion exercises and gradually increased activity. Persistent symptoms sometimes respond to bracing, and treatment with a brace or cast is advocated by some when an acute pars fracture is suspected. The majority of patients, both pediatric and adult, respond quite well to nonoperative treatment, although a return to high-level competitive sports is sometimes impossible.

Operative treatment is recommended for patients with progressive spondylolisthesis, for skeletally immature patients with spondylolisthesis exceeding 50%, and for patients with persistent, incapacitating pain. The overwhelming majority of surgical patients fall into the latter category. The hallmark of the surgical treatment of spondylolisthesis is spinal fusion. Intertransverse fusion between the transverse processes of L5 in the sacral alae, utilizing iliac crest bone graft, has a high rate of success with a low complication rate. In adult patients with significant buttock and leg pain, or in individuals with neurologic deficits secondary to root compression, removal of the loose posterior arch of L5 and decompression of the exiting L5 nerve root are recommended. Fusion is routinely performed in addition to decompression in these cases. Many authors recommend pedicle screw instrumentation as an adjunct to spinal fusion; instrumentation is routine in adults, in patients with spondylolisthesis greater than 25%, and in individuals with documented instability. Finally, operative reduction of the spondylolisthesis is advocated by some in cases of severe spondylolisthesis, usually exceeding 60% to 70% slippage, with a concomitant cosmetic deformity. The results of surgery are usually quite rewarding, particularly in the pediatric population. Complications of surgery include failure of fusion, progressive slippage, persistent or recurrent pain, and neurologic injury. Complication rates are higher in

adults, in higher grades of spondylolisthesis, and when reduction is attempted.

Suggested Readings

MacEwen GD. Pediatric Fractures. Malvern, PA: Williams & Wilkins, 1993.
Staheli L. Fundamentals of Pediatric Orthopaedics. New York: Raven Press, 1992.
Wenger D, Rang M. Art and Practice of Children's Orthopaedics. New York: Raven Press, 1993.

Questions

Note: Answers are provided at the end of the book before the index.

5-1. Skeletal dysplasias:
   a. Are focal abnormalities of the skeleton
   b. Are frequently hereditary
   c. Rarely involve the craniofacial structures
   d. Are typically due to a vitamin deficiency
   e. Are not associated with angular deformity of the knees

5-2. Developmental dysplasia of the hip:
   a. Is multifactorial in origin
   b. Is more common in females
   c. Usually involves the left hip
   d. All of the above
   e. None of the above

5-3. The periosteum:
   a. Is osteogenic in the child
   b. Usually blocks fracture reduction
   c. Is of no mechanical significance
   d. Is a cartilaginous membrane
   e. Extends over the articular surface

5-4. The physis:
   a. Is the strongest structure of a long bone
   b. Has three zones
   c. Is critical for growth in girth of the diaphysis
   d. Is rarely fractured
   e. Is the site of pathology in achondroplasia

5-5. Slipped capital femoral epiphysis:
   a. Is more common in thin children
   b. Usually is classified as stable versus unstable
   c. Is often treated by femoral osteotomy
   d. Causes an internal rotational deformity of the hip
   e. Presents as a painless limp

5-6. Avascular necrosis of the femoral head can be seen in:
   a. Perthes' disease
   b. Developmental dysplasia of the hip
   c. Slipped capital femoral epiphysis
   d. All of the above
   e. None of the above

5-7. Which of the following is not typical of Down syndrome?
   a. Trisomy 21
   b. C1–C2 subluxation
   c. Hip subluxation
   d. Cavus (high arch) feet
   e. Ligamentous laxity

5-8. Which of the following should not lead one to the diagnosis of battered child syndrome?
   a. Parietal skull fractures
   b. Humeral diaphyseal fracture
   c. Femoral fracture in a nonambulatory child
   d. Cigarette burns
   e. Retinal hemorrhages

5-9. In the workup for growing pain, leukemia must be considered. Which of the following is not a characteristic of "growing pain syndrome?"
   a. Nocturnal pain in the leg
   b. Symmetrical involvement, although not simultaneous
   c. Occurs in children 3 to 9 years of age
   d. Normal white count
   e. Metaphyseal banding on X-ray

5-10. Trendelenburg gait:
   a. Results from weakness of the adductor muscles
   b. Is not commonly caused by diseases of muscle weakness
   c. Is characterized by the pelvis dropping on the contralateral side when weight is borne on the affected side
   d. Follows lengthening of the lever arm at the hip
   e. Is not a characteristic of DDH

5-11. Pediatric fractures are known to show extensive degrees of remodeling. This assumption can often be misleading. All the following deformities typically cause problems simply because they do not remodel adequately, except:
   a. Rotational deformity
   b. Angulation not in the phase of motion of the joint
   c. Salter IV fractures of the physis
   d. Plastic deformation of the ulna with fractured radius
   e. Complete displacement in forearm fractures of a 4-year-old child

5-12. The Pavlik harness:
   a. Is the worldwide treatment for infants with DDH
   b. Can cause avascular necrosis
   c. Is not applicable for children over 1 year of age
   d. All of the above
   e. None of the above

6
Sports Medicine

John J. Klimkiewicz

The emphasis presently placed on physical fitness in society in terms of overall health is at an all-time high. Participation in both organized and recreational sports has escalated during the past several decades as a result. This increase in participation has lead to an emphasis on treating injuries associated with sporting activities. The advances within medicine regarding the diagnosis of these injuries, such as magnetic resonance imaging (MRI), as well as arthroscopy for their treatment, has improved results only to focus more attention within this field. A number of skilled physicians and other health professionals have developed interests regarding the specific care of athletes. The goal of sports medicine as a subspecialty is the prevention of injury, diagnosis and treatment of athletic injury, and returning athletes to preinjury activity with no acute or long-term sequelae. The purpose of this chapter is to focus on the biologic tissues involved in sporting injuries, highlighting the patterns in which they are injured. An overview then follows regarding the evaluation and treatment principles as they relate to the management of athletes and sport-specific injuries.

Patterns of Injuries

Injuries within the field of sports medicine can be generally classified into one of two categories: *microtrauma* and *macrotrauma*. Microtraumatic injuries are those that typically are associated with overuse injury by the athlete, such as many of the tendonopathies or stress fractures that are common in long-distance runners. Microtraumatic injuries are the result of repetitive stresses leading to structural breakdown of the tissue in question. Macrotrauma, on the other hand, involves a single traumatic episode resulting in injury to a specific region. A downhill skier fracturing the tibia, or a soccer player cutting and injuring the anterior cruciate ligament, are two examples of macrotraumatic injury. In these instances the force imparted to a specific tissue is greater than that tissue is able to withstand, resulting in catastrophic mechanical failure of that tissue.

Musculoskeletal Tissues

Tendons

Tendons are strong, inextensible tissue that attach muscle to bone. They are composed of closely packed, well-aligned collagen bundles within a matrix of proteoglycan. Fibroblasts are the predominant cell type and are arranged in parallel orientation between the bundles of collagen fibers. The tendon fibroblasts act to produce both collagen and proteoglycan within the tendon unit. Collagen is a major constituent of tendon. Type I collagen comprises 86% of a healthy tendon's dry weight, whereas type III is found in lesser amounts. It is the high concentration of collagen in combination with its parallel orientation that gives tendons their high tensile strength. Collagen chains are linked together to form fibrils that in turn are bound together by a proteoglygan matrix to form a fascicle, the primary unit in tendon structure. Fascicles in turn are bound by the endotenon, a layer of elastin-containing loose connective tissue that supports the blood, lymphatic, and neural supply to the tendon unit. It is the endotenon that is contiguous with both the muscle fibers and periosteum at the musculotendinous and tendoosseous junctions, respectively.

Acute tendon injuries may be direct, occurring as a result of laceration or contusion, or indirect, occurring secondary to tensile overload. Both are examples of macrotrauma. Tensile overload is a common injury within the field of sports medicine (i.e., patellar tendon, Achilles tendon ruptures). In the majority of these cases, because most tendons can withstand tensile forces greater than can be exerted by their muscular or bony attachments, avulsion fractures and muscle tendon junction ruptures are far more common than midsubstance ruptures of tendon.

Chronic tendon overload represents the classic microtraumatic injury in sports medicine. These injuries occur at the sites of high exposure to repetitive tensile overload. Examples can be found in Table 6-1. Whether inflammation has a role in the early stages of these overuse injuries is unclear. However, in cases that are not responsive to short periods of rest with persistence of symptoms, similar findings can be seen histologically, reflecting a more-degenerative process. Disruption of collagen fibrils, hyaline degeneration, and proliferation of vasculature are classic in these entities, termed angioplastic fibroplasias, and result in a tendonosis or breakdown of the corresponding tendinous unit. At this stage it is clear that this is not an inflammatory process, as no acute or chronic inflammatory infiltrates are demonstrable on these histologic specimens. Tendonosis is also observed in cases of spontaneous rupture and may be clinically silent until rupture occurs. An example is an Achilles tendon rupture seen in middle-aged athletes participating in strenuous sports.

Table 6-1. Common sites of sports-related tendon overload.

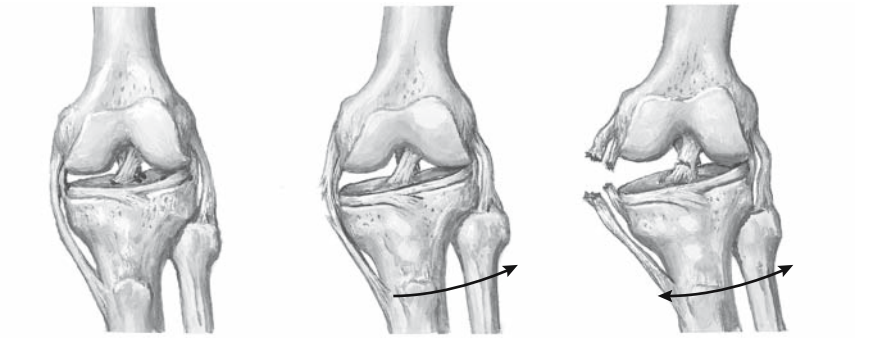
Site of injury	Sport
Achilles tendon	Running
Iliotibial band	
Flexor hallicus longus tendon	Dancing
Patellar tendon	Basketball, volleyball
Quadriceps tendon	
Supraspinatus tendon	Swimming, softball, baseball, golf, racquet sports
Extensor carpi radialis brevis tendon	
Flexor pronator origin	
Abductor pollicus longus tendon	Rowing
Extensor pollicus brevis tendon	

Ligaments

Ligaments are short bands of connective tissue that serve to connect two osseous structures. Similar to tendons, these are very organized hierarchical structures with high tensile strength. Ligaments are likewise composed of bundles of type I collagen fibers, which make up approximately 70% of its dry weight. Small amounts of elastin are combined with fibroblasts in a complex extracellular matrix. This collagen matrix comprises a series of fibers forming a subfasicular unit. Multiple subfascicular units are then bound together to form a fasciculus. These fasiciculi can in turn be oriented in a simple longitudinal fashion, such as the medial collateral ligament of the knee, or can spiral to form a more-helical structure, such as the anterior and posterior cruciate ligaments of the knee.

At their attachments to bone, the transition from ligament to bone occurs gradually in a series of distinct phases. These phases range from ligament to fibrocartilage, from fibrocartilage to mineralized fibrocartilage, and from mineralized fibrocartilage to bone. The size of each zone varies from ligament to ligament and is related to its structural properties. Collagen fibers, known as Sharpey's fibers, run in continuity throughout this zone of transition and have an important role in securing the ligament to bone. Although somewhat similar to tendons in their microscopic organization and composition, ligaments and tendons are structurally and biochemically different. Ligaments contain a lower percentage of collagen and a higher percentage of extracellular matrix. There is also a more-random alignment of collagen fibers than their tendinous counterparts.

In contrast to injuries to tendons that can be both acute and chronic processes, ligamentous injuries occur as a result of acute trauma and represent a macrotraumatic process. When a stress is applied to a ligament, a sprain occurs, whose severity (grades I–III) depends on the amount of stress applied (Fig. 6-1). A grade I sprain represents the least traumatic episode when some ligamentous fibers are torn on a microscopic level. Structural integrity of the ligament however is maintained. An example of



1st-degree sprain. Localized joint pain and tenderness but no joint laxity

2nd-degree sprain. Detectable joint laxity plus localized pain and tenderness

3rd-degree sprain. Complete disruption of ligaments and gross joint instability

FIGURE 6-1. Classification of ligamentous injuries (sprains). (Netter images reprinted with permission from Elsevier. All rights reserved.)

this is a common ankle sprain where traditionally the anterior talofibular ligament is injured. In a grade II sprain, some fibers are macroscopically torn in combination with microscopic damage resulting in a stretching of the ligament. Although the biomechanical properties of the ligament are compromised in this scenario, some structural integrity of the ligament remains. An example of this injury is an injury to the medial collateral ligament to the knee. On application of a valgus force the knee demonstrates increased laxity as compared to the other side, but an endpoint is present to the ligament, signifying some integrity to this structure remains. In a grade III sprain, the ligament structure fails, with no structural integrity of the ligament remaining. After rupture of the anterior cruciate ligament, there is both an increase in anterior translation when an anterior force is applied to the tibia and a nonexistent endpoint; this represents a complete failure.

Intra- and extraarticular ligaments differ in their response to acute trauma; this is influenced by a difference in the local vascular supply of these entities, as well as the degree of the injury, and whether a significant gap forms between the two ends of ligamentous rupture. Typically, extraarticular ligaments have a high potential for healing and gradually heal with predominantly type I collagen within 6 to 12 weeks. Maturation of this ligament scar can take up to 1 year in some cases despite histologic evidence of healing as early as 6 weeks. Contrastingly, intraarticular ligaments such as the anterior cruciate ligament have a poor healing potential. In

cases of complete disruption of this structure, dissociation of the midsubstance "mop ends" results in significant gap formation with inhibition of the healing process. These differences result in different treatment approaches to these injuries, as extraarticular ligamentous injuries are frequently treated conservatively whereas intraarticular injuries are typically treated surgically secondary to a poor healing response.

Muscle

Injuries of skeletal muscle and the musculotendinous junction commonly lead to prolonged clinical disability. Muscle strains alone account for up to 50% of injuries in particular sports.

Active force generation within muscle depends on its contractile apparatus. The contractile apparatus is composed of actin and myosin myofilaments that are arranged into functional units called sarcomeres. Muscle contraction consists of an energy-dependent process of cross-bridge unlinking and advancement of the myofilaments within the sarcomere. Either aerobic or anaerobic processes provide cellular energy for this process. Muscle fibers may be characterized by their capacity for aerobic respiration. Oxidative (red) fibers are characterized by sustained, slow contractions, whereas glycolytic (white) fibers contract rapidly under anaerobic conditions. Fiber type composition varies significantly between muscular groups and among different individuals. The force of muscle contraction is directly related to its cross-sectional area, which is reflective of its number of parallel contractile elements.

Muscular injury can result from direct mechanical deformations that occur in muscular strains, contusions, and lacerations or indirect mechanisms such as vasculature or neurologic injury as is seen in the cases of acute and chronic (exercise-induced) compartment syndromes.

Muscular strains involve either partial or complete disruption of the muscle–tendon unit; this represents a macrotraumatic process. Clinical and experimental observations suggest that most muscular strain injuries involve the muscle–tendon junction. Common examples involve hamstring and adductor strains surrounding the hip, which usually occur with passive stretch or with lengthening during muscular contraction (eccentric contraction). Complete injuries are often associated with muscle retraction, hematoma formation, and local inflammation, while lesser-degree strains involve more microscopic failure. Functional recovery is dependent on the coordinated specific repair of the contractile elements with their surrounding connective tissues and neurovascular structures. This process can take up to 6 months in some cases. After injury, individual muscular fibers may contract normally after repair and regeneration, but whole muscle contractile function rarely is normal after gross skeletal muscular injury.

Less common are muscular contusions that are a result of direct trauma. In these cases, such as a quadriceps contusion, skeletal muscle damage

results from nonpenetrating sudden high-energy force directed to the muscular group in question. These forces can result in the temporary or permanent loss of vascular and neurologic function secondary to direct trauma imparted to the musculature. These injuries are often characterized by a large associated hematoma. Ultimate recovery is often related to the magnitude of original injury. A relatively infrequent complication of this is myositis ossificans. In this case, normal mesenchymal cells involved in the healing process differentiate into osteoblasts, resulting in the formation of bone. This abnormal bone often results in a prominence in the injured area, with subsequent symptoms.

Articular Cartilage

Often associated with trauma surrounding a particular joint are injuries and more long-term degeneration of the articular cartilage. When diffuse and occurring over a period of time, this process can result in osteoarthritis (microtrauma); however, there is an additional subset of these injuries that are more focal and result from a direct injury, often referred to as osteochondral injuries (macrotrauma). Although highly desirable, functional restoration of injury to articular cartilage remains one of the most challenging of orthopedic problems with the sports medicine field.

Articular cartilage composition and thickness varies from joint to joint and is directly age dependent. The tissue typically is composed of 75% to 80% water and dense extracellular matrix consisting of 50% to 75% type II collagen and 15% to 30% proteoglycan macromolecules. Water and proteoglycans make up its extracellular matrix. A remarkable characteristic if articular cartilage is its acellularity, as chondrocytes occupy less than 10% of this tissue. These cells maintain the extracellular matrix and aid in cellular homeostasis. The collagen provides tensile strength to articular cartilage while the proteoglycans and extracellualr matrix provide its more important compressive role.

Structurally, articular cartilage is highly organized into four zones of depth from the articular surface to the underlying subchondral bone (Fig. 6-2). Zone 1, also called the *superficial layer*, makes up approximately 10% of cartilage, determines its load-bearing ability, and serves as a gliding surface. Within this layer chondrocytes are arranged with collagen fibers are parallel to the joint surface to provide high tensile strength and stiffness. Zone 2 is a *transitional layer* and is composed of chondrocytes and randomly oriented collagen fibers. It has a higher concentration of proteoglycan and lower concentration of collagen as compared to Zone 1. Zone 3 or the *deep layer* is composed of collagen fibers and clusters of chondrocytes oriented perpendicular to the underlying subchondral plate, providing compressive strength. Zone 4, the *calcified layer*, acts to join the deep zone of uncalcified cartilage to the subchondral bone. There are few cells within this layer. It contains the tidemark adjacent to the subchondral bone.

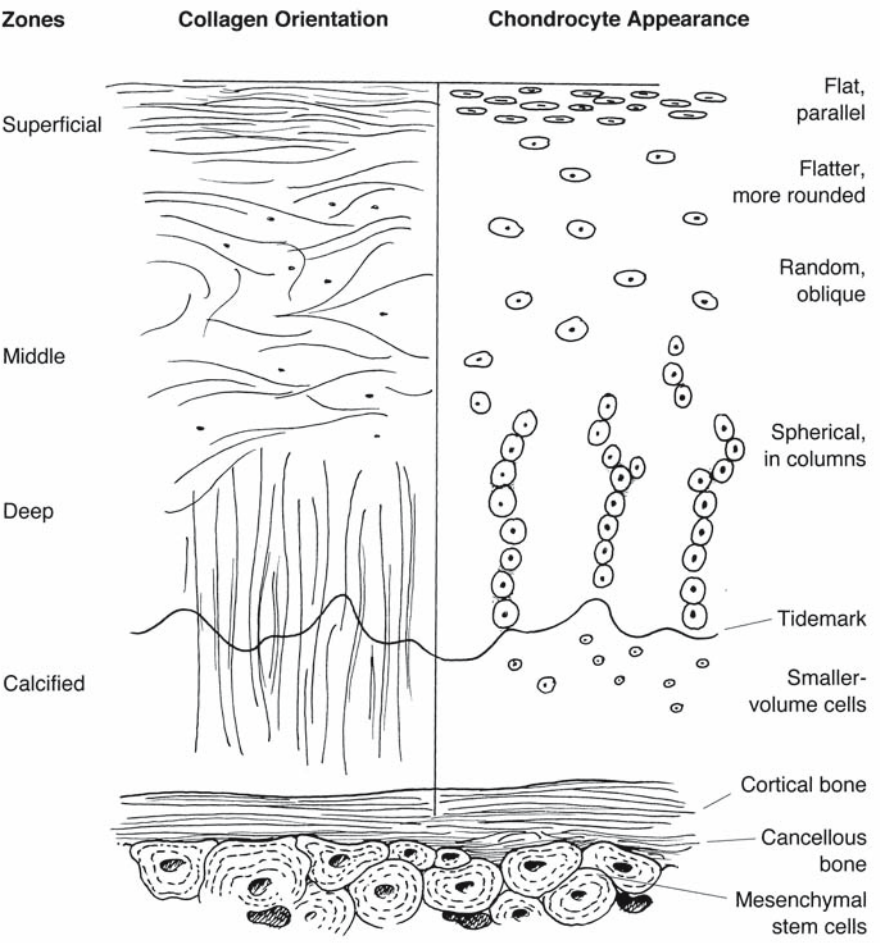


FIGURE 6-2. Morphology of articular cartilage. (From Browne JE, Branch TP. Surgical alternatives for treatment of articular cartilage lesions. Copyright 2000 American Academy of Orthopaedic Surgeons. Reprinted from the Journal of the American Academy of Orthopaedic Surgeons, Volume 8 (3), pp. 180–189 with permission.)

Articular cartilage is an avascular as well as aneural tissue. As an avascular tissue it exchanges gases, nutrients, and waste products through a process of diffusion through tissue fluid or synovium. This poor blood supply results in poor reparative capability in the event of acute injury or chronic wear.

Injuries to articular cartilage are best described by the Outerbridge classification system (Fig. 6-3). This system characterizes the injury to articular cartilage based on its qualitative appearance at the time of surgery: grade I, softening with swelling; grade II, fragmentation and fissuring; grade III,

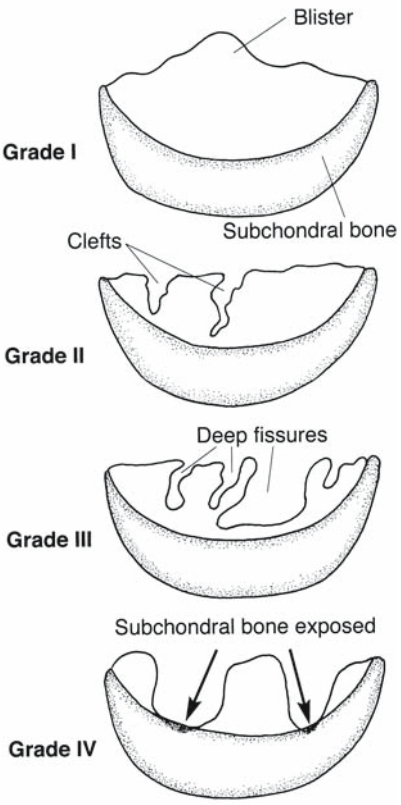


FIGURE 6-3. Outerbridge classification. (From Browne JE, Branch TP. Surgical alternatives for treatment of articular cartilage lesions. Journal of the American Academy of Orthopaedic Surgeons 2000;8:180–189. Reprinted by permission.)

fragmentation and fissuring down to subchondral bone; grade IV, exposed subchondral bone. Grade I/II lesions are thought to involve superficial injury and are best left untreated while grade III/IV lesions represent full-thickness cartilaginous injuries and are best treated surgically.

Meniscus

The meniscus of the knee is formed of a combination of fibrocartilage with some proteoglycan. The collagen fibers are type I and are arranged in a predominantly circumferential orientation. It is this orientation that gives this tissue its unique loading characteristics and function within the knee. This highly structured network provides the ability of the meniscus to allow the compressive forces of joint loading to be dissipated circumferentially along these parallel collagen fibers, termed hoop stresses. The meniscus biomechanically transmits a compressive force to one that is tensile in nature and absorbed within the meniscus. Injury to the meniscus results in a decreased ability to perform its function, resulting in higher compressive forces being transmitted across the knee joint.

Similar to articular cartilage, the vascularity of the meniscus is poor. Only the peripheral one-third of the meniscus receives a blood supply, and therefore the potential for healing after injury is limited. Location and type of meniscal tearing in a symptomatic knee determine one's ability for potential healing. Meniscal injuries are best categorized by the location of the tear as well as the morphology of the tear. The location can be best described in reference to the blood supply of the meniscus. *Red–red* tears involve the peripheral one-third of the meniscus and have excellent healing potential. *Red–white* tears involve a zone of the meniscus with good blood supply on the peripheral aspect of the tear and poor blood supply on the more-central portion and have intermediate healing potential. *White–white* tears involve those tears in the avascular zone completely with poor healing potential. Morphologic classification of meniscal tears is demonstrated in Fig. 6-4.

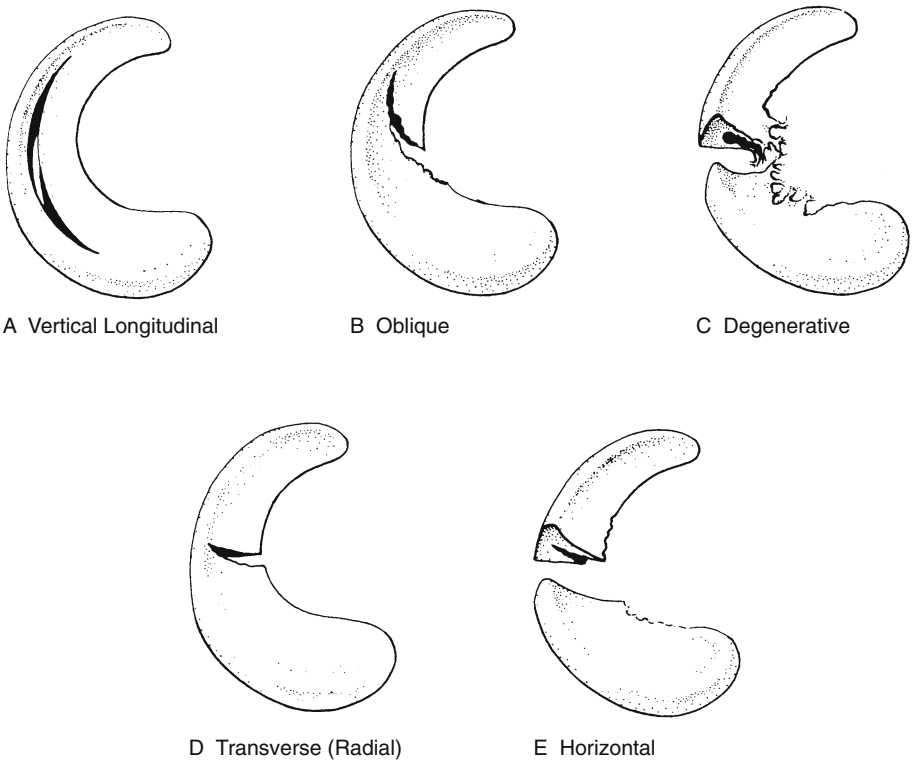


FIGURE 6-4. Morphology of meniscus tears. (From Fu FH, Harner CD, Vince KG (eds) Knee Surgery, vol 1. Philadelphia: Williams & Wilkins, 1994. Reprinted by permission.)

Evaluation of Common Sports Medicine Injuries

The principles involved in the initial evaluation of the injured athlete focus on history and physical examination in combination with auxiliary tests and are similar in comparison to other orthopedic injuries. This subspecialty differs from that of a general orthopedic setting in two distinct manners. One large difference in the management of the athlete is the ability to provide prompt "on-the-field" attention as a result of game time coverage by the sports medicine physician; this allows one to often visualize the injury directly and distinguish as to whether the mechanism was a direct result of blunt trauma as compared to a more-indirect mechanism (i.e., cutting injury). Additionally, it provides one with a golden window of time to evaluate the injury before the effects of swelling and subsequent pain and spasm complicate the physical exam. It often allows one the opportunity to make the diagnosis without the need for auxiliary tests that are often required when evaluating these injuries on a more-subacute basis. Furthermore, the sports medicine physician is often asked the safety of returning to play in light of a specific injury. Knowledge of the common injuries as well as the sporting activities themselves is important in making these decisions. The following sections focus on the history as well as physical examination in the sports medicine setting. Specifics regarding the injuries are elaborated in their respective chapters.

History

The history in many sporting injuries is straightforward and related to acute trauma. Examples include twisting the ankle when coming down for a rebound, feeling the shoulder "pop out" when being tackled, or hearing a "pop" within one's knee on cutting cross-field. Important in this history is the mechanism of injury, as this often relates very closely with the structure injured. When this is more ambiguous on questioning the athlete, input from other players, trainers, and coaches as well as game-time film can be invaluable in determining the mechanism of injury. Other injuries within this field are a result of microtrauma, or overuse, and have no specific mechanism of injury. Examples can include plantar fasciitis of the foot or shin splints. For these insidious conditions, its important to obtain the specifics of recent activity including change in recent activity, change in shoe wear or other equipment, the surface involved (track to road, flat surface to hills, etc.). Other pertinent details include whether this problem has occurred before, and if so, how it happened, what type of treatment was rendered, and what was the outcome. Previous problems may alert the clinician to a different treatment problem to prevent recurrence of the injury. Examples include the management of "first-time" as opposed to recurrent shoulder dislocations.

Symptoms that occur with activity and improve with rest are typical of overuse injuries. Nocturnal awakening usually indicates more serious injury or an underlying systemic disorder. Such a distinction is important in distinguishing shin splints from a stress fracture in a long-distance runner. Are there any specific activities that might cause symptoms? In the athlete with intermittent knee symptoms, pain in the anterior aspect of the knee that is worse with stair climbing or with prolonged sitting suggests problems related to the patellofemoral joint. Symptoms that occur predictably with cutting and pivoting activities, accompanied by swelling and instability, suggest an internal derangement of the knee such as a meniscus injury or tear of the anterior cruciate ligament.

Physical Examination

The specific examination depends on the nature of the symptoms and the region affected. Each anatomic region and orthopedic condition have pertinent special tests. All physical examinations, however, should begin with inspection and observation of the extremity. After acute injury one should compare the injured joint in question to its opposite side. Inspection for skin changes such as ecchymoses, abrasions, and associated swelling can be important clues in distinguishing macrotrauma from a microtraumatic event. Range of motion of the joint in question both actively and passively is imperative. First have the athlete move the joint in question and observe for associated pain or asymmetry as compared to the opposite side. Examples include a patient who presents with shoulder pain of insidious onset whose active and passive range of motion is asymmetrical and limited on the affected side suggesting an adhesive capsulitis as a diagnosis; this is compared to a rotator cuff injury where passive range of motion would be full despite a limited active range of motion secondary to pain. Other examples would be the active inability to extend one's knee after acute injury despite nearly full passive range of motion, suggesting injury (rupture) of the extensor mechanism that could be seen in patellar tendon or quadriceps tendon ruptures.

Strength assessment is an important component to the exam of any joint-related injury. During strength assessment, weakness may be the result of direct injury to a musculotendinous unit responsible for joint function. However, pain, guarding, or reflex inhibition of muscular contraction can also be responsible for perceived weakness on examination. The ability of the sports medicine professional to examine the athlete in the acute setting shortly after the injury (before pain and swelling set in) is especially helpful in obtaining an accurate assessment of strength. Although relatively uncommon, injuries to nerve and vasculature structures can and do occur and should be ruled out as a precipitating cause of injury, especially in the acute setting. Their examination is an essential component of a complete physical examination.

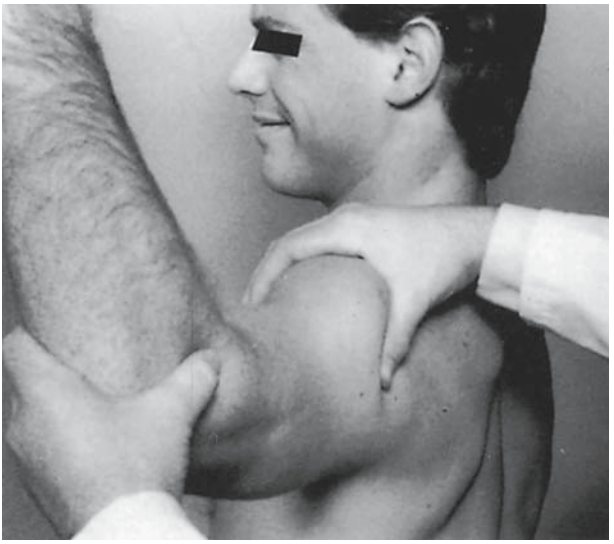


FIGURE 6-5. Examining for anterior instability, the apprehension test is performed by placing the shoulder in a provocative position of abduction and external rotation. Gentle anterior pressure is placed on the humeral head in this position, seeking to elicit patient apprehension as an indication of shoulder instability. (From Hawkins RJ, Bokor DJ. Clinical evaluation of shoulder problems. In: Rockwood CA, Matsen FA (eds) The Shoulder, vol. 1. Philadelphia: Saunders, 1990:149–177. Reprinted by permission.)

On initial examination one should always keep an open mind for referred symptoms. In addition to examining the joint in question, one should also focus particularly on the adjacent joints, as well as the spine, for a contributing role in the symptoms. Examples include a slipped capital femoral epiphysis (SCFE) of the hip in an adolescent with knee pain, or a cervical disk herniation as a cause for shoulder discomfort.

Applying special examination techniques specific to the area in question and suspected diagnosis completes the physical examination. These techniques can be found in their respective chapters. Examples of special tests include impingement signs in case of shoulder pain, or apprehension in the case of shoulder instability as the arm is placed in a position of abduction and external rotation (Fig. 6-5).

Special Tests

X-Rays

Radiographs are mandatory in any athlete with a history of trauma where macrotraumatic injury is in question. Microtraumatic injuries do not usually

demonstrate radiographic findings when a soft tissue component is suspected as a cause for pain. One exception, however, is when an osseous component is thought to be a cause for pain in the absence of trauma (i.e., stress fracture). In this setting, X-rays are helpful as an initial screening tool. When negative, other special tests such as magnetic resonance imaging (MRI) or bone scintigraphy can be especially helpful.

Specifically obtained stress views can be useful in assessing joint integrity. Common examples include stress views taken for grade III sprains of the acromioclavicular joint (Fig. 6-6).

Magnetic Resonance Imaging

Revolutionizing our ability to visualize soft tissues and establish diagnoses noninvasively, MRI is an exceptional diagnostic tool. In addition to

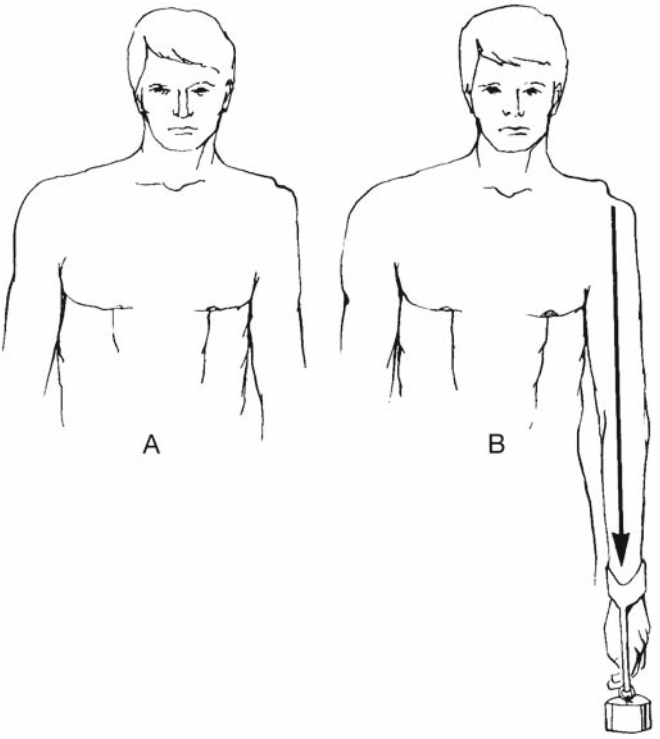


FIGURE 6-6. (A) Note the slight deformity at the acromioclavicular (AC) joint of this patient's left shoulder, sustained from landing directly on the point of the shoulder. (B) Note that with the application of weights to the patient's wrists, the slight deformity is exaggerated, and the AC joint displacement is easily seen; this is known as a stress view of a "separated shoulder." (From Rockwood CA, Green DP (eds) Fractures, 2nd ed, vol 3. Philadelphia: Lippincott, 1984. Reprinted by permission.)

demonstrating precise anatomic detail, MRI gives us a precise physiologic window with which to see various inflammatory, metabolic, and traumatic conditions. It is helpful in diagnosing both microtraumatic as well as macrotraumatic injuries. Variation in software techniques allows precise imaging of osseous structures, tendons, ligaments, menisci, and articular cartilage. The addition of intraarticular contrast has been especially helpful in the shoulder and hip in the diagnosis of injuries to the labral structures. MRI has emerged as the most common imaging modality within the field of sports medicine. It should be used judiciously, however, secondary to cost and not overshadow a thorough history and physical examination.

Bone Scintigraphy

Bone scans generate images based on dynamic physiology rather than static structure. Increased tracer uptake can occur because of a number of conditions and is pathognomonic for any one particular injury. Interpretation should be carried out in the context of history, physical examination, and routine X-rays. For example, in a runner with progressively increasing leg pain in which a bone scan displays focal uptake in the midtibia, a stress fracture is likely (Fig. 6-7).

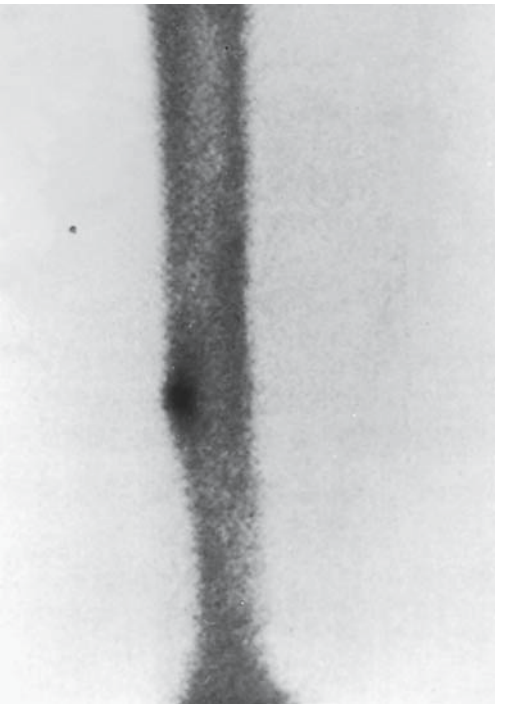


FIGURE 6-7. Bone scan of the tibia in a runner with leg pain reveals focal uptake at the junction of the mid- and distal third tibia, consistent with a stress fracture. (From DeLee JC, Drez Jr D (eds) Orthopaedic Sports Medicine: Principles and Practice, vol 2. Philadelphia: Saunders, 1994. Reprinted by permission.)

Arthroscopy

Most commonly applied to the knee, shoulder, ankle, elbow, and hip, arthroscopy is the gold standard for definitive diagnosis and treatment of joint-related injuries. Its utility in diagnosis is especially helpful in situations where all other diagnostic testing has been unsuccessful in establishing a diagnosis. Its overwhelming use in the field of sports medicine, however, is predicated on the treatment of joint injuries once a diagnosis is reached; for more-complex problems it often serves as an invaluable diagnostic tool.

Treatment of Sports Injuries

Treatment of macrotraumatic and microtraumatic injuries follows an algorithmic approach. The goals of treatment are to reduce pain, inflammation, swelling, and stiffness initially followed by an increase in strength and function to allow expeditious return to normal function and athletic activity. Treatment can be divided into three distinct but overlapping phases: immediate, early, and definitive.

Macrotraumatic Injuries

Immediate

Immediate treatment begins at the time of injury and involves the pneumonic "RICE" (rest, ice, compression, and elevation). Immobilization of the joint in the early stages after an injury with these treatment principles act to limit the initial swelling. By accomplishing this purpose, local soft tissue edema and pain are minimized; this often allows the treating physician an accurate physical exam, leading to a good working diagnosis, and the need for definitive tests can also be determined.

Early

Early treatment involves establishing a definitive diagnosis and minimizing the sequelae of trauma including joint stiffness and muscle atrophy. Often additional testing is required in this stage to help formulate both the diagnosis and the definitive treatment plan.

Late

Most macrotraumatic sports injuries are successfully treated nonoperatively, with physical rehabilitation necessary to provide normal strength and motion. Specific indications for operative management vary with the injury in question and its outcomes with different treatment options, as well as the athlete's goals and expectations both on and off the athletic

field. Surgical intervention may involve traditional open techniques or, more commonly, an arthroscopic approach to limit the morbidity imposed by a surgical approach.

Microtraumic Injuries

Immediate

Rest, in the treatment of overuse injury, does not necessarily require crutches, cast, or sling, but it does mean activity modification. Any activity that causes the athlete's symptoms should be avoided. The tissues involved must be allowed to rest to heal and resolve the inflammatory process causing their symptoms. For athletes, this aim often requires restriction from their sport.

Early

During the period of activity modification, a number of techniques can be helpful to further relieve pain and inflammation to restore normal function; these can begin with the use of nonsteroidal antiinflammatory drugs (NSAIDs). Various modalities such as ice, heat, electrical stimulation, ultrasound, and massage can all be of some help in decreasing pain and associated swelling.

Late

Although activity modification is the mainstay of treatment, with a prolonged period of inactivity muscular atrophy as well as overall deconditioning can result. Definitive treatment for these injuries often involves a dedicated physical therapy program aimed at restoring the athlete's strength and endurance required for a return to sport. Focus on the athlete's biomechanics is also an essential component in treating overuse injuries to prevent their recurrence. Attention to specifics of the supporting structures is often helpful in this regard. Alignment problems are often identified in this phase of treatment for lower extremity injuries. Fabrication of a shoe lift orthotic for a previously unrecognized leg-length discrepancy or a medial longitudinal arch support for overpronation can lead to a more-successful return to activity. Sometimes videotape analysis of the activity or technique is helpful to identify, correct, and prevent poor mechanics.

Occasionally, overuse injuries do not respond to nonoperative measures and surgical correction is required. Conditions occasionally associated with failure of conservative treatment include lateral epicondylitis, shoulder impingement, and patellar/Achilles tendonitis. Failure of conservative treatment in these cases involves long courses (often 6 months to 1 year)

of conservative management. Rarely, stress fractures are in high-risk areas (i.e., hip) or fail to respond to adequate immobilization and require surgical intervention.

Summary and Conclusion

As the numbers of active individuals continue to grow, so does the field of sports medicine. Emphasis at present within this field focuses on the prevention of injuries as well as minimizing the effects of surgery through less-invasive approaches such as arthroscopy. As knowledge within this field continues to grow, accomplishing the goal of a successful return to sport both safely and expeditiously becomes feasible. Appreciation of the basic science as it relates to these injuries and the means in which they are treated is essential in bridging the gap between the practice of clinical medicine and the successful return to the athletic field.

Suggested Readings

DeLee JC, Drez D Jr, Miller MD (eds) Orthopaedic Sports Medicine: Principles and Practice, 2nd ed. Philadelphia: Saunders, 2001.

Garrick JG, Webb DR. Sports Injuries: Diagnosis and Management. Philadelphia: Saunders, 1990.

Griffin LY (ed) Orthopaedic Knowledge Update: Sports Medicine. American Academy Orthopaedic Surgeons. Philadelphia: Saunders, 1994.

McGinty JB (ed) Operative arthroscopy, 2nd ed. Philadelphia: Lippincott-Raven, 1996.

Questions

6-1. Which best describes a tendon's histologic makeup and biomechanical function?
   a. Primarily made up of fibroblasts to effectively resist tensile forces
   b. Primarily made up of fibroblasts to resist compressive forces
   c. Primarily made of type I collagen to resist compressive forces
   d. Primarily made of type I collagen to resist tensile forces
   e. Primarily made of proteoglycan to resist tensile forces

6-2. A ballet dancer presents with a 6-month history of pain surrounding the ankle without any particular injury. Tenderness is present along the posteromedial aspect of her ankle. Which structure is most commonly associated with this overuse injury?
   a. Achilles tendon
   b. Peroneal longus

c. Peroneal brevis
d. Flexor hallicus longus
e. Extensor digitorum longus

6-3. Which best describes a grade III ligamentous injury?
a. Macroscopic injury associated with microscopic damage resulting in stretching of a ligament. Partial compromise in ligamentous strength.
b. Microscopic injury with no macroscopic injury. No functional compromise of strength.
c. Complete macroscopic ligamentous rupture with partial structural integrity remaining.
d. Complete macroscopic ligamentous rupture without any structural integrity remaining.
e. None of the above.

6-4. Muscle strains are most commonly caused by:
a. Concentric muscle contraction
b. Eccentric muscle contraction
c. Direct traumatic force
d. Laceration
e. None of the above

6-5. Articular cartilage is biomechanically most effective in resisting:
a. Compression
b. Tension
c. Rotation
d. Shear
e. Corrosion

6-6. Which type of meniscal tear has the best potential for healing?
a. Horizontal tear
b. Radial tear
c. White–white tear
d. White–red tear
e. Red–red tear

6-7. Which best describes a microtraumatic injury pattern?
a. Anterior shoulder dislocation
b. Lateral ankle sprain
c. Stress fracture of hip
d. Patellar dislocation
e. None of the above

6-8. Initial management of Achilles tendonitis includes:
a. Nonsteroidal medication
b. Activity modification
c. Physical therapy
d. Corticosteroid injection
e. Surgical debridement

6-9. Histologically, ligaments attach to bone via which microscopic entity?
   a. Proteoglycan
   b. Fasciles
   c. Type V collagen
   d. Sharpey's fibers
   e. Myofibroblasts

6-10. The primary unit of tendon structure is:
   a. Fascicle
   b. Endotenon
   c. Epitenon
   d. Paratenon
   e. Musculotendinous unit

7
The Spine

Sam W. Wiesel, William C. Lauerman, and
Steven C. Scherping, Jr.

The majority of adults are, at some point in their life, affected by disorders of the spine. Every physician should have a basic knowledge of the potential pathology and be able to distinguish a serious problem from a minor condition. Disastrous sequelae such as paralysis can occur if this differentiation is not appreciated. This chapter first addresses the cervical spine and then presents the lumbar spine. In each area, the history, physical, and appropriate diagnostic studies are reviewed. Next, a standardized protocol or algorithm for the diagnosis and management of these patients is described. Finally, several of the most common conservative treatment modalities is presented with special attention given to their efficacy.

Cervical Spine

Disorders of the neck are ubiquitous. Significant problems can arise from various types of arthritis as well as from trauma. In each instance, recovery or improvement is the usual outcome, but poor results can occur with paraplegia or death as the most disastrous. Every physician should be familiar with the signs and symptoms of the various diagnostic entities that occur in the cervical spine and be able to identify the serious problems that require immediate attention.

History

The location of the pain is the major point to obtain from the patient history. The majority of patients complain of localized symptoms in the neck, with and without referral of pain between the scapulae or shoulders. The pain is described as vague, diffuse, axial, nondermatomal, and poorly localized. The pathogenesis of this type of complaint is attributed to structures innervated by the sinuvertebral nerve or the nerves innervating the paravertebral soft tissues and is generally a localized injury.

Another group of patients complains of neck pain with the addition of arm involvement. This arm pain is secondary to nerve root irritation and is termed radicular pain. The degree of nerve root involvement can vary from a monoradiculopathy to multiple levels of involvement. It is described as a deep aching, burning, or shooting arm pain, often with associated paresthesias. The pathogenesis of radicular pain can derive from soft tissue (herniated disk), bone (spondylosis), or a combination of these two.

Finally, a third group of patients complains of symptoms secondary to cervical myelopathy, which is compression of the spinal cord and usually secondary to degenerative changes. The clinical complaints vary considerably. The onset of symptoms usually begins after 50 years of age, and males are more often affected. Onset is usually insidious, although there is occasionally a history of trauma. The natural history is that of initial neurologic deterioration followed by a plateau period lasting several months. The resulting clinical picture is often one of an incomplete spinal lesion with a patchy distribution of deficits. Disability varies with the number of vertebrae involved and with the degree of changes at each level.

Common presenting symptoms of cervical myelopathy include numbness and paresthesias in the hands, clumsiness of the fingers, weakness (greatest in the lower extremities), and gait disturbances. Abnormalities of micturition are seen in about one-third of cases and indicate more severe cord involvement. Symptoms of radiculopathy can coexist with myelopathy and confuse the clinical picture. Sensory disturbances may show a patchy distribution. Spinothalamic tract (pain and temperature) deficits may be seen in the upper extremities, the thorax, or the lumbar region and may be in a stocking or glove distribution. Posterior column deficits (vibration and proprioception) are more commonly seen in the feet than in the hands. Usually there is no gross sensory impairment, but a diminished sense of appreciation of light touch and pinprick. A characteristic broad-based, shuffling gait may be seen, signaling the onset of functionally significant deterioration.

Physical Examination

The physical examination should begin with observation of the cervical spine and upper torso unencumbered by clothing. The physical findings are of two different types. One set can be categorized as nonspecific and found in most patients with neck pain but will not help to localize the type or level of the pathologic process. A decreased range of motion is the most frequent nonspecific finding. It can be secondary to pain or, structurally, to distorted bony or soft tissue elements in the cervical spine. Hyperextension and excessive lateral rotation, however, usually cause pain, even in a normal individual.

Tenderness is another nonspecific finding that can be quite helpful. There are two types of tenderness that must be considered. One is diffuse,

elicited by compression of the paravertebral muscles, and is found over a wide area of the posterolateral muscle masses. The second type of tenderness is more specific and may help localize the level of the pathology. It can be localized by palpation over each intervertebral foramen and spinous process.

The next goal of the physical examination is to isolate the level or levels in the cervical spine responsible for the symptomatology. The exam is also important to rule out other sources of pain, which include compression neuropathies, thoracic outlet syndrome, and chest or shoulder pathology.

The major focus of the exam is directed at finding a neurologic deficit (Table 7-1). A motor deficit (most commonly weak triceps, biceps, or deltoid) or diminished deep tendon reflex is the most likely objective

Table 7-1. Cervical radiculopathy symptoms and findings.

Disk level	Nerve root	Symptoms and findings
C2–C3	C3	*Pain*: Back of neck, mastoid process, pinna of ear *Sensory change*: Back of neck, mastoid process, pinna of ear *Motor deficit*: None readily detectable except by EMG *Reflex change*: None
C3–C4	C4	*Pain*: Back of neck, levator scapula, anterior chest *Sensory change*: Back of neck, levator scapula, anterior chest *Motor deficit*: None readily detectable except by EMG *Reflex change*: None
C4–C5	C5	*Pain*: Neck, tip of shoulder, anterior arm *Sensory change*: Deltoid area *Motor deficit*: Deltoid, biceps *Reflex change*: Biceps
C5–C6	C6	*Pain*: Neck, shoulder, medial border of scapula, lateral arm, dorsal forearm *Sensory change*: Thumb and index finger *Motor deficit*: Biceps *Reflex change*: Biceps
C6–C7	C7	*Pain*: Neck, shoulder, medial border of scapula, lateral arm, dorsal forearm *Sensory change*: Index and middle fingers *Motor deficit*: Triceps *Reflex change*: Triceps
C7–T1	C8	*Pain*: Neck, medial border of scapula, medial aspect of arm and forearm *Sensory change*: Ring and little fingers *Motor deficit*: Intrinsic muscles of hand *Reflex cange*: None

Source: From Boden S, Wiesel SW, Laws E, et al. The Aging Spine. Philadelphia: Saunders, 1991:46. Reprinted by permission.

finding in a patient with a radiculopathy. Although less reproducible, manual tests and maneuvers that increase or decrease radicular symptoms may be helpful. In the neck compression test, the patient's head is flexed laterally, slightly rotated toward the symptomatic side, and then compressed to elicit reproduction or aggravation of the radicular symptoms. The axial manual traction test is performed in the presence of radicular symptoms in the supine position. With 20 to 25 lb axial traction, a positive test is the decrease or disappearance of radicular symptoms. All these tests are highly specific (low false-positive rate) for the diagnosis of root compression, but the sensitivity (false-negative rate) is less than 50%.

Myelopathic physical findings should also be specifically checked. These patients can have a gait disturbance, so they should be observed walking. The extent of motor disability can vary from mild to severe. Pyramidal tract weakness and atrophy are more commonly seen in the lower extremities and are the most common abnormal signs. The usual clinical findings in the lower extremities are spasticity and weakness.

Weakness and wasting of the upper extremities and hands may also be due to combined spondylotic myelopathy and radiculopathy. In this situation, the patient usually complains of hand clumsiness. A diminished or absent upper-extremity deep tendon reflex can indicate compressive radiculopathy superimposed on spondylotic myelopathy.

Sensory deficits in spinothalamic (pain and temperature) and posterior column (vibration and proprioception) function should be documented. Usually there is no gross impairment of sensation; rather, a patchy decrease in light touch and pinprick is seen. Hyperreflexia, clonus, and positive Babinski's signs are seen in the lower extremities. Hoffman's sign and hyperreflexia may be observed in the upper extremities.

Diagnostic Studies

In evaluating any pathologic process, one usually has a choice of several diagnostic tests. The cervical spine is no exception. This section presents the most common ones that are routinely used. In general, all these tests play a confirmatory role. In other words, the core of the information derived from a thorough history and physical examination should be the basis for a diagnosis; the additional tests are obtained to confirm this clinical impression. Trouble develops when these tests are used for screening purposes because most of them are overly sensitive and relatively nonselective. Thus, the studies discussed should never be interpreted in isolation from the overall clinical picture.

Plain Radiographs

Radiographic evaluation of the cervical spine is helpful in assessing patients with neck pain, and the routine study should include anteroposterior,

lateral, oblique, and odontoid views. Flexion–extension X-rays are necessary in defining stability. The generally accepted radiographic signs of cervical disk disease are loss of height of the intervertebral disk space, osteophyte formation, secondary encroachment of the intervertebral foramina, and osteoarthritic changes in the apophyseal joints.

It should be stressed that the identification of "some pathology" on plain cervical X-rays does not, per se, indicate the cause of the patient's symptoms. In several series, large numbers of asymptomatic patients have shown radiographic evidence of advanced degenerative disk disease. At approximately age 40, some degeneration (narrowing) can be expected, particularly at the C5–C6 and C6–C7 levels, and this is considered to represent a normal aging process. The difficult problem with regard to radiographic interpretation is not in the identification of these changes but rather in determining how much significance should be attributed to them.

Radiographic abnormalities of alignment in the cervical spine may also be of clinical significance, but they need to be correlated with the whole clinical picture; listhesis or slipping forward or backward (retrolisthesis) of one vertebra upon the vertebra below it is such a finding.

If "instability" is suspected, functional X-rays may be taken. These view the spine from the side, with the head flexed (bent forward) or extended (arched back); the spine normally flexes equally at each spinal level. If one vertebral level is "unstable," that particular vertebra moves more or less and disrupts the symmetry of motion. Again, this finding must be correlated with the whole clinical picture, as its mere presence may be asymptomatic.

Magnetic Resonance Imaging

Magnetic resonance imaging (MRI) provides an image on film that is obtained by measuring the differences in proton density between the various tissues evaluated. With the use of the computer, multiplanar images are obtainable. It is a safe test because it uses neither ionizing radiation nor invasive contrast agents.

The technical advances for MRI have rapidly changed. The distinction between soft tissues and bone and the relationship of both to the neural foramen are excellent (Fig. 7-1). MRI can also accurately detect rare conditions such as infection, tumor, or intrinsic abnormalities of the spinal cord. An excellent test, MRI can be combined with plain films to permit an accurate noninvasive evaluation of a cervical radiculopathy or myelopathy. It is currently the diagnostic study of choice in the cervical spine.

MRI should be used as a confirmatory test to substantiate a clinical impression; it should not be used as a screening test because there are many false-positive as well as false-negative results. Thus, some normal people have abnormal MRI findings whereas some abnormal people are found to have normal MRIs.

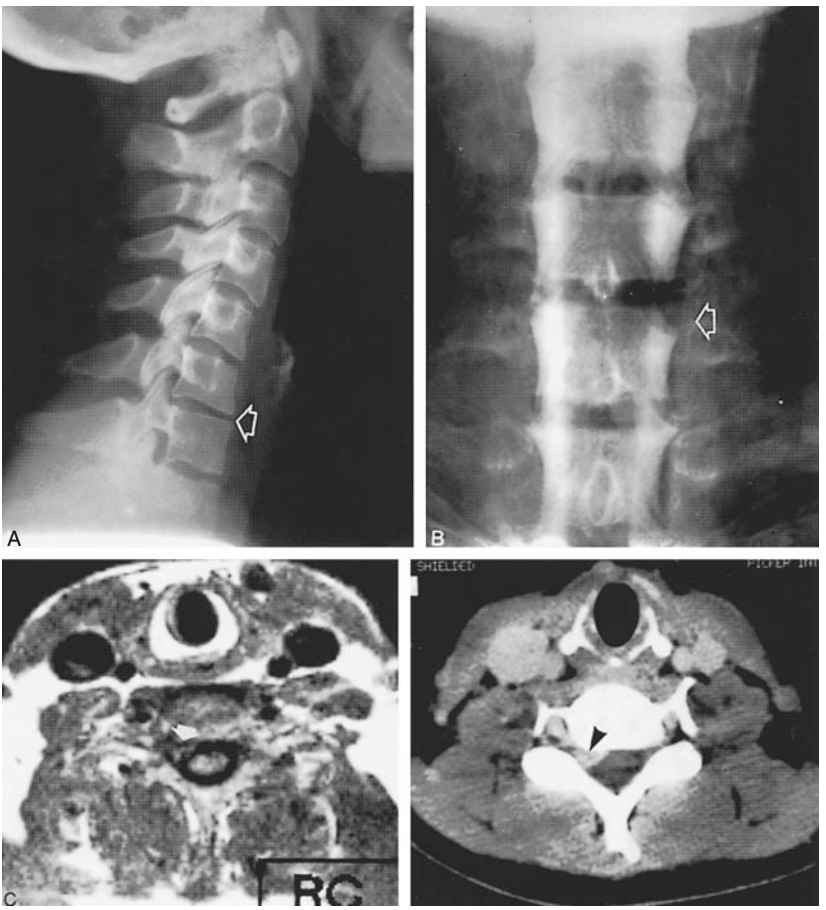


FIGURE 7-1. This 33-year-old man presented with right triceps weakness, C7 radicular pain, and absent triceps reflex. (A) Lateral radiograph of C6–C7 shows loss of disk height (*arrow*). (B) Anteroposterior myelogram confirms right C7 root sleeve cutoff. (C) Axial magnetic resonance imaging (*left*) and computerized tomography (*right*) show occlusion of the right C6–C7 foramen (*arrows*). (From Boden S, Wiesel SW, Laws E, et al. The Aging Spine. Philadelphia: Saunders, 1991. Reprinted by permission.)

Myelography

A myelogram is performed by injecting a water-soluble dye into the spinal sac so that the outline of the sac itself, as well as each nerve root sleeve, can be evaluated. If there is pressure upon the nerve root or dural sac from either a bony spur or disk herniation, it will be seen as a constriction on

the X-ray picture. Complications from myelography are rare, and it can be performed on an outpatient basis. The major disadvantages are its invasive nature, radiation exposure, and the lack of diagnostic specificity. Water-soluble myelography does provide excellent contrast for subsequent examination by computerized tomography (CT) (see Fig. 7-1).

Computerized Tomography

Computerized tomography (CT) permits one to create cross-sectional imaging of the cervical spine at any desired level. It is currently used after the instillation of water-soluble dye, which is termed a "CT-myelogram." The advantages of CT-myelography include excellent differentiation of bone and soft tissue (disk or ligament) lesions, direct demonstration of spinal cord and spinal cord dimensions, assessment of foraminal encroachment, and visualization of regions distal to a myelographic blockade.

Unfortunately, when combined with myelography, CT becomes an invasive procedure and involves radiation exposure. It does, however, provide very good information and is especially useful for patients who, for a variety of reasons, cannot undergo an MRI investigation.

Electromyography

Electromyography (EMG) is an electric test that confirms the interaction of nerve to muscle. The test is performed by placing needles into muscles to determine if there is an intact nerve supply to that muscle. The EMG is particularly useful in localizing a specific abnormal nerve root. It should be appreciated that it takes at least 21 days for an EMG to show up as abnormal. After 21 days of pressure on a nerve root, signs of denervation with fibrillation can be observed. Before 21 days, the EMG will be negative in spite of nerve root damage. It should be noted that there is no quantitative interpretation of this test. Thus, it cannot be said that the EMG is 25% or 75% normal.

The EMG is an electronic extension of the physical examination. Although it is 80% to 90% accurate in establishing cervical radiculopathy as the cause of pain, false-negative results do occur. If cervical radiculopathy affects only the sensory root, the EMG will be unable to demonstrate an abnormality. A false-negative examination can occur if the patient with acute symptoms is examined early (4–28 days from onset of symptoms). A negative study should be repeated in 2 to 3 weeks if symptoms persist. The accuracy of the EMG increases if both the paraspinal and extremity muscles innervated by the suspected root demonstrate abnormalities.

The EMG is not part of the routine evaluation of the cervical spine. It is indicated to confirm a clinical impression or to rule out other sources of pathology such as peripheral neuropathies or compressive neuropathies in the upper extremities.

Clinical Conditions

There are many conditions that may present as neck pain, with or without arm pain, in any particular individual. However, several that are quite common are presented here in detail.

Neck Sprain–Neckache

Neck sprain, although a misnomer, describes a clinical condition involving a nonradiating discomfort or pain about the neck area associated with a concomitant loss of neck motion (stiffness). Although the clinical syndrome may present as a headache, most often the pain is located in the middle to lower part of the back of the neck. A history of injury is rarely obtained, but the pain may start after a night's rest or on simply turning the head. The source of the pain is most commonly believed to be the ligaments about the cervical spine and/or the surrounding muscles. The axial pain may also be produced by small annular tears without disk herniation or from the facet joints.

The pain associated with a neck sprain is most often a dull aching pain that is exacerbated by neck motion. The pain is usually abated by rest or immobilization. The pain may be referred to other mesenchymal structures derived from a similar sclerotome during embryogenesis. Common referred pain patterns include the scapular area, the posterior shoulder, the occipital area, or the anterior chest wall (cervical angina pectoris). Those referred pain patterns do not connote a true radicular pain pattern and are not usually mechanical in origin.

Physical examination of patients with neckache usually reveals nothing more than a locally tender area or areas, usually just lateral to the spine. The intensity of the pain is variable and the loss of cervical motion correlates directly with the pain intensity. The presence of true spasm, defined as a continuous muscle contraction, is rare except in severe cases where the head may be tilted to one side (torticollis).

Because the radiograph in cervical sprain is usually normal, a plain X-ray is usually not warranted on the first visit. If the pain continues for more than 2 weeks or the patient develops other physical findings, then an X-ray should be taken to rule out other more serious causes of the neck pain such as neoplasia or instability. The prognosis for these individuals is excellent because the natural history is one of complete resolution of the symptoms over several weeks. The mainstay of therapy includes rest and immobilization, usually in a soft cervical orthosis. Although medications such as antiinflammatory agents or muscle relaxants may aid in the acute management of pain, they do not seem to alter the natural history of the disorder.

Acute Herniated Disk

A herniated disk is defined as the protrusion of the nucleus pulposus through the fibers of the annulus fibrosus (Fig. 7-2). Most acute disk her-

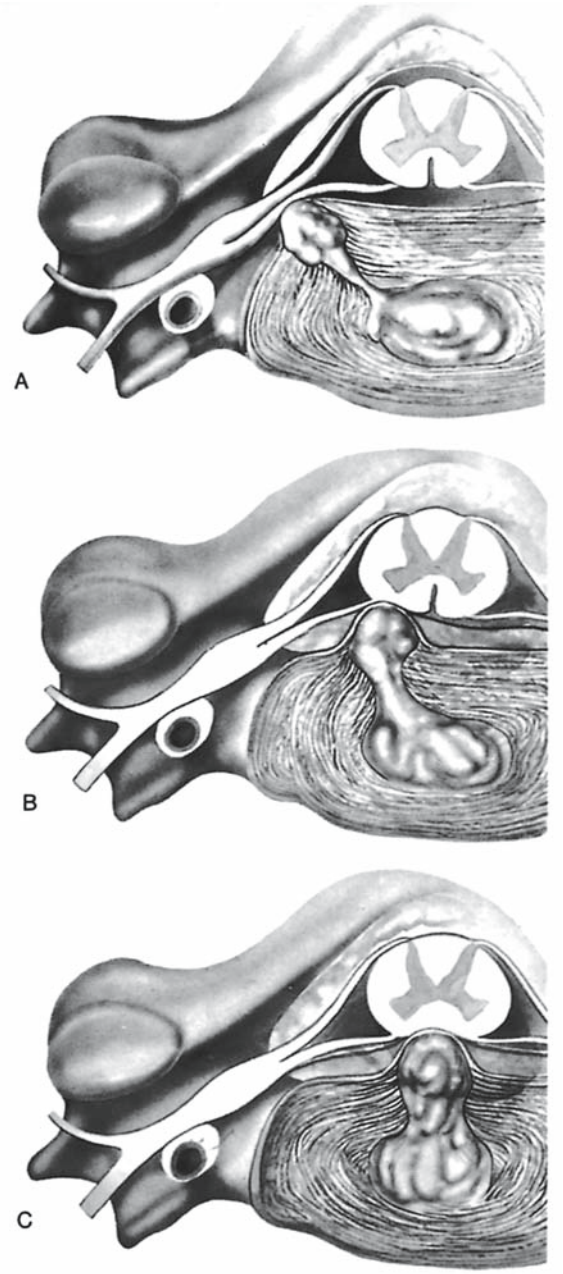


FIGURE 7-2. Types of soft disk protrusion. (A) Intraforaminal, most common. (B) Posterolateral, produces mostly motor signs. (C) Midline, may manifest as myelopathy. (Modified from DePalma AF, Rothman RH. The Intervertebral Disc. Philadelphia: Saunders, 1970. From Wiesel S, Delahay J (eds) Essentials of Orthopaedic Surgery, 2nd ed. Philadelphia: Saunders, 1997. Reprinted by permission.)

niations occur posterolaterally and in patients around the fourth decade of life when the nucleus is still gelatinous. The most common areas of disk herniation are C5–C6 and C6–C7, whereas C7–T1 and C3–C4 are infrequent. Disk herniation of C2–C3 is very, very rare. In contrast to the lumbar herniated disk, the cervical herniated disk may cause myelopathy in addition to radicular pain because of the presence of the spinal cord in the cervical region.

The disk herniation usually affects the root numbered lowest for the given disk level; for example, a C3–C4 disk affects the C4 root, C4–C5 the fifth cervical root, C5–C6 the sixth cervical root, C6–C7 the seventh nerve root, and C7–T1 the eighth cervical root. In contrast to the lumbar region, the disk herniation does not involve other roots, but more commonly presents some evidence of upper motor neuron findings secondary to spinal cord local pressure.

Not every herniated disk is symptomatic. The presence of symptoms depends on the spinal reserve capacity, the presence of inflammation, and the size of the herniation as well as the presence of concomitant disease such as osteophyte formation.

Clinically, the patient's major complaint is arm pain, not neck pain. The pain is often perceived as starting in the neck area, but then radiates from this point down the shoulder, arm, forearm, and usually into the hand, commonly in a dermatomal distribution. The onset of the radicular pain is often gradual, although there can be a sudden onset associated with a tearing or snapping sensation. As time passes, the magnitude of the arm pain clearly exceeds that of the neck or shoulder pain. The arm pain may vary in intensity from severe enough to preclude any use of the arm without severe pain to a dull cramping ache in the arm muscles with use of the arm. The pain is usually severe enough to awaken the patient at night.

Physical examination of the neck usually shows some limitation of motion, and on occasion the patient may tilt his head in a "cocked-robin" position (torticollis) toward the side of the herniated cervical disk. Extension of the spine will often exacerbate the pain because it further narrows the intervertebral foramina. Axial compression, Valsalva maneuver, and coughing may also exacerbate or recreate the pain pattern.

The presence of a positive neurologic finding is the most helpful aspect of the diagnostic workup, although the neurologic exam may remain normal despite a chronic radicular pattern. Even when a deficit exists, it may not be temporally related to the present symptoms but rather to a prior attack at a different level. To be significant, the neurologic exam must show objective signs of reflex diminution, motor weakness, or atrophy. Subjective sensory changes are often difficult to interpret and require a coherent and cooperative patient to be of clinical value. The presence of sensory changes alone is usually not sufficient to make a firm diagnosis.

Nerve root sensitivity can be elicited by any method that increases the tension of the nerve root. Radicular arm pain is often increased by the

Valsalva maneuver or by directly compressing the head. Although these signs are helpful when present, their absence alone does not rule out radicular pain.

The provisional diagnosis of a herniated disk is made by the history and physical examination. The plain X-ray is usually nondiagnostic, although occasionally disk space narrowing at the suspected interspace or foraminal narrowing is seen on the oblique films. The value of the films is largely to exclude other causes of neck and arm pain. MRI is a confirmatory examination and should not be used as a screening test because misinformation may ensue.

The treatment for most patients with a herniated disk is nonoperative because the majority of patients respond to conservative treatment over a period of months. The efficacy of the nonoperative approach depends heavily on the doctor–patient relationship. If a patient is well informed, insightful, and willing to follow instructions, the chances for successful nonoperative outcome are greatly improved.

The cornerstone to the management of a cervical herniated disk is rest and immobilization. The use of a soft cervical orthosis greatly increases the likelihood that the patient will rest. Patients should markedly decrease their physical activity for at least 2 weeks and wear the cervical orthosis at all times (especially at night). After the acute pain begins to abate, patients should gradually wean off the orthosis. Most persons will be able to return to work, or at least light duty, in a month.

Drug therapy is an important adjunct to rest and immobilization. Antiinflammatory medications, analgesics, and muscle relaxants have historically been used in the acute management of these patients. Because it is commonly believed that the radicular pain is in part inflammatory, the use of aspirin or other nonsteroidal antiinflammatory medications seems to be appropriate. All these medications have gastrointestinal side effects but are generally well tolerated for brief periods.

Analgesic medication is only rarely needed if the patient is compliant. However, if the pain is severe enough, a brief course of oral codeine may be prescribed. Muscle relaxants and the benzodiazepines are truly tranquilizers and central nervous system depressants. As such, they have at best a limited role in the management of the acute herniated disk patient. Although it is true that these medications help patients relax and get their needed rest, the potential for an addictive effect adding to any psychosocial problems patients may have is not, in the majority of patients, worth the long-term risk for the short-term gain.

Cervical Spondylosis

What was once commonly referred to as cervical degenerative disk disease more recently has been called cervical spondylosis. Cervical spondylosis is a chronic process defined as the development of osteophytes and other

stigmata of degenerative arthritis as a consequence of age-related disk disease. This process may produce a wide range of symptoms. However, it should be stressed that an individual may have significant spondylosis and be asymptomatic.

Cervical spondylosis is believed to be the direct result of age-related changes in the intervertebral disk. These changes include desiccation of the nucleus pulposus, loss of annular elasticity, and narrowing of the disk space with or without disk protrusion or rupture. In turn, secondary changes include overriding of facets, increased motion of the spinal segments, osteophyte formation, inflammation of synovial joints, and even microfractures. These macro- and microscopic changes can result in various clinical syndromes: spondylosis, ankylosis, central or foraminal spinal stenosis, radiculopathy, myelopathy, or spinal segmental instability.

The typical patient with symptomatic cervical spondylosis is over the age of 40 and complaining of neckache. Not infrequently, however, these patients have very few neck pain symptoms and present with referred pain patterns: occipital headaches, pain in the shoulder, suboccipital, and intrascapular areas and the anterior chest wall, or other vague symptoms suggestive of anatomic disturbances (e.g., blurring of vision, tinnitus). In patients with predominantly referred pain, a past history for neck pain is usually obtained.

Physical examination of the patient with cervical spondylosis is often associated with a dearth of objective findings. The patient usually has some limitation of neck motion associated with midline tenderness. Not infrequently, palpation of the referred pain areas also produces local tenderness and should not be confused with local disease. The neurologic examination is normal.

Anteroposterior (AP), lateral, and oblique radiographs of the cervical spine in cervical spondylosis show varying degrees of changes: these include disk space narrowing, osteophytosis, foraminal narrowing, degenerative changes of the facets, and instability. As previously discussed, these findings do not necessarily correlate with symptoms. In large part, the radiograph serves to rule out other more serious causes of neck and referred pain such as tumors. Further diagnostic testing is usually not warranted.

Cervical spondylosis alone is treated by nonoperative measures. The mainstay of treatment for the acute pain superimposed on the chronic problem is rest and immobilization. In addition, oral antiinflammatory medications such as aspirin are beneficial. Often these medications need to be administered on a chronic basis or at least intermittently. Trigger-point injections with local anesthetics (lidocaine) and corticosteroids (triamcinolone) may be therapeutic as well as diagnostic. Once the pain abates, the immobilization (usually a soft cervical collar) should be discontinued and the patient maintained on a series of cervical isometric exercises. Further counseling with regard to sleeping position, automobile driving,

and work is in order. Manipulation and traction are rarely needed and may, in fact, be deleterious to the patient.

Cervical Spondylosis with Myelopathy

When the secondary bony changes of cervical spondylosis encroach on the spinal cord, a pathologic process called myelopathy develops. If this involves both the spinal cord and nerve roots, it is called myeloradiculopathy. Radiculopathy, regardless of its etiology, causes shoulder or arm pain.

Myelopathy is the most serious sequela of cervical spondylosis and the most difficult to treat effectively. Less than 5% of patients with cervical spondylosis develop myelopathy, and they are usually between 40 and 60 years of age. The changes of myelopathy are most often gradual and associated with posterior osteophyte formation (called spondylitic bone or hard disk) and spinal canal narrowing (spinal stenosis). Acute myelopathy is most often the result of a central soft disk herniation.

The characteristic stooped, wide-based, and somewhat jerky gait of the aged summarizes the chronic effects of cervical spondylosis with myelopathy. The spinal cord changes may develop from single- or multiple-level disease and as such may not present in a singular or standard manner. A typical clinical presentation of chronic myelopathy begins with the gradual notice of a peculiar sensation in the hands, associated with clumsiness and weakness. The patient will also note lower extremity symptoms that may antedate the upper extremity findings, including difficulty walking, peculiar sensations, leg weakness, hyperreflexia, spasticity, and clonus. The upper extremity findings may start out unilaterally and include hyperreflexia, brisk Hoffman's sign, and muscle atrophy (especially of the hand muscles). Neck pain, per se, is not a prominent feature of myelopathy. Sensory changes can evolve at these levels and are often a less-reliable index of spinal cord disease. The protean nature of the signs and symptoms of cervical myelopathy, along with its potential for severe functional impairment, merits a high index of suspicion in patient evaluation.

Radiographs of the cervical spine in these patients often reveal advanced degenerative disease including spinal canal narrowing by prominent posterior osteophytosis, variable foraminal narrowing, disk space narrowing, facet joint arthrosis, and instability. Congenital stenosis of the cervical canal is frequently seen, predisposing the patient to the development of myelopathy. The myelogram is diagnostic, exhibiting a washboard appearance to the dye column with multiple anterior and posterior defects. The posterior defects are secondary to facet arthrosis and buckling of the ligamentum flavum. The MRI is also quite striking and diagnostic.

In general, myelopathy is a surgical disease, but it is not an absolute indication for surgical decompression. Conservative therapy consisting of immobilization and rest with a soft cervical orthosis offers the myelopathic patient, who is not a good operative risk, a viable option. The goals of surgery in the myelopathic patient are to decompress the spinal canal to

prevent further spinal cord compression and vascular compromise. If the myelopathy is progressive despite a trial of conservative treatment, surgery is clearly indicated. These indications may vary slightly from surgeon to surgeon because of the lack of absolute or definitive clinical data.

Rheumatoid Arthritis

Rheumatoid arthritis affects 2% to 3% of the population. About 60% of patients with rheumatoid arthritis exhibit signs and symptoms of cervical spine involvement, whereas up to 86% have radiographic evidence of cervical disease. Cervical spine involvement, secondary to the erosive, inflammatory changes of rheumatoid arthritis (synovitis), is divided into three categories: (1) atlantoaxial instability, (2) basilar invagination, and (3) subaxial instability. Atlantoaxial instability is the most common and most serious of the instability patterns, affecting 20% to 34% of hospitalized patients. The evaluation of a patient with rheumatoid arthritis is difficult because of the multiple system involvement. The physical examination should start with a careful neurologic evaluation to rule out upper motor neuron disease before moving to neck range-of-motion or other vigorous maneuvers that may harm the patient.

The patient with cervical spine involvement from rheumatoid arthritis most often has neck pain located in the middle posterior neck and occipital area. The range of motion is decreased, and crepitance or a feeling of instability may be noted. The neurologic changes can be variable and difficult to elicit in the context of diffuse rheumatoid changes. The evaluation of the patient with cervical rheumatoid arthritis begins with plain radiographs of the neck, which may reveal osteopenia, facet erosion, disk space narrowing, and subluxation of the lower cervical spine (stepladder appearance). To determine that atlantoaxial disease is present, dynamic flexion–extension views of the lateral upper cervical spine are required.

Basilar invagination is defined as upper migration of the odontoid projecting into the foramen magnum. The addition of a CT scan with and without contrast material in the upper cervical spine can provide valuable information as to the relationship of the bony elements to the spinal cord. Subaxial subluxations are identified by dynamic flexion–extension films.

The majority of these patients, despite rather dramatic disease patterns, can be successfully managed nonoperatively. Although the natural history of rheumatoid arthritis predicts a high incidence of involvement of the cervical spine, it is estimated that only a few patients die of medullary compression associated with significant atlantoaxial disease and that, although atlantoaxial disease worsens with time, only 2% to 14% of patients exhibit neurologic progression.

The mainstay in nonoperative therapy is the cervical orthosis. Although this does not fully immobilize the atlantoaxial interval, it does produce symptomatic relief. Some authors have advocated intermittent home traction, but this must be used only with great caution under a physician's

direction. Medications have a definite role in the nonoperative management of rheumatoid disease. Initial management includes aspirin in high dosages monitored by serum drug levels. Secondary agents such as methotrexate, chloroquine, or oral steroids are best administered under the direction of a rheumatologist.

Cervical Hyperextension Injuries

Hyperextension injuries of the neck occur most often when the driver of a stationary car is struck from behind by another vehicle. The driver is usually relaxed and unaware of the impending collision. The sudden acceleration of the struck vehicle pushes the back of the car seat against the driver's torso. The driver's torso is pushed forward and his or her head is thrown backward, causing hyperextension of the neck; this occurs very quickly after impact. If no head rest is present, the driver's head is hyperextended past the normal limit of stretch of the soft tissues of the neck. This injury has been descriptively termed whiplash because of the hyperextension of the head.

The sternocleidomastoid muscle, the scalenes, and the longus colli muscles may be mildly or severely stretched or, at worst, torn. Muscle tears of the longus colli muscles might involve injury to the symptomatic trunk unilaterally or bilaterally, resulting in Horner's syndrome, nausea, or dizziness. Further hyperextension may injure the esophagus, resulting in temporary dysphagia and injury to the larynx, causing hoarseness. Tears in the anterior longitudinal ligament may cause hematoma formation with resultant cervical radiculitis (arm pain) and injury to the intervertebral disk. In the recoil-forward flexion that occurs when the car stops accelerating, the head is thrown forward. This forward flexion of the head is usually limited by the chin striking the chest and does not usually cause significant injury. However, if the head is thrown forward and strikes the steering wheel or the windshield, a head injury can occur.

The driver is often unaware that he has been injured. He suffers little discomfort at the scene of the accident and often does not even wish to go to the hospital. Later that evening or the next day, 12 to 14 hours after the accident, the patient begins to feel stiffness in the neck. Pain at the base of the neck increases and is made worse by head and neck movements. Soon any movement of the head or neck causes excruciating pain. The anterior cervical muscles are often tender to the touch. The patient may have pain on mouth opening or chewing, hoarseness, or difficulty swallowing, and seeks medical care.

The physical examination must be detailed and complete. Abrasions on the forehead would suggest that forward flexion led to the head striking the steering wheel or windshield. A dilated pupil might suggest a case of Horner's syndrome secondary to the injury of the sympathetic chain or it might be a sign of significant intracranial injury if the patient's level of

consciousness is altered. Point tenderness in front of the ear would suggest injury to the temporomandibular joint, and tenderness to touch in the suboccipital area would suggest the head struck the back of the seat.

A complete neurologic examination is crucial. Any evidence of objective neurologic deficit merits immediate diagnostic tests to determine the cause. Although by definition hyperextension cervical injury causes damage only to the soft tissue structures of the neck, plain radiographs of the cervical spine should be obtained in all cases. Unsuspected fracture—dislocations of the cervical spine, facet fractures, odontoid fractures, or spinous process fractures—might be otherwise missed in the neurologically intact patient. Cervical spondylosis will be demonstrated on plain radiographs as well. Of course, if objective neurologic deficits are present, then further diagnostic aids are necessary (e.g., head CT, spine CT, myelogram, MRI).

A reasonable medical routine, because the majority of patients have no neurologic deficits, is based on the premise of resting the involved injured soft tissues. A soft cervical collar helps significantly in relieving muscle spasm and preventing quick head turns. The collar should not be worn for more than 2 to 4 weeks lest the recovering muscles start weakening from nonuse. Heat is helpful and should be applied by a heating pad, hot showers, or hot tub soaks. If neck pain is severe, a short period of bed rest may be necessary. Mild analgesics, nonsteroidal antiinflammatory drugs (NSAIDs), and muscle relaxants are all helpful and are generally indicated. Narcotic analgesics should be avoided if at all possible. Activity should be restricted as determined by the severity of the symptoms. Generally, driving should be avoided for the acute symptomatic period. After approximately 2 weeks of this regimen, significant improvement should be noted. If not, 2 more weeks of continued conservative care with the addition of some light home cervical traction should be employed. If symptoms persist at 4 weeks after injury, some further testing is necessary before emotional overlay is considered the cause. If headaches persist, a cranial MRI scan should be done. If normal at 4 weeks, the patient can be assured that no intracranial abnormality is present. If arm or shoulder pain persists, an MRI should be considered. If these tests are normal, the patient can be assured that no compression of neural structures is present.

Cervical Spine Algorithm

The task of the physician, when confronted with the cervical spine patient, is to integrate his or her complaints into an accurate diagnosis and to prescribe appropriate therapy. Achieving this goal depends on the accuracy of the physician's decision-making ability. Although specific information is not available for every aspect of neck pain, there is a large body of data to guide us in handling these patients. Using this knowledge, which has already been presented, an algorithm for neck pain has been designated.

Webster defines an algorithm as "a set of rules for solving a particular problem in a finite number of steps." It is, in effect, an organized pattern of decision making and thought processes that can be found useful, in this instance in approaching the universe of cervical spine patients. The algorithm can be followed in sequence (Fig. 7-3) and is also presented in table form (Table 7-2).

The primary objective for the physician is to return patients to their normal function as quickly as possible. In the course of achieving this goal, the physician must be concerned with other circumstances, which include making efficient and precise use of diagnostic studies, minimizing the use of ineffectual surgery, and making therapy available at a reasonable cost to society. The algorithm follows well-delineated rules, established from the consensus of a broad segment of qualified spine surgeons. It allows the patient to receive the most helpful diagnostic and therapeutic measures at optimal times.

The algorithm begins with the universe of patients who are initially evaluated for neck pain, with or without arm pain. Patients with major trauma, including fractures, are not included. After an initial medical history and physical examination—and assuming that the patient's symptoms are originating from the cervical spine—the first major decision is to rule in or out the presence of a cervical myelopathy.

The character and severity of the myelopathy depends on the size, location, and duration of the lesion. Ventrolateral lesions encroach on the nerve roots and lateral aspects of the spinal cord, producing all the manifestations accompanying nerve root compression. The chief radicular signs are weakness and loss of tone and volume of the muscles of the upper extremity, whereas the pressure on the spinal cord may produce pyramidal tract signs and spasticity in the lower extremities.

Midline lesions intrude on the central aspect of the anterior portion of the spinal cord. They produce no signs of nerve root compression. Both lower extremities are primarily involved, and the most common problem relates initially to gait disturbance. As the disease progresses, bowel and bladder control may be affected.

Once a diagnosis of cervical myelopathy is made, surgical intervention should be considered without delay. The best results are attained in patients with one or two motor units involved and with myelopathy of a relatively short duration. The longer pressure is applied to the neural elements, the poorer the results. A cervical MRI or CT-myelogram should be obtained in these patients to precisely define the neural compression, and an adequate surgical decompression should be performed as soon as possible to achieve the best results.

After cervical myelopathy has been ruled out, the remaining patients, who constitute an overwhelming majority, should be started on a course of conservative management. At this stage of the patient's course, a specific diagnosis, whether it be a herniated disk or neck strain, is not important because the entire group is treated in the same fashion.

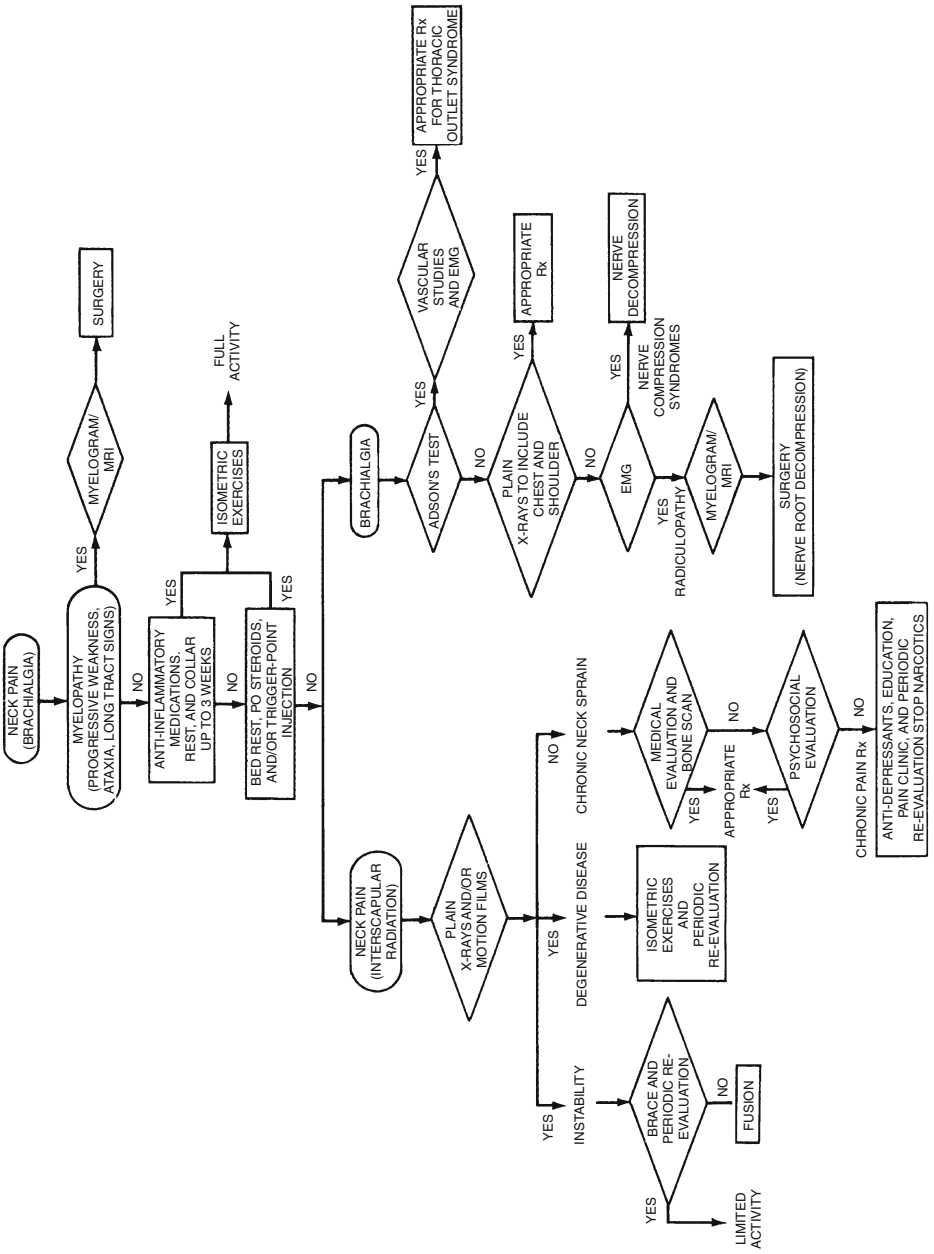


FIGURE 7-3. Cervical spine algorithm. (From Wiesel SE, Feffer HI, Rothman RH. Neck Pain. Charlottesville, VA: Michie, 1988, permission granted by LexisNexis Matthew Bender.)

TABLE 7-2. Differential diagnosis of neck pain.

Evaluation	Neck strain	Herniated nucleus pulposus	Instability	Degenerative disk disease	Myleopathy	Tumor	Spondyloarthropathy	Metabolic	Infection
Predominant pain (arm vs. neck)	Neck	Arm	Neck	Neck	Neck	Neck	Neck	Neck	Neck
Constitutional symptoms						+	+	−	+
Compression test		+							
Neurologic exam		+			+				
Plain radiographs			−	+	−	−	+	+	−
Lateral motion radiographs			+						
CAT scan		+		+	−	+			+
Myelogram		+			+				
Bone scan						+	+	−	+
ESR							+		+
Ca/P/alk phos						+		+	

Ca/P/alk phos, calcium, phosphate, and alkaline phosphatase; CAT, computerized axial tomography; ESR, erythrocyte sedimentation rate.

Conservative Treatment

The primary mode of therapy in both acute and chronic cervical spine disease is immobilization. In the acute neck injuries, immobilization allows for healing of torn and attenuated soft tissues, whereas in chronic conditions immobilization is aimed at reduction of inflammation in the supporting soft tissues and around the nerve roots of the cervical spine.

Immobilization is best achieved by the use of a soft felt collar. It needs to be properly fitted and comfortable for the patient. Initially, the collar is worn 24 hours a day. The patient must understand that during sleep the neck is totally unprotected from awkward positions and movement and that therefore the collar is most important at that time.

The other mainstay of the initial treatment is drug therapy, which is directed at reducing inflammation, especially in the soft tissues. A variety of antiinflammatory medications is available; however, there is no one drug that has proven to be significantly better than all the others. The dosage must be adequate to achieve a therapeutic blood level. The efficacy of this treatment regimen is predicated on the patient's ability to understand the disease process and the role of each therapeutic modality. Most patients will respond to this approach in the first 10 days, but a certain percentage will not heal rapidly.

At this juncture, a local injection into the area of maximal tenderness should be considered. Localized tender areas in the paravertebral musculature and trapezii will be found in many individuals and are referred to as trigger points. Marked relief of symptoms is often achieved dramatically by infiltration of these trigger points with a combination of lidocaine (Xylocaine) and 1 mL steroid preparation. The object of the injection is to decrease the inflammation in a specific anatomic area. The more localized the trigger point, the more effective this form of therapy.

The patient should be treated conservatively for up to 6 weeks. The majority of cervical spine patients get better and should be encouraged to gradually increase their activities. The goal is a return to their normal lifestyles. An exercise program should be directed at strengthening the paravertebral musculature, not at increasing the range of motion.

The pathway along this top portion of the algorithm is reversible. Should regression occur, with exacerbation of symptoms, the physician can resort to more stringent conservative measures. The majority of patients with neck pain will respond to therapy and return to a normal life pattern within 2 months of the beginning of their problem. If the initial conservative treatment regimen fails, symptomatic patients are divided into two groups. The first is composed of people who have neck pain as a predominant complaint, with or without interscapular radiation. The second group includes those who complain primarily of arm pain (brachialgia).

Neck Pain Predominant

After 6 weeks of conservative therapy with no symptomatic relief, plain roentgenograms with lateral flexion–extension films are carefully examined for abnormalities. One group of patients will have objective evidence of instability. In the lower cervical spine (C3 through C7), instability is identified by horizontal translation of one vertebra on another of more than 3.5 mm, or of an angulatory difference of adjacent vertebrae of more than 11 degrees. The majority of patients with instability will respond well to further nonoperative measures, including a thorough explanation of the problem and some type of bracing. In some cases, these measures fail and a surgical fusion of the involved spinal segments will be necessary.

Another group of patients complaining mainly of neck pain will be found to have degenerative disease on their plain X-ray films. The roentgenographic signs include loss of height of the intervertebral disk space, osteophyte formation, secondary encroachment of the intervertebral foramina, and osteoarthritic changes in the apophyseal joint. The difficulty is not in identifying these abnormalities on the roentgenogram but in determining their significance.

Degeneration in the cervical spine can be a normal part of the aging process. In a study of matched pairs of asymptomatic and symptomatic patients, it was concluded that large numbers of asymptomatic patients show roentgenographic evidence of advanced degenerative disease. The most significant roentgenographic finding relevant to symptomatology was found to be narrowing of the intervertebral disk space, particularly between C5–C6 and C6–C7. There was no difference between the two groups insofar as changes at the apophyseal joints, intervertebral foramina, or posterior articular process.

These patients should be treated symptomatically with antiinflammatory medication, support, and trigger-point injections as required. In the quiescent stages, they should be placed on isometric exercises. Finally, they should be reexamined periodically because some will develop significant pressure on the neurologic elements (myelopathy).

The majority of patients with neck pain have normal roentgenograms. The diagnosis for this group is neck strain. At this point, with no objective findings, other pathology must be considered. These patients should undergo a bone scan and medical evaluation. The bone scan is an excellent tool, often identifying early spinal tumors or infections not seen on routine roentgenographic examinations. A thorough medical search may also reveal problems missed in the early stages of neck pain evaluation. If these diagnostic studies are positive, the patient is treated appropriately. If the foregoing workup is negative, the patient should have a thorough psychosocial evaluation; this is predicated on the belief that a patient's disability is related not only to his pathologic anatomy, but also to his perception of

pain and his stability in relationship to his sociologic environment. Drug habituation, alcoholism, depression, and other psychiatric problems are frequently seen in association with neck pain. If the evaluation reveals this type of pathology, proper measures should be instituted to overcome the disability.

Should the outcome of the psychosocial evaluation prove to be normal, the patient can be considered to have chronic neck pain. One must be aware that other outside factors such as compensation and/or litigation can influence a patient's perception of his subjective pain. Patients with chronic neck pain need encouragement, patience, and education from their physicians. They need to be detoxified from narcotic drugs and placed on an exercise regimen. Many will respond to antidepressant drugs such as amitriptyline (Elavil). All these patients need periodic reevaluation to avoid missing any new or underlying pathology.

Arm Pain Predominant (Brachialgia)

Patients who have pain radiating into their arm may be experiencing their symptoms secondary to mechanical pressure and inflammation of the involved nerve roots. This mechanical pressure may arise from a ruptured disk or from bone secondary to degenerative changes. Other pathologic causes of arm pain should be carefully considered. Extrinsic pressure on the vascular structures or on the peripheral nerves are most likely imitators of brachialgia. Pathology in the chest and shoulder should also be ruled out.

A careful physical examination should be conducted. If there is any question about these findings, appropriate roentgenograms and an EMG should be obtained. If any of these are positive for peripheral pressure on the nerves or other pathology, the appropriate therapy should be administered.

Should all these studies prove negative and the EMG is consistent, the patient is considered to have brachialgia. One must carefully reevaluate the patient who has a neurologic deficit or a positive EMG; those who have either should undergo an MRI. If the MRI is positive and is consistent with the physical findings, surgical decompression should be considered at this juncture.

It has been repeatedly documented that for surgery to be effective, unequivocal evidence of nerve root compression must be found at surgery. One must have a strong confirmation of mechanical root compression from the neurologic examination and a confirming study before proceeding with any surgery. The indications for surgery are the subjective complaint of arm pain and a neurologic deficit or positive EMG. An MRI must confirm the pathology. If the patient does not have these, there is inadequate clinical evidence to proceed with surgery. For patients who have met these criteria for cervical decompression, the results will usually be satisfactory: 95% of them can expect good or excellent outcomes.

Conservative Treatment Modalities

Most patients with neck pain will achieve relief from a conscientious program of conservative care. As the algorithm indicates, all patients with either chronic or acute neck pain (except those with severe myelopathy) deserve an initial period of conservative therapy. There are a multitude of treatment modalities available, but many of them are based on empiricism and tradition. The purpose of this section is to discuss the rationale behind the use of some of the more common nonoperative therapeutic measures.

Immobilization

The cornerstone of conservative therapy is immobilization of the cervical spine. The goal of immobilization is to rest the neck so that healing of torn and/or attenuated soft tissues in acute cervical injuries can take place. In the chronic situation, the purpose of immobilization is to reduce any inflammation.

Immobilization can best be achieved by the use of a soft cervical collar that holds the head in a neutral or slightly flexed position. It is very important that the collar is fitted properly. If the neck is held in hyperextension, the patient is usually quite uncomfortable and does not derive any benefit from its use. In acute neck injuries, the collar should be worn on a full-time basis, night and day, until the acute pain subsides. This result may sometimes take as long as 4 to 6 weeks, and the patient should be aware of this time course from the outset of treatment so that the physician will not feel pressured to discontinue immobilization before the proper time.

Drug Therapy

There are different groups of medications that have proved helpful in the treatment of neck pain: antiinflammatory drugs, analgesics, and muscle relaxants. They are used as an important adjunct to adequate immobilization.

Antiinflammatory drugs are used because it is believed that inflammation in the soft tissues is a major contributor to pain production in the cervical spine, which is especially true for those patients with symptoms secondary to a herniated disk. The arm pain that these people experience is caused not only by the mechanical pressure from the ruptured disk but also by the inflammation in and around the involved nerve roots. Usually, if one can get rid of the inflammation, the patient's pain will markedly decrease.

There is a spectrum of antiinflammatory agents available, but none has been proven superior. The author's usual treatment plan is to begin the patient on adequate doses and, if the response is not satisfactory after 2

weeks, switch to another. Most patients will get significant relief from one of the agents presently available. It should be stressed that antiinflammatory medications are utilized in conjunction with immobilization; they do not replace adequate rest.

Analgesic medication is also very important during the acute phase of neck pain. The goal is to keep the patient comfortable. Most patients will respond to the equivalent of 30 to 60 mg codeine every 4 to 6 hours. If stronger medication is required, the patient should be monitored very closely. In some cases, narcotics are abused by the patient and addiction will become a problem to some degree. The treating physician must maintain control of the patient's drug use at all times.

Injuries to the cervical spine frequently result in painful muscle spasm. A vicious cycle is established whereby pain leads to muscle spasm, which leads to ischemia and a further increase in pain. Once the cycle is established, it tends to be self-perpetuating. An effective muscle relaxant frequently breaks this painful cycle and allows more comfort and an increased range of motion in the cervical spine. Methocarbamol or carisoprodol in adequate doses are the drugs recommended. They are safe and quite effective.

Traction

Cervical traction has been used for many years. Today, opinions regarding its effectiveness range from that of it being a valuable clinical therapy to the conclusion that it is ineffective or potentially harmful or both.

There is no uniform idea as to how traction actually works, and there are a number of methods of actually applying the traction. The three major ways of administering traction are mechanical, manual, and home traction. Many believe that manual traction is preferred due to the interaction between the therapist and patient and the potential specificity of individually varying the traction.

In certain situations, cervical traction is contraindicated. Malignancy, cord compression, infectious disease, osteoporosis. and rheumatoid arthritis are the major disorders for which cervical traction should *not* be employed. It is also thought that when there is a herniated disk present, either in the midline or laterally, traction should not be considered.

The author believes that cervical traction is useful when a collar has proved ineffective in those patients with a cervical strain or a hyperextension injury. The major benefit is considered to be continued rest, and a home traction device is preferred. When used in this situation, only minimal amounts of weight (4–6 lb) should be used, and the direction of pull should be in slight flexion. As already mentioned, there are other ways of applying traction, but to date there is no valid scientific evidence available that traction in and of itself is effective.

Trigger-Point Injection

Many patients will complain of a very localized tender spot in the paravertebral area. In some of these cases, the discomfort can be relieved by infiltration of the trigger point with a combination of Xylocaine and a steroid preparation or Xylocaine alone. There have been no true randomized clinical trials to study the efficacy of trigger-point injections, but empirical evidence indicates they seem to work on some patients. It is interesting to note that although the pharmacologic effects of these drugs may wear off in 2 to 3 hours, the relief may last indefinitely.

Before actually injecting a patient, a history of allergy to the drugs to be used should be obtained. The more localized the trigger point, the more effective the injection tends to be. An area of diffuse tenderness does not respond very well to this approach.

Manipulation

Manipulation of the cervical spine should be approached very carefully. In the United States, this is mainly performed by chiropractors, although other healthcare professionals are involved. The goal of manipulation is to correct any malalignment of the spinal structures, which is assumed to be the etiology of the patient's pain. There is no real scientific evidence that manipulation of the cervical spine is effective in the treatment of acute or chronic neck problems.

Exercises

After a patient's acute symptoms have cleared and there is no significant pain or spasm, an exercise regimen is reasonable. The exercises should be directed at strengthening the paravertebral musculature and not at increasing the range of motion. Motion will return with the disappearance of pain. The exercises are isometric in nature. They are performed once a day with increasing repetitions. It should be appreciated that at present there are no scientific studies demonstrating that isometric exercises or any other type of cervical exercises will reduce the frequency of recurrent neck pain episodes. Empirically, they do appear to have a positive psychologic effect and give the patient an active part in his treatment program.

Lumbar Spine

Low back pain occurs much more commonly than neck pain. The lifetime incidence of low back pain is estimated to be 65%. Every physician will either be personally affected (family, friends) or professionally challenged by this problem.

History

A general medical review, especially in the older patient, is imperative. Metabolic, infectious, and malignant disorders may initially present to the physician as low back pain.

The location of the pain is one of the most important historical points. The majority of patients just have back pain with or without referral into the buttocks or posterior thigh. Referred pain is defined as pain in structures that have the same mesodermal origin. These patients have a localized injury, and the referral of pain into the buttocks or thigh does not signify any compression on the neural elements. This type of pain is described as dull, deep, and/or boring.

Another group of patients complains of pain that originates in their back, but travels below the knee into the foot. It is described as sharp and lancinating. It may be accompanied by numbness and tingling. This pain is termed radicular pain or a radiculopathy. A radiculopathy is defined as a mechanical compression of an inflamed nerve root in which the pain travels along the anatomic course of the nerve. The compression can be secondary to either soft tissue (disk) or bone. The most common nerve roots affected are L5 and S1, levels that account for pain traveling below the knee. Finally, one should inquire about changes in bowel or bladder habits. Occasionally, a large midline disk herniation may compress several roots of the cauda equina (Fig. 7-4); this is termed cauda equina compression (CEC) syndrome. Urinary retention or incontinence of bowel or bladder are, along with severe pain, the major symptoms.

Physical Examination

The physical examination is directed at finding the location of the pain. All patients with low back pain can have some nonspecific findings, which vary in degree depending on the severity of the condition; these include a list to one side, tenderness to palpation and percussion, and a decreased range of motion of the lumbar spine. These findings can be present in both radiculopathy and referred pain patients. Their presence denotes that there is a problem but does not identify the etiology or level of the problem. The neurologic examination may yield objective evidence of nerve root compression if present (Table 7-3). A thorough neurologic evaluation of the lower extremities should be conducted on each patient, particularly to check the reflexes and motor findings. Sensory changes may or may not be present, but because of overlap in the dermatomes of spinal nerves, it is difficult to identify specific root involvement.

In patients with radiculopathies, there are several maneuvers that tighten the sciatic nerve and, in so doing, further compress an inflamed lumbar root against a herniated disk or bony spur. These maneuvers are generally termed tension signs or a straight leg-raising test (SLRT). The conven-

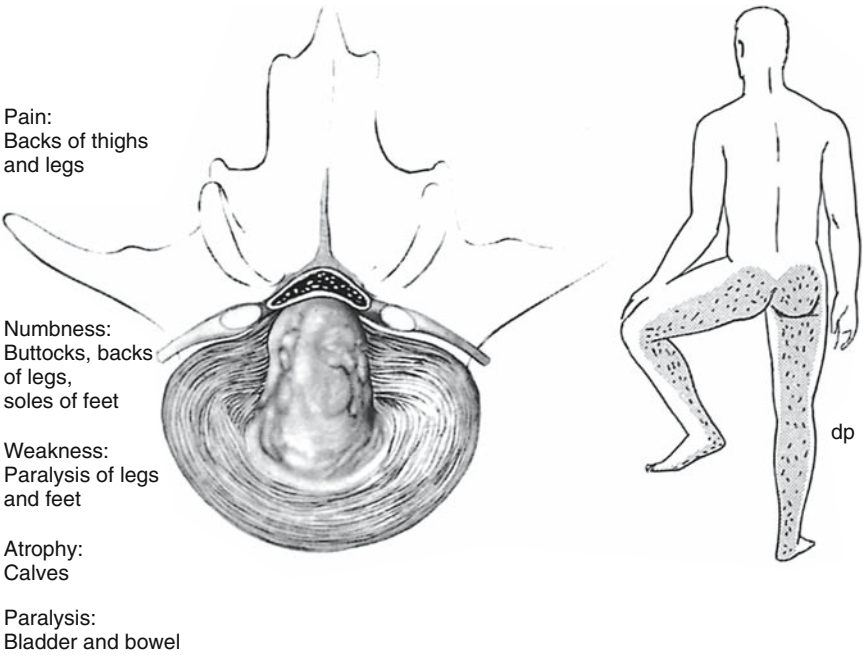


FIGURE 7-4. Massive herniation at the level of the third, fourth, or fifth disk may cause severe compression of the cauda equina. Pain is confined chiefly to the buttocks and the back of the thighs and legs. Numbness is widespread from the buttocks to the soles of the feet. Motor weakness or loss is present in the legs and feet with loss of muscle mass in the calves. The bladder and bowels are paralyzed. *DP*, distribution of pain and paresthesia. (From DePalma AF, Rothman RH. The Intervertebral Disc. Philadelphia: Saunders, 1970. Reprinted by permission.)

tional SLRT is performed with the patient supine. The examiner slowly elevates the leg by the heel with the knee kept straight (Fig. 7-5). This test is positive when the leg pain below the knee is reproduced or intensified; the production of back and/or buttock pain does not constitute a positive finding. The reliability of the SLRT is age dependent. In a young patient, a negative test most probably excludes the possibility of a herniated disk. After the age of 30, however, a negative SLRT no longer reliably excludes the diagnosis.

Finally, the physical examination should evaluate some specific problems that can present as low back pain. This phase includes a peripheral vascular examination, hip joint evaluation, and abdominal examination.

Diagnostic Studies

As in the cervical spine, diagnostic tests should be used to confirm the core of information gathered from a thorough history and physical examination.

Table 7-3. Clinical features of herniated lumbar disks.

L3–L4 disk: L4 nerve root	
Pain	Lower back, hip, posterolateral thigh, across patella, anteromedial aspect of leg
Numbness	Anteromedial thigh and knee
Weakness	Knee extension
Atrophy	Quadriceps
Reflexes	Knee jerk diminished
L4–L5 disk: L5 nerve root	
Pain	Sacroiliac region, hip, posterolateral thigh, anterolateral leg
Numbness	Lateral leg, first webspace
Weakness	Dorsiflexion of great toe and foot
Atrophy	Minimal anterior calf
Reflexes	None, or absent in posterior tibial tendon reflex
L5–S1 disk: S1 nerve root	
Pain	Sacroiliac region, hip, posterolateral thigh/leg
Numbness	Back of calf; lateral heel, foot, and toe
Weakness	Plantar flexion of foot and great toe
Atrophy	Gastrocnemius and soleus
Reflexes	Ankle jerk diminished or absent

Source: From Boden S, Wiesel SW, Laws E, et al. The Aging Spine. Philadelphia: Saunders, 1991:177. Reprinted by permission.

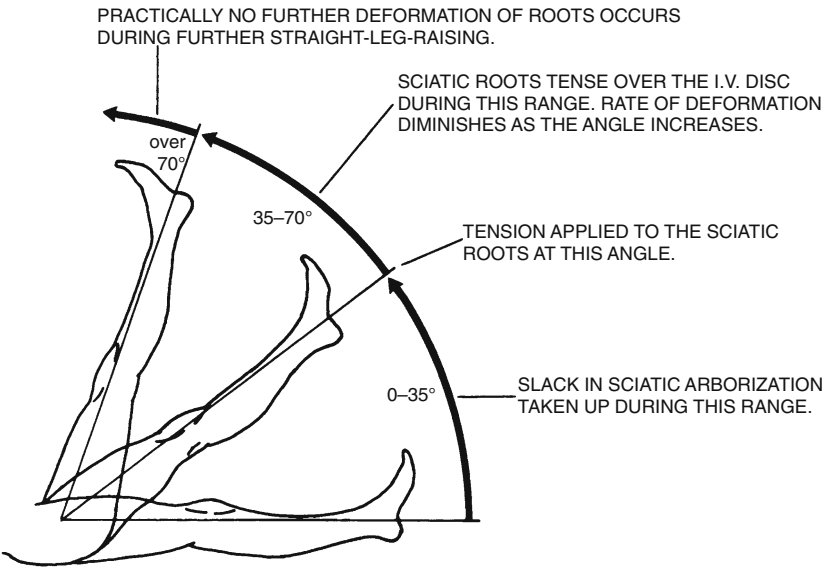


Figure 7-5. The dynamics of the straight leg-raising test. (Modified from Fahrni WH. Observations on straight leg-raising, with special reference to nerve root adhesions. Can J Surg 1966;9.)

Several lumbosacral imaging modalities are currently available including plain films, myelography, CT, and MRI.

To evaluate the true clinical value of any diagnostic study, one must know its sensitivity (false negatives) and specificity (false positives). The specificity, or false-positive rate, is usually measured in a population of symptomatic patients who have undergone surgery; however, often there is a much higher rate of false positives when an asymptomatic group is studied. The accuracy of any single test increases when it is combined with a second or third diagnostic study: the challenge for the physician is to select diagnostic tests on the basis of their performance characteristics so that the correct diagnosis is obtained with the least cost and morbidity. The studies most frequently utilized in the diagnostic assessment of low back pain are described next and critically analyzed with this in mind.

Plain Radiographs

The diagnosis of disk herniation can usually be made on the basis of a history and physical examination. Plain radiographs of the lumbosacral spine must be obtained in the appropriate setting to rule out other pathologic conditions such as infection or tumor. Plain radiographs are valuable for seeking the diagnosis of spinal stenosis, spondylolisthesis, gross segmental instability, or fracture.

The radiograph must be of excellent quality and taken with attention to detail. In general, three views are all that are required to assess the lumbosacral spine: an AP view, a lateral view, and a coned-down lateral view of the lower two interspaces. On occasion, two oblique views are also taken to identify subtle spondylolysis or pars interarticularis defects. However, oblique views provide limited information and should not be routinely included.

Although plain films are useful for surveying the bony elements of the spine and paraspinal soft tissues, the contents of the spinal canal, including cord, dura, ligaments, and encroaching disk are not visualized. In addition, bony lesions may not be apparent until 50% of the cancellous bone has been destroyed.

Finally, degenerative changes such as disk space narrowing, traction osteophytes, vacuum disk phenomenon, and end-plate sclerosis are quite prevalent in older individuals. Unfortunately, these radiographic findings have been shown to correlate poorly with clinical symptoms.

Magnetic Resonance Imaging

Magnetic resonance imaging (MRI) is the diagnostic modality of choice when trying to evaluate the different tissues in the spine (Fig. 7-6); it is especially good for observing disk pathology. MRI with gadolinium-diethylenetriaminopentaacetic acid (DTPA) contrast enhancement is superb for demonstrating intraspinal tumors and for distinguishing recurrent disk

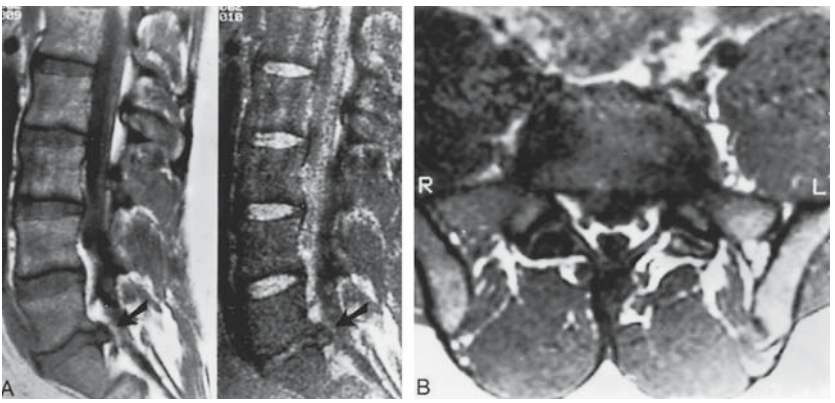


FIGURE 7-6. (A) Magnetic resonance imaging (MRI) scan of a herniated disk, sagittal view. T_1-weighted image (*left*) demonstrates a herniated disk (*arrow*) at the L5–S1 level. The T_2-weighted image (*right*) shows loss of the normal white signal within the nucleus pulposus (*arrow*), a sign of degenerative disk disease. (From Boden SD, Davis DO, Dina TS, et al. Abnormal lumbar spine MRI scans in asymptomatic subjects: a prospective investigation. J Bone Joint Surg 1990;72A:403–408. Reprinted by permission.) (B) MRI scan of a herniated disk, axial view. T_1-weighted image at the L5–S1 disk space demonstrates a large, central herniated disk with lateral displacement of both S1 nerve roots and posterior displacement of the cauda equine. (From Boden S, Wiesel SW, Laws E et al. The Aging Spine. Philadelphia: Saunders, 1991. Reprinted by permission.)

herniation from scar tissue. As with other diagnostic imaging modalities discussed, MRI also has been shown to have a significant clinical false-positive rate in asymptomatic individuals. In one prospective and blinded study, 22% of the asymptomatic subjects under age 60 and 57% of those over age 60 had significantly abnormal scans. In addition, the prevalence of disk degeneration on the $T1_2$-weighted MRI scans was found to approach 98% in subjects over the age of 60.

Myelography

Myelography is employed for evaluating neural compression when an MRI cannot be used. Dye is injected into the dural sac and mixes with the spinal fluid. The outline of the contents of the spinal canal can be visualized on X-ray; any extradural mass such as a herniated disk appears as a filling defect in the dye column (Fig. 7-7) whereas an intrathecal mass appears as an outward protrusion.

The myelogram is an invasive procedure and should not be taken lightly. Complications include severe headache, nausea, vomiting, and, although rare, even seizures. Before the utilization of the water-soluble dye metri-

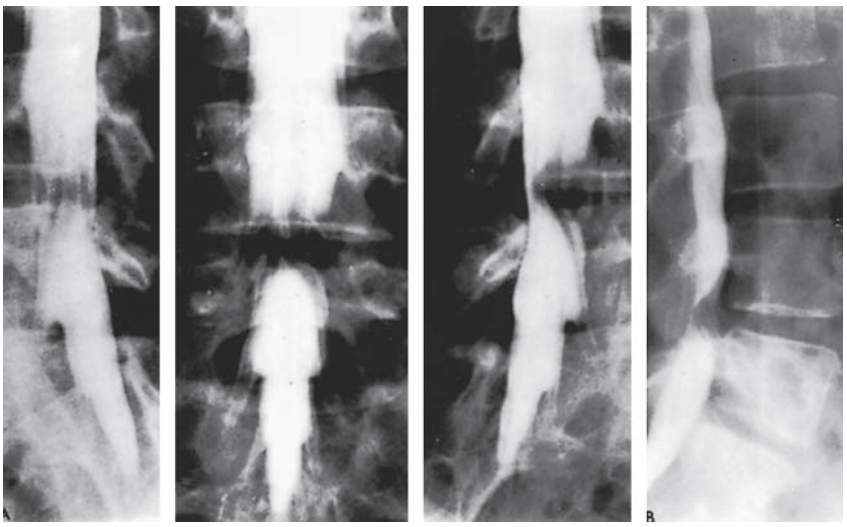


FIGURE 7-7. This metrizamide myelogram illustrates a large central disk herniation at the L4–L5 level. (A) Anteroposterior and oblique views reveal this prominent defect more marked on the *right*. (B) This lateral view illustrates a "double-density" prominent ventral indentation of the dye column. (From Rothman RH, Simeone FA. The Spine, 2nd ed. Philadelphia: Saunders, 1982, reprinted with permission.)

zamide, the oil-based agent Pantopaque had a much higher incidence of complications and was known to cause a crippling arachnoiditis. Newer contrast agents are now available that are reported to have fewer side effects.

Computed Tomography

Computed tomography is a very versatile and widely available noninvasive modality for evaluating abnormalities of the lumbosacral spine. Multiple cross-sectional (axial) images of the spine are made at various levels and, with reformatting, coronal, sagittal, and three-dimensional images may be created. The CT scan demonstrates not only the bony spinal configuration, but also the soft tissue in graded shading, so that ligaments, nerve roots, free fat, and intervertebral disk protrusions can be evaluated as they relate to their bony environment (Figs. 7-8, 7-9).

The CT scan is an extremely valuable diagnostic tool when it is used appropriately to confirm the patient's clinical findings. However, recent studies reveal the pitfalls of making clinical decisions on the basis of isolated CT scan findings. Despite many reports in the literature indicating that CT scanning has a mean accuracy of 90% in symptomatic patients, 34% of asymptomatic patients had abnormal CT scans when reviewed by

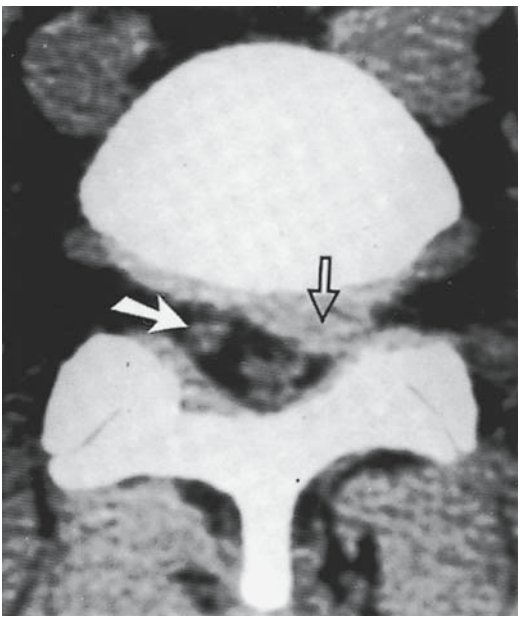


FIGURE 7-8. Posterolateral disk herniation. A posterolateral disk herniation at L5–S1 on the left (*open arrow*) is encroaching on epidural fat and compressing the S1 nerve root. Notice the uninvolved S1 nerve root on the right (*white arrow*), which is surrounded by epidural fat. (From Kricun ME. Imaging Modalities in Spinal Disorders. Philadelphia: Saunders, 1988. Reprinted by permission.)

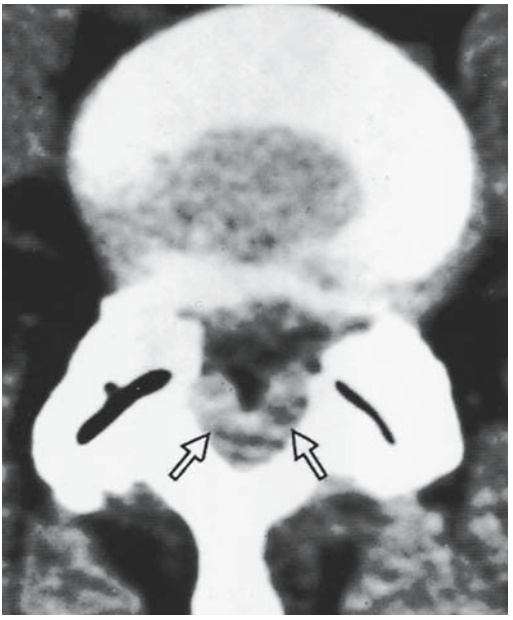


FIGURE 7-9. Spinal stenosis. The size of the thecal sac is diminished because of thickening of the ligamenta flava (*arrows*). Gas within the facet joints (vacuum facet) is evident. (From Kricun ME. Imaging Modalities in Spinal Disorders. Philadelphia: Saunders, 1988. Reprinted by permission.)

three independent expert interpreters. The implication is that a patient with a negative history and physical examination for a spinal lesion has a one-in-three chance of having an abnormal CT scan. If the decision for surgery is based only on scan results, there is a 30% chance that the patient will undergo an unnecessary and unsuccessful operation. However, if the patient's clinical picture correlates with the CT scan abnormalities, CT can be a useful confirmatory diagnostic tool.

Electrodiagnostic Testing

The EMG is performed by placing needles into muscles to determine if there is an intact nerve supply to that muscle. An abnormal EMG can demonstrate impaired nerve transmission to a specific muscle and isolate the nerve root involved. Initially, the EMG will be negative in spite of nerve entrapment and only show muscle irritability. After 3 weeks of significant pressure on a nerve root, signs of denervation with fibrillation can be observed.

The EMG, similar to all the other confirmatory tests already discussed, is not a screening tool. In fact, when dealing with the average low back problem, the EMG rarely provides any information that cannot be derived from a careful physical examination. It may even confuse the picture, because an EMG may be abnormal from diabetic neuropathy, previous peripheral nerve entrapment, or trauma. In cases in which the correlation of clinical signs and imaging is equivocal, especially with chronic unexpected sciatica, nerve conduction studies and EMG may be helpful. Electromyography can also detect the involvement of a secondary nerve root in cases of complex back injury preoperatively, sometimes prompting a more-extensive operation.

Clinical Conditions

There are a number of conditions that can present as low back pain in any particular individual. However, the following four, the most common of those typically evaluated by orthopedic surgeons, are discussed in detail: back strain, herniated disk, spinal stenosis, and spondylolisthesis.

Back Strain–Lumbago

The vast majority of people who have low back discomfort suffer from a nonradiating type of low back pain called back sprain or lumbago. The etiology is not always clear but is probably a ligamentous or muscular strain secondary to either a specific traumatic episode or the continuous mechanical stress of a postural inadequacy. These patients may also include those with a small tear in the annulus fibrosus, which would account for the frequent prior history of low back pain in patients with a ruptured disk.

The main complaint of these patients is back pain, and it can be limited to one spot or cover a diffuse area of the lumbosacral spine. At times, there may be a referral of pain to the buttocks or posterior thigh because the lower back, buttocks, and posterior thigh all originate from the same embryonic tissue, or mesoderm. Such referral of pain does not necessarily connote any mechanical compression of the neural elements and should not be called sciatica.

The usual findings are limited to local tenderness over the involved area and muscle spasm; however, the attacks vary in intensity and can conveniently be divided into three categories: mild, moderate, and severe. Those placed in the mild group have subjective pain without objective findings and should be able to return to customary activity in less than a week. The moderate group is characterized by a limited range of spinal motion and paravertebral muscle spasm as well as pain, and these patients should be able to resume full activity in less than 2 weeks. The severe group includes those patients who are tilted forward or to the side. They have trouble ambulating and can take up to 3 weeks to become functional again.

Because a normal X-ray is a standard occurrence with a patient complaining of back strain, a radiographic study is usually not necessary on the first visit if the physician feels comfortable with the diagnosis; however, if the response to treatment does not proceed as expected, films should be taken to rule out other more serious problems such as spondylolisthesis or tumor. The authors' usual recommendation is that if a patient fails to respond to conservative treatment for an acute attack of low back pain after a period of 2 weeks, then a routine lumbosacral spine X-ray series is clinically indicated.

The authors' preferred treatment for low back strain is the functional restoration approach. The mainstay of treatment is controlled physical activity, with the judicious use of trunk flexibility and strengthening exercises as the acute phase subsides. Often, particularly in the obese patient with weak abdominal muscles, a lightweight lumbosacral corset is useful in helping to mobilize those encumbered by low back strain.

Herniated Disk

A herniated disk can be defined as the herniation of the nucleus pulposus through the torn fibers of the annulus fibrosus. Most disk ruptures occur during the third and fourth decade of life while the nucleus pulposus is still gelatinous. The perforations usually arise through a defect just lateral to the posterior midline where the posterior longitudinal ligament is weakest. The two most common levels for disk herniation are L4–L5 and L5–S1. These two disks account for 95% of all lumbar disk herniations; pathology at the L2–L3 and L3–L4 levels can occur, but is relatively uncommon.

Disk herniations at L5–S1 usually compromise the first sacral nerve root. A lesion at the L4–L5 level most often compresses the fifth lumbar root, whereas a herniation at the L3–L4 more commonly involves the fourth lumbar root. It should be pointed out, however, that variations in root configuration as well as in the position of the herniation itself can modify these relationships. An L4–L5 disk rupture can at times affect the first sacral as well as the fifth lumbar root and, in extreme lateral herniations, the nerve ending exiting at the same level as the disk is involved.

Not everyone with a disk herniation has significant discomfort. A large herniation in a capacious canal may not be clinically significant because there is no compression of the neural elements, whereas a minor protrusion in a small canal may be crippling because there is not enough room to accommodate both the disk and the nerve root.

Clinically, the patient's major complaint is pain. Although there may be a prior history of intermittent episodes of localized low back pain, this is not always the case. The pain not only is present in the back but also radiates down the leg in the distribution of the affected nerve root. It is usually described as sharp or lancinating, progressing from the top downward in the involved leg. Its onset may be insidious or sudden and associated with a tearing or snapping sensation in the spine. Occasionally, when the sciatica develops, the back pain may resolve because once the annulus has ruptured, it may no longer be under tension. Finally, the sciatica may vary in intensity; it may be so severe that patients are unable to ambulate and feel that their back is "locked." Conversely, the pain may be limited to a dull ache that increases in intensity with ambulation.

On physical examination, there is usually a decreased range of motion in flexion, and patients will tend to drift away from the involved side as they bend. On ambulation, the patient walks with an antalgic gait, holding the involved leg flexed so as to put as little weight as possible on the extremity.

Although neurologic examination may yield objective evidence of nerve root compression, these findings are often undependable because the involved nerve is often still functional. In addition, such deficit may have little temporal relevance because it may relate to a prior attack at a different level. To be significant, reflex changes, weakness, atrophy, or sensory loss must conform to the rest of the clinical picture.

When the first sacral root is compressed, the patient may have gastrocnemius–soleus weakness and be unable to repeatedly raise up on the toes of that foot. Atrophy of the calf may be apparent, and the ankle (Achilles) reflex is often diminished or absent. Sensory loss, if any, is usually confined to the posterior aspect of the calf and lateral side of the foot.

Involvement of the fifth lumbar nerve root can lead to weakness in extension of the great toe and, less often, to weakness of the everters and dorsiflexors of the foot. An associated sensory deficit can appear over the anterior leg and the dorsomedial aspect of the foot down to the great toe. There are usually no primary reflex changes, but, on occasion, a diminution

in the posterior tibial reflex can be elicited. The absence of this reflex, however, must be asymmetrical for it to have any clinical significance.

With compression of the fourth lumbar nerve root, the quadriceps muscle is affected. The patient may note weakness in knee extension, and it is often associated with instability. Atrophy of the thigh musculature can be marked. A sensory loss may be apparent over the anteromedial aspect of the thigh, and the patellar tendon reflex is usually diminished.

Nerve root sensitivity can be elicited by any method that creates tension; however, the SLRT is the one most commonly employed. As discussed previously, a positive test reproduces the patient's pain down the leg. The reproduction of back pain is not considered positive.

The initial diagnosis of a herniated disk is generally made on the basis of the history and physical examination. Plain X-rays of the lumbosacral spine rarely add to the diagnosis but should be obtained to help rule out other causes of pain such as infection or tumor. Other tests such as the EMG, the computerized axial tomography (CAT) scan, and MRI are confirmatory by nature and can be misinformative when they are used as screening devices.

The treatment for most patients with a herniated disk is nonoperative because 80% of them will respond to conservative therapy when followed over a period of 5 years. The efficacy of nonoperative treatment, however, depends upon a healthy relationship between a capable physician and a well-informed patient. If a patient has insight into the rationale for the prescribed treatment and follows instructions, the chances of success are greatly increased.

One of the most important elements in the nonoperative treatment is controlled physical activity. Patients should markedly decrease their activity; this sometimes requires bed rest and in most cases can be accomplished at home. An acute herniation usually takes at least 2 weeks of significant rest before the pain substantially eases.

Drug therapy is another important part of the treatment, and three categories of pharmacologic agents are commonly used: antiinflammatory drugs, analgesics, and muscles relaxants or tranquilizers. Inasmuch as the symptoms of low back pain and sciatica result from an inflammatory reaction as well as mechanical compression, the authors believe that antiinflammatory medication should be taken in conjunction with rest. It should be stressed, however, that no medication can take the place of controlled physical activity. The patient's pain generally is relieved when the inflammation is brought under control. There may be some numbness or tingling in the involved extremity, but this is usually tolerable.

Analgesic medication is rarely needed if the patient really rests, because the pain is usually adequately controlled by decreased activity.

There is some question as to whether there actually is a muscle relaxant; all drugs that are so designated probably act to some degree as tranquilizers. If one is required, however, methocarbamol and carisoprodol are most frequently used and can be employed intravenously as well as orally. The

use of diazepam (Valium) for this purpose should be discouraged because it is actually a depressant and often adds to the patient's psychologic problems.

Eighty percent of those who follow the foregoing regimen will be markedly improved, but it requires patience because frequently at least 6 weeks have passed before any additional therapy is indicated. Although the noninvasive treatment of a herniated disk can be quite gratifying, it generally requires a significant period of rest, and the patient must be aware of the time constraints from the beginning to understand the rationale behind the measures employed.

The long-term prognosis for patients with disk herniation is quite good. It has been shown that between 85% and 90% of surgically treated and nonsurgically treated patients were asymptomatic at 4 years. Less than 2% of both groups were symptomatic at 10 years.

Spinal Stenosis

Spinal stenosis can be defined as a narrowing of the spinal canal, and the mechanical pressure on the neural structures within depends upon the degree of narrowing. Every person's spine, however, becomes narrower with age as a result of osteoarthritis. Not everyone with a narrowed spinal canal, however, has symptoms.

For those who do suffer, the discomfort can vary from mild annoyance to an inability to walk. The symptom complex is well documented. Patients of either sex, usually not before their fifth decade, first complain of vague pains, dysesthesias, and paresthesias with ambulation, but typically have excellent relief of their symptoms when they are sitting or lying supine. The increased lordotic stance assumed when walking, and particularly walking down grades, is most likely the inciting cause. The hyperextension further narrows the spinal canal and increases the symptoms.

With maturation of the syndrome, symptoms may even occur at rest. Muscle weakness, atrophy, and asymmetrical reflex changes may then appear; however, so long as the symptoms are only aggravated dynamically, neurologic changes occur only after the patient is stressed. The following stress tests can be used in an outpatient clinic: after a neurologic examination has been performed on the patient, he or she is asked to walk up and down the corridor until symptoms occur or the patient has walked 300 feet. A repeat examination is then done, and in many cases the second examination is positive for a focal neurologic deficit when the first was negative. Plain X-rays are often helpful in visualizing spinal stenosis, particularly degenerative spinal stenosis. One can see intervertebral disk degeneration, decreased interpedicular distance, a decreased sagittal canal diameter, and facet degeneration. If a patient fails conservative treatment and becomes a surgical candidate, the location and degree of neurologic compression can be assessed with MRI or a CT scan/myelogram.

The majority of patients with spinal stenosis, especially the degenerative and combined variety, can be treated nonsurgically with antiinflammatory medication.

Finally, a lumbosacral corset is often helpful in reminding the patient to avoid excessive motion. Symptoms are usually intermittent, and the individual often needs encouragement in getting through the episode without getting depressed. Nonoperative management is preferable so long as the pain is tolerable.

Spondylolisthesis

Spondylolisthesis is a spinal condition in which all or part of a vertebra has slipped forward on another. The word is derived from the Greek *spondylos*, meaning vertebra, and *olisthesis*, meaning to slip. There are several different types of spondylolisthesis, but the most common is that in which the lesion is in the isthmus or pars interarticularis. If a defect can be identified, but no slipping has occurred, the condition is termed spondylolysis; if one vertebra has slipped forward on another (horizontal translation), it is referred to as spondylolisthesis.

The etiology of the defect in spondylolysis is not clear. Although there may be a hereditary component, the lesion is seldom seen in patients under the age of 5 and is found in 5% of people over the age of 17. The most attractive explanation is that although these children inherit a potential deficiency in the pars, they are not born with any identifiable defect. Between the ages of 5 and 17 years, however, they become more active and a stress fracture, caused by repetitive hyperextension stresses, can develop into a spondylolysis. It is likely that most of these fractures occur during the period of rapid growth known as the adolescent growth spurt, and they are particularly prevalent in gymnasts and football players.

Spondylolisthesis has several characteristic features, but the forward displacement is easily recognized radiographically on the lateral projection (Figs. 7-10, 7-11). The degree of slip varies from patient to patient and can range from minimal displacement to complete dislocation of the vertebral body. Increased slipping rarely occurs after the age of 20 unless there has been a severe superimposed injury or surgical intervention. The period of most rapid progression coincides with the rapid growth spurt between the ages of 9 and 15.

The most common clinical manifestation of spondylolisthesis is low back pain. Although the cause of this type of back pain in the adult has been studied extensively, its origin is still not clear. There is no clear understanding of how so many patients develop this lesion between the ages of 5 and 17 but still have no back complaints until perhaps age 35, when a sudden twisting or lifting motion precipitates an acute episode of back and leg pain. Other patients with significant degrees of slipping, however, will go through life with no discomfort.

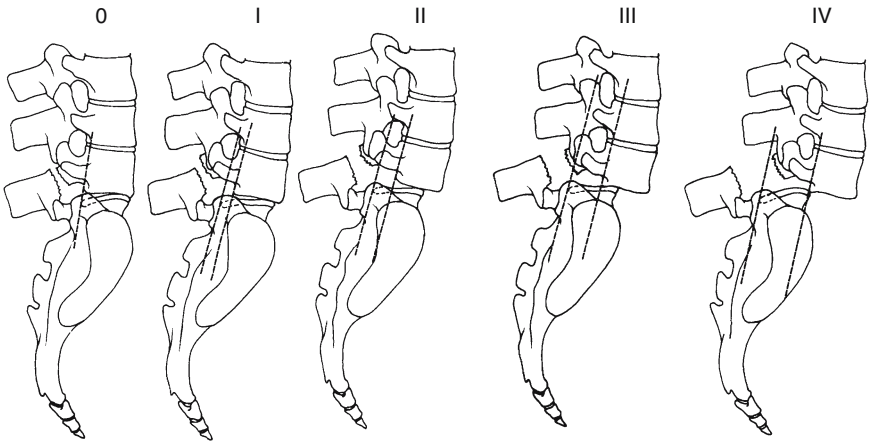


FIGURE 7-10. Grading system for spondylolisthesis. (From Borenstein DG, Wiesel SW. Low Back Pain: Medical Diagnosis and Comprehensive Management. Philadelphia: Saunders, 1989. Reprinted by permission.)

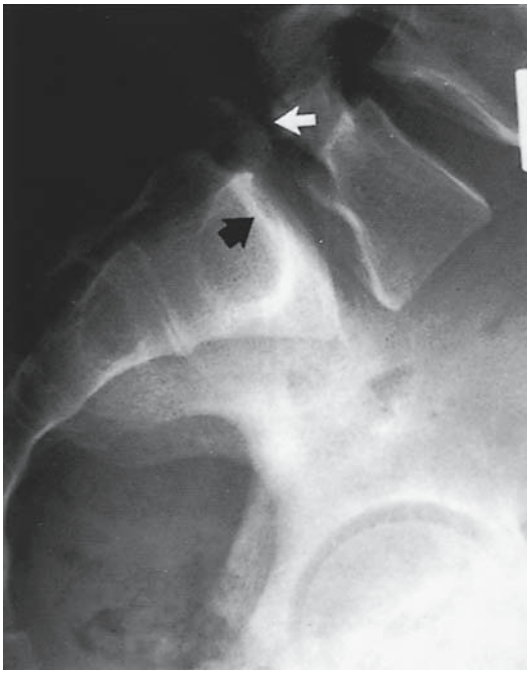


FIGURE 7-11. Lateral spot view of the lumbosacral junction. A grade I spondylolisthesis is present with 25% slippage of the superior vertebral body (*black arrow*). This view demonstrates a type II spondylolisthesis with a pars defect (*white arrow*). (From Borenstein DG, Wiesel SW. Low Back Pain: Medical Diagnosis and Comprehensive Management. Philadelphia: Saunders, 1989. Reprinted by permission.)

Although 50% of patients overall normally cannot associate an injury with the onset of the symptoms, of those working in industry almost all report an associated incident. It is possible to sustain an acute fracture of the pars, but it is a very rare occurrence. If the acuity of a pars defect is in question, it can be documented by a bone scan within 3 months of the injury; if the defect is long standing, the scan will be negative.

There is also frequently a buildup of a fibrocartilaginous mass at the defect, and this can cause pain by irritating the nerve root as it exits. It is thus not unusual that the patient with spondylolisthesis first complains of back pain but over time develops leg pain as the most annoying part of the problem.

Once the symptoms begin, the patient usually has constant low-grade back discomfort that is aggravated by activity and relieved by rest. There are some periods during which the pain is more intense than others, but unless the picture is complicated by severe leg pain, total incapacitation is rare. The patients are seldom aware of any sensory or motor deficit. At this point, it should be reemphasized that in some people even severe displacement is asymptomatic and gives rise to no disability. It is not uncommon to pick up a previously unrecognized spondylolisthesis on a routine gastrointestinal radiologic study of a 50-year-old patient.

The physical findings of this syndrome are fairly characteristic. In the absence of any radicular pain, the patient exhibits no postural scoliosis; but there is usually an exaggeration of the lumbar lordosis and a palpable "stepoff" with a dimple at the side of the abnormality. Occasionally, mild muscle spasm is demonstrable and, in most instances, some local tenderness can be elicited. Although the range of motion is usually complete, some pain can be expected on hyperextension.

Radiographs, particularly the lateral views, confirm the diagnosis. Even the slightest amount of forward slipping of the body of the involved vertebra is readily discernible, and the oblique views will disclose the actual defect in the pars.

The nonoperative treatment of the adult with spondylolisthesis is much the same as that used for backache from other causes. When the symptoms are acute, rest is indicated. If leg pain is a significant problem, then antiinflammatory medication can be quite beneficial. Exercises, usually a flexion–extension program, should be started once patients are in remission, and they are usually advised to own a corset for use during occasional strenuous activity. If conservative treatment is not successful, an operative approach can be considered that would include a spinal fusion.

Lumbar Spine Algorithm

As with patients with neck pain, the task of the physician when confronted with low back pain patients is to integrate their complaints into an accurate diagnosis and to prescribe appropriate therapy. This problem (universe of low back pain patients) has been formatted into an algorithm (Fig. 7-12),

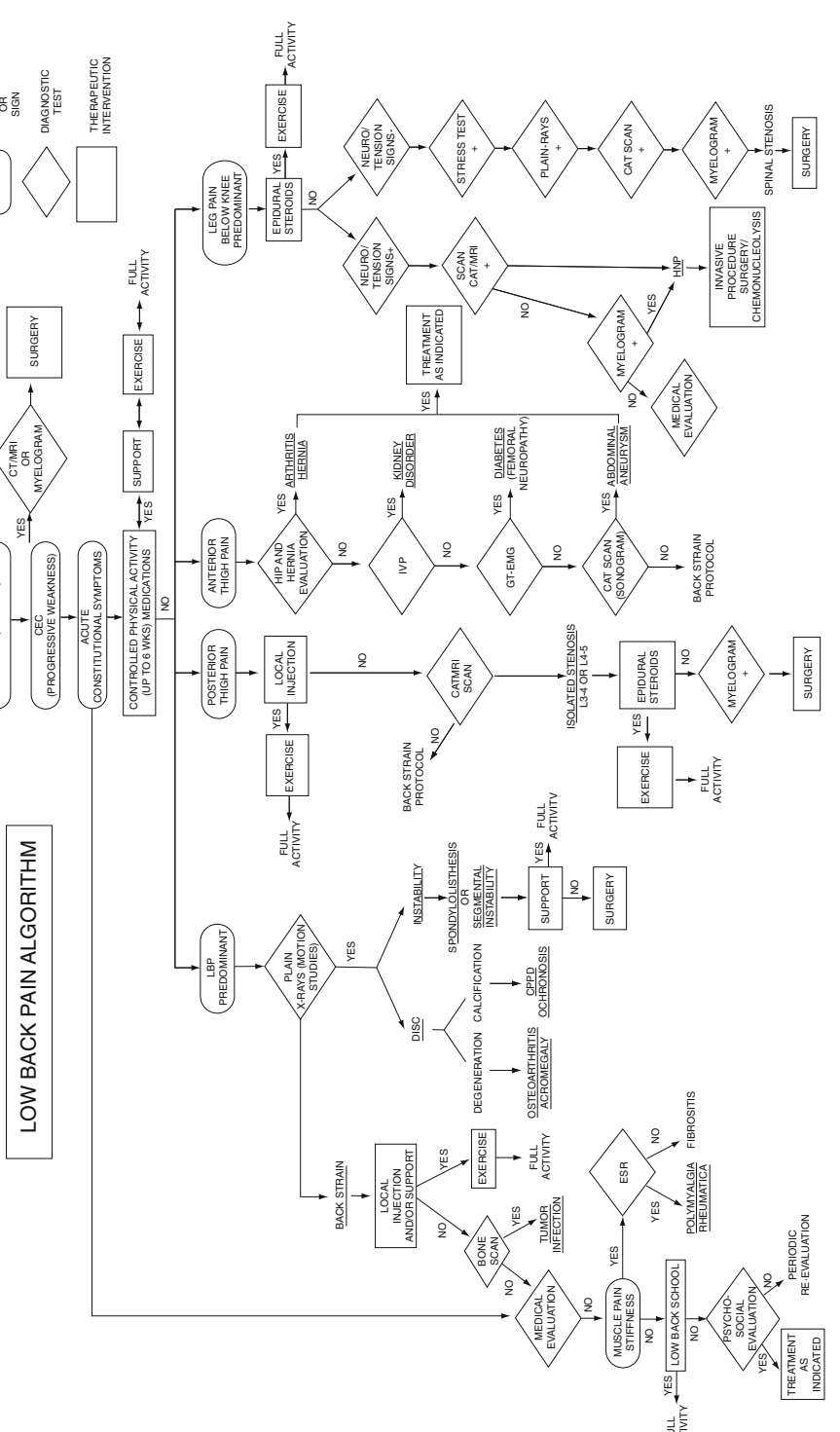


FIGURE 7-12. Algorithm for the differential diagnosis of low back pain. (From Boden S, Wiesel SW, Laws E, et al. The Aging Spine. Philadelphia: Saunders, 1991. Reprinted by permission.)

the aim of which is to select the correct diagnostic category and proper treatment avenues for each patient with low back pain. A specific patient may fall outside the limits of the algorithm and require a different approach, and the physician must constantly be on the alert for exceptions. The algorithm can be followed in sequence and is also presented in table form (Table 7-4).

The information necessary to use the algorithm is initially obtained through the history and physical examination. The key points in the history are differentiation of back pain that is mechanical in nature from nonmechanical pain which is present at rest, detecting changes in bowel or bladder function, and defining the precise location and quality of the pain. The physical examination must be oriented toward ruling out other medical causes of low back pain, assessing neurologic function, and evaluating for the presence of tension signs.

Following the low back pain algorithm, the first major decision is to make a ruling on the presence or absence of CEC syndrome. Mechanical compression of the cauda equina, with truly progressive motor weakness, is the only surgical emergency in lumbar spine disease. This compression from a massive rupture of the L4–L5 disk in the midline is usually caused by pressure on the caudal sac, through which pass the nerves to the lower extremities, bowel, and bladder.

The signs and symptoms of CEC are a complex mixture of low back pain, bilateral motor weakness of the lower extremities, bilateral sciatica, saddle anesthesia, and even frank paraplegia with bowel and bladder incontinence or urinary retention. CEC can be caused by either bone or soft tissue damage, the latter generally a ruptured or herniated disk in the midline. These patients should undergo an immediate definitive diagnostic test and, if it is positive, emergency surgical decompression. Historically, the myelogram was the study used in this setting; however, the development of the MRI has facilitated the noninvasive diagnosis of CEC. The principal reason for prompt surgical intervention is to arrest the progression of neurologic loss; the chance of actual return of lost neurologic function following surgery is small. Although the incidence of CEC syndrome in the entire back pain population is very low, it is the only event that requires immediate operative intervention; if its diagnosis is missed, the consequences can be devastating.

The remaining patients make up the overwhelming majority. They should be started on a course of conservative (nonoperative) therapy regardless of the diagnosis. At this stage the specific diagnosis, whether a herniated disk or simple back strain, is not important to the therapy because the entire population is treated the same way. A few of these patients will eventually need an invasive procedure (surgery), but at this point there is no way to predict which individuals will respond to conservative therapy and which will not.

TABLE 7-4. Differential diagnosis of low back pain.

Evaluation	Back strain	Herniated nucleus pulposus	Spinal stenosis	Spondylolisthesis/ instability	Spondyloarthropathy	Infection	Tumor	Metabolic	Hematologic	Visceral
Predominant pain (arm vs. neck)	Back	Leg (below knee)	Back/leg	Back	Back	Back	Back	Back	Back	Back (buttock, thigh)
Constitutional symptoms					+	+	+	+	+	
Tension sign		+		−						
Neurologic exam		−	− After stress							
Plain X-rays			+	+	+	−	−	+	+	
Lateral motion X-rays				+						
CT/MRI		+	+			+	+			+
Myelogram		+	+							
Bone scan					+	+	+	+	+	
ESR					+	+	+		+	+
Serum chemistries							+	+	+	+

Ca/P/alk phos, calcium, phosphate, and alkaline phosphatase; CT, computerized tomography; MRI, magnetic resonance imaging; ESR, erythrocyte sedimentation rate.

Conservative Treatment

Most of this initial group have nonradiating low back pain, termed lumbago or back strain. The etiology of lumbago is not clear. There are several possibilities, including ligamentous or muscular strain, continuous mechanical stress from poor posture, facet joint irritation, or a small tear in the annulus fibrosis. Patients usually complain of pain in the low back, often localized to a single area. On physical examination they demonstrate a decreased range of lumbar spine motion, tenderness to palpation over the involved area, and paraspinal muscle spasm. Their roentgenographic examinations are usually normal, but if therapy is not successful, films should be obtained to rule out other possible etiologic factors. Two exceptions to this rule are patients younger than 15 years of age and patients over age 60; X-rays are important early in the diagnostic process because these patients are more likely to have a diagnosis other than back strain (tumor or infection). Other situations warranting X-rays sooner rather than later include a history of serious trauma, known cancer, unexplained weight loss, and fever.

The early stage of the treatment of low back pain (with and without leg pain) is a waiting game The passage of time, the use of antiinflammatory medication, and controlled physical activity are the modalities proven safest and most effective. Most of these patients respond to this approach within the first 10 days, although a small percentage does not. In today's society with its emphasis on quick solutions and high technology, many patients are pushed too rapidly toward more complex (i.e., invasive) management. This quick-fix approach has no place in the treatment of low back pain. The physician should treat the patient conservatively and wait as long as 6 weeks for a response. As already stated, most of these patients will improve within 10 days; some need a longer time.

Once the patients have achieved approximately 80% relief, they should be mobilized with the help of a lightweight, flexible corset. After they are more comfortable and have increased their activity level, they should begin a program of lumbar exercises and return to their normal lifestyle. The pathway along this section of the algorithm is a two-way street: should regression occur with exacerbation of symptoms, the physician can resort to more stringent conservative measures. The patient may require further bed rest. Most acute low back pain patients will proceed along this pathway, returning to their normal life patterns within 2 months of onset of symptoms.

If the initial conservative treatment regimen fails and 6 weeks have passed, symptomatic patients are sorted into four groups. The first group is composed of people with low back pain predominating. The second group complains mainly of leg pain, defined as pain radiating below the knee and commonly referred to as sciatica. The third group has posterior thigh pain, and the fourth group has anterior thigh pain. Each group follows a separate diagnostic pathway.

Refractory Patients with Low Back Pain

Those patients who continue to complain predominantly of low back pain for 6 weeks should have plain X-rays carefully examined for abnormalities. Spondylolysis with and without spondylolisthesis is the most common structural abnormality to cause significant low back pain. Approximately 5% of the population has this defect, thought to be caused by a combination of genetics and environmental stress. In spite of this defect, most people are able to perform their activities of daily living with little or no discomfort. When symptoms are present, these patients usually respond to nonoperative measures, including a thorough explanation of the problem, a back support, and exercises. In a small percentage of such cases, conservative treatment fails and a fusion of the involved spinal segments becomes necessary. This is one of the few times primary fusion of the lumbar spine is indicated, and it must be stressed that it is a relatively infrequent occurrence.

Most patients with pain predominantly in the low back have normal plain X-rays. Before there is any additional workup, a local injection of steroids and Xylocaine may be tried at the point of maximum tenderness. This intervention can be quite successful, and if there is a good response, the patient is begun on exercises with gradual resumption of normal activity. In some instances, if there are no objective findings, such a trigger-point injection can be considered as early as the third week after onset of symptoms.

Should the patient not respond to local injection, other pathology must be seriously considered. A bone scan, along with a general medical evaluation, should be obtained. The bone scan is an excellent tool, often identifying early bone tumors or infections not visible on routine radiographic examinations. It is particularly important to obtain this study in the patient with nonmechanical back pain. If the pain is constant, unremitting, and unrelieved by postural adjustments, more often than not the correct diagnosis is an occult neoplasm or metabolic disorder not readily apparent from other testing.

Approximately 3% of cases of apparent low back pain that present at orthopedic clinics are attributable to extraspinal causes. A thorough medical search also frequently reveals problems missed earlier such as a posterior penetrating ulcer, pancreatitis, renal disease, or an abdominal aneurysm. If these diagnostic studies are positive, the patient should be transferred into a nonorthopedic treatment mode and would no longer be in the therapeutic algorithm.

Those patients who have no abnormality on their bone scans and do not show other medical disease as a cause for their back pain are then referred for another type of therapy: low back education. It is believed that many of these patients are suffering from discogenic pain or facet joint pain syndrome. The low back education concept has as its basis the belief that

patients with low back pain, given proper education and understanding of their disease, can often return to a productive and functional life. Ergonomics, the proper and efficient use of the spine in work and recreation, is stressed. Back education need not be an expensive proposition. It can be a one-time classroom session with a review of back problems and a demonstration of exercises with patient participation. This type of educational process has proved to be very effective. It is most important, however, that patients be thoroughly screened before they are referred to this type of program. One does not want to be in the position of treating a metastatic tumor in a classroom.

If low back education is not successful, the patient should undergo a thorough psychosocial evaluation in an attempt to explain the failure of the previous treatments. This step is predicated on the knowledge that a patient's ability is related not only to his or her pathologic anatomy but also to the patient's perception of pain and stability in relation to the social environment. It is quite common to see a stable patient with a frank herniated disk continue working, regarding the disability as only a minor problem, while a hysterical patient takes to bed at the slightest twinge of low back discomfort.

Drug habituation, depression, alcoholism, and other psychiatric problems are seen frequently in association with back pain. If the evaluation suggests any of these problems, proper measures should be instituted to overcome the disability. There are a surprising number of ambulatory patients addicted to commonly prescribed medications using complaints of back pain as an excuse to obtain these drugs. Oxycodone (Percodan) and diazepam, alone or in combination, are the two most popular offenders. Oxycodone is truly addictive; diazepam is both habituating and depressing. Because the complaint of low back pain may be a common manifestation of depression, it is counterproductive to treat such patients with diazepam.

Approximately 2% of patients who initially present with low back pain will fail treatment and elude any diagnosis. As there is no evidence of any structural problem in the back or criteria for any underlying medical disease or psychiatric disorder, this is a very difficult group to manage. The authors' strategy has been to discontinue narcotics, reassure patients, and periodically reevaluate them. Over time, one-third of these patients will be found to have an underlying medical disease; thus, one cannot abandon this group and discontinue treatment. For the remainder, as much physical activity as possible should be encouraged.

Refractory Patients with Sciatica

The next group of patients consists of those with sciatica, which is pain radiating below the knee. These patients usually experience their symptoms secondary to mechanical pressure and inflammation of the nerve

roots that originate in the back and extend down the leg. The etiology of the mechanical pressure can be soft tissue, that is, a herniated disk, or bone, or a combination of the two.

At this point in the algorithm, the patient has had up to 6 weeks of controlled physical activity and medication but still has persistent leg pain. The next therapeutic step is an epidural steroid injection, which is performed on an outpatient basis. An epidural injection is worth trying; the chance of success is 40% and morbidity is low, particularly compared with the next treatment step—surgery. The maximum benefit from a single injection is achieved at 2 weeks. The injection may have to be repeated once or twice, and 4 to 6 weeks should pass before its success or failure is judged.

If epidural steroids are effective in alleviating patients' leg pain or sciatica, they are begun on a program of back exercises and encouraged to return promptly to as normal a lifestyle as possible. Should the epidural steroids prove ineffective, and 3 months have passed since the initial injury without relief of pain, some type of invasive treatment should be considered. The patient group is then divided into those with probable herniated disks and those with symptoms secondary to spinal stenosis.

The physician must now carefully reevaluate the patient for a neurologic deficit and for a positive tension sign or SLRT. For those who have either a neurologic deficit or positive tension signs along with continued leg pain, an MRI scan should be obtained. If the MRI scan is clearly positive and correlates with the clinical findings, there is no need for myelography because it is invasive.

As in the cervical spine, there is repeated documentation that for surgery to be effective in treatment of a herniated disk, the surgeon must find unequivocal operative evidence of a nerve root compression. Accordingly, nerve root compression must be firmly substantiated preoperatively, not only by neurologic examination but also by radiographic data. There is no place for "exploratory" back surgery. Many asymptomatic patients have been found to have abnormal myelograms, EMGs, CT scans, and MRI scans. If the patient has neither a neurologic deficit nor a positive SLRT, then regardless of radiographic findings there is not enough evidence of root compression to proceed with successful surgery. These patients without objective findings are the ones who have poor results and who have given back surgery a bad name.

If there are no objective findings, the physician should avoid surgery and proceed to the psychosocial evaluation. Exceptions should be few and far between. When sympathy for the patient's complaints outweighs the objective evaluation, surgery is fraught with difficulties. For those who meet these specific criteria for lumbar laminectomy, results are satisfactory: 95% of them can expect a good-to-excellent result.

The second group of patients whose symptoms are based on mechanical pressure on the neural elements are those with spinal stenosis. The diagnosis of spinal stenosis usually can be inferred from the plain X-rays, which

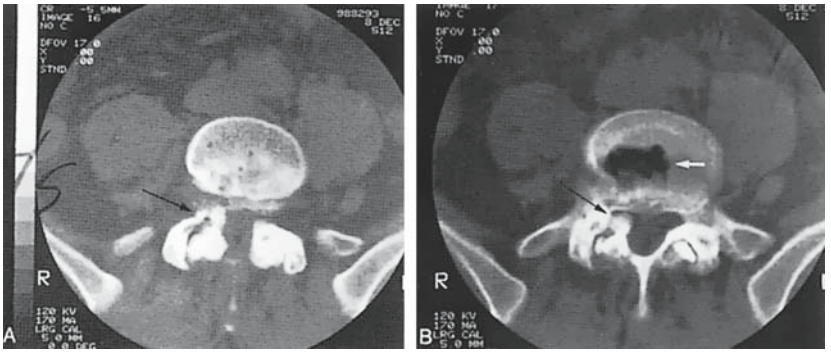


FIGURE 7-13. Computerized tomography scan of a 68-year-old man with back pain that is exacerbated with standing. Cross-sectional views demonstrate vacuum phenomenon in intervertebral disk (*white arrow*) and facet hypertrophy (most prominent on the *right*), resulting in canal stenosis at multiple levels (*black arrows*). The patient's symptoms responded to epidural steroid injections. (From Borenstein DG, Boden S, Wiesel SW. Low Back Pain: Medical Diagnosis and Comprehensive Management, 2nd ed. Philadelphia: Saunders, 1995. Reprinted by permission.)

will demonstrate facet degeneration, disk degeneration, and decreased interpedicular and sagittal canal diameters. A CT scan and/or MRI can confirm the diagnosis (Figs. 7-13, 7-14). If symptoms are severe, and there is radiographic evidence of spinal stenosis, surgery is appropriate. Age alone is not a deterrent to surgery; many elderly people who are in good health except for a narrow spinal canal will benefit greatly from adequate decompression of the lumbar spine.

Refractory Patients with Anterior Thigh Pain

A small percentage of patients have pain that radiates from the back into the anterior thigh, which usually is relieved with rest and antiinflammatory medication. If the discomfort persists after 6 weeks of treatment, a workup should be initiated to search for underlying pathology. Although an upper lumbar radiculopathy can cause anterior thigh pain, several other entities must be considered.

A hip problem or hernia can be ruled out with a thorough physical examination. If the hip examination is positive, radiographs should be obtained. An IV pyelogram is useful to evaluate the urinary tract, because kidney stones often may present as anterior thigh pain. Peripheral neuropathy, most commonly secondary to diabetes, also can present initially with anterior thigh pain; a glucose tolerance test as well as an EMG will reveal the underlying problem. Finally, a retroperitoneal tumor can cause symptoms by mechanically pressing on the nerves that innervate the anterior thighs. A CT or MRI scan of the retroperitoneal area will eliminate or confirm this possibility.

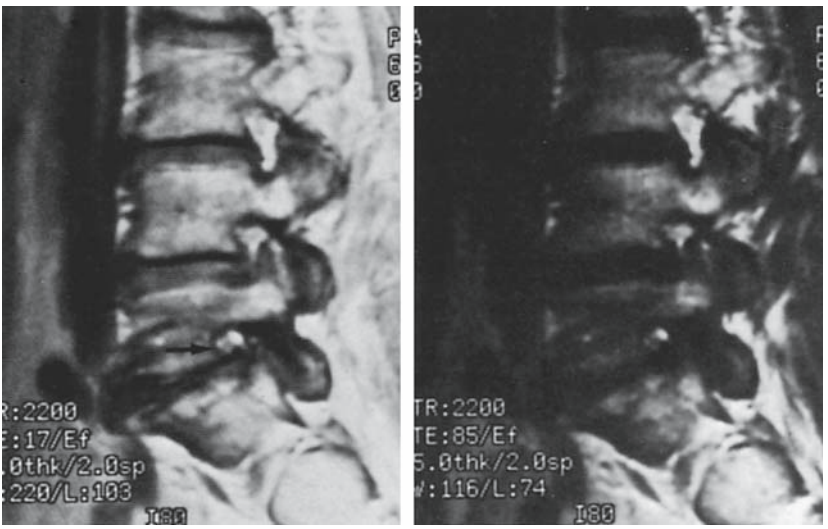


FIGURE 7-14. Magnetic resonance imaging of the lumbar spine. Sagittal view of a T_2-weighted image demonstrates foraminal narrowing at the L5–S1 interspace (*black arrow*) with associated intervertebral disk degeneration. (From Borenstein DG, Boden S, Wiesel SW. Low Back Pain: Medical Diagnosis and Comprehensive Management, 2nd ed. Philadelphia: Saunders, 1995. Reprinted by permission.)

If any of the entities just reviewed is diagnosed, the patient is treated accordingly. If no physical cause can be found for the anterior thigh pain, the patient is treated for recalcitrant back strain by the method already outlined.

Refractory Patients with Posterior Thigh Pain

This final group of patients complains of back pain with radiation into the buttocks and posterior thighs. Most of them will be relieved of their symptoms with 6 weeks of conservative therapy. However, if their pain persists after the initial treatment period, they can be considered to have back strain and given a trigger-point injection of steroids and Xylocaine in the area of maximum tenderness. If the injection is unsuccessful, it is necessary to distinguish between referred and radicular pain.

As noted earlier, referred pain is pain in the mesodermal tissues of the same embryologic origin. The muscles, tendons, and ligaments of the buttocks and posterior thigh have the same embryologic origin as those of the low back. When the low back is injured, the pain may be referred to the posterior thigh, where it is perceived by the patient. Referred pain from irritated soft tissues cannot be cured with a surgical procedure.

Radicular pain is caused by compression of an inflamed nerve root along the anatomic course of the nerve. A herniated disk or spinal stenosis in the high lumbar area can cause radiation or pain into the posterior thigh. An MRI or CT scan and an EMG may be used in this situation to differentiate radicular etiology from referred pain or a peripheral nerve lesion. If the studies are within normal limits, the patient is considered to have back strain and treated accordingly to the algorithm. If a radicular abnormality is found, the patient is diagnosed as having mechanical compression on the neural elements either from a herniated disk or spinal stenosis. Epidural steroids should be tried first; if these do not provide adequate relief, surgery should be contemplated.

This group of patients with unexplained posterior thigh pain is very difficult to treat. The biggest mistake made is the performance of surgery on people thought to have radicular pain who actually have referred pain. Again, referred pain in this setting is not responsive to surgery.

In most instances, the treatment of low back pain is no longer a mystery. The algorithm described here presents a series of easy-to-follow and clearly defined decision-making processes. Use of this algorithm provides patients with the most helpful diagnostic and therapeutic measures at the optimal time. It neither denies them helpful surgery nor subjects them to procedures that are useless technical exercises.

Conservative Treatment Modalities

As the algorithm indicates, all low back pain patients, regardless of diagnosis (except those with CEC syndrome), require an initial period of conservative therapy. At present, there are many modalities available, but few have been scientifically validated because of the difficulty in performing a prospective double-blind study in this field. Each treatment plan in popular use today is surrounded by conflicting claims for its indications and efficacy. The purpose of this section is to discuss the rationale behind the use of some of the more common therapeutic measures.

Bed Rest (Controlled Physical Activity)

Decreased activity has evolved over the years as one of the most important elements in the treatment of low back pain. The degree of rest depends on the severity of the symptoms and can vary from complete bed rest to just a decrease in active exercise.

The amount of rest prescribed varies for each patient; these people should not be mobilized until reasonably comfortable. The type of pathology will determine the duration of rest required. Most patients with acute back strain will need only 2 to 7 days of bed rest before they can ambulate.

However, a patient with an acute herniated disk may require up to 1 week of complete bed rest with another 10 days for gradual mobilization. Complete bed rest for long periods (more than 2 weeks) has a deleterious effect on the body in general and should be closely monitored. As their discomfort eases, the patient should be strongly encouraged to take short walks but to do as little sitting as possible. Each patient should be followed carefully and not allowed complete mobility until the objective signs, such as a list and/or paravertebral muscle spasm, disappear. The patient's physical activity is tailored to increase movement without incurring a return of symptoms.

The purpose of controlled physical activity is to allow any inflammatory reaction that is present to subside. Bed rest will not result in the disk's return to its original position. However, as the disk herniates, it causes a secondary inflammatory process responsible for the patient's pain; if this reaction can be brought under control, the patient's symptoms will disappear. This relief may or may not be permanent.

Drug Therapy

The judicious use of drug therapy is an important adjunct in the treatment of low back pain. As in the cervical spine, there are three main categories of drugs in common use: antiinflammatories, analgesics, and muscle relaxants.

Antiinflammatory agents are employed because of the belief that inflammation within the affected tissues is a major cause of pain in the low back; this is especially true for those patients with symptoms secondary to a herniated disk.

There are a variety of NSAIDs available. Based on several scientific studies, none of these appear to be superior to the others. Most patients obtain significant relief. Again, all antiinflammatory medications are utilized in conjunction with controlled physical activity to relieve pain; they do not replace adequate rest. Occasionally, after an initial recovery, a patient will experience intermittent recurrent attacks or complain of a chronic low backache; in some instances, these patients are helped by a maintenance dose of an antiinflammatory drug.

Analgesic medication is very important during the acute phase of low back pain. The goal is to keep the patient comfortable while in bed. Most of the antiinflammatory agents also have analgesic properties. In more severe cases, patients will respond to 30 to 60 mg codeine every 4 to 6 hours. As the pain decreases, nonnarcotic analgesics may be substituted for the more potent drugs.

The biggest mistake seen is treatment with very strong narcotics such as meperidine (Demerol) or oxycodone (Percodan, Tylox) on an outpatient basis. Many of these patients become addicted to the medication. In other cases, patients try to shortcut the controlled physical activity and use anal-

gesic medication instead. This, of course, does not work, and when the patient tries to stop the drug, the back pain returns.

Muscle relaxants generally are not recommended for the treatment of low back pain. In most cases, the muscle spasm is secondary to a primary problem such as a herniated disk. If the pain from the ruptured disk can be controlled, the muscle spasm will usually subside.

Occasionally, muscle spasm will be so severe that some type of treatment is required. Carisoprodol (Soma), methocarbamol (Robaxin), or cyclobenzaprine (Flexeril) are the drugs recommended. Diazepam (Valium) should be discouraged because it is actually a physiologic depressant and depression is often an integral feature of back pain syndromes. Administering diazepam to depressed patients only increases their problems. If anxiety is prominent and a sedative is needed, phenobarbital will alleviate the symptoms.

In summary, drug therapy for low back pain should be viewed as an adjunct to adequately controlled physical activity. Antiinflammatory medication should be the primary agent employed. Analgesic medication should be used selectively in a controlled environment and not for extended periods. Muscle relaxants are generally not recommended and if employed, should be carefully monitored.

Trigger-Point Injection

Trigger-point therapy is indicated for nonradiating low back pain when a point of maximal tenderness can be identified. This procedure involves the injection of steroids and Xylocaine at an area of maximal tenderness in the low back. The precise mechanism of action is not clear but may be related to modulation of peripheral nerve stimulation as it affects the afferent input perceived as pain.

Trigger-point therapy is easy to perform, has a negligible risk, and may help certain patients. Further controlled research is required to delineate the true value of this modality in the treatment of low back pain.

Epidural Steroid Injection

Epidural steroid injections are indicated for severe lumbar radiculopathy, not, in most cases, for nonradiating low back pain. These injections have generally been viewed as an intermediate form of treatment between conservative and surgical management. It is a more-aggressive attempt at pain relief after conservative therapy has failed yet avoids the disadvantages of surgery. The rationale for this therapy is that lumbar radiculopathy (in the early phase) involves a significant inflammatory component, evoked by chemical or mechanical irritation or an autoimmune response—all of which should be amenable to treatment with corticosteroid drugs in the early stages.

Unfortunately, few studies have systematically and accurately studied the efficacy of this treatment modality. Poorly controlled, nonrandomized studies have yielded controversial results with a range of success rates from 25% to 75%. Another problem is that some studies have attempted to determine the efficacy of epidural steroids compared to epidural saline injection whereas others have compared their results to a true placebo.

Despite the lack of optimally designed investigations, on review of the literature, certain trends seem to be evident. Epidural steroids appear to be more beneficial in acute rather than chronic radiculopathy, especially when no neurologic deficit is present. Improvement may not be noted until 3 to 6 days after injection and may be only temporary. No neurotoxicity has been reported in humans or animal models; complications stem from the technique of epidural injection and are rare. Suppression of plasma corticosteroid concentration may occur up to 3 weeks following the injection.

The authors maintain that epidural steroids may be helpful in relieving some component of radicular pain in 40% of patients. Until controlled investigations indicate otherwise, this is a treatment worth trying in patients who have failed 6 weeks of conservative management in an effort to avoid a major invasive procedure.

Traction

The application of traction to the lumbar spine is a popular treatment for patients with herniated disks. The theory is that stretching the lumbar spine distracts the vertebrae so that the protruded disk is allowed to return to a more normal anatomic position. In fact, the disk material probably does not change position at all. Scientific evidence indicates that a traction force equal to 60% of body weight is needed just to reduce the intradiscal pressure at the third lumbar vertebra by 2.5%. Such a force could not practically be applied to a patient. Furthermore, there has never been any proof that disk material returns to its normal position following herniation.

Traction can be applied as gravity lumbar traction, or autotraction, and through motorized techniques. None of these methods has been proven to be more effective than the others. Although a few studies have shown traction to have a short-lived benefit on sciatica patients, most double-blind studies have not demonstrated any positive effect. In one study, two groups of patients with proven herniated disks (by myelogram) were treated by applying traction apparatuses to each group in the hospital. However, for one group there were weights in the traction bag; for the other, no weights. There was no statistically significant difference between the two groups in terms of relief of symptoms. Traction had no effect on spinal mobility, tension signs, deep tendon reflexes, paresis, or sensory deficit, and although it usually was well tolerated, it made some patients worse.

Manipulation

Spinal manipulation is another popular conservative modality in treating low back pain. In the United States, it is somewhat controversial because it is performed mostly by chiropractors. The principle involved is that any malalignment of the spinal structures can be corrected by manipulation; the assumption here is that the malalignment is the etiology of the patient's pain. Unfortunately, there is no scientific proof for or against either the efficacy of this therapy or its pathophysiologic foundation.

The authors' experience is that some patients do have short periods of symptomatic relief after manipulation, but must keep returning for repeated sessions to maintain it, substantially increasing the cost of treatment. Some patients, in fact, may be harmed if pathologic bone disease such as a tumor or osteopenia is present when manipulation is performed. At present, it is thought that manipulation is not indicated for the routine treatment of chronic low back pain. There is not adequate scientific evidence to justify its routine use.

Braces and Corsets

External support of the lumbar spine with a corset or brace is indicated for only a short period in the average patient's recovery process, and not every patient requires it. As the acute symptoms subside, a properly fitted corset or brace will aid the patient in regaining mobility sooner. As the recovery progresses, the patient usually should abandon the brace in favor of an exercise program. With continued long-term use of a brace, soft tissue contractures and muscle atrophy will occur. The young patient should rely on a brace only to hasten ambulation. In theory, strong, flexible lumbar and abdominal muscles function as an excellent internal brace because they are adjacent to the structures (vertebrae) that they are supporting.

Exercises

Some form of exercise is probably the most commonly prescribed therapy for patients recovering from low back pain. There are two regimens commonly advocated: isometric flexion exercises and hyperextension exercises. These programs are purported to reduce the frequency and intensity of low back pain episodes, although there is no scientific evidence to support this contention.

The isometric flexion exercises are the most popular. They are based on the theory that by reducing the lumbar lordosis, back pain is decreased. This goal is achieved by strengthening both the abdominal and lumbar muscles, thereby creating a corset of muscles to support the lumbar spine. Flexion exercises are commonly utilized in patients with spondylolisthesis or spinal stenosis.

Hyperextension exercises are the other form of therapy. They are purported to strengthen the paravertebral muscles. These exercises generally are used after a patient has satisfactorily performed a course of isometric flexion exercises. The goal is to have the paravertebral muscles act as an internal support for the lumbar spine.

The authors believe that an exercise regimen is very important for the rehabilitation of low back patients. This regimen should not be instituted while the patient is experiencing acute pain but may be started after symptoms have subsided to the point where no list or paravertebral muscle spasm is present. The number of repetitions is increased gradually; if the patient has any recurrence of acute symptoms, the exercises are stopped. The patient is then closely monitored; when symptoms again decrease, the exercises can be resumed.

Physical Therapy

Many other treatment modalities are used for low back pain, including hot packs, cold packs, light massage, ultrasound, transcutaneous electrical nerve stimulation, and diathermy. They are all well tolerated and pleasant. Most patients experience some immediate relief of symptoms, but unfortunately there is not a long-lasting impact on the disease process. There is no evidence that any of these treatment modalities offers any long-term benefit or even adds to the efficacy of decreased physical activity alone.

Summary and Conclusion

Neck and low back pain affects the majority of adults at some time during the course of their lives. Every physician should have a working knowledge of the common pathologic conditions and be able to differentiate a serious problem from the more common benign types. In both the cervical spine (myelopathy) and the lumbar spine (cauda equina compression), disastrous sequelae such as paralysis or loss of bowel and bladder control can occur if these serious conditions are not recognized in a timely fashion.

To help in the decision-making process, algorithms for both the cervical and the lumbar spine are described. These schemes allow the physician to make the right diagnosis using the indicated diagnostic procedures at the correct time.

Suggested Readings

Borenstein DG, Wiesel SW, Boden SD. Low Back and Neck Pain, 3rd ed. Philadephia: Saunders, 2004.

Frymoyer JW, Wiesel SW. The Adult and Pediatric Spine, 3rd ed. Philadephia: Lippincott, Williams & Wilkins, 2004.

Wiesel SW, Delahay JN. Principles of Orthopaedic Medicine and Surgery. Philadephia: Saunders, 2001.

Questions

Note: Answers are provided at the end of the book before the index.

7-1. Which of the following can be the presenting symptoms of patients with cervical myelopathy?
   a. Gait disturbance
   b. Clumsiness and loss of manual dexterity
   c. Weakness in the lower extremities
   d. Urinary incontinence
   e. All the above

7-2. A unilateral decrease in the triceps reflex is most likely evidence of what clinical syndrome?
   a. C5 radiculopathy
   b. C6 radiculopathy
   c. C7 radiculopathy
   d. Cervical myelopathy
   e. None of the above

7-3. Which of the following physical findings is consistent with cervical myelopathy?
   a. A hyperactive knee-jerk
   b. A positive jaw-jerk
   c. Cog-wheel rigidity
   d. Absent ankle reflexes
   e. A positive axial manual traction test

7-4. Which of the following pathologic changes IS NOT seen in cervical spondylosis?
   a. Increased water in the nucleus pulposus
   b. Loss of annular elasticity
   c. Disk space narrowing
   d. Disk protrusion
   e. Osteophyte formation

7-5. In an otherwise healthy 57-year-old patient, which of the following represents the most pressing relative indication for surgical treatment?
   a. A history of chronic, severe axial neck pain
   b. A large herniated disk on MRI of the neck
   c. Cervical radiculopathy with neurologic findings
   d. Cervical myelopathy
   e. All the above require surgical treatment

7-6. What is the most common instability pattern seen in patients with rheumatoid arthritis of the cervical spine?
   a. Atlantoaxial instability
   b. Basilar invagination
   c. Subaxial instability
   d. Mixed
   e. No one pattern is most common

7-7. What is the closest estimate of the lifetime incidence of low back pain in the United States?
   a. 0%
   b. 25%
   c. 45%
   d. 65%
   e. 90%

7-8. Weakness of the extensor hallucis longus is evidence of nerve root compression at what level?
   a. L2
   b. L3
   c. L4
   d. L5
   e. S1

7-9. Spondylolysis (pars defect) is most widely believed to be caused by what?
   a. A congenital defect in the pars
   b. An acute traumatic defect in the pars
   c. A stress fracture of the pars
   d. A benign neoplasm involving the pars
   e. None of the above

7-10. Canda equina compression (CEC) syndrome is most typically manifested by:
   a. Foot-drop
   b. Severe back pain
   c. Parasthesias in a nonanatomic distribution
   d. Urinary retention
   e. Priapism

8
The Shoulder

Raymond M. Carroll

The shoulder joint, as it is commonly called, is not a single joint but a complex arrangement of bones, ligaments, and musculotendinous units that is more aptly called the shoulder girdle. The primary role of the shoulder girdle is to provide a tremendous range of motion for positioning the upper extremity in space. The shoulder girdle also provides power and support for the upper extremity throughout and at the extremes of the range of motion. Many shoulder girdle problems stem from overuse injuries during activities such as pitching a baseball or serving a tennis ball that exploit both the power and range of motion of the shoulder girdle. This chapter reviews the anatomy of the shoulder girdle and provides an approach to evaluating and treating common shoulder problems.

Functional Anatomy

The shoulder girdle includes three bones (scapula, clavicle, and proximal humerus) (Fig. 8-1), three joints (glenohumeral, acromioclavicular, and sternoclavicular), an additional articulation (scapulothoracic), and some 17 musculotendinous units. These individual elements function in a synchronous and interdependent manner to maximize the power and range of motion of the shoulder girdle. The clavicle is the bony strut that links the upper appendicular skeleton to the axial skeleton at the sternum (sternoclavicular joint).

The Glenohumeral Joint

The glenohumeral (GH) joint is the articulation of the proximal humeral epiphysis (ball) with the glenoid fossa (socket) of the scapula. This joint contributes to the majority of motion in the shoulder girdle. As only 20% to 30% of the humeral head is in contact with the glenoid fossa at any point in the shoulder's arc of motion and the radius of curvature of the glenoid is greater than that of the humeral head, there is little inherent bony stability of the GH joint. As a result, the soft tissues surrounding the joint

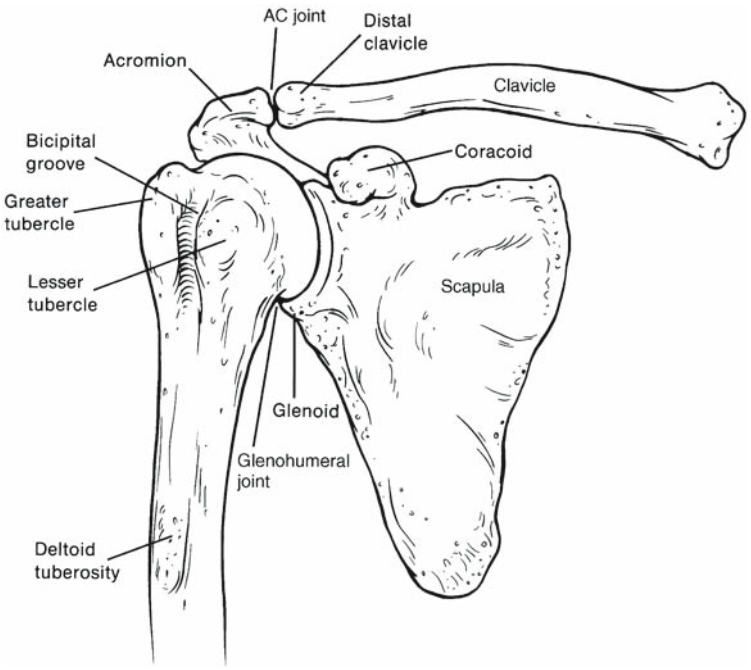


FIGURE 8-1. Anterior view of the shoulder demonstrates the skeletal anatomy and two of the four articulations, the glenohumeral and acromioclavicular joints.

are responsible for maintaining joint stability and congruity while allowing a tremendous range of motion. These soft tissue stabilizers include the joint capsule, glenohumeral ligaments, glenoid labrum, long head of the biceps tendon, and the rotator cuff musculature. The burden placed upon these soft tissues leads to the majority of degenerative and traumatic conditions affecting the shoulder girdle.

The Glenohumeral Ligaments

The capsule of the shoulder is a specialized structure that contains distinct thickenings referred to as ligaments (Fig. 8-2). The glenohumeral ligaments are named for their origin from the glenoid rim. This ligamentous complex includes the superior glenohumeral ligament (SGHL), the middle glenohumeral ligament (MGHL), the anterior band of the inferior glenohumeral ligament (AIGHL), and the posterior band of the inferior glenohumeral ligament (PIGHL). These ligaments function as static stabilizers of the glenohumeral joint. The SGHL is the primary restraint to inferior translation and external rotation with the arm in adduction. The MGHL is the primary

stabilizer to anterior translation with the arm in 45 degrees of abduction. The inferior glenohumeral ligament complex includes an anterior band, a posterior band, and an intervening sling or pouch. The inferior glenohumeral ligament complex becomes taut when the arm is abducted to 90 degrees. In this position, the anterior band resists anterior translation with external rotation and the posterior band resists posterior translation with internal rotation forces. The sling supports the humeral head.

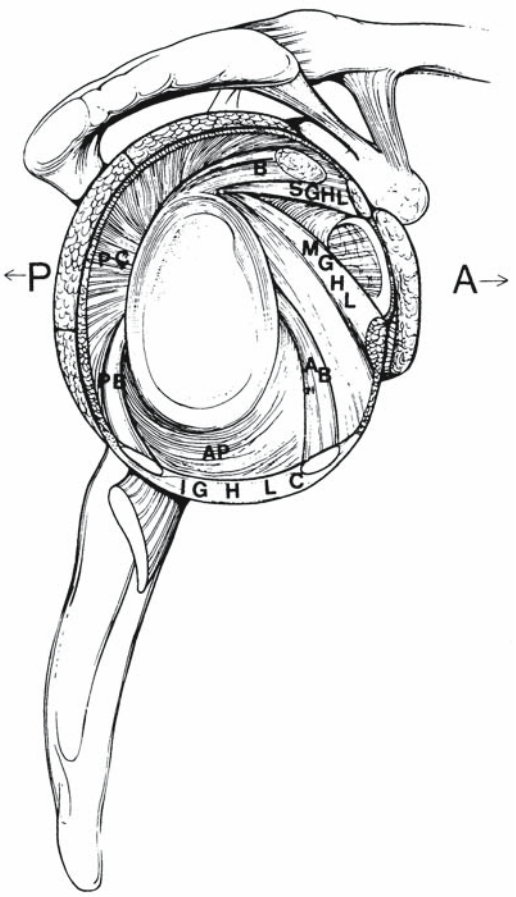


FIGURE 8-2. In this cutaway view of the shoulder joint, the humeral head has been removed, allowing visualization of the interior of the normal glenohumeral anatomy. Notice the discrete ligaments that constitute the anterior shoulder capsule, namely the superior (*SGHL*), middle (*MGHL*), and anterior inferior glenohumeral ligaments. In this illustration, the most important anterior restraining structure, the inferior glenohumeral ligament complex (*IGHLC*), is shown further subdivided into having anterior (*AB*) and posterior (*PB*) bands and an axillary pouch (*AP*). (From Rockwood CA Jr, Matsen FA III (eds) The Shoulder, vol 1. Philadelphia: Saunders, 1990. Reprinted by permission.)

The Labrum

The labrum is a fibrous structure of variable anatomy that attaches to the rim of the glenoid cartilage through a fibrocartilaginous zone, increasing the depth of the glenoid concavity by 50%. The labrum functions to increase the surface contact area with the humeral head; to act as a static stabilizer through a buttress effect; and to serve as an attachment site for the shoulder capsule, glenohumeral ligaments, and long head of the biceps tendon. The labrum has a variable cross-sectional anatomy, the superior aspect of the labrum being more triangular shaped and well defined and the inferior aspect of the labrum more rounded and less distinct. Common anatomic variations include a sublabral hole (foramen) or an absent labrum in the anterosuperior quadrant of the glenoid. The combination of a cord-like MGHL and absent anterosuperior labrum has been termed a Buford complex. Additionally, the labrum may attach directly to the rim of the surface of the glenoid cartilage or it may have a reflected, or meniscal-type, attachment.

The Rotator Interval

The rotator interval is the triangular region between the superior aspect of the subscapularis tendon and the anterior aspect of the supraspinatus tendon whose base is the coracoid. The rotator interval includes a number of fibrous structures including the coracohumeral ligament, the SGHL, and the transverse humeral ligament. The coracohumeral ligament (CHL) is the most significant structure in the rotator interval and is extraarticular. It originates from the lateral base of the coracoid, fanning out to envelop the supraspinatus tendon inserting on the greater tuberosity and to envelop the subscapularis tendon inserting on the lesser tuberosity. The CHL is a primary restraint to inferior translation and external rotation in the adducted arm. The transverse humeral ligament forms the apex of the rotator interval and contributes to the superior soft tissue sling that stabilizes the long head of the biceps tendon as it passes through the interval to enter (or exit) the glenohumeral joint.

The Long Head of the Biceps Tendon

The long head of the biceps tendon (LHBT) remains somewhat enigmatic with respect to its function in the shoulder girdle, but it is nonetheless a potential source of pain and disability. The long head of the biceps enters/exits the glenohumeral joint at the rotator interval by way of the bicipital groove and is an intraarticular structure. The LHBT originates from the superior glenoid tubercle and blends with the fibers of the superior labrum. This intimate relationship of the LGBT with the superior labrum is a significant source of morbidity in the throwing athlete. Although there are

conflicting data, the long head of the biceps is thought to be a humeral head depressor and may contribute to glenohumeral instability. Potentially more relevant is the theory of the "peel-back" mechanism of superior labral tears or SLAP (superior labrum anteroposterior) tears. This theory suggests that the LHBT and superior labrum detach from the superior glenoid in the late cocking position of a baseball pitch as the LHBT becomes taut and "peels back" the superior labrum off the glenoid rim. Whether or not this theory is correct, SLAP tears can be a significant problem in the throwing athlete. Tendonitis of the LHBT is also a common source of morbidity in the shoulder and is often a component of the impingement syndrome.

The Rotator Cuff

The rotator cuff consists of four muscle–tendon units including the subscapularis, supraspinatus, infraspinatus, and teres minor. These muscles originate on the scapula and insert onto the tuberosities of the proximal humerus. The subscapularis originates on the anterior surface of the scapula and inserts onto the lesser tuberosity. The remaining rotator cuff muscles originate from the posterior surface of the scapula and insert along the greater tuberosity. The roles of the rotator cuff are to keep the humeral head centered in the glenoid fossa throughout the range of shoulder motion and to contribute to the rotation and elevation of the extremity. As such, the rotator cuff is the primary dynamic stabilizer of the glenohumeral joint. Traumatic and overuse injuries to the rotator cuff are the most common problems in the shoulder girdle.

The Subacromial Space

The subacromial space is a potential space beneath the acromion and above the rotator cuff. The subacromial bursa outlines the subacromial space and provides frictionless gliding of the rotator cuff beneath the acromion and coracoacromial arch. Bony osteophytes on the undersurface of the anterior acromion have been postulated to narrow the subacromial space, irritate the subacromial bursa, and contribute to rotator cuff tears.

The Acromioclavicular Joint

The acromioclavicular (AC) joint is a true diarthrodial joint containing a fibrocartilaginous disk. The AC joint helps link the appendicular skeleton with the axial skeleton through the clavicle. Because there is little intrinsic bony stability to the AC joint, a number of ligaments and other soft tissues serve to stabilize this articulation (Fig. 8-3). The superior AC ligament is the most important horizontal stabilizer. The coracoclavicular (CC) ligaments, consisting of the conoid ligament (medial) and the trapezoid

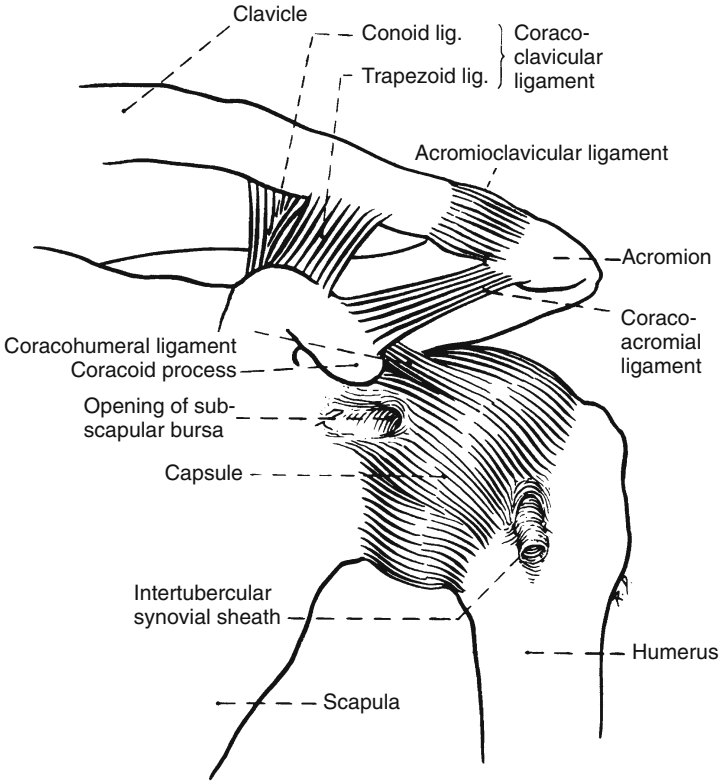


FIGURE 8-3. In this anterior view, note the acromioclavicular joint surrounded by the capsule (acromioclavicular ligament), in addition to the supporting coracoclavicular ligaments, the conoid and trapezoid. (From Rockwood CA Jr, Matsen FA III (eds) The Shoulder, vol 1. Philadelphia: Saunders, 1990. Reprinted by permission.)

ligament (lateral), provide the primary restraint to vertical displacement of the clavicle. A significant amount of rotation occurs in the clavicle throughout the arc of elevation of the upper extremity. Approximately 10% of this rotation occurs at the acromioclavicular joint.

The Sternoclavicular Joint

The sternoclavicular (SC) joint is the only bony connection between the upper appendicular skeleton and the axial skeleton and has the least bony stability of any major joint. The majority of clavicular rotation occurs at the sternoclavicular joint, but less than 50% of the bulbous medial clavicle is in contact with the shallow sternal articular fossa. Thus, the soft tissues provide stability to the sternoclavicular joint. The ligamentous anatomy of the SC joint includes the intraarticular disk ligament, the costoclavicular

ligament, the interclavicular ligament, and the capsular ligament. Of these, the posterior sternoclavicular joint capsule has been shown to be the most important structure for preventing both anterior and posterior displacement of the medial clavicle.

The Scapulothoracic Articulation

The scapulothoracic articulation includes the scapula, posterior thorax, and interposed bursae, which provide frictionless motion between the scapula and posterior thorax. The scapulothoracic articulation provides a significant percentage of motion to the shoulder girdle. Specifically, the glenohumeral joint and scapulothoracic articulation function in a synchronous fashion to provide full forward elevation of the upper extremity in a 2:1 ratio. The scapular stabilizer muscles include the trapezius, levator scapulae, rhomboids, latissimus dorsi, and serratus anterior. Dysfunction of scapulothoracic motion, seen clinically as scapular winging, may be a result of nerve injury or muscle dysfunction. Damage to the spinal accessory nerve results in trapezius dysfunction and lateral scapular winging. Long thoracic nerve injury leads to serratus anterior dysfunction and medial scapular winging. Pain and loss of motion in the glenohumeral joint can lead to overuse and fatigue of the scapular stabilizer muscles, resulting in scapular winging.

The Brachial Plexus

The brachial plexus is composed of the ventral rami of cervical roots C5, C6, C7, and C8 and ventral thoracic root T1. With the exception of the spinal accessory nerve (XI), which innervates the trapezius, all the muscles contributing to the function of the shoulder girdle and upper extremity are innervated by nerves originating from the brachial plexus. The brachial plexus includes five nerve roots, three trunks (superior, middle, and inferior), six divisions (three anterior, three posterior), three cords (lateral, medial, and posterior), and six terminal branches (musculocutaneous, ulnar, medial cord branch to median nerve, lateral cord branch to median nerve, axillary, and radial). With the exception of the divisions, nerves originate from each level of the brachial plexus to innervate muscles of the shoulder girdle. Brachial plexus injuries are relatively common with traumatic shoulder girdle injuries such as proximal humerus fractures, glenohumeral dislocations, and fracture-dislocations.

Clinical Examination of the Shoulder Girdle

The history of present illness is critical in evaluation of shoulder girdle pathology and should be used to develop a reasonable differential diagnosis based on the patient's story and the epidemiology of shoulder pathology.

For example, a high-school athlete with activity-related shoulder pain is more likely to have instability or labral pathology than a rotator cuff tear. Conversely, a 65-year-old who has shoulder pain with activities of daily living is more likely to have rotator cuff disease than a labral tear or instability. The physical examination is used to narrow the differential diagnosis and make the definitive diagnosis. Most of the time an accurate diagnosis can be made using only the history and physical examination. Indiscriminate use of imaging studies and additional testing is not recommended. Before ordering additional studies, the examiner must have a clear understanding of how the study will contribute to the evaluation and treatment of the patient.

History

Patients with shoulder pathology most often complain of pain, stiffness, instability, and weakness. When pain is the chief complaint, the examiner must characterize the pain, with particular attention to location. Pain from the glenohumeral joint and its surrounding soft tissues typically is localized to the anterosuperior aspect of the shoulder. Localization of the pain to the deltoid insertion in the arm is common in rotator cuff or subacromial pathology. Pain emanating from the neck or to the posterior scapular region is often due to cervical spine disease. Pain and crepitation in the periscapular region, however, may be related to scapulothoracic bursitis.

The timing and frequency of shoulder pain must also be given careful consideration. Activity-related pain can provide valuable clues as to the underlying diagnosis. Pain with overhead activities of daily living is common in rotator cuff pathology. Pain with sporting activities such as swimming, throwing, or serving is often related to the labrum or glenohumeral ligaments. Night pain is often reported with shoulder girdle pathology, especially in the setting of rotator cuff tears. Patients often report the inability to sleep on the affected side. Rest pain is uncommon but may occur with severe arthropathy or radicular pain from the cervical spine. If rest pain is the predominant complaint, the examiner should consider infection or malignancy as a possible source of pain.

The relationship of pain to injury is important to establish. Pain that begins with a traumatic event such as a fall on an outstretched hand, direct blow to the shoulder, or shoulder dislocation may represent significant damage to the rotator cuff, ligaments, or bony structures. Pain that begins days or weeks after a seemingly innocuous event such as shoveling snow; trimming hedges, or painting may represent tendonitis or early capsulitis. Pain that begins more insidiously or over time is more likely to be related to degenerative lesions of the shoulder girdle such as rotator cuff tears or osteoarthritis.

Complaints of shoulder instability are relatively common. The patient may describe the shoulder “slipping out of place” or “getting stuck” in

extreme positions. It is important to establish whether a frank shoulder dislocation was ever documented. True traumatic shoulder dislocations are the result of significant trauma and require a manipulative reduction. Unfortunately, subsequent dislocations may occur with less trauma. Patients who have shoulders that "slip out of place" and "slide back in" on their own are more likely to have multidirectional instability as opposed to traumatic instability.

Weakness or loss of shoulder function is an infrequent complaint. In the absence of pain, a neurologic origin of the deteriorating function should be considered. Insidious onset of pain with deteriorating function may represent a degenerative condition of the shoulder or adhesive capsulitis.

A careful review of systems is important to document as there are a number of disease processes remote from the shoulder girdle that can result in shoulder pain. Cervical spine pathology, cardiac disease, gallbladder disease, and lung disease (pancoast tumor) can present with shoulder pain. A history of cancer is also important to document because metastatic cancer can present with shoulder pain and lesions in the shoulder girdle.

Functional Assessment

In addition to establishing the history of present illness, it is imperative to establish the functional status of the patient. Important patient factors to note include the handedness (right, left, or ambidextrous) of the patient; the vocation of the patient; extracurricular/sporting activities enjoyed by the patient, and, most importantly, the expectations of the patient with regard to the shoulder problem. Understanding the patient's functional demands and expectations allows the clinician to prescribe appropriate treatment regimens and to provide reasonable expectations for functional recovery.

Inspection

The physical examination begins with inspection of the shoulder girdle. The region must be adequately exposed for the examination. The inspection begins with assessment of symmetry between the involved and uninvolved shoulder girdles. Gross deformity such as distal clavicle prominence in an AC separation, prior surgical incisions, skin discoloration, or open wounds are readily appreciated. A more subtle finding is muscle atrophy, which may be the result of disuse or injury. Patients with long-standing rotator cuff tears often have atrophy of the supraspinatus and infraspinatus fossae, resulting in prominence of the spine of the scapula. Traumatic injuries can produce subtle deformities. In the setting of an anterior dislocation, the anterior aspect of the shoulder may appear "full" and the posterior aspect may lose its normal contour, making the posterior acromion

appear more prominent. Inspection should continue through the entire exam as some deformities such as scapular winging may only be revealed during provocative testing.

Palpation

The primary importance of palpation is to localize the source of pain. Palpation of bony prominences and superficial joints yields the most information. In the absence of trauma, palpation includes the SC joint, AC joint, the greater and lesser tuberosities, and the intertubercular or bicipital groove. Tenderness on palpation at any of these sites can be a valuable clue in making a diagnosis. When the presenting complaint is neck or periscapular pain, palpation of the posterior elements of the cervical spine and bony elements of the scapula is warranted. In the setting of trauma, palpation of all bony structures and areas of deformity is critical to localize the zone of injury.

Range of Motion

The evaluation of range of motion is straightforward. The examiner directs the motions and observes for symmetry. The standard motions include forward elevation, external rotation, internal rotation, and abduction. Forward elevation occurs in the plane of the scapula and is a combination of scapulothoracic and glenohumeral motion. Loss of glenohumeral motion can lead to scapulothoracic substitution and scapular winging. External rotation is evaluated with the arms at the side to prevent scapulothoracic contribution to rotation. Internal rotation is evaluated by having the patient place his hands as high as possible along the midline of the back. Internal rotation is graded by the approximate vertebral level the patient is able to reach. Assessment of abduction, including internal and external rotation in abduction, is critical for unmasking subtle losses of motion. Baseball pitchers often lose some internal rotation in abduction while gaining external rotation in abduction in their throwing arm. There is no net loss of motion, only a resetting of the range of motion relative to the nonthrowing shoulder.

When loss of active motion is identified, the examiner must assess the passive range of motion. If there is loss of active and passive motion, there is likely a soft tissue contracture or a physical block to motion (dislocation, loose body, or osteophyte). In the absence of trauma, loss of both active and passive motion usually represents adhesive capsulitis (frozen shoulder) or arthropathy. If there is loss of active motion with preserved passive motion, the examiner must consider tendon (rotator cuff) rupture or, potentially, nerve damage. When examining the rotator cuff muscles, the examiner must appreciate lag signs.

A lag sign can be documented when the patient has a loss of active motion with preservation of passive motion. The examiner positions the shoulder at the end range of full passive motion and instructs the patient to maintain the position. If the patient is unable to maintain the position and the extremity falls away, the patient is considered to have a positive lag sign. The hornblower's sign is the lag sign for the abducted, externally rotated position and is suggestive of a massive rotator cuff tear involving the posterior cuff.

Strength Assessment

The relative strength of muscle groups can be assessed during the physical examination. To assess strength, the examiner manually resists the patient's active motion in a defined plane such as abduction, adduction, or internal or external rotation. Asymmetrical weakness on the involved side can provide additional diagnostic information. Weakness or paralysis of the scapular stabilizer muscles can be assessed by having the patient perform pushups against a wall. Scapular winging can be elicited using this technique.

Neurologic Examination

In the absence of trauma or brachial plexopathies, most neurologic lesions about the shoulder involve a peripheral nerve. Common peripheral neuropathies in the shoulder girdle include the suprascapular, spinal accessory, and long thoracic nerves. Although these conditions can be painful, many patients report dysfunction or cosmetic deformity as the presenting complaint. These lesions are appreciated during the inspection, range of motion, and strength testing of the shoulder girdle. Suprascapular neuropathy can occur at the level of the suprascapular notch or proximal and involve both the supra and infraspinatus tendons, resulting in prominence of the scapular spine and weakness of forward elevation and external rotation. Suprascapular nerve lesions at the level of the spinoglenoid notch involve only the infraspinatus muscle, resulting in atrophy of the infraspinatus fossa and weakness of external rotation. Spinal accessory nerve injury is often iatrogenic from a posterior cervical node biopsy or a radical neck dissection for malignancy. Injury to the spinal accessory nerve (cranial nerve XI) results in trapezius dysfunction and lateral scapular winging. Long thoracic nerve injury is thought to be secondary to traction or contusion and affects the serratus anterior muscle, resulting in medial scapular winging. Medial or lateral refers to the direction toward which the inferior border of the scapula is directed. Nerve lesions in the shoulder girdle should be further evaluated with electromyography (EMG) and nerve conduction testing. The majority of these nerve lesions (except iatrogenic laceration) recover without surgical intervention.

Special Tests and Signs

A variety of special tests or maneuvers have been described to evaluate individual structures or reveal specific pathology. A few of these tests and signs are reviewed here.

Rotator Cuff

The most commonly used tests attempt to recreate the pain that occurs with rotator cuff impingement under the coracoacromial (CA) arch by rotating the greater tuberosity under the acromion. The painful arc sign occurs when the patient experiences pain while elevating the upper extremity from 70 to 120 degrees. The Neer impingement sign is positive when shoulder pain is reproduced as the upper extremity is passively elevated in the scapular plane with the scapula stabilized (Fig. 8-4). Hawkins's impinge-

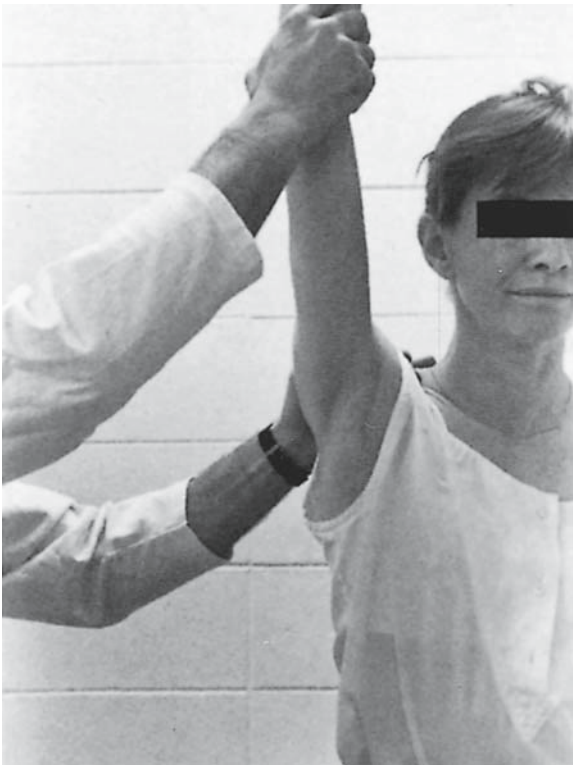


FIGURE 8-4. Impingement of the rotator cuff is demonstrated by passively elevating the shoulder against the fixed scapula. Pain suggests the possibility of mechanical compression of the rotator cuff against the anterior inferior acromion, a process known as impingement. (From DeLee JC, Drez D Jr. Orthopaedic Sports Medicine: Principles and Practice, vol 1. Philadelphia: Saunders, 1994. Reprinted by permission.)

ment sign is tested by passively internally rotating the humerus when the arm is at 90 degrees of forward flexion with the elbow flexed. A positive test is defined as shoulder pain with this maneuver. The drop-arm test is performed by placing the upper extremity at shoulder level (90 degrees) in the scapular plane with the thumb pointing downward. The test is considered positive when the patient is unable to maintain the extremity in this position and is indicative of superior rotator cuff pathology.

Two tests have been described to evaluate the subscapularis. The lift-off test is performed by having the patient place the hands behind the back with the arm internally rotated and the elbow flexed. The patient is then asked to lift the hands off the back without extending the elbows. If the patient is unable to perform the lift-off, the test is considered positive and indicative of subscapularis insufficiency. For patients who are unable to reach behind their back, the belly-press test can be used to evaluate the subscapularis. The belly-press test is performed by having the patient place the hands on the abdomen and, while pressing the hands to the abdomen, bringing the elbows anterior to the coronal plane of the body. Inability to perform the belly-press maneuver is a positive test.

Biceps Tendon (Long Head)

Speed's test is used to evaluate the long head of the biceps tendon. The test is performed by having the patient maintain forward elevation of the upper extremity at shoulder height against resistance with the elbow extended and the forearm supinated. The test is considered positive when pain is produced in the area of the bicipital groove with this maneuver.

The active compression test, or O'Brien's test, is used to evaluate the superior labral–biceps tendon complex. The test is performed in two steps. The upper extremity is brought to shoulder height in forward flexion with the forearm fully pronated (thumb down) and adducted approximately 15 degrees. The patient resists the examiner's downward pressure from this position. If this maneuver elicits pain in the shoulder, the test is repeated with the forearm supinated. If the pain is reduced or absent with the second maneuver, the test is considered positive. A positive test indicates that the biceps tendon–superior labral complex is torn or detached from the superior glenoid.

Shoulder Instability

A number of tests have been described to evaluate shoulder instability. All the following tests can be performed with the patient is supine on the examining table. The apprehension test is performed with the shoulder abducted to 90 degrees and externally rotated to 90 degrees in the coronal plane of the body. From this position, the examiner continues to externally rotate the shoulder. If the patient experiences apprehension (fear of the shoulder dislocating), the test is considered positive. If the patient has a

positive apprehension test, the examiner can reduce the subluxated humeral head by applying a posterior-directed force against the proximal humerus, thereby reducing the humeral head. If the apprehension is relieved, the relocation test is positive. The examiner can then release the proximal humerus. If apprehension recurs with release of the posterior-directed force, the release test is positive.

The load-and-shift test is used to assess the direction and degree of shoulder laxity. The examiner uses one hand to apply a longitudinal load to the humerus directed toward the glenohumeral joint. This hand is located at the elbow with the elbow flexed. The other hand is used to apply a perpendicular force to the proximal humeral shaft in an attempt to shift (subluxate or dislocate) the humeral head relative to the glenoid. The test is performed while maintaining the upper extremity in the coronal plane of the body. The degree of abduction/rotation and the direction of the applied force can be varied to evaluate the various glenohumeral ligaments. The test is graded by the examiner who determines through tactile sense whether the humeral head translates to the glenoid rim (1+); over the glenoid rim but spontaneously reduces (2+); or over the rim requiring manual reduction (3+).

Imaging Studies and Other Diagnostic Tests

The use of routine imaging studies and tests to evaluate the shoulder girdle for diagnostic purposes is not recommended. At the conclusion of the history and physical examination, the examiner should have a reasonable diagnosis. Additional tests or studies are used to answer specific questions. If the clinical diagnosis is frozen shoulder but the examiner is concerned that the patient has glenohumeral arthritis, it is reasonable to order radiographs to rule out osteoarthritis because the natural history and treatment of osteoarthritis and adhesive capsulitis are dissimilar. If the clinical diagnosis is rotator cuff impingement or tendonitis, there is no reason to obtain further studies initially as they will not change the recommended course of treatment.

Radiographs

The standard shoulder series includes an anteroposterior (AP) X-ray in the plane of the scapula, a Y-outlet view, and an axillary view. This series of X-rays is mandatory in the evaluation of shoulder girdle trauma. Unfortunately, the axillary view is often not obtained, yet it is the most sensitive for documenting shoulder dislocations. AP views with the humerus internally and externally rotated may be used to critically evaluate greater tuberosity fractures or calcific tendonitis. The scapula is approximately 45 degrees oblique to the coronal plane of the body; therefore, to obtain a true AP view of the glenohumeral joint, the X-ray beam must be obliquely oriented to the coronal plane of the body (Fig. 8-5). The AP view is useful

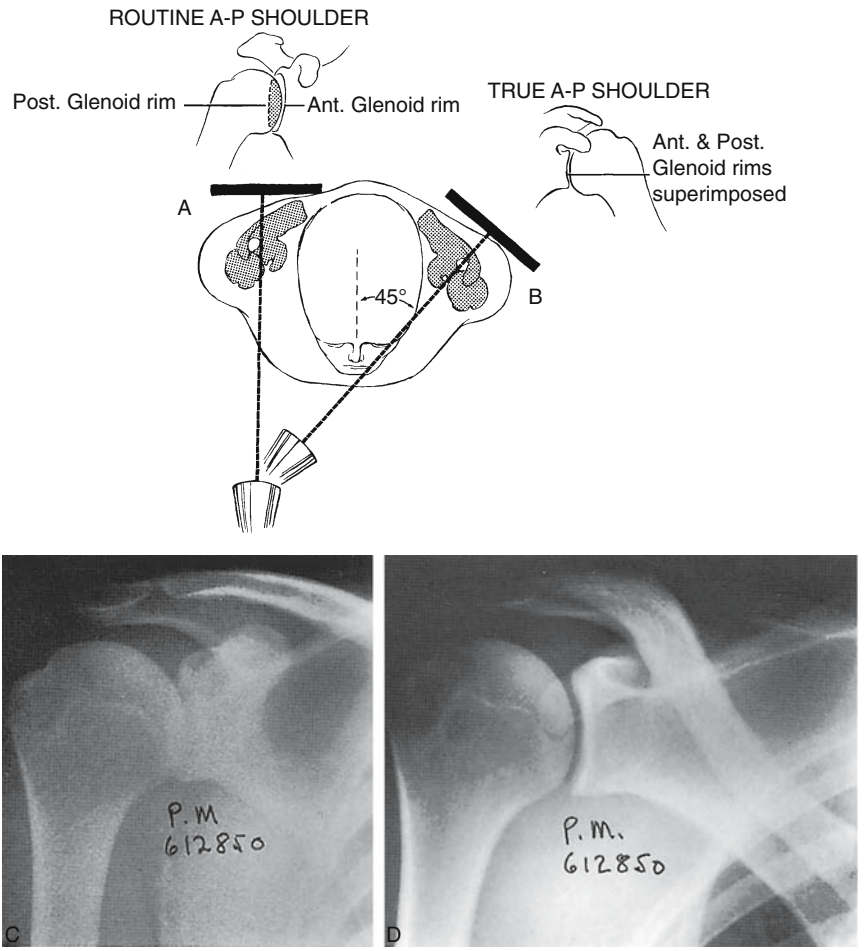


FIGURE 8-5. These illustrations and X-rays demonstrated the importance of obtaining a "true" anteroposterior (AP) perspective of the glenohumeral joint. In the X-ray beam in (A), note that the AP view is actually one of the thorax, yielding an X-ray that shows overlap of the glenohumeral joint. When the beam is angled, however, as in (B), a "true" AP view of the glenohumeral joint is obtained. Note the differences in appearance in these views in (C) (AP view of the thorax) and (D) (true AP view of the glenohumeral joint). (From Rockwood CA Jr, Matsen FA III (eds) The Shoulder, vol 1. Philadelphia: Saunders, 1990. Reprinted by permission.)

for evaluating the clavicle, AC joint, glenohumeral joint space, glenoid, scapular body, proximal humeral shaft, surgical neck, and greater tuberosity. The Y-outlet view is useful for evaluating the scapular spine, scapular body, coracoid, shape of the acromion, and spur formation in the CA ligament. The axillary view is critical in evaluating glenohumeral joint

congruence. Anterior or posterior dislocations are best seen on the axillary view.

Magnetic Resonance Imaging

The magnetic resonance imaging (MRI) scan is commonly employed to evaluate the soft tissues of the shoulder girdle and is considered is the gold standard for evaluating the rotator cuff tendons. Subacromial fluid, tendon inflammation, and rotator cuff tears are all visible with MR imaging. MRI scans can be performed with an arthrogram (intraarticular contrast dye) to better delineate intraarticular structures such as labral tears and articular-sided partial rotator cuff tears. Standard MRI views of the shoulder include coronal oblique, sagittal oblique, and axial cuts. The coronal and sagittal views are termed oblique because they are obtained in the plane of the scapula that is oblique to the coronal and sagittal planes of the body. Although the MRI scan is a powerful tool in the evaluation of shoulder problems, it is a very sensitive test. Positive findings, therefore, may correlate poorly with a patient's clinical presentation. For example, MRI scans have been obtained on patients with normal, painfree shoulders and documented that not only did a large number of these healthy patients have rotator cuff tears, but that the incidence of such asymptomatic tears increased with increasing age. It is therefore important to treat the patient and NOT the MRI scan.

Computerized Tomography

Computerized tomography (CT) scans are useful in the evaluation of bony abnormalities. In the setting of complex or comminuted shoulder girdle fractures, CT scanning with or without image reconstruction is a powerful tool for clinical decision making or preoperative planning. CT scans are also valuable in assessing bony deficiencies such as glenoid wear before reconstructive shoulder surgery. The CT scan has been demonstrated to be superior to the axillary radiograph in evaluating the glenoid before prosthetic arthroplasty.

Electrodiagnostic Testing

Electromyography (EMG) and nerve conduction velocity (NCV) testing are commonly used to evaluate neurologic lesions of the shoulder girdle. EMG testing involves placing small needle electrodes into the muscles to record resting potentials and firing patterns. NCV testing is used to document the speed with which an impulse is conducted along a peripheral nerve. Abnormalities such as a conduction block may indicate severe nerve injury. Electrodiagnostic testing is useful in documenting both the presence and recovery of peripheral nerve lesions.

Evaluation and Treatment of Common Shoulder Problems

The majority of common shoulder girdle problems result from degenerative changes, overuse, or traumatic injury. Atraumatic shoulder pain is common and includes rotator cuff disease, arthropathy, adhesive capsulitis, calcific tendonitis, and multidirectional instability. Most atraumatic shoulder pain is initially treated with activity modification, antiinflammatory medication, and physical therapy. Treatment regimens may vary depending on the specific diagnosis. Calcific tendonitis, for example, responds well to subacromial corticosteroid injections. The physical therapy prescription may also vary depending on the diagnosis. Patients with adhesive capsulitis require stretching exercises, in contrast to patients with rotator cuff tendonitis who are treated with rotator cuff strengthening exercises. Surgical treatment in the atraumatic population is generally reserved for those patients who fail to respond to nonoperative treatment regimens. A basic algorithm for the evaluation of atraumatic shoulder pain is provided in Figure 8-6.

Traumatic injuries to the shoulder girdle are common and include both soft tissue and bony injury. Treatment is individualized based on the age of the patient, functional status of the patient, and the severity of the injury. Depending on the injury, nonoperative or operative treatment may be appropriate. Common traumatic injuries to the shoulder girdle include shoulder dislocations, AC joint injuries, clavicle fractures, and proximal humerus fractures, and these are reviewed in the skeletal trauma chapter. Contrary to popular belief, traumatic rotator cuff tears are relatively uncommon.

Rotator Cuff Disease

Degenerative and overuse injuries of the rotator cuff are common sources of shoulder pain and disability. Anterosuperior shoulder pain emanating from the rotator cuff (RC) under the coracoacromial arch has historically been called impingement syndrome. Impingement syndrome encompasses a spectrum of pathology in the subacromial region including subacromial bursitis, RC tendinopathy, partial-thickness RC tears, and full-thickness RC tears. Partial- and full-thickness tears of the rotator cuff become more prevalent with increasing age. It is unusual for patients under the age of 40 years to present with RC tears in the absence of significant trauma. Conversely, older patients may present with massive RC tears after an innocuous event. There are two main theories that attempt to explain such degenerative cuff tears. The external impingement model suggests an extrinsic cause of RC tears such as abrasion of the anterosuperior cuff

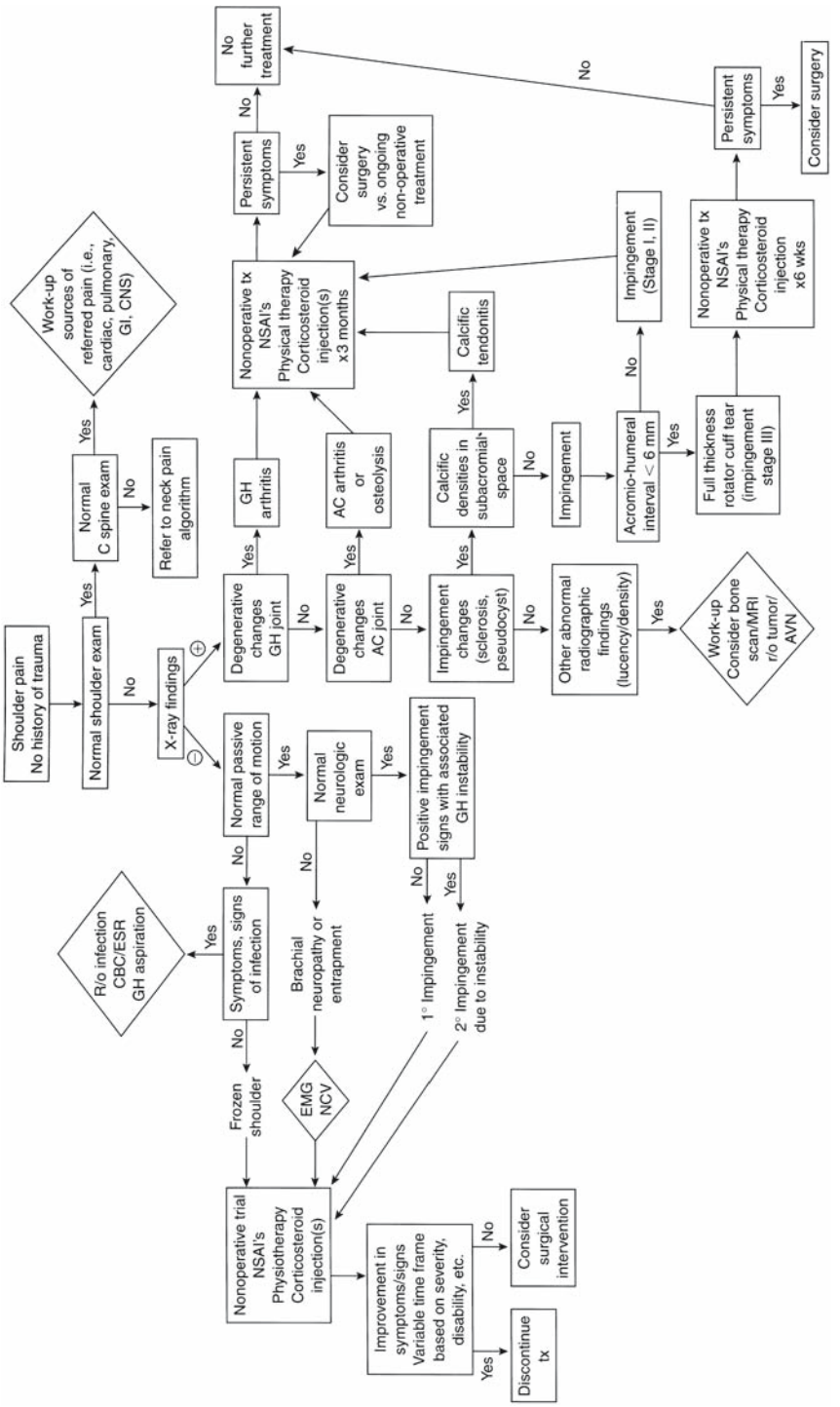


FIGURE 8-6. Algorithmic approach to the diagnosis and treatment of atraumatic shoulder pain.

under the acromion and coracoacromial arch. The intrinsic model suggests that a relatively poor blood supply to the critical zone of the rotator cuff in combination with high stresses across the cuff leads to RC tears. The true pathophysiology likely results from a combination of these models.

History

The chief complaint is usually anterosuperior shoulder pain, which often radiates to the lateral deltoid region. The pain is typically worse with overhead activities and at night. The patient may recall a minor traumatic event, or the pain may have started insidiously.

Examination

Inspection of the shoulder girdle usually reveals symmetry, but patients with degenerative cuff tears may present with atrophy of the supra or infraspinatus fossae. The patient typically has discrete tenderness at the cuff insertion on the greater tuberosity. The active range of motion is generally normal; however, some patients with RC tears may exhibit loss of active motion with preservation of passive motion. In this setting, the clinician may be able to document lag signs. Strength testing may reveal weakness of the supraspinatus or infraspinatus tendons. Special tests include the Neer and Hawkins's impingement signs. If the patient has concomitant biceps tendon pathology, there may be tenderness at the bicipital groove, and Speed's test may be positive. Tenderness over the AC joint may indicate that the AC joint is contributing to the painful condition. A cross-body adduction test recreating pain at the AC joint is considered confirmatory.

Differential Diagnosis

The differential diagnosis varies with the age of the patient. In older patients, the differential diagnosis includes arthritis, cervical spine pathology, metastatic disease, and visceral pathology such as cardiac disease. In younger patients, instability and labral pathology should be considered. In any age group, the differential diagnosis includes adhesive capsulitis, calcific tendonitis, and a variety of other less common shoulder problems (avascular necrosis, scapulothoracic dysfunction, and infection).

Radiographic Evaluation and Magnetic Resonance Imaging

The AP radiograph may reveal sclerosis and cyst formation of the greater tuberosity. The Y-outlet view shows the acromial morphology with potential narrowing of the subacromial space. In patients with long-standing RC tears, the distance between the humerus and acromion may be narrowed. The axillary view illustrates the joint space and may reveal an os acromiale. An MRI scan is useful for a number of reasons. Confirmation of RC disease (and exclusion of other etiologies) is reassuring, but not necessary.

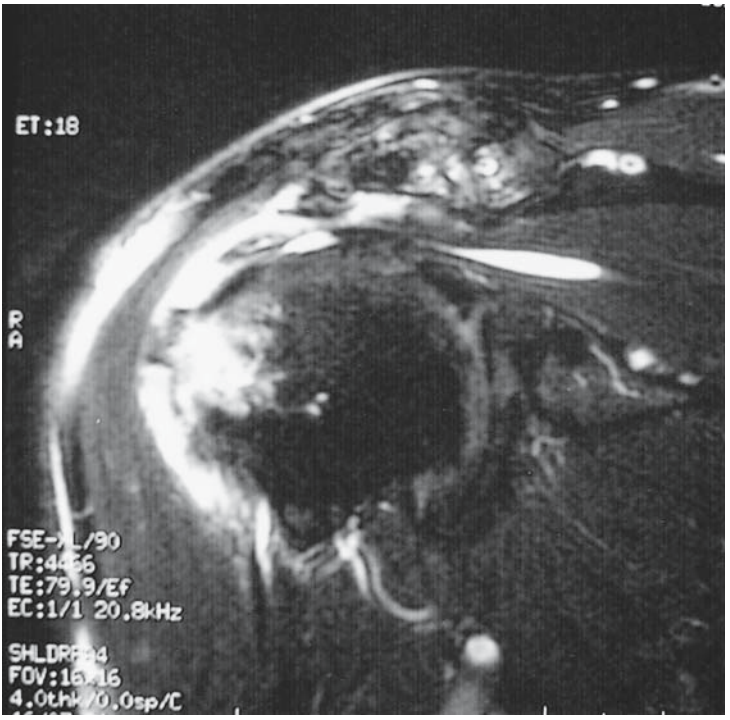


FIGURE 8-7. A tear of the supraspinatus tendon with fluid in the gap is easily appreciated in this coronal oblique magnetic resonance imaging (MRI) scan image of the glenohumeral joint.

The MRI scan is extremely useful for assessing the RC tendons and muscle bellies (Fig. 8-7). The presence, size, and chronicity of a RC tear directly impact patient care (surgical options), recovery, and, ultimately, prognosis.

Initial Treatment

The goal of treatment is to return the patient to painfree activity. Initially, treatment consists of education, rest, and activity modifications. If the pain is significant, an oral antiinflammatory medication can be prescribed. Once the painful period subsides, the patient may benefit from a course of physical therapy to strengthen the rotator cuff and scapular stabilizers. Radiographs are generally obtained in patients who fail initial therapy. A subacromial corticosteroid injection can be considered in a patient who fails to respond to the initial treatment over 2 to 3 months. Additional physical therapy can also be helpful. Patients who fail to respond to nonoperative management over 3 to 6 months may benefit from surgical treatment. Most surgeons will obtain an MRI scan before surgical treatment.

Surgical Treatment

In the absence of a RC tear, most surgeons recommend a subacromial decompression performed either open or arthroscopically. This procedure involves removing the inflamed subacromial bursa and shaving the undersurface of the acromion (acromioplasty) to create more room in the subacromial space for the rotator cuff. Patients who have reparable RC tears are treated with primary repair, and most surgeons perform an acromioplasty. Care should be taken to preserve the CA ligament in patients with large tears and multiple tendon tears to prevent superior migration of the humeral head. There are a variety of options for patients with irreparable tears, including arthroscopic debridement, partial tendon repair, and tendon transfers. Patients with irreparable RC tears and arthropathy may be candidates for shoulder arthroplasty with a humeral head replacement. If biceps tendon pathology is found at the time of surgery, either tenodesis or tenolysis can be performed. Patients who are noted to have AC joint arthropathy and pain before surgery may benefit from a distal clavicle resection. Recovery from RC surgery can take from 4 to 6 months. The goal of early (4–6 weeks) postoperative physical therapy is recovery of passive shoulder motion. Restoration of strength and function is the goal of subsequent postoperative therapy. Failure of the patient to adhere to postoperative physical therapy can result in a poor outcome.

Osteoarthritis

Degenerative or osteoarthritis occurs in the glenohumeral joint but is less common than in the hip or knee joints. Osteoarthritis of the glenohumeral joint has the same pathophysiology as in other joints with progressive articular cartilage destruction.

History

Patients with early osteoarthritis may have a clinical syndrome that is virtually indistinguishable from impingement syndrome. In patients with advanced osteoarthritis, pain is more likely to be chronic, occur at rest, and be resistant to standard analgesics and antiinflammatory medications. In addition, loss of shoulder motion is a common complaint.

Examination

Patients with early osteoarthritis (OA) may examine similarly to those with impingement syndrome. In more-advanced OA, generalized disuse atrophy of the shoulder girdle may be noticeable. In general, active motion is decreased in all planes but loss of external rotation is often the most dramatic. Passive motion is similarly decreased.

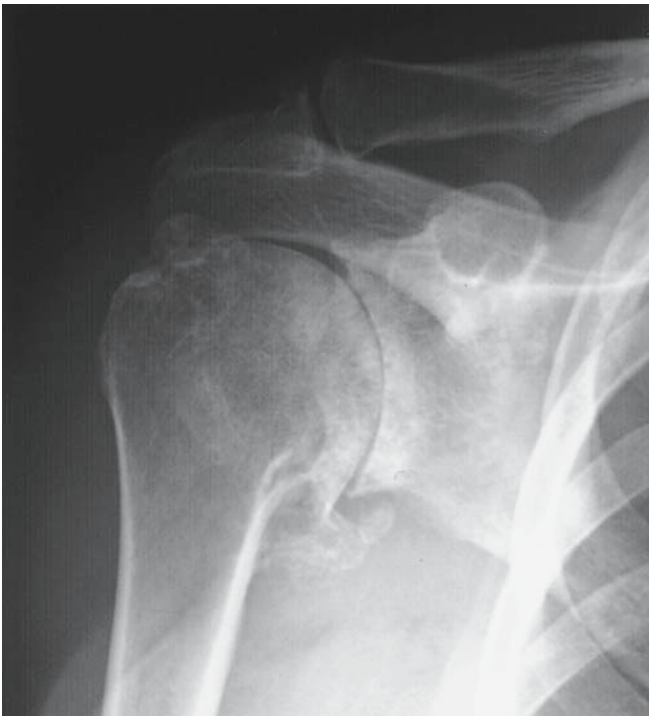


FIGURE 8-8. All the classic findings of osteoarthritis are present in this true AP X-ray of the glenohumeral joint, including joint space narrowing, subchondral sclerosis, osteophyte formation, and subchondral cyst formation.

Differential Diagnosis

Adhesive capsulitis and inflammatory arthropathy can have similar presentations. The examiner must have a high index of suspicion for locked posterior shoulder dislocations in older patients who are poor historians as a result of dementia or stroke.

Radiographs

A standard shoulder series is recommended. Joint space narrowing, subchondral sclerosis, osteophytes, and subchondral cyst formation are classic findings in osteoarthritis and are best seen on the AP and axillary view (Fig. 8-8). In the glenohumeral joint, inferior humeral osteophytes predominate. Often, eccentric posterior glenoid wear is present. MRI scans are generally not used in the evaluation of OA. A CT scan to assess the glenoid for eccentric wear or bone loss is common during preoperative evaluation for shoulder arthroplasty.

Treatment

Initial treatment for OA includes education, rest, activity modification, and antiinflammatory medications. Physical therapy for stretching and maintenance of motion is an important component of nonoperative treatment. Corticosteroid injections provide inconsistent and incomplete pain relief in this setting. With advanced disease, some patients require narcotic analgesia for pain relief. When nonoperative management is no longer able to control the patient's pain, surgical management is a reasonable option. Patients with concentric wear with or without some joint space preservation and reasonable motion may benefit from arthroscopic debridement. The goal of debridement is pain relief and postponement of prosthetic joint arthroplasty. In the setting of painful, end-stage OA, prosthetic joint replacement with a humeral head replacement (HHR) or total shoulder arthroplasty (TSA) is recommended (Fig. 8-9). Slight improvement with

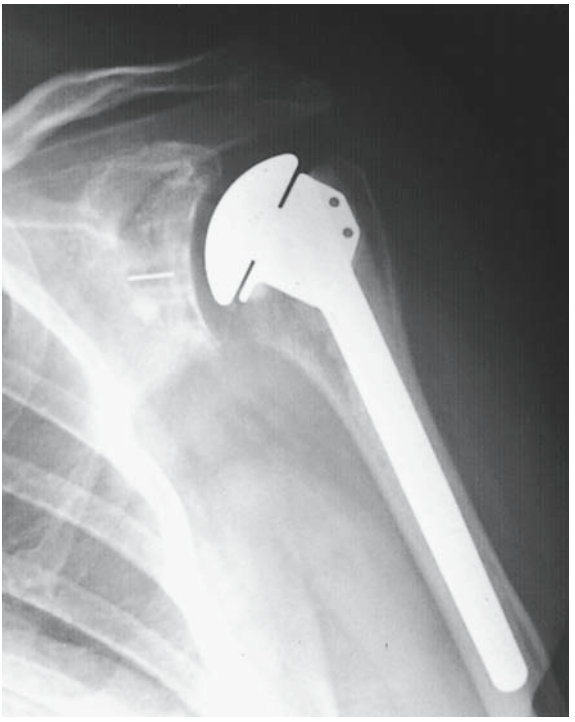


FIGURE 8-9. A total shoulder arthroplasty is demonstrated in this true AP X-ray of the glenohumeral joint. The metallic humeral component is cemented into the proximal humerus. The pegged glenoid component is cemented into the glenoid and is represented by the reproduction of the joint space. The central peg of the polyethylene glenoid component is identified by the horizontal radiopaque marker.

respect to motion and pain relief has been demonstrated with TSA relative to HHR. Total shoulder arthroplasty introduces the risk of glenoid-sided prosthetic loosening and wear, which may require revision surgery. Humeral head replacement can fail as a result of inadequate pain relief.

Miscellaneous Arthropathy

A variety of other disease processes can lead to glenohumeral joint destruction. Inflammatory arthropathy such as rheumatoid arthritis can lead to joint destruction as a result of synovial disease. Although the clinical presentation may be similar to osteoarthritis with pain and loss of motion, there are some important differences. In particular, rheumatoid arthritis can result in rotator cuff deficiency and incompetence. In these patients, total shoulder arthroplasty is contraindicated because glenoid loosening in the setting of rotator cuff deficiency is a common problem. Progressive bony destruction of the humeral head and glenoid can result from rheumatoid arthritis, making prosthetic arthroplasty difficult if not impossible. Avascular necrosis can occur as a result of trauma, corticosteroid use, alcoholism, and other less common etiologies. Avascular necrosis of the humeral head can lead to pain and loss of motion in the glenohumeral joint. Humeral head replacement is an option for patients with humeral head collapse and chronic pain. Total shoulder arthroplasty is indicated when secondary destruction of the glenoid is present. Charcot or neuropathic arthropathy is typically a painless condition that results in severe joint destruction. Charcot arthropathy in the glenohumeral joint is commonly related to a cervical spine syrinx. There are no reliable surgical options for Charcot arthropathy.

Adhesive Capsulitis

Adhesive capsulitis, or frozen shoulder, is a painful condition in which the synovial lining of the glenohumeral joint is inflamed. Adhesive capsulitis is a clinical diagnosis in which examination reveals an equal loss of active and passive motion. Primary adhesive capsulitis is idiopathic, meaning that no trigger can be identified; it occurs in middle-aged persons and is associated with diabetes. Secondary adhesive capsulitis implies that a trigger or cause of the disease process can be identified. Trauma, surgery, and concomitant shoulder girdle pathology may result in secondary adhesive capsulitis.

History

The patient reports an insidious onset of shoulder pain. Pain often occurs during rotational movements such as reaching behind the back, putting on a coat, or fastening a bra. Often the patient may recall a minor event that

precipitated the condition. It is important to obtain a past medical and surgical history to identify possible risk factors. Insulin-dependent diabetes is a strong risk factor for adhesive capsulitis.

Examination

In the absence of prior trauma or surgery to the shoulder girdle, the inspection and palpation portions of the examination are usually unremarkable. Active motion can be extremely limited in all planes of motion, and passive motion is similarly restricted. The patient often experiences pain at the end range of motion (active or passive).

Differential Diagnosis

Early adhesive capsulitis can mimic impingement. Subtle losses of internal and external rotation in abduction may be the only clues to differentiate between the two diagnoses. Unrecognized trauma (locked posterior shoulder dislocations) and glenohumeral joint arthropathy can mimic adhesive capsulitis.

Radiographs

A standard shoulder series is useful in excluding other diagnoses; however, there are no radiographic findings for adhesive capsulitis. Further studies are generally not indicated unless additional pathology is suspected.

Treatment

Once the diagnosis is made, education of the patient is paramount. In general, the treatment of adhesive capsulitis is twofold: treatment of the synovial inflammation and restoration of motion. Antiinflammatory medications can be used, but a corticosteroid injection into the glenohumeral joint space is more efficient and effective for treating the synovial inflammation. The patient must start a stretching program to regain motion in all planes. Initially, supervised physical therapy is helpful, but the patient must independently perform a battery of home stretching exercises daily. A gradual restoration of motion is the anticipated course. In patients who fail to respond to nonoperative treatment over the course of 3 to 6 months, surgery may be a reasonable option. Historically, patients with diabetes have a higher failure rate of nonoperative treatment compared to patients without risk factors. Additionally, patients with secondary adhesive capsulitis from trauma or prior shoulder surgery often fail to respond fully to nonoperative treatment.

Manipulation of the shoulder under anesthesia was once the preferred treatment and continues to be a reasonable option. Proximal humerus

fractures can occur with manipulations under anesthesia, however, and osteoporosis is a risk factor for this complication. Arthroscopic adhesiolysis is a more-invasive, yet more-anatomic, procedure. Arthroscopic adhesiolysis involves releasing the shoulder capsule under direct vision with some form of electrofrequency device. Because of the risk of axillary nerve damage, most surgeons prefer to gently manipulate the shoulder in abduction to release the inferior capsule. Aggressive physical therapy with active-assisted and active range of motion is mandatory to maintain the postoperative range of motion. Shoulder strengthening and resistance therapy is instituted only after restoration of full, active shoulder motion.

Calcific Tendonitis

Calcific tendonitis of the rotator cuff is a painful condition of the shoulder girdle and is a common clinical problem (Figure 8.10). The etiology of calcific tendonitis is a matter of debate. The pathogenesis of calcifying tendonitis includes various stages of tendon degeneration, calcium deposition, and calcium resorption. In the formative phase of calcium deposition, there may be little or no pain. Typically, the resorptive phase is more painful and clinically relevant.

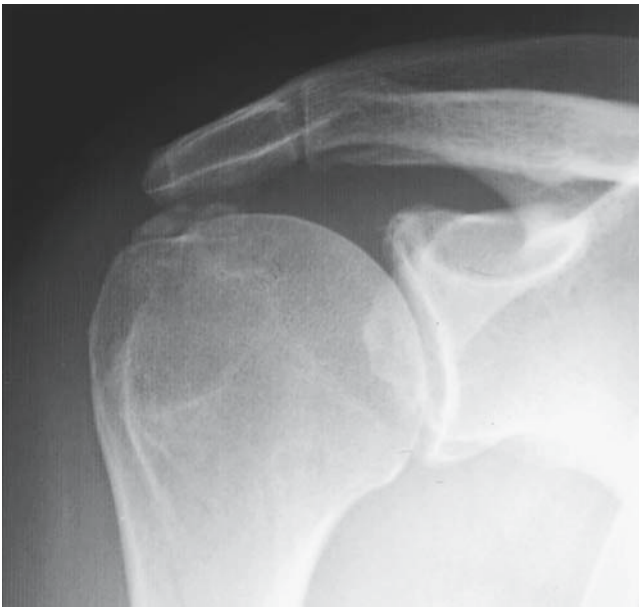


Figure 8-10. A calcium deposit is present in the supraspinatus tendon immediately medial to its attachment site on the greater tuberosity in this true AP X-ray of the glenohumeral joint.

History

In the resorptive phase, the patient may present with an acute onset of severe shoulder pain. In the formative phase, the patient may present with more chronic symptoms that mimic impingement syndrome.

Examination

Acute bursitis in the resorptive phase may lead to fullness of the anterosuperior shoulder, but otherwise the inspection is typically unremarkable. There may be tenderness at the rotator cuff insertion corresponding to the calcium deposition. There may be a loss of active motion secondary to pain, but passive motion, although painful, is generally preserved. Impingement signs are often positive.

Differential Diagnosis

The differential diagnosis includes rotator cuff disease and adhesive capsulitis. Referred pain from cardiac origin or other visceral organs and radicular pain from the cervical spine should be considered.

Radiographs

The appearance of calcific tendonitis on radiographs varies depending on the phase of the disease. In the formative phase, the calcium deposit is usually well circumscribed and easily identified. In the resorptive phase, the deposit may appear fluffy and less well defined. In addition to the standard shoulder series, internal and external rotational views (AP) can be helpful for identifying more subtle deposits. Additional studies are not usually indicated.

Treatment

Treatment generally involves pain management. Noninvasive treatment options include antiinflammatory medications and extracorporeal shock wave therapy. More-invasive options include corticosteroid injections and lavage therapy. Surgical treatment is a last resort and involves arthroscopic debridement of the calcium deposit.

Multidirectional Instability

Shoulder instability is a complex problem with a spectrum of pathology ranging from atraumatic multidirectional shoulder instability to traumatic, unidirectional shoulder dislocations. Multidirectional instability (MDI) generally refers to shoulder pain and disability caused by excessive laxity of the static shoulder stabilizers (capsule and glenohumeral ligaments).

History

In the overhead athlete (pitchers, swimmers, and volleyball players), MDI can present with activity-related pain, scapular winging, and occasionally with neurologic symptoms down the arm. Other patients may present with shoulder subluxations and dislocations that may easily reduce on their own but are a significant source of disability and distress to the patient.

Examination

Scapular winging may be noticeable on inspection during range of motion and strength testing. The active and passive ranges of motion are often excessive compared to the average shoulder. Additionally, the patient may exhibit generalized ligamentous laxity at other joints. The sulcus sign (hollowing of the subacromial region with downward traction on the arm) may be noticeable and indicative of shoulder laxity. Provocative shoulder testing such as the apprehension test may produce pain rather than apprehension. This pain is often related to secondary rotator cuff irritation. Other patients may have true apprehension. Load-and-shift testing often reveals subluxation or dislocation in multiple directions.

Differential Diagnosis

The differential diagnosis includes rotator cuff disease, labral pathology, and peripheral nerve injury in the setting of scapular winging.

Radiographs

The standard radiographs are typically unremarkable, although bony abnormalities such as glenoid hypoplasia can be identified. Patients who have had previous traumatic anterior shoulder dislocation may have a posterosuperior impression fracture of the humeral head (Hill–Sachs lesion) or a bony deficiency of the anteroinferior glenoid rim (bony Bankart lesion). An MRI arthrogram can be useful to exclude labral injury (Bankart lesion) and document the patulous capsule.

Treatment

The mainstay of treatment for MDI is rehabilitation. Physical therapy is focused on strengthening the dynamic stabilizers of the shoulder girdle, including the rotator cuff and scapular stabilizers. More-specialized therapy can be prescribed for athletes and is based on their specific sport and needs. Patients who fail rehabilitation may be candidates for surgical treatment. In most cases, rehabilitation should be continued for at least 6 to 12 months. Surgical treatment involves decreasing the volume of the shoulder joint by surgically altering the capsule (capsulorraphy). Surgery may be

performed by arthroscopic or open methods. Arthroscopic methods tend to preserve motion better and may be preferable in athletes who would not tolerate minor losses of motion. Open surgical treatments historically have had lower rates of recurrent instability. Criticisms of open procedures such as the inferior capsular shift include loss of motion and potential subscapularis deficiency.

Summary

The shoulder is a complex structure that provides tremendous versatility and power to the upper extremity. The majority of painful shoulder girdle conditions are readily diagnosed with a thorough history and physical examination. Successful treatment of shoulder girdle problems is often accomplished by following a relatively simple algorithm of rest, activity modification, nonsteroidal antiinflammatory drug therapy, and physical therapy. More-invasive treatment options such as arthroscopic and open surgery are highly effective in appropriately selected patients.

Suggested Readings

Norris TR. Orthopaedic Knowledge Update: Shoulder and Elbow, 2nd ed. Rosemont, IL: American Academy of Orthopaedic Surgeons, 2002.

Rockwood CA, Matsen F, Wirth M. The Shoulder, 3rd ed. Philadephia: Saunders, 2004.

Questions

Note: Answers are provided at the end of the book before the index.

8-1. Which of these articulations is not a true diarthrodial joint?
   a. Sternoclavicular
   b. Acromioclavicular
   c. Scapulothoracic
   d. Glenohumeral
   e. Hip joint

8-2. The primary, passive restraint to anterior displacement of the humeral head when the shoulder is abducted and externally rotated to 90 degrees is the:
   a. Coracohumeral ligament
   b. Anterior band of the inferior glenohumeral ligament complex
   c. Superior glenohumeral ligament
   d. Long head of the biceps tendon
   e. Posterior band of the inferior glenohumeral ligament complex

8-3. Which of the following radiographic findings is not a hallmark of glenohumeral osteoarthritis?
   a. Central erosion of the glenoid
   b. Osteophyte of the inferior humeral head
   c. Subchondral sclerosis
   d. Joint space narrowing
   e. Subchondral cysts

8-4. Which of these peripheral nerves does not exit from the brachial plexus?
   a. Long thoracic nerve
   b. Thoracodorsal nerve
   c. Axillary nerve
   d. Suprascapular nerve
   e. Spinal accessory nerve

8-5. The rotator cuff includes all the following muscles except:
   a. Supraspinatus
   b. Teres minor
   c. Deltoid
   d. Subscapularis
   e. Infraspinatus

8-6. What is the most common origin of shoulder pain that does not originate within the shoulder girdle?
   a. The cervical spine
   b. The heart
   c. The gallbladder
   d. The lungs
   e. The thoracic spine

8-7. Which of the following procedures is not an option for the treatment of glenohumeral osteoarthritis?
   a. Total shoulder arthroplasty
   b. Humeral head replacement
   c. Arthroscopic debridement
   d. Arthroscopic labral repair
   e. Fusion

8-8. What is the best noninvasive study to evaluate the integrity of the rotator cuff tendons?
   a. Computerized tomography scan
   b. Plain AP radiograph in the plane of the scapula
   c. Electromyography study
   d. Magnetic resonance imaging arthrogram
   e. Magnetic resonance imaging scan

8-9. All the following are treatment options for adhesive capsulitis except:
   a. Arthroscopic rotator cuff repair
   b. Arthroscopic adhesiolysis

c. Manipulation under anesthesia
d. Glenohumeral corticosteroid injection
e. Physical therapy

8-10. Which of the following statements is not true of rotator cuff tears?
a. Most rotator cuff tears are degenerative in nature
b. Most rotator cuff tears involve the supraspinatus tendon
c. Some rotator cuff tears can be asymptomatic
d. Some rotator cuff tears can be treated without surgery
e. Most rotator cuff tears are the result of high-energy trauma

9
The Elbow

Mustafa A. Haque

Although the elbow is rarely given top priority in teaching or training situations, its function is critical to upper extremity use. In looking at the arm as a unit, the tremendous range of motion of the shoulder can be thought of positioning the hand on the outer surface of a sphere. It is the flexion, extension, pronation, and supination of the elbow and forearm that allow positioning of the hand within that sphere, thus creating the ability to function throughout a huge volume of space surrounding a person. When elbow and forearm function are compromised by pain, injury, or loss of motion, significant disability can result. The goals of this chapter are to present the elbow's functional anatomy, describe how to evaluate this region, and present an approach to diagnosis and treatment of common elbow problems.

Functional Anatomy

Skeletal

The elbow contains two distinct types of joints that allow hinge-type motion in the flexion–extension plane and rotatory motion in the pronation–supination plane. Its bony anatomy starts several centimeters proximal to the joint itself, as the humeral shaft divides and flares into medial and lateral columns that end in condyles (Fig. 9-1). The lateral condyle consists of the lateral epicondyle and the capitellum, a hemispherical structure that articulates with the proximal surface of the radial head. The medial column develops a broad outcropping called the medial epicondyle; laterally it is bridged to the capitellum by the trochlea, a spool-shaped articular segment that engages the proximal ulna with a high degree of congruity and constraint. The trochlea has a 300 degree arc of cartilage when viewed in the sagittal plane, allowing for the tremendous flexion–extension arc of the elbow while maintaining stability. The humeral columns and condyles create two fossae on the volar and dorsal aspects of the distal humerus. They are respectively called the coronoid and olecranon fossa; they allow

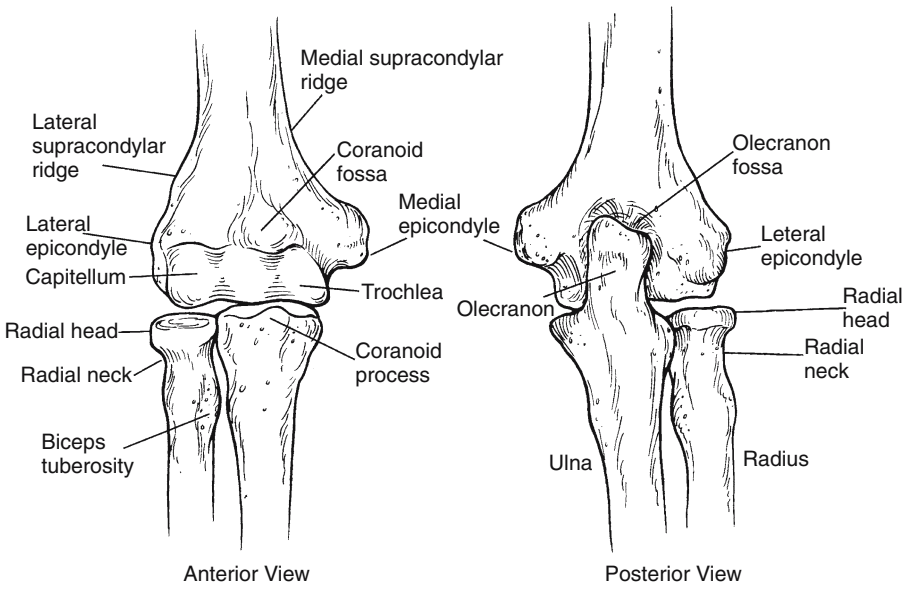


FIGURE 9-1. Anterior and posterior views of the elbow joint demonstrate normal skeletal anatomy, including the three articulations, including the ulnotrochlear joint, the radiocapitellar joint, and the proximal radioulnar joint.

for the coronoid and olecranon processes of the ulna to recess below the surface level of the humerus in extremes of flexion and extension.

The proximal ulna has a deep sigmoid notch, framed by the olecranon and coronoid processes, which cradles the trochlea. Radially, it has a lesser sigmoid notch, which articulates with the periphery of the radial head. Distally, it narrows to the tubular bone of the ulnar shaft. The radial head has a cup-shaped proximal surface articulating with the capitellum; its sides are covered with a 240 degree arc of articular cartilage, which interfaces with the lesser sigmoid notch and allows nearly 180 degree of pronation and supination. Distally, a prominent tuberosity is present on the radius for the attachment of the biceps.

In contrast to the shoulder, whose stability is dependent on surrounding soft tissues, the elbow is highly constrained skeletally. It is further supplemented by two important ligament complexes medially and laterally. The medial ulnar collateral ligament has three segments; the most important for stability is the anterior bundle (Fig. 9-2). The lateral complex consists of the lateral ulnar collateral ligament, which originates on the lateral epicondyle and inserts on the ulna; the annular ligament, which surrounds

and stabilizes the radial head; and the radial collateral ligament, which extends from the lateral epicondyle to the annular ligament.

Anteriorly and posterior the elbow joint is lined by a single cell layer of synovium, which in turn is covered by a relatively thick fibrous capsule. In the olecranon and coronoid fossa, a fatty layer of tissue is present between the synovium and the capsule. This layer is of significance in radiographic evaluation of elbow trauma, in which intraarticular (intracapsular) effusion (fluid) or hemarthrosis (bleeding into the joint) causes capsular distension and displacement of these fat pads either anterior or posterior to their usual position (Fig. 9-3). Identification of these usually absent fat pads (particularly the posterior fat pad, which is usually deeply contained within the olecranon fossa) suggests joint injury or fracture.

Muscles

The muscles surrounding the elbow can be divided into five separate groups on the basis of location and function. The two groups that originate in the upper arm include the elbow flexor and extensor compartments. The flexor compartment is on the anterior surface and consists of the brachialis, which inserts on the coronoid process, and the biceps, which inserts primarily on the radial tuberosity to provide both flexion and supination. The extensor compartment of the elbow consists of the triceps, which inserts on the olecranon process to provide a powerful extension moment.

The three forearm muscle groups originating around the elbow include the mobile wad, the extensor compartment, and the flexor–pronator mass.

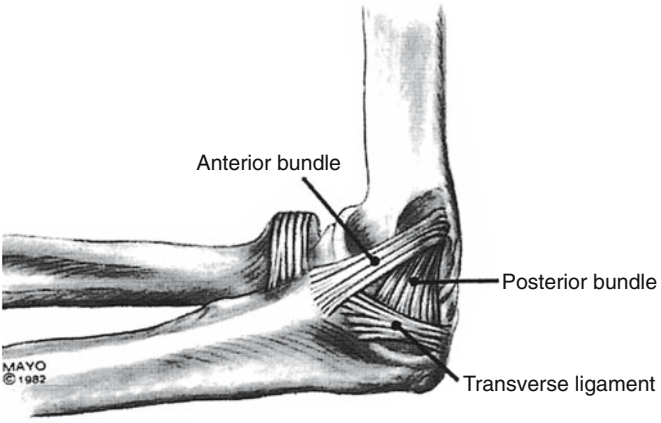


FIGURE 9-2. This sagittal view demonstrates the three bundles or bands of the normal medial collateral ligament. The anterior band is most important in elbow stability. (From Morrey BF (ed) The Elbow and Its Disorders, 2nd ed. Philadelphia: Saunders, 1993. Reprinted by permission of Mayo Foundation for Medical Education and Research. All rights reserved.)

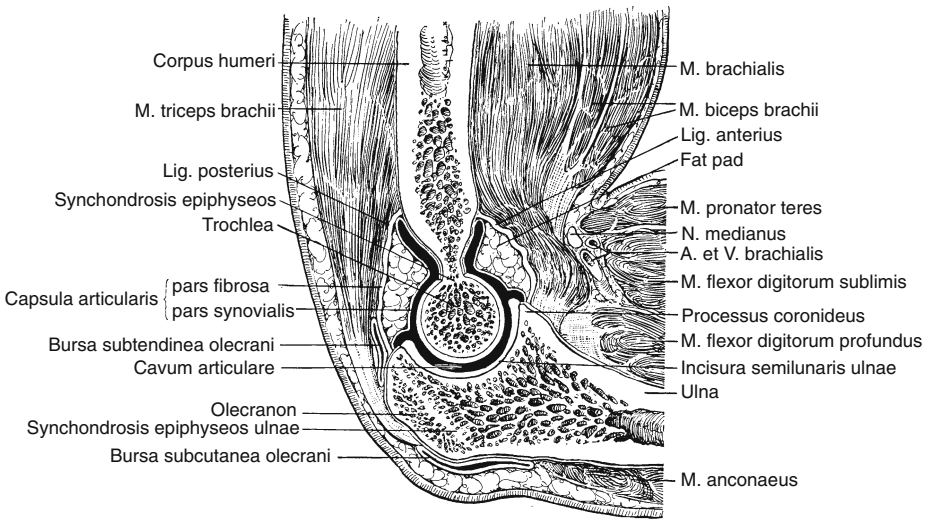


FIGURE 9-3. Sagittal illustration of the elbow joint demonstrates the normal skeletal and soft tissue anatomy. Note the presence of fat pads both anteriorly and posteriorly, directly outside the joint capsule. Intraarticular swelling can lead to displacement out of the olecranon (posterior) or coronoid (anterior) fossae, leading to the appearance of "positive fat pad sign(s)" on lateral X-rays. (From Morrey BF (ed) The Elbow and Its Disorders, 2nd ed. Philadelphia: Saunders, 1993. Reprinted by permission of Mayo Foundation for Medical Education and Research. All rights reserved.)

The mobile wad is an outcropping of three muscles arising from the lateral humerus and running on the radial aspect of the forearm. They are the brachioradialis, which inserts on the radial styloid and flexes the elbow in pronation, and the extensor carpi radialis longus and brevis, which insert on the index and middle metacarpal, respectively. They are the most important extensors of the wrist. The extensor compartment of the forearm has a common origin from the region of the lateral epicondyle and distally. It consists of all the finger extensors and the extensor carpi ulnaris. In addition, there is a muscle called the anconeus. This relatively small triangular structure originates on the lateral epicondyle and inserts on the lateral aspect of the olecranon. It is thought to assist with elbow extension. The flexor–pronator mass takes its origin from the medial epicondyle, the medial ulna, and the interosseous membrane. It consists of the muscles that flex the fingers and wrist as well as the pronator teres.

Neurovascular

In contrast to the deeper-seated neurovascular structures of other extremities, those about the elbow are both tightly concentrated and superficial,

making them uniquely vulnerable to both direct and indirect injury. Injuries or symptoms resulting from nerve involvement around the elbow make familiarization with normal neurovascular anatomy crucial.

Musculocutaneous Nerve

Continuing from the lateral cord of the brachial plexus and composed of fibers from the C5–C8 nerve roots, this nerve travels through (and innervates) the biceps and brachialis, terminating as the lateral antebrachial cutaneous nerve of the forearm.

Median Nerve

Arising from C5–T1 nerve roots, combined from the upper and lower cords, the median nerve travels along anterior to the brachialis muscle, enters the antecubital fossa, then passes medial to the biceps tendon and the brachial artery. It then passes through the pronator teres and gives off the anterior interosseous branch, which supplies motor innervation to the flexor pollicis longus, the index and middle flexor digitorum profundus, and the pronator quadratus. The remainder continues distally in the forearm under the flexor digitorum sublimis. Distally the median nerve provides motor and sensory innervation to part of the radial aspect of the hand.

Radial Nerve

Originating from C6–C8 nerve roots, the radial nerve is a continuation of the posterior cord, which travels in the radial groove of the humerus. It innervates the triceps, brachioradialis, and extensor carpi radialis longus and brevis muscles. In the antecubital fossa the nerve divides into a deep motor branch (posterior interosseous nerve) and a superficial sensory branch. The superficial branch continues underneath the brachioradialis to provide sensation to the dorsum of the radial aspect of the wrist and hand.

Ulnar Nerve

Derived from roots C8 and T1, the ulnar nerve continues from the medial cord of the brachial plexus along the arm until passing posteriorly through the intermuscular septum at the level of the midhumerus. It then travels through the cubital tunnel, where pathologic compression, traction, or irritation can occur. In the forearm, the ulnar nerve innervates the flexor carpi ulnaris and the ulnar half of the flexor digitorum profundus. Distally, it continues to provide motor function to many of the intrinsic hand muscles and sensation to the skin of the ulnar wrist and hand.

Brachial Artery

The brachial artery lies anterior to the medial aspect of the brachialis muscle, entering the antecubital space medial to the biceps tendon and

lateral to the median nerve. At the level of the radial head, it divides into its terminal branches, the ulnar and radial arteries.

Evaluation of Elbow Problems

The evaluation of elbow problems relies on a thorough history, physical examination, and radiographic examination, supplemented by other pertinent tests when indicated.

History

Elbow problems can be divided into two major categories: (1) acute traumatic injuries, and (2) atraumatic problems, which tend to be more chronic. In a situation of acute trauma, a detailed history of the event must be obtained. The mechanism of injury including the position of the arm at the time, initial treatment, and subsequent symptoms are all very important in guiding further evaluation and management. It is also important to elicit a history of any prior injury or underlying symptoms in the elbow and forearm.

For nonacute elbow conditions, the most common complaint is pain, although stiffness or other mechanical symptoms such as locking, catching, or instability may accompany or become the primary problem. The examiner must try to define the complaint as completely and accurately as possible. Identify the onset of the symptoms, including the time frame before the examination and whether it was acute or insidious. Try to pinpoint the exact location of the symptoms and any zone to which it radiates. Characterize the nature of the pain: is it burning or radiating (nerve), or is it an aching related only to activity (tendonitis)? Does it hurt at rest or at night (tumor, infection)? Is it associated with any other symptoms, such as neck pain (referred pathology from the cervical spine) or wrist pain (distal radioulnar joint problem)?

What is the relationship of the patient's activity to their symptoms? For example, in a throwing athlete, when during the pitch or throw does the pain occur? Medial elbow pain when the arm is in the "cocking position" suggests medial collateral ligament pathology, whereas medial pain during follow-through suggests involvement of the flexor pronator group.

Determine what treatments, if any, have helped. Has the patient had any cortisone injections? What type of other treatments (physical therapy, antiinflammatories, etc.) have they had, and with what effect? Has there been previous surgery?

The elbow is commonly involved (and sometimes one of the first joints affected) in inflammatory arthritides, so it is important to elicit a history of other joint complaints, known arthritis, and family history. Is there a history of skin problems (lupus, dermatitis, psoriasis) or gastrointestinal

problems (colitis)? Have there been any systemic symptoms of illness (malaise, fevers)?

Numbness, tingling, and weakness may be obvious clues to neurologic involvement, but sometimes nerve entrapment syndromes present with pain only. In addition to inquiring about tingling or numbness, ask about weakness or loss of dexterity.

Perhaps the most important part of the history is determining how the symptoms interfere with function, as this directs the treatment more than any other factor. For example, inability to flex the elbow completely is well tolerated by most patients, because we generally rely on an arc of 30 to 130 degrees for most activities of daily living. But in the patient with rheumatoid arthritis, for example, in whom shoulder motion is also compromised, elbow restriction may interfere with their ability to feed or clean themselves.

Physical Examination

The examination of the elbow begins with inspection, palpation, range-of-motion assessment, and evaluation for strength and neurovascular integrity. These features are then followed by special tests designed to evaluate specific conditions, based on a differential diagnosis from the history and initial tests. A thorough physical examination must also include a directed evaluation of the shoulder, wrist, and hand, and, when relevant, the cervical spine.

Inspection begins with careful observation of elbow use as soon as one begins interaction with the patient. Does the patient extend the elbow to shake hands with the examiner? Are there obvious adaptive maneuvers that the patient uses to avoid pain or compensate for functional loss? A more formal visual exam is then performed to look for presence of swelling, ecchymosis, atrophy, asymmetry, or masses. One should evaluate the "carrying angle" formed between the longitudinal axis of the humerus and the forearm, normally 10 to 15 degrees.

With the elbow flexed 90 degrees, note that the normal bony prominences (medial and lateral epicondyles and the olecranon) form an equilateral triangle. In dislocations, this normal relationship is distorted. Look for evidence of joint swelling laterally by inspection of the soft tissue triangle bordered by the radial head, olecranon tip, and lateral epicondyle.

Palpate for tenderness, soft tissue integrity, and crepitus. Include the anterior, medial, lateral, and posterior structures in an organized, systematic fashion. Be specific in trying to identify the exact area of tenderness. For example, lateral epicondylitis (lateral tennis elbow) causes focal tenderness over the lateral epicondyle. Tenderness more distally in the proximal forearm may instead suggest posterior interosseous nerve entrapment. Medial elbow pain may reflect medial epicondylitis (medial

tennis elbow) if tender directly over the epicondyle. When more distal, it may be caused by medial ulnar collateral ligament (MCL) insufficiency. Palpate posteriorly over the olecranon fossa. Notice the presence of any bursae over the olecranon tip, occasionally containing fluid, palpable fibrous fragments, or both (olecranon bursitis). Palpate over the antecubital fossa for any defect in the biceps tendon attachment (distal biceps tendon rupture).

Check both active and passive motion, noting any difference between them. If passive motion is greater than active motion, consider pain, muscle, or nerve injury as possible causes. Patients tend to splint their elbow at 80 to 90 degrees following trauma because the capsule accommodates the maximum amount of fluid in this position. In the absence of trauma, pain on passive elbow motion suggests infection.

Note the location and timing of pain during motion. Discomfort at terminal extension is common in posterior olecranon impingement. Crepitus over the radiocapitellar joint during pronation/supination may indicate synovial or chondral pathology, degenerative changes, or radial neck fracture.

The extent of neurologic evaluation depends on the patient's symptoms, but be familiar with sensory, motor, and reflex exam. Check for sensation to light touch in the distribution of the specific peripheral nerves. For the ulnar nerve, check the ulnar border of the little finger. For the median, use the radial border of the index finger. Check radial sensory function over dorsal thumb–index web space. The specific nerve roots have overlapping innervation, but in general, the lateral aspect of the deltoid is the C5 dermatome, the dorsal first web space is C6, the middle finger tip is C7, and the ulnar aspect of the forearm and arm is T1.

Strength testing depends on familiarity with the innervation of the various muscle groups. Elbow flexion relies on C5, whereas wrist extension is mainly C6. Elbow extension is from C7, which also provides finger extension and wrist flexion. Reflex testing is performed for the biceps (C5), brachioradialis (C6), and triceps (C7).

Vascular assessment includes palpation of the radial and ulnar arteries at the wrist and the brachial artery in the antecubital fossa.

Additional specific physical examination tests may be useful depending on the condition suspected. When considering medial epicondylitis, check for pain on wrist flexion or forearm pronation against resistance. Medial collateral ligament sprain or attenuation is determined by applying a valgus stress to the 15 to 30 degree flexed elbow, looking to reproduce pain or joint opening. Lateral epicondylitis can be assessed by eliciting pain with wrist extension or grip, whereas radial tunnel syndrome is implied by pain with resisted middle finger extension or forearm supination.

The Tinel's sign is useful in assessment of nerve problems. Gently tapping over a nerve in the vicinity of suspected entrapment or pathology reproduces the symptoms, causing numbness, tingling, or pain in the nerve's

distribution. During flexion and extension, the ulnar nerve may be "unstable" and can be felt subluxating or completely dislocating out of its groove posterior to the medial epicondyle in the cubital tunnel.

Radiographic Evaluation

Anteroposterior (AP) and lateral X-rays are the minimum views necessary to evaluate the elbow joint. Following trauma, additional views are sometimes helpful, including oblique and radial head views. Beyond this, the following special radiographic tests can be helpful.

Stress X-Rays

Stress views may be helpful in evaluating the patient with a suspected tear of the medial collateral ligament. This view is achieved through manual stress, during which the clinician applies a valgus stress to the elbow in an effort to open up the medial side. A difference in medial gapping of more than 2 mm between the affected and normal elbow is usually significant.

Computed Tomography/Magnetic Resonance Imaging Examination

Computed Tomography (CT) scans are effective in preoperative planning of complex elbow trauma, assessment of bony and joint deformity, and occasionally for evaluation of loose bodies of the elbow.

Magnetic Resonance Imaging (MRI) provides superior soft tissue imaging and allows visualization of marrow and vascularity changes in bone. Its current use about the elbow includes imaging occult fractures, tumors, infections, synovitis or other causes of joint effusion, and osteochondritis dissecans. It is occasionally useful in evaluating ligament disruptions, but it is usually unnecessary in evaluating medial or lateral epicondylitis and rarely helpful in nerve entrapment syndromes.

Technetium-99 Bone Scan

Technetium-99 injected intravenously is taken up in areas of increased vascularity. Although it is very sensitive, this test is not very specific, because increased blood flow can occur as a result of fracture, infection, tumor, or arthritis. In patients with heterotopic ossification, serial bone scans may help determine when the process has become quiescent enough to permit safe bone mass excision.

Electrodiagnostic Tests

Electromyography (EMG) and nerve conduction velocity (NCV) testing have definite indications in the patient with suspected nerve entrapment or injury. Such testing may indicate the site of the compression or injury.

However, failure to demonstrate specific neurologic findings by electrodiagnostic testing does not rule out their presence. This problem is common in the workup of the patient with early ulnar nerve symptoms, or the patient with suspected radial tunnel syndrome, in whom such tests are commonly negative.

Arthroscopy

The techniques and procedures for arthroscopy of the elbow have developed more slowly than in other joints such as the knee, shoulder, or wrist. Because of the very tight concentration of nerves and blood vessels in the area, the depth of the joint capsule under the musculature, and the tight articular constraint, it can be difficult and involves more risk than arthroscopy at most other joints. Although it provides a minimally invasive means with which to visually inspect and, when necessary, to palpate the intraarticular structures, it is rarely used for diagnostic purposes alone.

Treatment of Elbow Problems

Treatment of elbow problems is algorithmic, dividing conditions into either traumatic or atraumatic cause (Figs. 9-4, 9-5). One general principle of treatment in the elbow is to minimize the time of immobilization. The elbow has a high propensity for developing contractures with immobilization, especially after fractures or dislocations. The resultant loss of motion can be disabling, and treatment for it can be prolonged and difficult. When necessary, splinting is usually done with the elbow in 90 degrees of flexion and neutral pronation to allow for maximal capsular volume and maintenance of the most useful arc of function.

With any significant elbow trauma, after appropriate initial treatment, one should carefully follow the patient's neurovascular examination, as the multiple confined fascial compartments of the forearm leave patients vulnerable to compartment syndrome or other severe compromise.

Nonoperative Treatment

Rehabilitation

Rehabilitation, either through a patient self-guided program or by formal occupational or physical therapy, plays an important role in the treatment of elbow problems. The goals should include (1) reduction of pain and inflammation, (2) restoration of motion, (3) rebuilding strength, and (4) return to normal function and activity. These goals should be carefully monitored by the treating physician until the patient is discharged or alternative management is instituted.

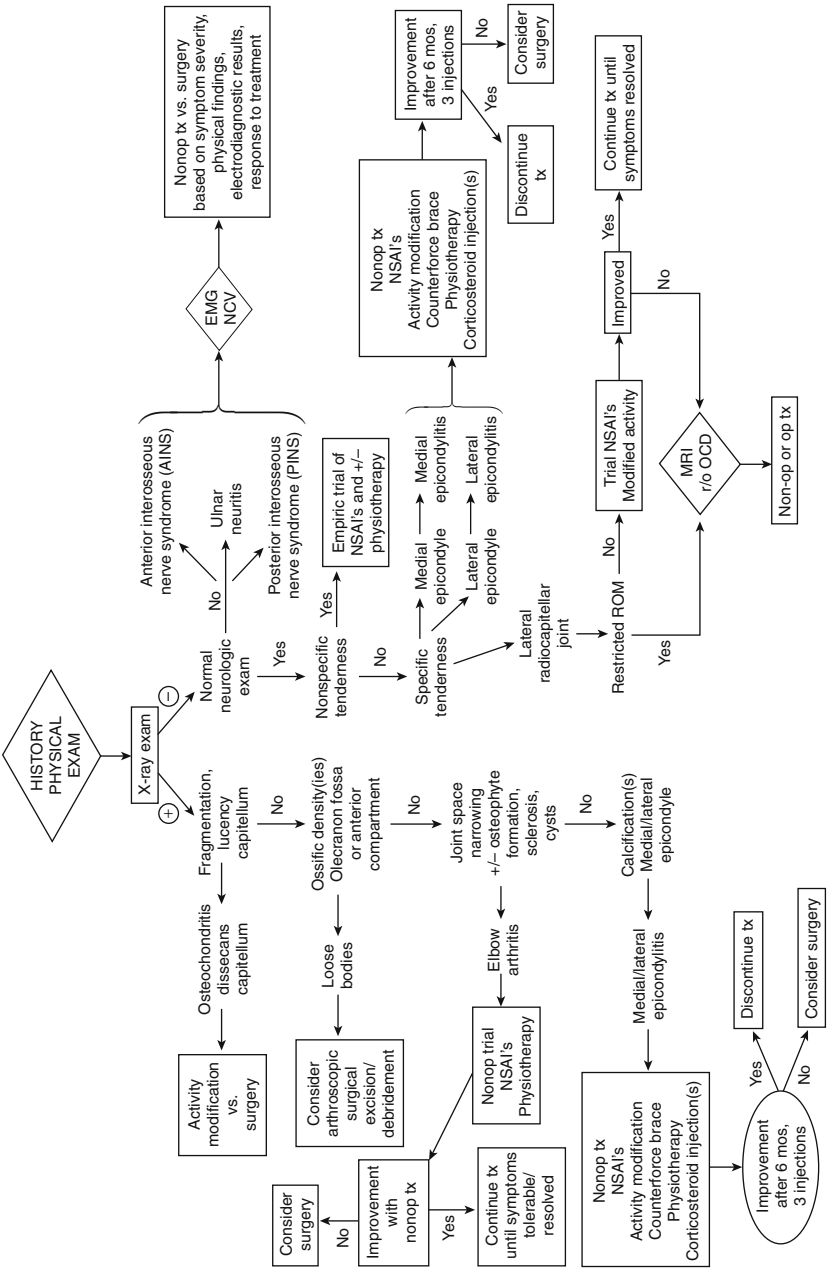


FIGURE 9-4. Algorithmic approach to the diagnosis and treatment of atraumatic elbow pain.

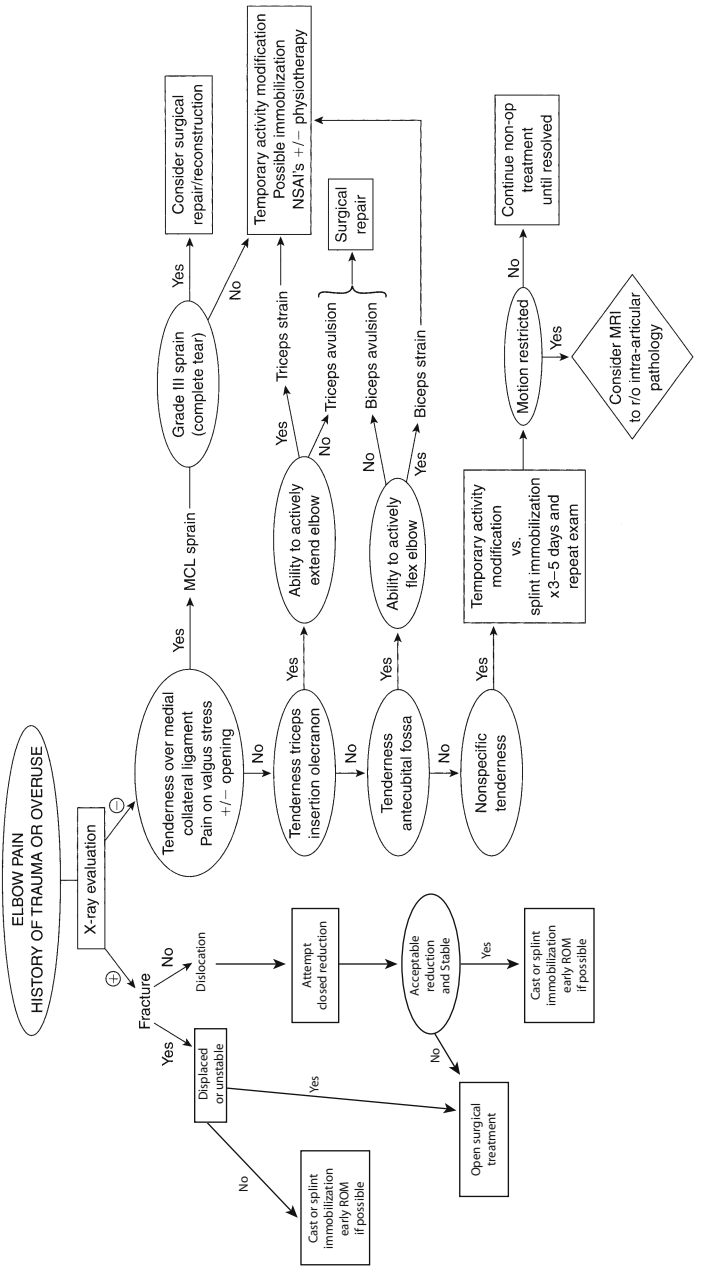


FIGURE 9-5. Algorithmic approach to the diagnosis and treatment of traumatic elbow pain.

Inflammation and pain are treated acutely with rest, ice, compression, and elevation (RICE). Later treatment includes activity modification, analgesics, nonsteroidal antiinflammatories, and local modalities, including ice, heat, electrical stimulation, and ultrasound. Occasionally, corticosteroid injection or systemic therapy is warranted.

Restoration of motion is done through careful stretching exercises. Elbow stiffness is best treated by prevention. Do not immobilize or use a sling any longer than absolutely necessary. Motion loss is usually in extension (inability to completely straighten the elbow) and takes much longer to regain than to lose. Once lost, motion return is best achieved through active exercise by the patient rather than passive stretching by the therapist. A unique characteristic of the elbow is its propensity to develop heterotopic ossification (HO), bone formation within the soft tissues. This problem is particularly common anteriorly because of the presence of the brachialis muscle immediately anterior to the elbow capsule. The risk of ossification is increased with passive stretching, and for this reason aggressive passive motion is discouraged. Specially designed splints that exert a dynamic force across the elbow are sometimes effective in restoring motion.

Corticosteroid Injections

The use of corticosteroids about the elbow facilitates treatment of a number of conditions, including medial and lateral epicondylitis, olecranon bursitis, and, less commonly, inflammatory or degenerative arthritis.

Because corticosteroid injections can lead to tendon damage, dermal depigmentation, and infection, they should not be used arbitrarily or excessively. Generally, their use is reserved for conditions that fail initial activity modification, antiinflammatories, and therapy. The exact timing and number of injections is controversial, but in general no more than three injections should be given over a 6-month time period.

Some authors have argued against using corticosteroids for conditions such as epicondylitis, contending that the disease does not involve inflammation. Despite this, most orthopedic surgeons believe they are a useful treatment adjunct at this time.

Operative Treatment

Surgery for the elbow is reserved for patients in whom nonoperative management has failed or is inappropriate, such as trauma requiring rigid fixation and early mobilization. Surgery can be performed via open or arthroscopic methods. Elbow arthroscopy should only be done by surgeons who are very comfortable with the surrounding anatomy and even then should be approached cautiously. Therapeutically it has been used effectively for removal of loose bodies, synovectomy, debridement of the capsule and extensor carpi radialis brevis (ECRB) origin for lateral epicondylitis,

radial head resection, release of contracture, excision of osteophytes, and osteochondral debridement (osteochondritis dissecans, arthritis). Relative contraindications include severe contracture, previous nerve transposition, significant bone or joint distortion, and prior open elbow surgery.

Evaluation and Treatment of Common Elbow Problems

The following discussion highlights selected examples of common elbow problems.

Trauma

Fractures

Fractures around the elbow at the distal humerus, radial head and neck, and proximal ulna are fairly common. They occur through a wide variety of mechanisms, and one must be vigilant for associated soft tissue injuries. The treatment goals are complete healing of the fracture with painfree motion and good function. Treatment options include casting, traction, percutaneous pin fixation, rigid internal fixation, resection, and replacement arthroplasty. Stable, nondisplaced injuries such as simple radial head fractures can be treated with a brief period (1–2 weeks) of splinting followed by gentle range of motion. Most other fractures require operative management with rigid internal fixation and early motion to avoid stiffness, nonunion, and other complications. Severely comminuted, intraarticular fractures in elderly or rheumatoid patients are sometimes best treated with a total elbow arthroplasty.

Dislocations

Elbow dislocations are second only to those of the shoulder in frequency for major joints; they usually occur after a fall on an outstretched hand. By far the most common type is posterior, in which the olecranon dislocates posteriorly relative to the humerus. Associated injuries are common, such as radial head and neck fractures (5%–10%), avulsion fractures from the medial or lateral epicondyle (12%), and fractures of the coronoid process (10%).

On physical examination, there is visible deformity, with loss of the normal bony equilateral triangle, significant swelling, and loss of motion. A careful neurologic exam is mandated, the ulnar nerve is the most commonly injured nerve. Significant swelling anteriorly can lead to compartment syndrome of the forearm.

An AP and lateral X-ray are sufficient to make the diagnosis. The radial head should line up with the capitellum on both views. Failure to do so suggests residual subluxation. Special tests are rarely necessary. In the

patient with median nerve injuries, think of arterial injury because of the proximity of the median nerve to the brachial artery. If there is any question, arteriography is appropriate.

Initial neurovascular and radiographic assessment is followed by prompt reduction. Reduction is effected through manual forearm traction and brachial countertraction. The elbow is assessed for stability following reduction. If it is stable throughout the range of motion, application of a splint and sling, followed by early range-of-motion exercises, is indicated. If the elbow starts to sublux or dislocate, immobilization at 90 degrees is appropriate for a longer period, but usually no more than 3 weeks to minimize the risk of permanent stiffness.

Ligamentous Injuries

Ligamentous injuries causing chronic elbow instability can be difficult to diagnose and treat. Anterior or posterior instabilities are usually caused by displaced olecranon or coronoid fractures or, more rarely, anterior capsule and brachialis disruptions. Addressing the source of pathology usually leads to a stable elbow. Other types include varus, valgus, and posterolateral rotatory instabilities. These conditions can all result from a single traumatic event such as a dislocation, but they can also come from repetitive stresses or iatrogenic injuries from excessive removal of epicondyles for ulnar nerve decompression or treatment of epicondylitis.

Patients with varus instability or posterolateral rotatory instability have a spectrum of injury starting with disruption of the lateral ulnar collateral ligament and progressing to posterior capsule and even medial collateral ligament injury. They usually present with lateral elbow pain and often a mild flexion contracture. They have clicking and recurrent symptoms of popping or subluxation of the elbow. Varus stress test and elbow pivot shift test help make the respective diagnoses. X-rays are usually negative. Treatment involves reconstruction of the lateral ligamentous structures; this often requires a tendon graft.

Injuries to the medial ulnar collateral ligament (MCL) cause valgus instability. It ranges from the grade I sprains with microscopic hemorrhage causing chronic pain to complete grade III disruption and true instability to valgus stress. The problem is particularly common in throwing athletes. Patients have a sense of “giving way” of the medial elbow. They have medial elbow pain and tenderness, especially with throwing. Pain typically occurs when the arm is in the “cocking position” of throwing, that is, with the shoulder abducted and externally rotated. Occasionally the patient has sudden onset of symptoms with one particular event such as in javelin throwing, but more commonly, prodromal symptoms precede the “final event” when the ligament completely tears.

Physical examination shows focal tenderness over the MCL or its coronoid insertion. On valgus stress there may be pain, tenderness, or the subtle

sensation of medial joint opening. Look for signs of ulnar nerve irritability, which commonly accompanies MCL pathology. X-rays may show ossification or the spur sign at the ulnar insertion of the ligament.

The most difficult differential diagnosis is that of medial epicondylitis. Valgus stress may cause pain in this condition as well because of stress on the medial epicondylar tendinous origin. However, in the isolated MCL sprain, forearm pronation or wrist flexion against resistance (common in epicondylitis) should not cause pain.

Special stress X-rays may be helpful to document this subtle instability. By flexing the elbow 30 degrees, thereby unlocking the olecranon from its fossa, either gravity or manual force can apply a valgus stress. Probably any opening is of some significance, although it is appropriate to compare with the other side. When positive, these stress views are confirmatory. When negative, however, they do not exclude MCL insufficiency.

In almost all grade I and II injuries, symptomatic treatment, including rest, ice, compression, and strengthening, allow return to activity. Grade III tears often require surgical reconstruction, in which a palmaris longus tendon graft is used to reconstruct the MCL.

Tendon Ruptures

Ruptures of the distal biceps tendon, which are uncommon, nearly always occur in muscular men aged 30 to 50 years. They can occur as partial tears at the insertion or the musculotendinous junction, but they are most commonly complete insertional detachments from the biceps tuberosity of the radius. They almost always occur from a very heavy eccentric load to the biceps, and patients usually feel a "pop" and sharp pain in the antecubital space at the time. Patients are tender anteriorly and have weakness to elbow flexion and supination. If the diagnosis is unclear, an MRI can be helpful, but it is rarely needed.

Complete ruptures should be surgically reattached as soon as possible. In chronic presentations, patients can be treated with graft reconstructions or just observed if their functional losses are tolerated.

Triceps tendon ruptures are even more uncommon. Patients again present after an eccentric load. A defect in the triceps is often palpable, and elbow extension is weak. These injuries should be treated with surgical reattachment of the tendon to the olecranon process.

Atraumatic and Overuse Injuries of the Elbow

Lateral and Medial Epicondylitis

In skeletally mature adults, strains to the medial and lateral epicondyle can result in epicondylitis. These conditions can also result from a single,

particularly strenuous action, or with any repetitive stress such as sports (especially racket sports, golf, and baseball), carrying heavy bags, or even typing or cleaning activities. The tendon origin is thought to undergo microtears, degeneration, and replacement with abnormal scar and granulation tissue (called angiofibroblastic hyperplasia because of its microscopic appearance) within the extensor carpi radialis brevis (ECRB) on the lateral side or the flexor carpi radialis (FCR) and pronator teres (PT) muscles on the medial side.

Lateral epicondylitis is popularly known as tennis elbow, despite the fact that only 5% of patients play tennis. Conversely, nearly 50% of tennis players will develop the condition during their sports careers. Medial epicondylitis is often called golfer's elbow.

Patients complain of pain on activity over the medial or lateral epicondyles of the elbow, often with some radiation into the forearm. The key physical exam finding is focal tenderness over the epicondyle or the muscles just anterior to it. Resisted wrist extension and grip reproduce symptoms in lateral epicondylitis, and wrist flexion and forearm pronation against resistance reproduce the symptoms in medial epicondylitis. X-rays are usually normal.

On the lateral side, the differential diagnosis includes radial tunnel syndrome (which coexists in 5% of patients), varus or posterolateral rotatory instability, or radiocapitellar arthrosis. On the medial side, the main diagnoses to also consider are ulnar nerve compression (which frequently coexists) and medial collateral ligament injury.

Treatment is almost always conservative, emphasizing rest, ice, avoidance of provocative activities, and nonsteroidal antiinflammatory drugs (NSAIDs). In addition, modalities such as ice, heat, or contrast therapy are helpful. Identification and correction of faulty technique, use of a counterforce brace, and a structured physical therapy program can be helpful. Cortisone injections are used in those unresponsive to early conservative management or those presenting with severe symptoms.

Surgery is required for less than 10% of patients who develop epicondylitis. It may be indicated in patients who fail an appropriate conservative trial, usually considered at least 6 months duration, and up to three injections of cortisone. Successful surgery involves identification and debridement of the pathologic tissue, usually located within the substance of the flexor carpi radialis and pronator teres on the medial side or the extensor carpi radialis brevis on the lateral side. Most surgeons also drill or osteotomize the epicondyle itself to promote new vascularity to the overlying soft tissues. For lateral epicondylitis, some surgeons are now advocating an arthroscopic technique in which the lateral joint capsule and the ECRB origin are debrided from the joint surface outward, without opening the superficial skin or musculature.

Ulnar Nerve Compression (Cubital Tunnel Syndrome)

Patients with cubital tunnel syndrome present with complaints of numbness and tingling in the distribution of the ulnar nerve. They often have elbow pain with or without radiation; it is usually worse with sleep or long periods of elbow flexion. The patient may feel clumsy or weak in grasping or throwing; he or she may note actual "snapping" in cases in which the ulnar nerve is unstable.

The position of the ulnar nerve at the elbow renders it susceptible to both compression and direct trauma. There are five major sites of compression of the ulnar nerve in the region: the arcade of Struthers (a fascial band 5–10 cm proximal to the medial epicondyle), the medial intermuscular septum, the groove behind the medial epicondyle, the ligament of Osborne [a fascial band between the humeral and ulnar heads of the flexor carpi ulnaris (FCU) muscle], and the exit of the nerve from the FCU. Extremes of elbow flexion can cause tethering of the ulnar nerve around the medial epicondyle and compression. Up to 16% of patients are further predisposed to symptoms by having "instability," with either subluxation or frank dislocation out of the groove.

In early disease, there is usually no sensory or motor deficit, although Tinel's sign over the cubital tunnel may be positive. Check for nerve instability by flexing and extending elbow while feeling the ulnar nerve. As the compression progresses, patients can lose sensation over the ulnar border of the ring finger and all of the small finger. Weakness to finger abduction and eventually intrinsic atrophy can develop. A positive Froment's test, in which the thumb collapses into interphalangeal (IP) joint flexion and is weak with key pinch is an important diagnostic sign. X-rays are almost always negative. Electrodiagnostic tests are often negative in early disease but can show slowing of conduction velocity specifically at the elbow in later disease. It is important to rule out other similarly presenting compressive neuropathies such as thoracic outlet or ulnar tunnel syndrome, as well as medial epicondylitis.

Treatment is usually nonoperative, with rest, ice, NSAIDs, nighttime extension splinting, or occasional cast immobilization for 2 to 3 weeks. In some patients, conservative management fails and surgery is necessary. Surgery usually involves decompression and anterior transposition of the ulnar nerve (Fig. 9-6).

Little Leaguer's Elbow

In the skeletally immature athlete, injury to the medial epicondylar apophyseal structures is known as little leaguer's elbow because of its high incidence in young baseball players. Repetitive stresses to the vulnerable epicondylar origin of the flexor-pronator group and MCL, during both

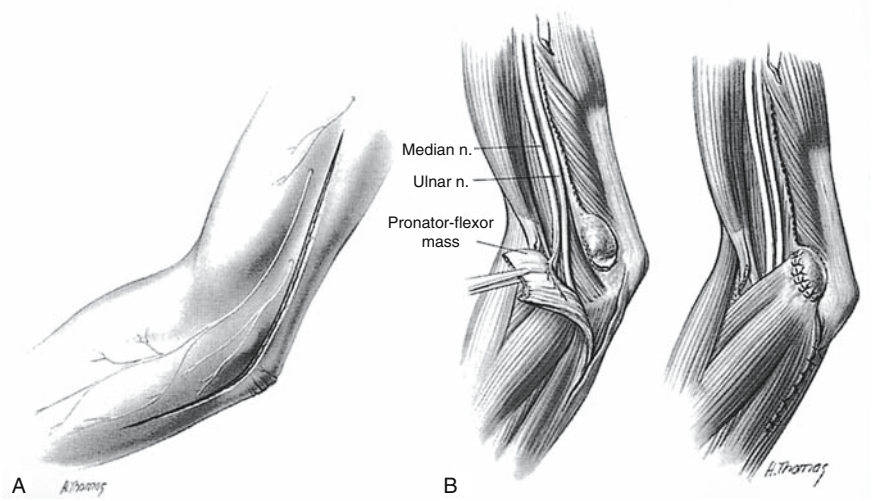


FIGURE 9-6. (A) A medial incision is made over the elbow, allowing exposure of the ulnar nerve proximal, through and distal to the cubital tunnel through which it travels. (B) The ulnar nerve is transposed submuscularly underneath the flexor-pronator muscle mass, after which the muscle origin is reattached to the medial epicondyle. (From Morrey BF (ed) The Elbow and Its Disorders, 2nd ed. Philadelphia: Saunders, 1993. Reprinted by permission of Mayo Foundation for Medical Education and Research. All rights reserved.)

acceleration and follow-through phases of throwing, result in abnormalities in secondary ossification and physeal plate structures. These children present with medial elbow pain, diminished throwing effectiveness, and decreased throwing distance.

On examination, there is focal tenderness over the medial epicondyle and pain on attempting active wrist flexion or forearm pronation, especially against resistance. X-ray findings vary, and include apophyseal fragmentation, irregularity or enlargement, abnormality of the physis, or avulsion of the medial epicondyle. Stress views are useful; even an innocent-appearing minimally displaced fracture may be unstable.

Fortunately, treatment is rarely operative, and includes rest, ice, and gradual return to activity as pain resolves. Restricting the number of innings pitched in Little League has led to a reduction in the incidence of elbow complaints. Surgery is reserved for those with displaced or unstable avulsion injuries or symptomatic nonunions.

Osteochondritis Dissecans (Panners' Disease)

This condition is particularly common among adolescent throwing and gymnastic athletes. It has been described as the leading cause of permanent disability in the young throwing athlete. The most common symptom

is that of lateral elbow pain, related to activity. There may be associated swelling, limitation of motion, or catching or locking episodes.

In throwing, enormous valgus stresses are imparted to the elbow joint. Absorbed primarily by the medial collateral ligament, the second line of defense is the radiocapitellar buttress, which is subjected to significant compression and shear. This stress also occurs in gymnastics, particularly during vaulting, balance beam, uneven parallel bars, and floor exercises. In skeletally immature individuals, such repetitive stresses are thought to compromise the vascularity to the vulnerable epiphysis, with consequent avascular necrosis (AVN) of the capitellum.

There is a classification system based on articular involvement. Type I lesions have no articular involvement. In types II and III, there is articular involvement; in type II, there is no fragment separation, and in III there is separation with loose body formation.

On physical examination, there may be restriction in motion, crepitus on supination/pronation, and tenderness over the radiocapitellar joint. X-rays are initially often normal, although there may be lucency or irregular ossification of the capitellum. In later stages, there may be a crescent sign, fragmentation, or loose-body formation. MRI or CT with arthrogram is probably the best method of establishing the diagnosis and assessing the degree of articular involvement. MRI is also useful in assessing subchondral involvement and the extent and status of healing of the lesion.

Treatment depends on clinical and radiographic findings. Nonoperative treatment for type I includes rest, ice, NSAIDs, and physical therapy with modalities. Resumption of activities is usually contraindicated because of the time required for healing. Because the healing process is slow, the area must be protected against overzealous activity (i.e., hard throwing or weight-bearing) for a long time.

Treatment of type II and III (articular involvement) lesions is usually operative, arthroscopically removing loose bodies, curetting, and/or drilling the base of the lesion.

Arthritis

Arthritis of the elbow is much less common than that of the hip or knee. The three major types are primary osteoarthritis, posttraumatic arthritis, and inflammatory. In patients with inflammatory (especially rheumatoid) arthritis, 20% to 50% have elbow involvement. It can lead to severe loss of arm function because of pain, instability, or loss of motion, especially when there is concomitant shoulder and hand involvement. In some cases, rheumatoid disease first presents in the elbow. These patients require appropriate laboratory tests for evaluation of systemic arthritis including erythrocyte sedimentation rate (ESR), antinuclear antibody (ANA) test, rheumatoid factor (RF) test, and complete blood count (CBC). Additional rheumatologic tests should be determined in consultation with a rheuma-

tologist. The differential diagnosis includes septic arthritis, gout or other crystalline arthropathy, or osteoarthritis. Aspiration for cell count with differential, Gram stain, and crystal examination of the joint fluid are very helpful. X-ray changes are variable, ranging from periarticular osteopenia in early disease to subchondral erosions, destructive-appearing joint collapse, and ultimately bony ankylosis as the disease progresses.

Treatment of the rheumatoid elbow varies with the stage of presentation. Early in the course, antiinflammatory and antirheumatoid medication, analgesics, and activity modification may be sufficient. Initial goals are to decrease pain and inflammation, maintain motion, and avoid further destructive changes. Later, efforts to relieve pain and improve function may rely on surgical treatment such as arthroscopic or open synovectomy with or without radial head resection. In end-stage disease, a total elbow replacement may be the only option.

Summary and Conclusions

The elbow is the critical link between the mobile positioning shoulder joint and the precisely coordinated wrist–hand complex. Conditions that interfere with the elbow's normal motion can significantly compromise a patient's ability to feed, dress, and clean himself or herself. In the athlete, compromise in function precludes the ability to participate. Fortunately, most conditions affecting the elbow do not result in significant limitations. Most elbow problems can be readily diagnosed with a thorough history, physical examination, and basic radiographic examination. An algorithmic approach to treatment facilitates resolution of most problems of the elbow.

Suggested Readings

Morrey BF, ed. The Elbow and Its Disorders, 3rd ed. Philadelphia: Saunders, 2000.

Norris TR, ed. Orthopaedic Knowledge Update: Shoulder and Elbow, 2nd ed. Rosemont, IL: American Academy of Orthopaedic Surgeons, 2002.

Questions

Note: Answers are provided at the end of the book before the index.

9-1. Which of the following is NOT a common finding in cubital tunnel syndrome?
   a. Finger abduction weakness
   b. Numbness over the small finger
   c. Thenar atrophy
   d. Positive Froment's sign
   e. Tinel's sign posterior to the medial epicondyle

9-2. Treatment options for lateral epicondylitis include which of the following choices?
   a. Corticosteroid injection
   b. Arthroscopic debridement
   c. Counterforce bracing
   d. Physical therapy
   e. All the above

9-3. Which of the following muscles is innervated by the musculocutaneous nerve?
   a. Brachioradialis
   b. Extensor carpi ulnaris
   c. Flexor carpi radialis
   d. Brachialis
   e. Triceps

9-4. The pathologic tissue in tennis elbow is called:
   a. Dermatofibroma protuberans
   b. Angiofibroblastic hyperplasia
   c. Pyogenic granuloma
   d. Osteochondritis dissecans
   e. None of the above

9-5. Treatment for a displaced, unstable, intraarticular fracture of the distal humerus would most likely involve which of the following?
   a. Closed reduction and casting
   b. Open reduction and pin fixation
   c. Hinged splinting without any fixation
   d. Open reduction and rigid internal fixation
   e. External fixation

9-6. The function of the brachioradialis muscle is:
   a. Pronation
   b. Supination
   c. Elbow flexion
   d. Elbow extension
   e. Wrist extension

9-7. Sites of compression of the ulnar nerve at the elbow do not include:
   a. Arcade of Frohse
   b. Medial intermuscular septum
   c. The ligament of Osborne
   d. The exit from the flexor carpi ulnaris
   e. None of the above

9-8. The anterior interosseous nerve innervates all of the following except:
   a. The pronator quadratus
   b. The index flexor digitorum profundus
   c. The middle finger flexor digitorum profundus
   d. The flexor pollicis longus
   e. None of the above

9-9. Indications for elbow arthroscopy include all the following except:
   a. Release of contracture
   b. Debridement for lateral epicondylitis
   c. Release of the median nerve at the pronator teres
   d. Removal of loose bodies in the elbow joint
   e. Synovectomy

9-10. Magnetic resonance imaging of the elbow can be helpful for all the following conditions except:
   a. Infection
   b. Synovitis
   c. Tumors
   d. Osteochondritis dissecans
   e. None of the above

10
The Hand

Mustafa A. Haque

The human hand is one of the most important interfaces of a person's body with the outside world. It allows us to touch, feel, manipulate, and modify our environment. Its cortical representation in the brain is nearly as large as the rest of the musculoskeletal system combined. Loss of hand function can have devastating effects on a person's ability to work or perform activities of daily living. Unfortunately, because of its constant use and its position at the forefront of human activity, it is frequently affected by trauma and other disease processes. Nearly all physicians will see patients with hand problems, so some familiarity with these processes and basic hand evaluation is very important.

History

As in all fields of medicine, the history begins by carefully determining the patient's chief complaint, followed by a detailed history of the present illness. It is also very important to obtain supplemental information important to hand function, such as hand dominance and the patient's specific use patterns for his or her hands such as occupation, sports involvement, and hobbies.

The history of present illness is tailored to the patient's chief complaint and does require some background understanding of various pathologic processes in the hand and upper extremity. In patients with congenital hand differences or birth-related injuries, one must obtain a careful understanding of the gestational and birth history. One must inquire about gestational diabetes, preeclampsia, and other maternal and fetal health problems, including exposure to teratogens. The presence of consanguinity or a family history of similar anomalies should also be determined. The physician should also see if improvement in the condition has occurred and determine some of the parental goals and expectations of outcome.

In nontraumatic situations, it is important to have the patient focus as closely as possible on the exact site of the problem and to try to analyze

the history of onset, the progression, and interventions. An understanding of what helps relieve symptoms and what aggravates them can be very important in determining treatment. In patients who attribute their problems to repetitive activities, it is further important to understand the length of time it takes before symptoms begin, how long the patient had been doing this activity before this problem developed, and whether symptoms are now present when the patient is not involved in these activities.

When a traumatic injury is present, the exact nature of the injury and the surrounding circumstances under which it occurred should be carefully noted and documented; this includes such information as the environment in which this occurred, whether it was clean or dirty, and whether the patient perceives that the injury was caused by another person's fault, their own error, or an unavoidable circumstance. Many of these patients later become involved in worker's compensation or other medicolegal litigation. By carefully determining and recording the events that occurred, the treating physician can give the most accurate representation of the injury and avoid later difficulties in trying to reconstruct events from memory.

Many times these patients present late after having been treated elsewhere or having avoided treatment altogether. In these stages, it is very important to note the evolution of the patient's problems, what treatments have occurred, and what are the current functional losses.

The remainder of the patient's medical history is also quite important. A good understanding of the patient's diseases including the presence of diabetes, hypothyroidism, heart disease, or other problems can help determine factors contributing to a hand problem. Previous surgical history, including complications of anesthetics, is also very important in the treatment process. Medications and allergies have obvious implications in the treatment. Social history should include the patient's occupation and hobbies as well as tobacco, alcohol, and illicit drug use. Family history and review of systems that include questions about the patient's psychiatric history help complete a thorough evaluation of the patient's history.

Physical Examination

In the physical examination of the hand and upper extremity, one must often start proximally at the neck or shoulder, especially for nerve and tendon problems. One begins the evaluation with observation of the upper extremity, looking for atrophy, deformity, or any other lesions with comparison to the opposite side. Palpation of the area of the chief complaint should be performed next. In this section, one should make every effort to localize the patient's pain or other complaints as anatomically as possible to help define the diagnosis. An understanding of the surface anatomy is critical. For example, one must know that the scaphoid waist underlies

the anatomic snuff box and that the A-1 pulley of the flexor tendon sheath is at the level of the metacarpophalangeal joint. Next, one should determine both the active and passive range of motion of the elbow, wrist, and hand. This information should be recorded carefully for later comparison testing.

Injuries that involve open wounds of the hand and upper extremity should rarely, if ever, be probed or explored on the initial evaluation. Examination of the distal hand function can usually determine what structures are injured. Vascular function can be determined by evaluating capillary refill or performing a Doppler ultrasound evaluation of pulses distal to the laceration. Flexor and extensor tendon function can almost always be determined by evaluation of active range of motion. Nerve function can be assessed by performing motor and sensory examination as well. In evaluating the sensory function, it is often helpful to obtain some quantifiably measured data such as two-point discrimination or Semmes–Weinstein monofilament threshold testing. For young children, assessment of wrinkling after immersion under water or the presence or absence of sweating can be helpful, as they are functions of the autonomic nervous system and cease as soon as a peripheral nerve is cut.

Specialized testing for specific injuries or problems can help confirm a diagnosis, and these tests are addressed under the sections describing those specific disease processes.

Imaging

Imaging of the hand and upper extremity typically starts with plain radiographic evaluation. The standard views used in the hand and wrist include anteroposterior (AP), lateral, and oblique views, and all physicians who will ever evaluate the hand should have some familiarity with the basic radiographic anatomy of the carpal, metacarpal, and phalangeal bones in these views. In particular, one should be recognize the overall alignment and arcs that are present to avoid missing a dislocation in an emergency room setting. There are many additional special views, such as a carpal tunnel, a Brewerton, and scaphoid views, that help profile specific injury patterns.

Advanced imaging modalities are used for disease or injury processes that are more difficult to define. Bone scans can be very useful for helping define infection, reflex sympathetic dystrophy, and occult fractures. Computed tomography (CT) scans are helpful for better understanding bony lesions and defining tumors. Magnetic resonance imaging (MRI) is typically the imaging modality of choice for soft tissue lesions, and it is also becoming more frequently used for occult fractures. When accompanied by an arthrogram, it can be very helpful in diagnosing ligamentous injuries of the wrist. Ultrasound is rapidly becoming a very useful imaging tech-

nique as well, especially to define soft tissue lesions, bony abnormalities, and ligamentous injuries. It can be particularly helpful in differentiating between rupture or scarring of a tendon repair and for visualizing foreign bodies that are not radiopaque. Ultrasound allows for a dynamic study in which tendons or other soft tissue structures can be evaluated while they are moving. It is an extremely cost-effective imaging modality, but, unfortunately, at this time it is still very operator dependent.

Arthroscopy

Arthroscopy has become an important treatment modality for the wrist in particular. In some situations, such as chondral injuries, some ligament tears, and capsular tears, it is the best way to make a diagnosis as well. As the technology and experience level increases in these techniques, arthroscopy may become an important diagnostic and treatment method for the metacarpophalangeal and other small joints also.

Pathophysiology

Hand problems can be grouped into seven major categories of disease: congenital, developmental/idiopathic, inflammatory/infectious, traumatic, metabolic, vascular, and neoplastic. There is tremendous overlap between these divisions, and a given disease process may actually have roots in more than one category. However, keeping these major categories in mind and eliminating those that do not fit a patient's complaint can help narrow down one's differential diagnosis and arrive at the proper diagnosis and treatment protocol. The remainder of this section reviews the most common disease entities within each category.

Congenital Hand Differences

In the human embryo, the upper extremity begins to develop as a limb bud at 4 weeks after fertilization when a segment of mesoderm outgrows and protrudes into the overlying ectoderm. A small segment of ectoderm then condenses and forms the apical ectodermal ridge, which guides further longitudinal growth of the limb. A second area, named the zone of polarizing activity, forms in the posterior margin of the limb bud and controls radial and ulnar growth and differentiation. A third area in the dorsal ectoderm helps control formation of volar and dorsal characteristics of the limb. From weeks 4 to 8 after fertilization, this small outgrowth of mesoderm becomes a fully differentiated upper extremity with separated joints and digits. It is during this time that most congenital upper extremity anomalies originate.

Failure of Formation of Parts (Arrest of Development)

Failures of formation of parts come in two varieties: transverse and longitudinal. Transverse failures are caused by injuries to the apical ectodermal ridge. They result in complete congenital amputation distal to the site of injury, which can vary from loss of fingertips to complete absence of the arm. The most common presentation is a congenital below-elbow amputation at the level of the proximal third of the forearm; it is treated by fitting a passive mitten when the child is old enough to sit, then a prosthesis a few years later.

Longitudinal failures of formation involve loss of only part of the distal segment. They can be divided into radial (preaxial), central, and ulnar (postaxial). The most common of these are the radial-sided deficiencies such as congenital absence of the thumb or radial clubhand (Fig. 10-1A). These problems are often associated with visceral and bone marrow abnormalities and abnormalities such as Holt–Oram (cardiac septal defects), thrombocytopenia absent radius (TAR), and vertebral, anal, cardiac, tracheoesophageal, renal, and limb abnormalities (VACTRL). These patients should all undergo evaluation by the appropriate pediatric subspecialists. Central defects are much less common and mainly involve the cleft hand. Ulnar-sided deficiencies include ulnar clubhand and its variations; these are often associated with other orthopedic anomalies. A very uncommon form of longitudinal growth arrest involves intrasegmental losses such as phocomelia, in which a relatively normal hand is attached to either the trunk or a very short segment of arm.

Failure of Differentiation (Separation of Parts)

Failure of differentiation occurs when the normal programmed cell death between tissues fails to occur and bones, joints, or individual digits fail to form. The most common manifestation of this is syndactyly, in which individual digits are still linked together, either by webs of skin or sometimes by continued fusion of the bones (see Fig. 10-1C). These parts often require surgical separation when the patient reaches the appropriate age. Other fairly common failures of separation include the congenital lunatotriquetral coalition; this rarely causes any problems and is often an incidental finding. Synostosis, particularly of the proximal radius and ulna, which restricts pronation and supination, and symphalangism, in which there is congenital fusion of the proximal interphalangeal (PIP) joint, are other manifestations that can be more problematic.

Duplication

Duplication or polydactyly, another fairly common congenital hand difference, can range in scope from a simple skin tag attached to the small finger to a complete mirror hand. The very small skin tags formed on the ulnar aspect of the hand can sometimes be treated with suture ligation in the

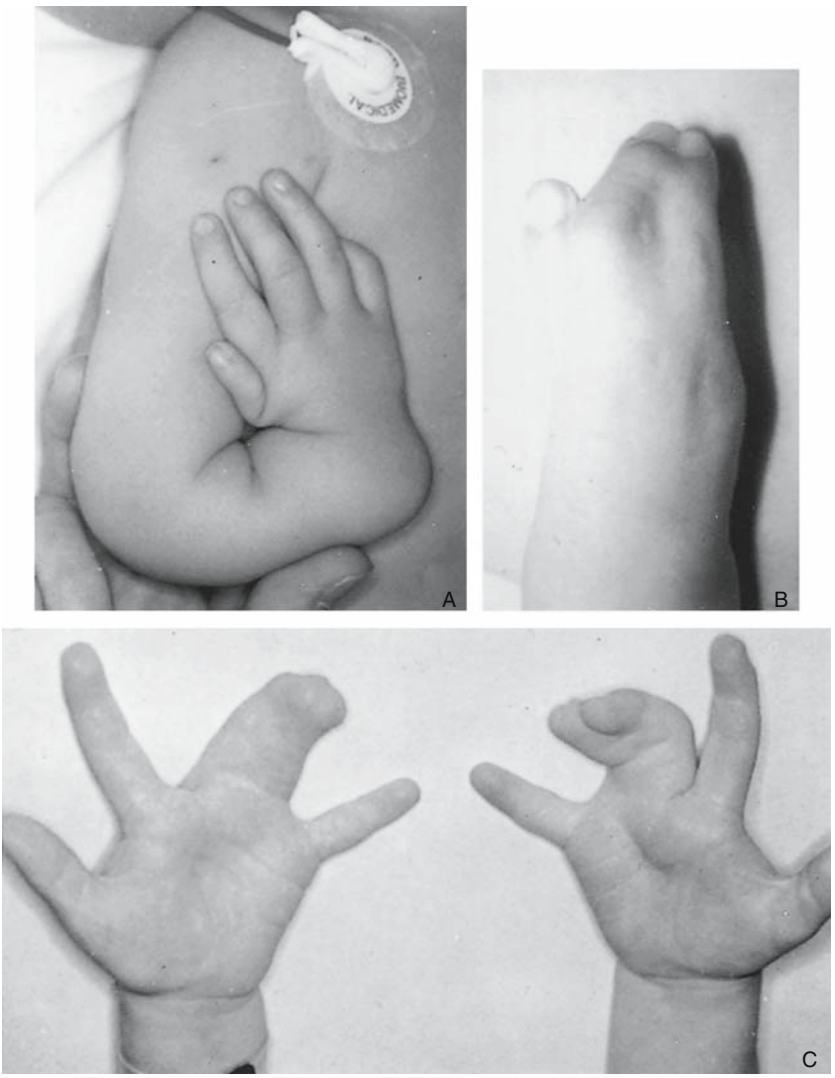


FIGURE 10-1. Congenital malformations. (A) Radial clubhand produced by longitudinal absence of radius. (B) Failure of formation of parts combined with failure of separation. (C) Simple syndactyly of middle and ring fingers.

nursery, but more complex polydactylies require formal surgical resection and reconstruction. This is particularly true when a joint is involved, as osteotomy to allow the joint surfaces to maintain normal congruity and ligament reconstruction to reestablish stability may be required. Often the

individual duplicated segments are not equal in size to a normal part, and function may not be completely normal after reconstruction. Many of the thumb reconstructions, in particular, require later secondary operations to fine-tune the result or to make adjustments for growth-induced deformities (Fig. 10-2A).

Other Congenital Anomalies

The remaining categories of congenital hand differences are less common. Overgrowth is a condition that can affect either an entire limb or an individual digit or section of the upper extremity (see Fig. 10-2B). When

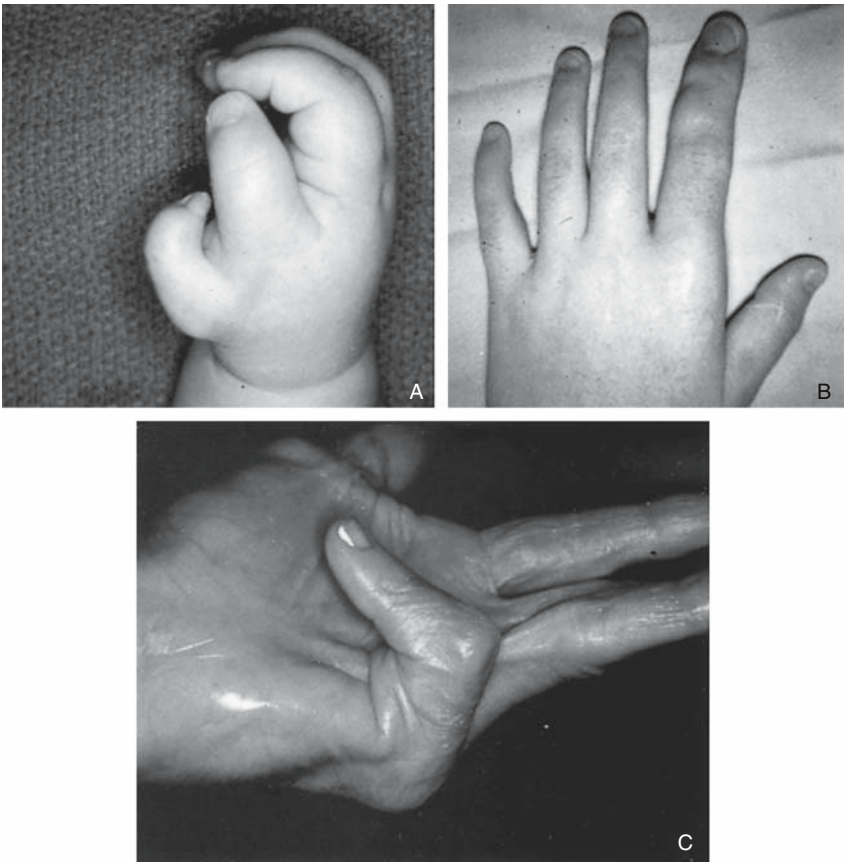


FIGURE 10-2. Congenital and developmental anomalies. (A) Duplication of thumb. (B) Gigantism of index finger with enlarged soft tissues as well as skeleton. (C) Dupuytren's contracture. Bands extending from proximal palm into middle segment of finger have caused nearly 90 degree contractures of MCP and PIP joints with dimpling and shortening of skin.

this is encountered, the physician should look for an underlying cause such as a vascular malformation or neurofibromatosis. The problem can be exceedingly difficult to treat, and when debulking procedures fail, ray amputation of affected digits often is required.

Undergrowth or hypoplasia also shows a wide spectrum of problems including such minor differences as brachymetacarpia (short metacarpals) or involving significant hypoplasias of the entire upper extremity. It is sometimes associated with other syndromic conditions such as Poland syndrome (pectus excavatum and other chest wall abnormalities, hypoplasia of the hand, syndactyly, and other associated abnormalities). The treatment is very patient specific, and often supportive care is all that is needed.

Congenital constriction band syndrome is a process in which the underlying cause is not fully understood. It is thought that amniotic bands form across segments of the extremities, causing deep constriction rings, amputations, or fusions of distal parts. In some rare instances, surgery very soon after birth is required to prevent neurovascular compromise, but most cases this can be treated in a delayed fashion. Treatment often involves excision of the deep constriction band and multiple Z-plasties for reconstruction. In some situations, a separation of distal syndactyly of the digits can be required.

The final category of congenital hand differences involves generalized skeletal abnormalities: these are disease processes such as enchondromatosis, multiple hereditary exostoses, and chondroplasia. Frequently, no hand surgery is required. One should only monitor the patient's symptoms closely and ensure that they follow up with the appropriate specialists if the symptoms become worse.

Developmental or Acquired Disease

Arthritides

Arthritis of the hand and wrist is a fairly common problem, and as it becomes progressively more severe, patients can experience marked limitation in hand use because of pain or loss of function.

Nearly all types of arthritis eventually affect the hand, but osteoarthritis is by far the most common form that develops. The distal interphalangeal (DIP) joints of the fingers and interphalangeal (IP) joints of the thumbs are the usual sites where this first develops, and patients often notice painless nodules early on in the disease process. Mucous cysts can result at these joints. The PIP joints also become involved and can develop significant angular deformity. The thumb carpometacarpal (CMC) joint, also known as the basilar joint or trapeziometacarpal joint, is a common site of early involvement; it can be extremely painful and cause debilitating loss of pinch and grasp function. In the carpus itself, the scaphotrapeziotrape-

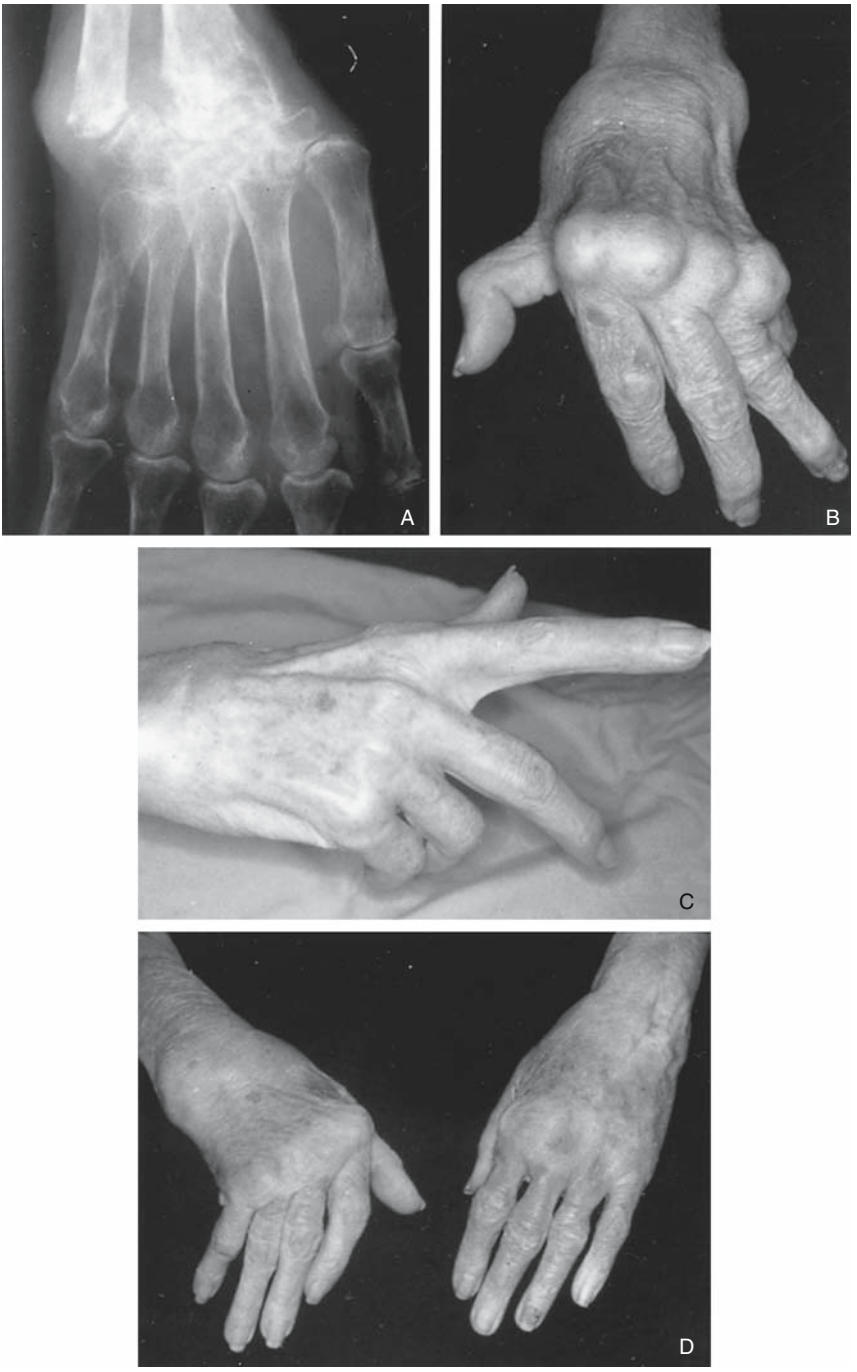
zoid (STT) joint also has fairly high rates of involvement and is often accompanied by thumb CMC arthritis.

The diagnosis can often be made by the patient's description of their symptoms alone. Physical examination often shows a deformity and nodule formation. Thumb CMC arthritis can further be diagnosed by a positive thumb CMC grind test. The thumb metacarpal is carefully grasped between the examiner's thumb and index finger. The remainder of the wrist is stabilized with the other hand, and an axial load and circumduction force are applied to the thumb metacarpal. This procedure usually results in severe pain for patients who have arthritis of this joint. Plain radiographs confirm the diagnosis in nearly all cases and advanced imaging is rarely, if ever, needed. Classic radiographic findings are joint space narrowing, subchondral sclerosis, subchondral cyst formation, and osteophyte formation.

Treatment is usually directed by the patient's level of symptoms and their radiographic staging. For moderate pain and earlier radiographic stages, simple rest and antiinflammatories can often help tremendously. Splinting is often a very usual adjunct, particularly for the thumb CMC joint and for the STT joint. Corticosteroid injections can also give tremendous pain relief, again, particularly at the thumb CMC joint and the STT joint. If patients have significant mucous cysts at the DIP joint causing pain, skin breakdown, or nail deformities, surgical treatment with resection of the mucous cysts and the underlying osteophytes is indicated. More severe PIP and DIP joint involvement causing unremitting pain or deformity is usually treated by a fusion. Joint replacement arthroplasties are available for very limited indications. Isolated STT joint arthritis is usually treated with fusion. Arthritis of the CMC joint can be treated with arthrodesis or arthroplasty using trapezial resection and ligament reconstruction. Some surgeons prefer implant arthroplasties, but these have had problems with stability and wear.

Posttraumatic arthritis is another very common form of arthritis caused by a ligament, cartilage, or bone injury resulting in increased wear of the joint surface and eventual loss of the cartilage space and arthritis formation. One of the most frequently seen forms is the scapholunate advanced collapse pattern or SLAC wrist. The underlying problem here is a rupture of the scapholunate interosseous ligament that goes untreated. The scaphoid eventually assumes a flexed posture and rotates within the scaphoid fossa of the radius, the lunate goes into a hyperextended position, and arthritis develops. This process first starts in the radial styloid region and extends to the entire scaphoid fossa and then to the scaphocapitate interval and eventually around the entire wrist. Treatment options depend upon the stage and include symptomatic treatment initially, followed by scaphoid excision and capitate-hamate-triquetral and lunate fusion, or proximal row carpectomy and total wrist fusion for more-advanced states.

Rheumatoid arthritis has extensive involvement in the hand and wrist (Fig. 10-3). This disease is a systemic problem, and in the hand nearly all tissues can be involved including bone, joint, tendon, and vascular tissues.


A
B
C
D

The distal radioulnar joint is frequently involved with erosions into the ulnar head, eventually causing instability that allows the ulnar head to abrade the overlying extensor tendons and cause rupture; this is called a Vaughn–Jackson lesion. The remainder of the carpus can develop extensive erosion, frequently causing volar and ulnar subluxation of the carpus on the radius and a radial deviation deformity of the wrist. The thumb CMC joint often erodes and dislocates, pushing the thumb into an adduction deformity. The metacarpophalangeal (MP) joint of the thumb is also frequently involved. The MP joints of the remaining digits usually drift into an ulnar deviation deformity, further compromising hand function. The PIP joints develop severe synovitis that can lead to either a boutonnière or swan-neck deformity. The DIP joints are usually spared. In the early phases of the disease, treatment is focused on medical management. Accompanying therapy and splinting can be useful adjuncts for maintaining strength and slowing the progress of deformity. As the disease progresses, the individual problems that develop must be addressed. Persistent tenosynovitis is treated with surgical tenosynovectomy; resection of the ulnar head or bony osteophytes at Lister's tubercle or the scaphoid is also often performed. Rheumatoid destruction of the wrist itself is usually addressed with a fusion. Several types of wrist replacements are available, including Silastic implants and metal and plastic options. The thumb CMC joint is usually addressed with a non-implant arthroplasty, with trapeziectomy and ligament reconstruction. The MP joint of the thumb is usually fused when necessary, and MP joints of the other digits are either fused or replaced with Silastic or other implant arthroplasties. Fusions and replacements are available for the PIP joints and DIP joints. Many other treatments and surgical options are available. Needless to say, these procedures need to be done by an experienced hand surgeon who can follow the many problems that these patients develop over time.

Nerve Compression Syndromes

Compressive neuropathies of the upper extremity are common problems that cause significant disability and pain in many patients. Carpal tunnel

FIGURE 10-3. Rheumatoid arthritis. (A) Severe erosive destruction of carpal and forearm bones with dislocation of distal radioulnar joint and moderate osteoporosis of all bones. (B) Clinical picture of advanced rheumatoid changes with tenosynovitis at wrist, dislocations of MCP joints of fingers resulting in ulnar drift, and typical deformities of the thumb. (C) Rupture of extensors of ulnar three digits as a result of tenosynovitis at wrist with dislocation of distal radioulnar joint. (D) Results of surgery with relocation of MCP joints of fingers by prosthetic insertion, fusion of thumb joints, and synovectomy of wrist joint and extensor tendons.

syndrome is by far the most common of these problems. Unfortunately, this condition has received so much attention that people are often labeled with this disease as soon as they present with any hand problems, and the diagnosis can often be faulty. Carpal tunnel syndrome is caused by compression of the median nerve at the wrist underneath the transverse carpal ligament. The hallmark symptoms include numbness, tingling, and paresthesias in a median nerve distribution (the thumb, index, and middle and radial half of the ring finger), loss of dexterity in the hand, and discomfort particularly with wrist flexion or at sleep. In more-advanced stages, patients may develop weakness of the hand and dropping of objects, pain radiating to the elbow or even the shoulder, or atrophy of the thenar musculature.

The underlying cause of carpal tunnel syndrome is unknown in most patients. Patients with metabolic diseases such as hypothyroidism, diabetes, and renal failure are at much higher risk for developing this disease. The relationship of repetitive motion tasks, especially keyboarding, with carpal tunnel syndrome is very controversial, and hand surgeons still debate the causal role of such activities.

Physical examination findings include a positive Tinel's sign, in which tapping over the median nerve at the wrist crease elicits paresthesias in a median nerve distribution. A positive Phalen's sign occurs when symptoms are reproduced by holding maximal flexion of the wrist for a minute or less. The carpal tunnel compression test is positive if pressure directly over the carpal tunnel applied by the examiner elicits symptoms within 30 seconds or less. Thumb abduction strength should be tested, and a sensory evaluation should be documented. When patients have an atypical presentation or physical examination, an electromyograph (EMG) and nerve conduction study as well as X-rays can be very helpful for sorting out other diseases or making sure that a more-proximal nerve compression process is not present.

Carpal tunnel syndrome can be treated initially by bracing and oral antiinflammatory medications. If this does not help, a corticosteroid injection into the carpal tunnel gives temporary relief in nearly 80% of patients with true disease. Finally, when conservative measures have failed and the patient has had persistent symptoms for more than 3 to 6 months, a surgical release is indicated. This operation can be done through one of many open techniques or through an endoscopic technique. Overall results are excellent through both methods.

Cubital tunnel syndrome, or compression of the ulnar nerve at the elbow, is the second-most common compressive neuropathy. Patients present with numbness and tingling in the small finger and the ulnar half of the ring finger and frequently complain of elbow pain. Symptoms are often worse at night or after long periods in which the elbow has been flexed. Physical examination findings include a positive Tinel's sign over the ulnar nerve and behind the medial epicondyle, a positive elbow flexion test in which full flexion of the elbow for more than 30 seconds reproduces symptoms, and in some cases subluxation of the ulnar nerve out of the retrocondylar

groove when flexing the elbow. Distally, one can often find decreased sensation in an ulnar nerve distribution. In advanced cases, weakness to finger abduction or even intrinsic atrophy can be present. Froment's test, in which the patient is required to pinch a card between the thumb and index finger, is positive when the patient either cannot strongly pinch the card or collapses into a flexed IP joint position and hyperextended MP joint position of the thumb. The main differential diagnosis includes cervical radiculopathy, thoracic outlet syndrome (i.e., brachial plexus compression in the region from the scalenes to the clavicle), and ulnar nerve compression at the wrist. An EMG and nerve conduction study can be helpful to differentiate between these sites, but these are often negative even in moderately advanced stages of cubital tunnel syndrome. Treatment usually starts with extension splinting, activity modification, and antiinflammatories. If symptoms do not resolve in 3 to 6 months or patients begin to develop significant atrophy, an anterior transposition of the ulnar nerve or a medial epicondylectomy may be indicated.

Tendon Compression Syndromes

Stenosing tenosynovitis is the name given to conditions in which tendon segments with a synovial sheath become compressed by the overlying ligamentous or retinacular structures. Patients initially present with pain and eventually develop problems with gliding motion and sometimes even develop frank catching or triggering of the tendon as it passes through its retinacular housing. These problems are frequently associated with diabetes and renal failure. They are sometimes thought to be caused by overuse. Most of the time, however, the underlying cause is unknown. The most common of these tendon disorders is trigger finger, in which the flexor tendons are entrapped underneath the A-1 pulley of the flexor tendon sheath. Patients often develop locking of the finger in flexion, requiring a prying open of the digit with a palpable and sometimes visible pop as the finger fully extends. This condition can be treated with very high success rates with a corticosteroid injection initially. If symptoms recur or do not remit, a surgical release of the A-1 pulley is indicated.

Another very common stenosing tenosynovitis is de Quervain's tenosynovitis, in which the abductor pollicis longus and extensor pollicis brevis tendons become constricted under the extensor retinaculum at the first dorsal compartment of the wrist; this is especially common in mothers with newborn children. Hallmark physical findings are significant tenderness over the first dorsal compartment at the radial styloid and a positive Finkelstein's test, in which the thumb and wrist are forcibly maneuvered into ulnar deviation, eliciting severe pain over the first dorsal compartment. Treatment options include nonsteroidal antiinflammatory medications, corticosteroid injections, bracing, which must include the thumb and wrist, and, eventually, surgical release of the first dorsal compartment. Other

less-common tendon compressions around the wrist include tendonitis of the FCR tendon, ECU tendon, and ECRB and ECRL tendons (intersection syndrome). Treatment of these conditions proceeds in a similar fashion to that of de Quervain's tenosynovitis.

Dupuytren's Contracture

This disease involves changes in the palmar fascia in which normal fibroblast cells become transformed into myofibroblasts and thicken and contract, turning the normal fascial bands anchoring the fat of the palm into thickened, contractile cords that pull the digits into flexion contractures and cause web space narrowing (see Fig. 10-2C). Over time, the contractures can become so severe that patients cannot place their hands in their pockets or put on a glove. The disease is particularly common in older men of Celtic and Scandinavian origin, suggesting a hereditary component to the process. The usual presentation starts as a painless nodule in the palm. Over time it often progresses into a cord along the digit, pulling the MP or PIP joint into a flexion contracture. Therapy, splinting, and other modalities have shown no effect on the progression of the disease. The mainstay of treatment at this time is surgical, with excision of the cords, but this does not halt the disease process. There is still a 10% per year risk of recurrence of the disease in a digit that has had cords removed. Clostridial collagenase enzyme injection is another way to rupture the cord and relieve the contracture; it has shown good promise in early trials, and it may eventually become the treatment of choice for these problems.

Kienböck's Disease

This rare condition is caused by osteonecrosis of the lunate bone. Over time, collapse of the carpus may occur, resulting in severe pain and loss of wrist function. It most commonly occurs in the second, third, and fourth decades of life. It is seen somewhat more often in patients with repetitive loading-type activities such as gymnastics or football. X-rays often make the diagnosis, and the patients have a tendency to be ulnar negative, that is, the radius is longer than the ulna. If X-rays do not show the disease, but it is still suspected, one should obtain an MRI, which will definitively make or rule out the diagnosis. Treatment options include immobilization and rest for the earliest phases, drilling and vessel implantation and bone grafting, joint-leveling procedures, intracarpal fusions, proximal row carpectomies, and, for the most advanced stages, a total wrist fusion.

Inflammation and Infection

Although the hand is relatively resistant to infection as a result of its excellent blood supply, its frequent exposure to trauma, particularly lacerations, open fractures, puncture wounds, foreign-body penetration, and paronych-

ial or cuticle injuries, does lead to a fairly high incidences of infection overall. A paronychia is an infection that affects the soft tissues overlying the proximal nail fold or the lateral edges of the nail (Fig. 10-4A). It is usually caused by *Staphylococcus* and presents as a red, swollen, painful abscess overlying the nail fold. If it is diagnosed at an early enough stage, warm water soaks and oral antibiotics can cure it. In more-advanced stages, surgical drainage is required.

A felon is a more-involved infection that invades into the pulp of the fingertip. Patients present with a very swollen, tense, and painful finger pulp (see Fig. 10-4B–D). It is very important to drain this as soon as possible and release all the septa between the skin of the pulp and the bone, thereby completely decompressing the infection. If this is not done, the infection can spread to the bone or to the tendon sheath.

Purulent or septic flexor tenosynovitis is an extremely serious infection that can result in loss of the finger if not treated aggressively. The four

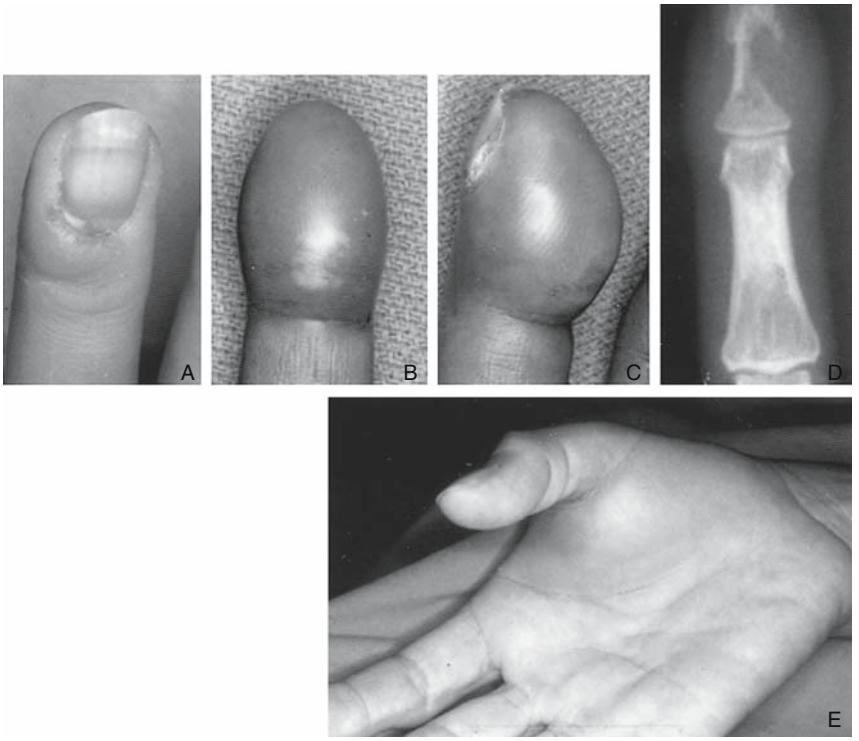


FIGURE 10-4. Infections of the hand. (A) Paronychia with collection of pus beneath eponychium and base of nail. (B–D) Felon with marked distension of pulp of finger, impending necrosis of skin on palmar surface, and dissolution of bone of distal phalanx. (E) Thenar space abscess.

classic findings for this are called Kanavel's signs: fusiform swelling of the digit, severe tenderness over the flexor tendon sheath, semiflexed posture of the digit, and severe pain to passive extension of the digit. This infection should be surgically drained as soon as possible and subsequently treated with several weeks of antibiotics and soaks. If left untreated, it can spread into the palmar bursa and enter the thenar space, the palmar space, or even the carpal tunnel, causing a more severe and widespread infection.

Human bite infections can cause extensive damage before treatment has begun. The injury often occurs in a fight with the patient's metacarpal head striking a tooth and seeding the MP joint and the metacarpal head with several different bacteria. These wounds should be debrided aggressively and allowed to heal by secondary intent or a delayed primary closure. The antibiotic selected should cover *Eikenella corrodens*. Dog and cat bite wounds can also cause significant hand infections, including septic flexor tenosynovitis and septic arthritis. Appropriate debridement should be performed when necessary, and antibiotic coverage should include drugs that will eradicate *Pasteurella multocida*. Infections to the hand and wrist from fungi, mycobacteria, and other atypical flora are relatively rare but should be kept in mind. A history of exposure to soil, birds, or seawater is particularly important to check. These infections often require extensive debridement and long periods of antibiotic therapy.

Trauma

As mentioned earlier, the hand is subject to high rates of trauma, ranging from very minor accidents to devastating injuries to the hand and wrist. It is important for all physicians to have a basic approach to dealing with trauma of the hand and to know when to urgently involve a hand surgeon with these problems.

Lacerations

Lacerations and puncture injuries to the hand can show obvious and extensive injury in some situations, but many of the more subtle small lacerations can also mask significant deep injury. In general, these wounds should not be probed in an emergency room or office setting; all the necessary information can be gleaned by distal evaluation of the affected digit or hand. A careful assessment of nerve, vessel, tendon, ligament, and bone function should be assessed, and plain X-rays should also be taken to ensure that no fracture or residual foreign body is present. Appropriate tetanus and antibiotic coverage should be instituted. If the decision is made to take a wound to the operating room right away, the wound can just be loosely dressed and splinted to await passage to surgery. If the external wound is minor, but the patient needs a tendon or other repair, a loose closure can be performed in the emergency room. Splinting is usually initiated, and the patient

can follow up with the hand surgeon on an elective basis. Minor lacerations that are clean and do not have deep tissue involvement should be definitively closed and dressed in the emergency room. It is important to note here that whenever nerve, tendon, or other significant structural involvement is present, the hand surgeon who will eventually definitively treat this should be contacted so that appropriate care and follow-up can be arranged and the patient does not fall through the cracks or lose an opportunity for timely care. Nerve and flexor tendon injuries, in particular, must be addressed within 1 or 2 weeks to avoid permanent loss of function.

Fractures and Dislocations

Fractures and dislocations of the hand and wrist can occur through a variety of mechanisms, including falls on an outstretched wrist or hand, crush injuries, or direct blows. Appropriate X-rays can usually make the diagnosis, but for some of the carpal injuries in particular, bone scans and MRIs are needed to confirm the problem. Assessment of the fracture should also include whether this is open or if there is associated soft tissue injury involving the nerves, tendons, or vessels. Fractures of the phalanges can involve a variety from simple tuft fractures to extensive intraarticular fractures with comminution. The fractures must be assessed for stability, angular deformity, rotational malalignment, and shortening. If these factors are all found to be acceptable, the fracture can be treated closed with 3 to 4 weeks of immobilization or protected early range of motion until healing occurs. If these factors are not acceptable in the fracture pattern, surgical management should be initiated; the most commonly used fixation techniques involve K-wire or plate-and-screw fixation. This procedure is especially important for intraarticular fractures that are displaced to restore adequate range of motion.

Most metacarpal fractures can be treated nonoperatively. Exceptions include fractures with rotational malalignment, excessive angular deformity, or intraarticular displacement, especially of the thumb or small metacarpal bases. Fractures of the thumb metacarpal base often occur in a pattern in which the ulnar segment of the base stays attached to the trapezium and index metacarpal through the volar oblique ligament and the remainder of the metacarpal shaft subluxates radially. This pattern is called a Bennett's fracture and often requires fixation. Boxer's fractures are small metacarpal neck fractures that are extremely common. If no rotational deformity is present, up to 70 degrees of apex dorsal angulation can be treated nonoperatively in most cases. Index and middle metacarpal neck fractures are more problematic as their metacarpal bases are quite stiffly attached to the carpus and less compensation can occur.

Carpal bone fractures occur frequently as well. The most commonly injured wrist bone is the scaphoid (Fig. 10-5). When patients are tender over the anatomic snuff box or the scaphoid tubercle, one should maintain

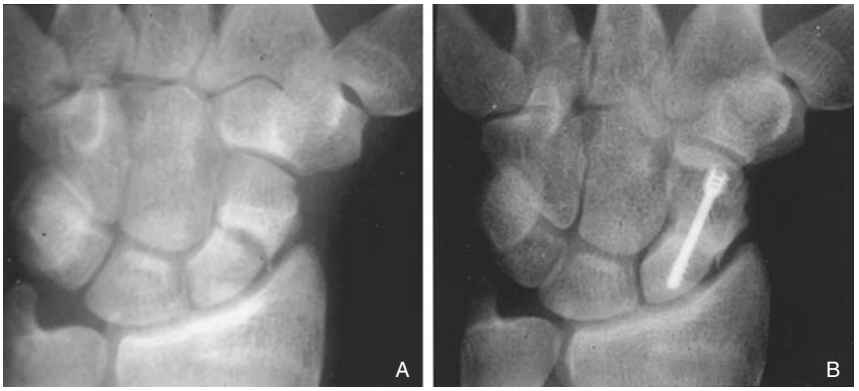


FIGURE 10-5. Fracture with nonunion of carpal scaphoid. (A) Established nonunion with sclerosis and cyst formation 6 months after untreated "wrist sprain." (B) Operative treatment with screw resulted in union.

a high index of suspicion for this fracture. If initial X-rays are negative, advanced imaging techniques such as bone scan or MRI should be obtained, or the patient should be immobilized for 3 weeks and repeat radiographic views considered. Scaphoid fractures have high rates of complications because of the poor vascularity of this bone; nonunions and avascular necrosis of the proximal pole can occur, especially when treatment is delayed or missed. Another common carpal fracture is the dorsal triquetral avulsion injury, which often occurs after a fall on an outstretched wrist; this is best seen on lateral radiographic views in which a small fleck of bone is noted dorsal to the triquetral region. Immobilization in a cast or brace for 3 to 4 weeks usually results in a very good outcome.

Dislocations of the interphalangeal joints are quite common and can usually be reduced using closed techniques. It is important to initiate early range of motion soon after this to avoid excessive stiffness. It is particularly important to do brief periods of extension splinting, once the joint is stable enough, to prevent flexion contractures from developing. At the MP joints, dislocations can result in irreducible situations in which the volar plate becomes incarcerated between the articular surfaces. This situation requires surgical treatment, but again, nearly always excellent stability can be expected once reduction is obtained. Here, too, it is very important to initiate range-of-motion exercises soon after surgical treatment to avoid subsequent stiffness. Injuries to the collateral ligaments of the PIP and MP joints are common, especially at the thumb. An injury to the thumb MP joint ulnar collateral ligament is often called a "gamekeeper's" or "skier's" thumb and is a frequent athletic injury. Patients who have tenderness over the ligament, but good stability, should be immobilized for 3 to 4 weeks, and then

range of motion should be initiated. If the patient has more than 45 degrees of opening to radially directed stress, or more than 50% subluxation of the joint on stress views, or has a palpable Stener's lesion (a completely ruptured ulnar collateral ligament that is incarcerated in the adductor pollicis muscle), surgical repair of the ligament is indicated. It is also important to note that sprains and strains of the PIP joints can result in very long periods of swelling and stiffness of the joint and, in some patients, can lead to some permanent thickening of the collateral ligaments.

Severe and Complex Upper Extremity Injuries

Amputations of portions of the upper limb, especially the fingers, are very common especially in industrial and agricultural environments. Modern microvascular surgical techniques allow reimplantation of the amputated parts in many situations. The severed part should be wrapped in a gauze dressing soaked in sterile saline and placed in a container or sealed plastic bag that can be immersed in ice and transported to a treating facility. The part should never be placed directly on ice, and dry ice should never be used. An experienced hand or reimplantation surgeon should be consulted immediately to assess whether the part is a good candidate for reattachment. Typical indications at this time include any part that is large enough in a child, the thumb at any level that can be reattached, multiple digits, or an amputation through the midpalm or proximal. Severe contamination, crush injury, avulsion, or broad areas of vascular damage are contraindications to reimplantation of the part.

Extensive mangling injuries must be treated by an experienced hand surgeon as soon as possible. Initial care rendered often determines the final outcome and, therefore, must be carefully planned with a long-term treatment plan and an outcome firmly in mind. Inadequate debridement, primary closure, improper splinting, and nominal or poor understanding of the injury all too often result in more significant disability than necessary.

Crush injuries and high-energy trauma should always be carefully evaluated for the development of compartment syndrome. The early symptoms may be very subtle. The history may be vague, for example, an intoxicated patient sleeping on an arm for a long period of time (and the damage may take a long time to develop). Iatrogenic causes include cast or dressings that are too tight or extravasation injuries. One should maintain a high degree of suspicion for this problem and observe for the five P's: pain out of *p*roportion to the injury, severe pain with *p*assive stretch, later *p*aresthesias, *p*allor, and *p*ulselessness. The condition occurs from increased pressure in the forearm or hand muscle compartments preventing flow through the venules and capillaries and preventing perfusion of the soft tissues of the compartment. Compartment pressures can be measured, but determining the threshold pressure at which to release the compartments is not always easy.

When this diagnosis is confirmed, it constitutes a surgical emergency. It is imperative to take the patient to the operating room and release the compartments as soon as possible to prevent necrosis of the muscle and other tissues, resulting in severe patterns of function loss, such as a Volkmann's contracture.

Thermal, chemical, or electrical injuries cause soft tissue problems of varying depth. The skin is the initial point of contact and may show first-degree (redness), second-degree (blistering), or third-degree (full-thickness or charring) injuries, particularly with burns. Early care of the second-degree injury can minimize the chance of an infection converting it to a third-degree injury. Early referral to a hand therapist for exercise and splinting may avoid extensive late contractures. Third-degree burns should be treated by early surgical excision of the eschar and skin grafting. Chemical injuries should be treated in a facility that has experience in managing these conditions as specific antidotes can be used to neutralize many chemicals and minimize damage.

Cold injury varies from minor frostbite to extensive freezing of tissues and peripheral parts. The initial treatment should involve rapid rewarming of the area of frostbite followed by observation to see what survives. Early amputation is not necessary in the absence of infection. Electrical burns can be quite deceptive as to the extent of damage and require repeated evaluation.

Other Injuries

Mallet finger may occur from rupture of the terminal extensor tendon, often with trivial injury. Fracture of the dorsal lip of the distal phalanx may be seen on X-ray in some cases. Full passive extension is present, but active extension is not. Treatment usually involves splinting in full extension for 6 or more weeks.

Boutonnière deformities occur from disruption of the central slip of the extensor tendon over the PIP joint by blunt trauma or laceration. Over time, the lateral bands slip progressively volar to the axis of rotation of the PIP joint, especially if the triangular band is disrupted. The patient develops a flexion deformity at the PIP joint and compensatory hyperextension at the DIP joint. When diagnosed early, this can be treated with closed extension splinting of the PIP joint. After prolonged presence of deformity, surgical treatment can be required.

Metabolic Disease

Many metabolic illnesses such as diabetes, hyperthyroidism, hyperparathyroidism, and renal failure can be underlying causes to hand problems such as carpal tunnel syndrome. One should be careful to check a patient's medical history and make sure these underlying problems are adequately treated before initiating any surgical intervention.

Gout is a common metabolic illness in which uric acid forms crystals and accumulates in joints or soft tissues. Although it is most common in the first metatarsophalangeal (MTP) joint of the foot, it can occur in the joints and soft tissues of the hand. Often, it presents as a warm, tender, swollen, erythematous region and can mimic infection. Aspiration of a joint and visualization of negatively birefringent crystals under polarized light microscopy evaluation of the fluid confirms the diagnosis. The condition of severe tophaceous gout in the hands, which can cause extensive destruction of tendons or joints, is fairly uncommon because of improvements in medical management of this disease, but it still can be seen. Treatment options include rest, immobilization, antiinflammatory medications, corticosteroids, and other antigout medications. Surgery can sometimes be indicated for erosive tophi.

Calcium pyrophosphate dihydrate deposition disease is another metabolic problem in which crystals accumulate in joints and around tendons. This accumulation, too, can cause redness, swelling, and warmth over a joint, and again, aspiration and visualization of crystals in the fluid can be diagnostic for the problem. Treatment includes corticosteroid injections, nonsteroidal antiinflammatories, prednisone or colchicine for acute flare-ups, and surgery in severe cases.

Vascular

Arterial occlusions and small vessel disease in the hand can cause severe problems with pain and, occasionally, necrosis of the fingers. Although uncommon, ulnar artery occlusions, which usually occur at the level of the hamate hook, can cause significant ulnar nerve symptoms as well as diminished flow to the digits. When this occurs after a repetitive trauma situation, it is called hypothenar hammer syndrome, and it is seen in manual laborers who use their hypothenar eminence as a hammer on the objects with which they are working. A diagnosis for this can be made at times with ultrasound but an angiogram is usually required. The treatment involves decompression of the nerve and artery and reconstruction or ligation of the thrombosed segment of the artery. Thrombosis of digital arteries is sometimes seen in patients with atherosclerotic disease proximally, but it is quite uncommon.

Vascular deficiencies secondary to other underlying diseases can be a significant problem in the hand, particularly in diabetes and scleroderma. Many of these patients go on to require amputations of digits, but in earlier stages of scleroderma, a digital sympathetectomy or removal of the vascular adventitia can decrease the amount of spasm that occurs and limit the damage to the digits.

Patients who have severe loss of flow to the hands can also develop gangrene of the digits. This condition is particularly common in patients who go into systemic vascular shock and require vasopressors, which restrict flow to the extremities. Once again, many of these patients develop gangrene of the digits and require formal amputations later.

True aneurysms of the wrist and hand are relatively uncommon. Usually occurring in the ulnar artery, they cause symptoms very similar to hypothenar hammer syndrome and can be treated the same way. Pseudoaneurysms are more common and can occur anywhere in the hand as the result of trauma to an artery. They are usually treated by ligating or reconstructing the artery involved.

Neoplasms

Skin Cancer

Skin cancers (squamous cell and basal cell carcinomas, and melanoma) are relatively common, especially in the elderly or those with predisposing factors. These factors include prolonged exposure to the sun in farmers and other outdoor workers, and excessive exposure to X-rays, arsenicals, or other chemicals (Fig. 10-6A). Squamous and basal cell carcinomas can usually be cured by wide excision if they have not already metastasized. Melanomas are much more unpredictable in their behavior and need to be addressed quickly (Fig. 10-6B).

Other Soft Tissue Masses

Benign soft tissue masses are very common in the hand and wrist. They can arise in any of the tissues making up the hand including nerves, vessels, fat, and fascia. The most common "tumors" of the hand arise from the synovium and include ganglions, mucous cysts, and giant cell tumors of the tendon sheath. Ganglia occur in four locations: on the dorsum of the wrist, on the volar aspect of the wrist adjacent to the radial artery, in the flexor tendon sheath at the base of the finger, and over the dorsum of the DIP joint (mucous cyst), usually associated with osteoarthritis and osteophyte formation of the joint. A ganglion on the dorsum of the wrist or over the flexor tendon sheath can be aspirated, although rates of recurrence are fairly high. Aspiration of a volar wrist ganglion should be approached cautiously, if at all, because of the proximity of the radial artery. Surgical resection is a more definitive option, with only 5% to 10% recurrence rates when done correctly. Arthroscopic resection is now available for dorsal wrist ganglia. Giant cell tumors of the tendon sheath are solid lesions arising from the synovium of the tendon sheath or from the finger joints. Simple excision is usually curative, although occasional recurrences are seen.

Other common benign soft tissue masses include foreign-body granulomas, epidermal inclusion cysts, arteriovenous malformations and hemangiomas, neurilemmoma, and glomus tumors.

Malignant soft tissue tumors in the hand are very rare aside from skin cancers. The most common ones are epithelioid sarcomas, synovial cell sarcomas, and malignant fibrous histiocytoma. Delay in diagnosis is a common problem to these tumors. Limb salvage surgery is the treatment of choice whenever possible.

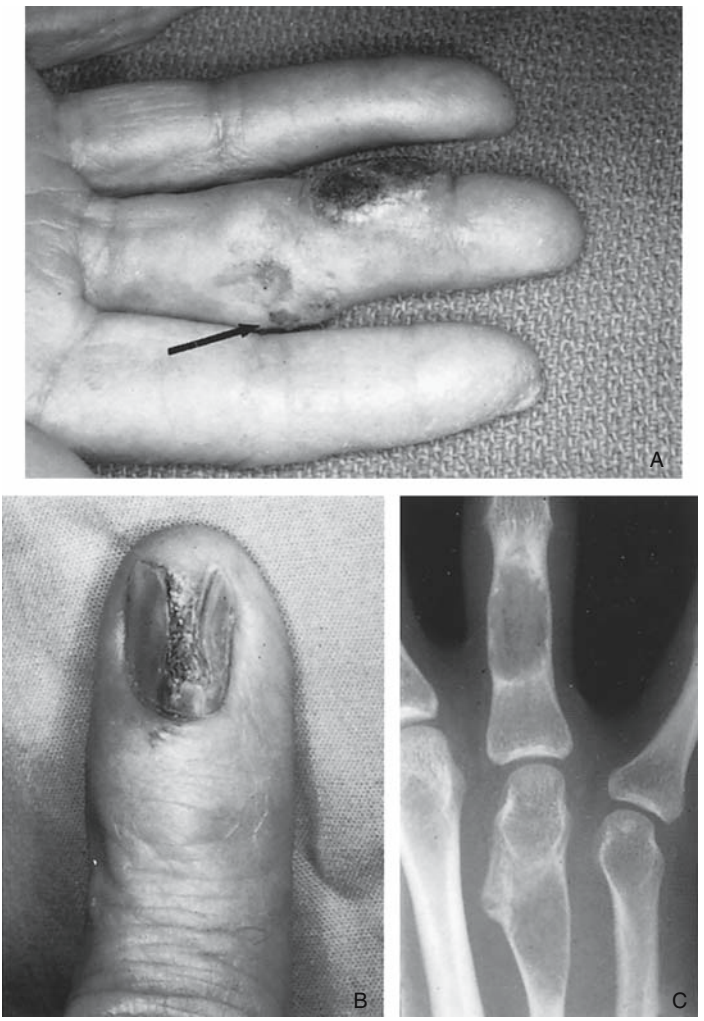


FIGURE 10-6. Neoplasms of the hand. (A) Squamous cell carcinoma of finger in patient with 30-year history of holding children being radiographed. Note atrophic skin changes (*arrow*) from the radiation exposure. (B) Subungual melanoma with splitting of the nail from involvement of nail bed. (C) Enchondroma of proximal phalanx with expansion of the diaphysis. Note the enchondroma of the metacarpal with callus from a healed pathologic fracture.

Tumors of Bone

Benign tumors of the hand bones are often diagnosed incidentally on radiographic examination for trauma. The most common is the enchondroma (see Fig. 10-6C). Treatment is not required unless pathologic

fracture through the lesion has occurred or is impending. Simple curettage, with or without bone grafting, often suffices. Osteochondromas, fibrous dysplasia, and giant cell tumor of bone can also present in the small hand bones and may require surgery for diagnosis or treatment. Malignant tumors of the hand skeleton are very rare. Partial or total hand amputation may be required along with adjuvant radiation therapy or chemotherapy. Metastatic tumors of the hand seldom occur as isolated metastases but are not uncommon during widespread metastatic disease, especially from lung or breast lesions.

Management Protocols

As one can see, a broad variety of complex problems can affect the hand and wrist. It is, therefore, important to have in mind a standardized approach to patients with these problems to help arrive at the correct diagnosis and management options. The physician should start with a careful and detailed history of the chief complaint, then with a differential diagnosis in mind should perform a directed but thorough physical examination. Plain radiographs are usually, but not always, indicated. We have developed algorithms beyond this to help streamline a patient's care and avoid missing important diagnoses. Although the algorithms are overall quite complete, one should be wary of unusual presentations or diagnoses that are not included. These rare occurrences may require further evaluation or consultation by a hand specialist. The algorithms divide patients into groups with or without a specific history of injury (Figs. 10-7, 10-8).

Nearly all patients with a specific injury should be X-rayed. If the initial radiographs show a fracture, dislocation, or carpal instability pattern, appropriate operative or nonoperative treatment should be initiated. When X-rays are negative, a soft tissue injury may have occurred or an occult fracture may be present. When a specific soft tissue injury is noted, appropriate treatment should be initiated. If none is found and the patient's symptoms cannot be explained, either further imaging should be performed or splinting or casting for a period of time followed by reevaluation should be considered.

Figure 10-8 concerns patients who have had no specific history of trauma or injury. Unless patients have a very classic history and physical examination for a soft tissue process, plain X-rays should be taken. If they are positive for arthritis, tumor, or occult bony injury, appropriate operative or nonoperative management should be undertaken. If they are negative, further evaluation or indicated treatment should be initiated according to the algorithm.

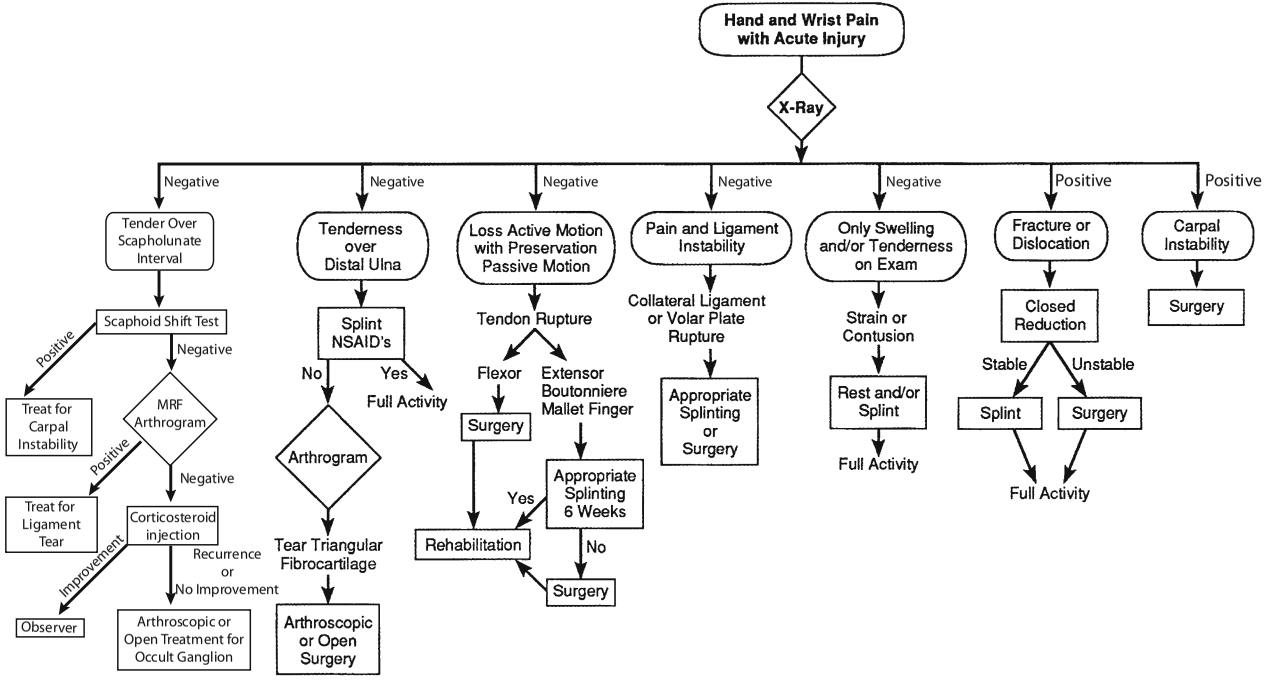


FIGURE 10-7. Management algorithm for hand and wrist pain with history of acute injury.

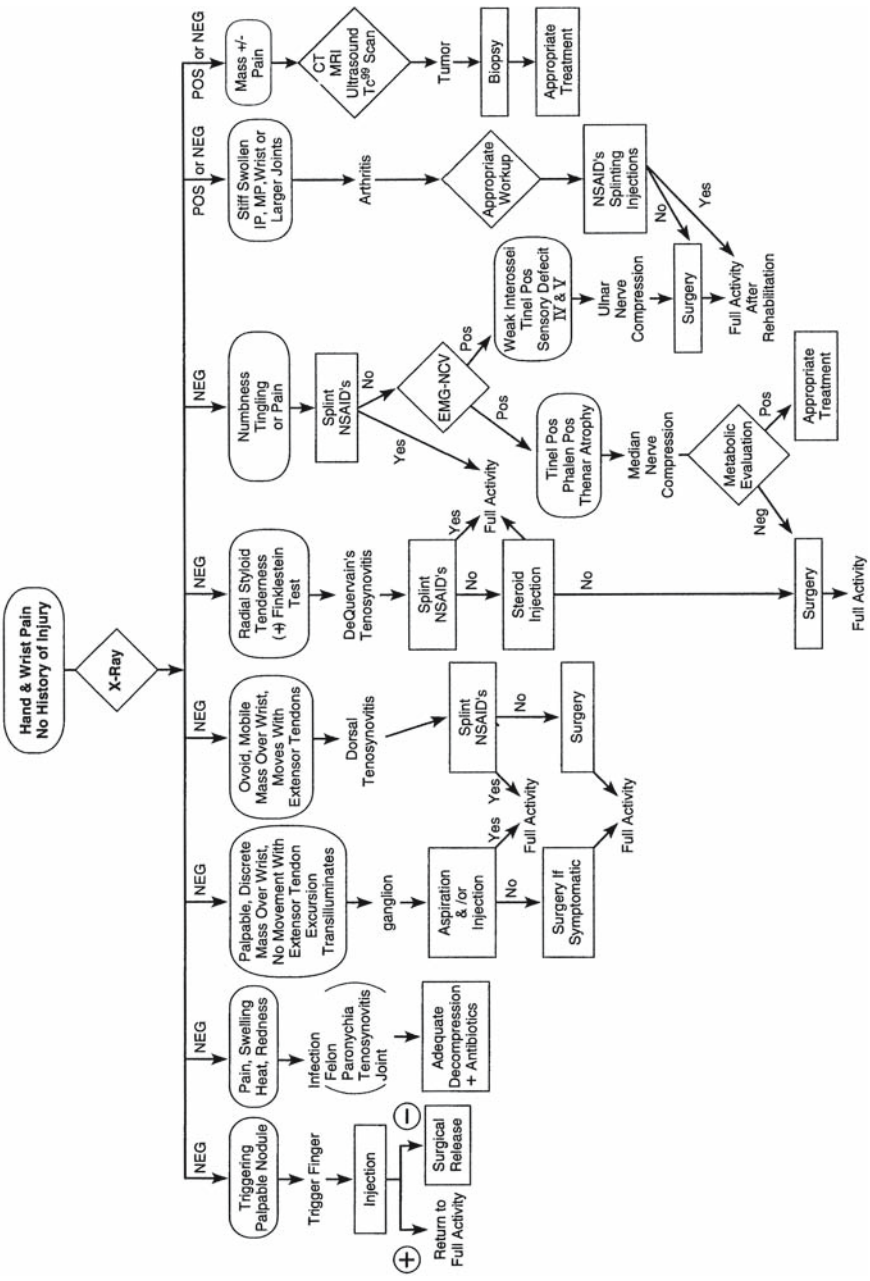


FIGURE 10-8. Management algorithm for hand and wrist pain with no history of injury.

Suggested Readings

Green DP, Hotchkiss RN, Peterson WC (eds) Green's Operative Hand Surgery. New York: Churchill Livingstone, 1999.
Seiler JG (ed) Essentials of Hand Surgery. American Society for Surgery of the Hand, Chicago, IL, 2002.
Trumbull TE (ed) Hand Surgery Update III. American Society for Surgery of the Hand, Chicago, IL, 2003.

Questions

Note: Answers are provided at the end of the book before the index.

10-1. Which of the following is a particularly uncommon malignancy in the hand?
   a. Epithelioid sarcoma
   b. Squamous cell carcinoma
   c. Malignant fibrous histiocytoma
   d. Isolated metastatic prostate carcinoma
   e. Synovial cell sarcoma

10-2. Which of the following conditions can be causative factors in carpal tunnel syndrome?
   a. Renal failure
   b. Pregnancy
   c. Hypothyroidism
   d. Diabetes
   e. All the above

10-3. Which of the following congenital hand differences is associated with visceral anomalies?
   a. Syndactyly
   b. Radial clubhand
   c. Phocomelia
   d. Mirror hand
   e. Occasional constriction band syndrome

10-4. Which of the following joints is usually spared in osteoarthritis?
   a. Metacarpophalangeal joints of the fingers
   b. Thumb carpometacarpal joint
   c. Distalinterphalangeal joints of the fingers
   d. Proximal interphalangeal joints of the fingers
   e. None of the above

10-5. A positive Finkelstein's test suggests which of the following diagnoses?
   a. Trigger thumb
   b. Thumb carpometacarpal arthritis
   c. Scaphotrapeziotrapezoid arthritis
   d. de Quervain's tenosynovitis
   e. Carpal tunnel syndrome

10-6. Which of the following is not a common symptom in carpal tunnel syndrome?
   a. Night pain
   b. Loss of dexterity
   c. Numbness localized to the small finger
   d. Global numbness in the hand
   e. Weakness of the hand

10-7. When evaluating an open wound in the emergency room, a physician should:
   a. Appropriately numb the hand and wrist before further evaluation
   b. Explore the wound directly
   c. Clamp off any large blood vessels that are clearly cut
   d. Cover the wound with a clean sterile dressing and avoid further probing
   e. Avoid documentation of injury until definitive management in the Operating Room

10-8. Which of the following bacteria must be covered when a human bite wound is involved?
   a. *Mycobacterium avium-intracellulare*
   b. *Staphylococcus aureus*
   c. *Borrelia burgdorferi*
   d. *Eikenella corrodens*
   e. b and d

10-9. Scaphoid fractures are commonly associated with:
   a. Anatomic snuff box tenderness
   b. Nonunions
   c. Avascular necrosis
   d. Delays in diagnosis
   e. All the above

10-10. Which of the following is not a common finding in infectious flexor tenosynovitis?
   a. Fusiform swelling
   b. Semiflexed posture of the digit
   c. Destructive bone erosions on plain X-ray
   d. Tenderness over the flexor tendon sheath
   e. Severe pain with passive extension of the digit

10-11. A Stener lesion is associated with which of the following diagnoses?
   a. Trigger thumb
   b. Deep space infection of the hand
   c. de Quervain's tenosynovitis
   d. Gamekeeper's thumb
   e. Extensor tendon rupture

11
The Hip and Femur

Brian G. Evans

The primary function of the lower extremities is locomotion. Any alteration of the function of the lower extremities will result in an alteration in the ability to walk and run. The hip is the most proximal joint in the lower extremity. Alteration in the hip as a result of disease will significantly effect the biomechanics of gait and place abnormal stress on the joints above and below the hip.

This chapter briefly reviews the anatomy of the hip and its relationship to normal and pathologic gait. The important history and physical examination findings of hip pathology are discussed. Diseases affecting the hip are reviewed and their treatment outlined. Surgical management of end-stage disease of the hip commonly are treated by one of several options, and these are reviewed. The indications and outcome for each treatment option are also reviewed. In addition, trauma to the pelvis, acetabulum, and proximal femur are summarized and treatment alternatives outlined.

Anatomy

Development

The hip joint is a ball-and-socket joint with the round femoral head articulating within the round acetabular socket. The acetabulum is formed from the confluence of three bones: the ischium, the ilium, and the pubis. In skeletally immature patients these three bones are joined in the medial acetabulum by the triradiate cartilage, which is a growth plate for the acetabulum. There is also appositional growth from the edges of the acetabulum and pelvis, resulting in increased depth of the acetabulum and size of the pelvis. Normal development of the acetabulum requires the femoral head to articulate with the acetabular cartilage. If the femoral head is chronically dislocated or subluxed within the acetabular fossa, the acetabular socket does not develop fully, resulting in developmental dysplasia of the hip (DDH). The severity of this condition is determined by the degree of subluxation of the femoral head. If DDH is identified at birth or soon

thereafter, the hip can be reduced either with casting or surgery. This treatment can allow the hip to grow and develop almost normally. If the hip is left subluxed or dislocated, the acetabulum will be shallow and predispose the patient to develop osteoarthritis as an adult. This condition is reviewed in greater detail in the chapter on pediatric orthopedic conditions.

Osteology and Musculature

The innominate bone consists of the ilium, ischium, and pubis, which are joined in the area of the acetabulum (Fig. 11-1). The ilium is a large flat bone providing broad surfaces for muscular attachment. The ischium extends posteriorly and forms the posterior aspect of the acetabulum. The ischium joins the ilium superiorly and the pubis inferiorly through the inferior pubic ramus. The ischium also serves as the origin of the hamstring and short external rotator muscles of the hip. The pubis consists of the superior pubic ramus, the inferior pubic ramus, and the pubic symphysis. The superior pubic ramus joins the pubic symphysis with the ilium, and the inferior pubic ramus connects the pubic symphysis with the ischium. The pubis serves as the site of insertion of the musculature of the abdominal wall as well as the site of origin for the adductor muscles of the thigh.

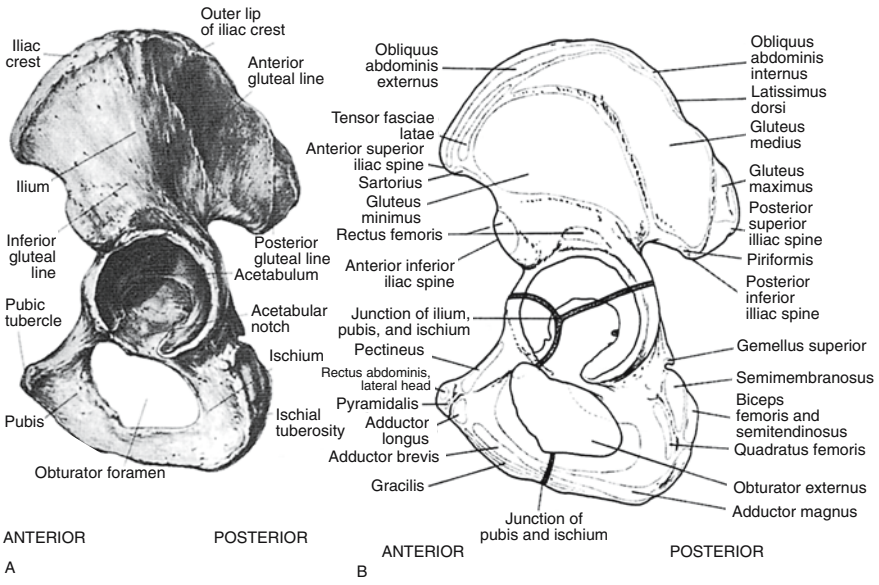


FIGURE 11-1. (A) Lateral aspect of left hip bone. (B) Attachments and epiphyseal lines are shown. (From Willams PL, Warwick R: Gray's Anatomy, ed 36. Churchill Livingstone, 1980, pp 378–379. Reprinted by permission. From Steinberg M (ed). The Hip and Its Disorders. Philadelphia, WB Saunders Company, 1991, P 32. Reprinted by permission.)

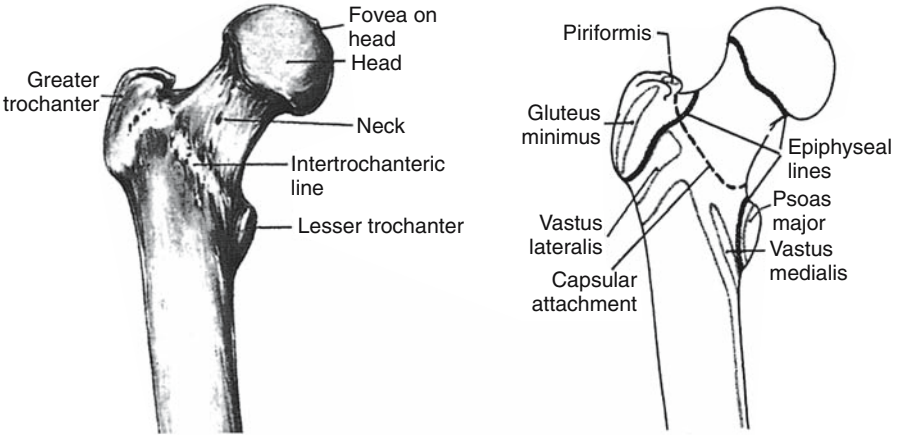


FIGURE 11-2. (A) Anterior aspect of proximal right femur. (B) Attachments and epiphyseal lines. (From Willams PL, Warwick R. Gray's Anatomy, ed 36. Churchill Livingstone, 1980, pp 392–393. Reprinted by permission. From Steinberg M (ed) The Hip and Its Disorders. Philadelphia, WB Saunders Company, 1991, p 28. Reprinted by permission.)

The acetabulum is formed at the junction of the ilium, ischium, and pubis. The ilium forms the superior dome of the acetabulum. The ischium forms the posterior acetabulum and the pubis the anterior acetabulum. The lateral opening of the acetabulum forms a horseshoe with the open end directed inferiorly. The medial base of the acetabulum contains a depression called the acetabular fovea, which is filled with a fatty tissue called the pulvinar and the ligamentum teres. The ligamentum teres is a ligament that extends from the acetabular fovea and the fovea of the femoral head. The artery of the ligamentum teres is a branch of the obturator artery and supplies approximately 10% to 20% of the bone of the femoral head.

The fovea of the femur is a depression on the femoral head that serves as the site of attachment of the ligamentum teres. Attached to the rim of the horseshoe is a fibrocartilaginous labrum, which is similar to the meniscus in the knee. This structure serves to improve stability and to cushion the femoral neck when the femur is rotated and impinges upon the acetabular rim at the extremes of motion. The hip joint capsule is a dense fibrous structure extending from the base of the intertrochanteric region of the femur to the acetabular rim. Thickenings within the capsule are the iliofemoral and pubofemoral ligaments anteriorly and the ischiofemoral ligament posteriorly. These ligaments as well as the ligamentum teres and the labrum augment the stability of the hip joint.

The femoral head is essentially spherical in geometry (Figs. 11-2, 11-3). The spherical portion of the femoral head is covered by articular cartilage. The sphere is altered in two areas, laterally where the femoral neck begins

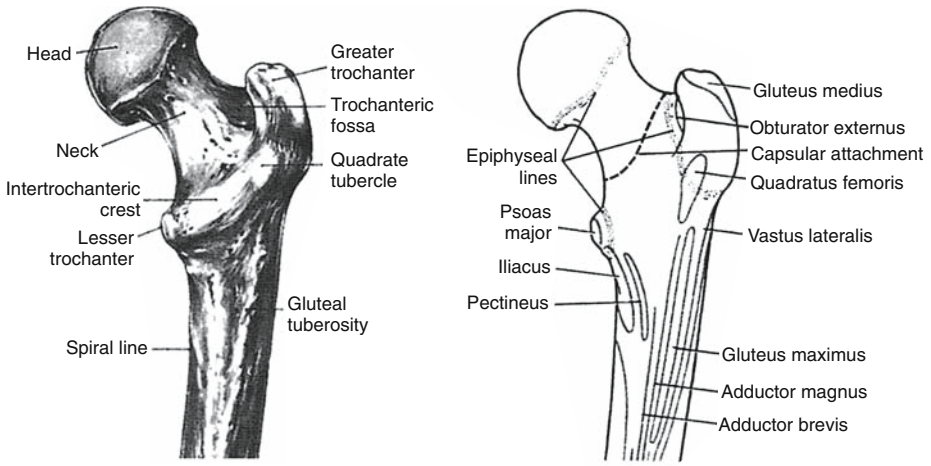


FIGURE 11-3. (A) Posterior aspect of proximal right femur. (B) Attachments and epiphyseal lines. (From Willams PL, Warwick R: Gray's Anatomy, ed 36. Churchill Livingstone, 1980, p 394. Reprinted by permission. From Steinberg M (ed) The Hip and Its Disorders. Philadelphia, WB Saunders Company, 1991, p 28. Reprinted by permission.)

and medially at the fovea of the femoral head. The femoral neck joins the femur at an angle of approximately 125 degrees. The neck is also rotated anteriorly 12 to 14 degrees relative to the axis represented by the posterior femoral condyles (Fig. 11-4). The femoral neck flares laterally to join the proximal femur in between the greater and lesser trochanters. The greater trochanter, a large osseous prominence at the proximal lateral aspect of the femur, serves as the site of attachment of the abductor musculature. Between the greater and lesser trochanters is an osseous ridge that serves

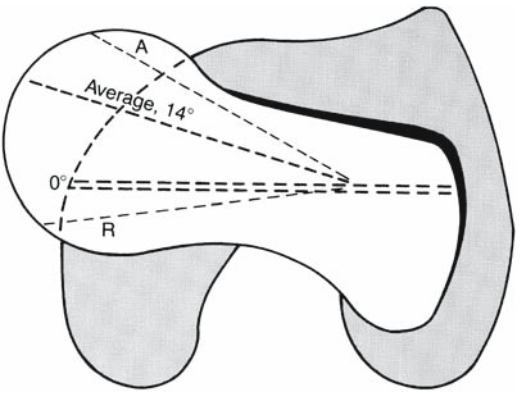


FIGURE 11-4. Average rotary, or torsion, angle of the femur. It may be anteverted (A) or retroverted (R). (From Steinberg M (ed) The Hip and Its Disorders. Philadelphia, WB Saunders Company, 1991, p 29. Reprinted by permission.)

as the site of attachment of the short external rotators. The lesser trochanter is the site of attachment of the iliopsosas tendon. This tendon leaves the pelvis over the anterior column and superior pubic ramus and then travels over the anterior femoral neck to insert on the lesser trochanter, which lies on the posterior inferior aspect of the intertrochanteric ridge. Within the proximal femur and femoral neck is a large and dense trabecula known as the calcar. The calcar provides increased strength to the proximal femur. Frequently the proximal posteromedial femur from the base of the femoral neck including the lesser trochanter is also referred to as the calcar. If the calcar region of the proximal femur is a separate fragment of a proximal femur fracture, this usually implies that the fracture is very unstable.

The muscles of the hip form several distinct groups. The anterior muscles are the hip flexors, which consist of the iliopsoas and rectus femoris and sartorius muscles. The femoral nerve innervates the rectus and sartorius muscles. Motor branches from spinal roots L2, L3, and L4 innervate the iliopsoas. The lateral group consists of the abductors, the gluteus medius, minimus, and tensor fascia lata. These muscles are essential for normal gait. They stabilize the pelvis in the single limb stance phase of normal gait. The anterior one-third of the gluteus medius muscle is also the principal internal rotator of the hip. The superior gluteal nerve innervates the gluteus medius, minimus, and tensor fascia lata. Surgical dissection that extends greater than 5 cm proximal to the greater trochanter can disrupt the nerve and result in a limp.

The posterior muscles are in two layers. The superficial layer consists of the gluteus maximus, the primary extensor of the hip, which is innervated by the inferior gluteal nerve. The deep layer consists of the short external rotators of the hip, the piriformis, superior gemellus, obturator internus, inferior gemellus, obturator externus, and the quadratus femoris and gluteus minimus and medius. These muscles externally rotate the femur and provide abduction. Small branches from the sacral plexus innervate the short external rotators. The medial muscle group consists of the pectineus, the adductor brevis, longus, and magnus, and the gracillis. The adductors and gracillis are supplied by the obturator nerve, with the posterior portion of the adductor magnus also receiving innervation from the tibial division of the sciatic nerve. The femoral nerve innervates the pectineus.

The sciatic nerve crosses the hip joint posteriorly. It exits the pelvis through the superior sciatic notch, under the piriformis muscle, and lies superficial to the short external rotators. The nerve has two distinct divisions within the single nerve sheath, the tibial and peroneal divisions. The peroneal division is more susceptible to injury, compared to the tibial division, at all levels along the course of the sciatic nerve. The increased susceptibility is the result of the more-lateral location and a more-tenuous blood supply of the peroneal division within the sciatic nerve sheath.

Therefore, a partial injury to the sciatic nerve commonly results in a foot drop, clinically similar to the deficits seen in an isolated injury to the common peroneal nerve injury at the level of the fibular neck. One anatomic point with important clinical relevance is that the peroneal division of the sciatic nerve has only one motor branch in the posterior thigh supplying the short head of the biceps. Determining if the short head of the biceps is normally innervated can assist in determining the level of peroneal nerve injury clinically (i.e., the hip or knee).

Vascular Anatomy of the Proximal Femur and Femoral Head

The medial and lateral femoral circumflex vessels in conjunction with the artery of the ligamentum teres provide the vascular supply to proximal femur and femoral head (Fig. 11-5). The medial femoral circumflex artery extends posteriorly and ascends proximally deep to the quadratus femoris muscle. At the level of the hip it joins an arterial ring at the base of the femoral neck. The lateral femoral circumflex artery extends anteriorly and gives off an ascending branch, which also joins the arterial ring at the base

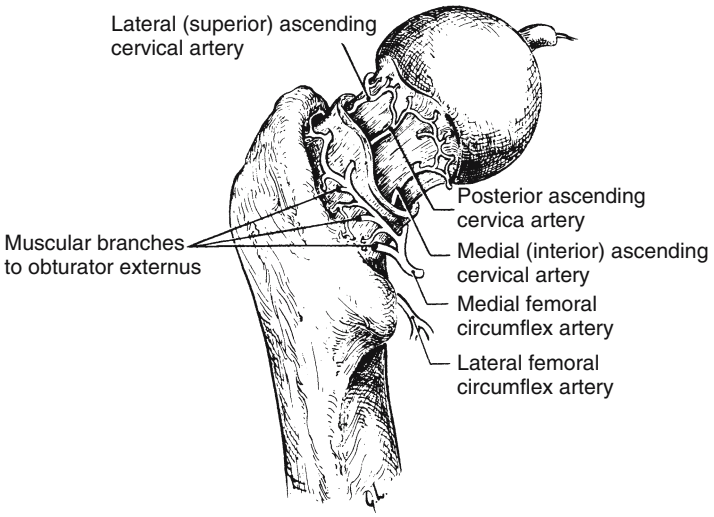


FIGURE 11-5. Arterial supply to the head and neck of the posterior aspect of the left proximal femur. Note the extracapsular arterial ring on the surface of the capsule, the ascending cervical arteries on the neck of the femur, and the intra-articular sub-synovial arterial ring at the articular cartilage margin. (From Steinberg M (ed) The Hip and Its Disorders. Philadelphia, WB Saunders Company, 1991, p 19.)

of the femoral neck. This vascular ring gives rise to a group of vessels that run in the retinacular tissue inside the capsule to enter the femoral head at the base of the articular surface. These vessels provide 80% to 90% of the blood supply to the femoral head. The artery of the ligamentum teres, a branch of the obturator artery, travels within the ligamentum teres and supplies only 10% to 20% of the blood supply to the femoral head.

Biomechanics

The joint reaction force is the sum of all the forces that cross a joint, including components from gravity, body weight, and muscle forces acting upon the joint. In two-legged stance with both feet on the ground and static conditions, a joint reaction force of approximately 1.3 to 1.5 times body weight will cross each hip joint. However, in single-limb stance this force increases to 2.5 to 3 times body weight across the hip joint. The primary contribution to the increase is the force generated by the abductor muscles to maintain balance and to keep the pelvis level. If the system is in motion, such as with walking, the joint reaction forces can be as high as 4 times body weight.

Several studies have measured the actual joint reaction forces during rehabilitation using an implanted instrumented prosthesis. The greatest joint reaction force was noted when the patients arose from a low chair or during stair climbing. However, even nonweight-bearing activities such as getting onto a bedpan were found to have a joint reaction force of 1.5 to 1.8 times body weight. The lowest joint reaction forces with ambulation were recorded when patients used touch-down weight-bearing. Touch-down weight-bearing allows the patient to rest the foot on the ground to balance the weight of the leg but not to step down or weight-bear on the involved lower extremity.

Gait

The principal function of the lower extremities is ambulation. In gait analysis, a gait cycle examines one leg, beginning with heel strike and continuing until the next heel strike of the same leg. Gait can be divided into two principal phases, stance and swing. The stance phase is defined as that portion of the gait cycle when the foot is in contact with the ground. The swing phase is therefore the portion of each step when the foot is not in contact with the ground. The stance phase makes up 60% of each step with the remainder being made up by the swing phase. Therefore, during 20% of the gait cycle both feet are in contact with the ground. Normal gait requires a stable pelvis, which is provided by the hip abductor muscles. Normal gait also requires 40 degrees of hip flexion and 10 degrees of internal rotation and external rotation.

Patient Evaluation

History

The evaluation of a patient with hip pain requires careful attention to the history, physical examination, and radiographic studies. The character, nature, and duration of the patient's pain should be documented. Acute or recent-onset pain is more commonly associated with trauma or infection. Chronic and gradually progressive pain is associated with arthritic conditions. Intraarticular pain is usually described as a deep aching pain. Pain from the hip joint is commonly noted anteriorly in the groin or in the region of the greater trochanter. Hip pain can radiate down the inner and anterior thigh to the knee with little or no pain in the area of the hip. Only rarely does hip pain radiate distal to the knee. In adolescent patients, it is not uncommon for hip pathology to present as knee pain. Therefore, a thorough physical and radiographic evaluation of the hips is necessary to identify the pathology in these patients. Posterior pain and buttock pain is more commonly associated with lumbar spine pathology. Spine pain also more commonly radiates down the posterior thigh and below the knee. The insidious onset of a deep boring pain and pain that awakens the patient at night suggest either infection or neoplastic disease.

Hip pain is commonly aggravated by activity and relieved by rest. Patients will report difficulty donning and doffing their shoes and socks and difficulty with toenail care on the involved extremity. As the pain progresses, patients begin to have pain with prolonged sitting and at night as they try to sleep. Patients with hip arthritis will report that, if they sit for a prolonged period of time, when they get up to walk the hip feels out of place or painful for the first few steps. This feeling usually resolves quickly after a few minutes of walking.

The use of a cane, walking stick, or crutch should be documented. The patient may also have begun to take over-the-counter antiinflammatory medication or pain relievers. The medication and the amount the patient is taking as well as the level of relief this provided needs to be recorded. The patient's walking tolerance can be measured in terms of blocks the patient can walk or in terms of how many minutes the patient can be ambulatory doing activities such as grocery shopping or walking in a mall. Documentation of these data will give a detailed picture of the degree of pain and the patient's functional limitations.

Patients should also be questioned about past problems with the hip such as hip dislocation at birth, delays in ambulation as an infant, and any bracing as a child. Previous surgery or trauma to the hips should be explored in detail. The past medical history and any medications the patient is taking should be noted. This information can have implications for the patient's hip problems and may have an impact upon what treatment may be instituted.

Physical Examination

The most important aspect of the physical examination in patients with hip disease is to evaluate their gait pattern as this reveals important information about the patient's ambulatory status and pain. Patients with significant hip pain manifest a coxalgic gait. This gait pattern is represented by a reduced stance phase on the painful leg, and the shoulders will lurch laterally over the affected hip. Patients with mild pain or weakness in the abductor muscles may have a stance phase equal to the opposite leg but the shoulders will continue to lurch over the affected leg. This lurch results in moving the center of gravity closer to the center of rotation of the hip, which in turn reduces the force necessary to stabilize the pelvis in stance phase. This gait is referred to as a Trendelenburg gait (equal stance phase and the shoulders lurching over the affected hip).

The hip should be inspected for previous scars, swelling, bruises, or abrasions. The region then should be palpated to identify areas of focal tenderness such as over the greater trochanter, sciatic nerve, or anterior hip capsule. The range of motion of the hip should then be determined. Normal range of motion of the hip is flexion to 130 degrees, extension to 20 degrees, adduction to 30 degrees, abduction to 40 degrees, internal rotation to 30 degrees, and external rotation to 70 degrees. When assessing the range of motion of the hip it is important to stabilize the lumbar spine. Motion in the lumbar spine may be attributed to the hip if the examiner is not careful. The Thomas test will stabilize the lumbar spine to measure for a flexion contracture of the hip (Fig. 11-6). Movement of the pelvis with abduction and adduction can be accurately assessed by placing a hand on the opposite anterosuperior iliac spine and recording the amount of motion before pelvic abduction.

To assess the function of the hip abductor muscles, the patient should lift the involved leg off the floor while standing. The patient should now be standing on the uninvolved leg and the pelvis should remain level. The patient now stands on the involved leg and lifts the uninvolved leg off the floor. If the pelvis is level, then the patient has normal strength of the abductor muscles. If the pelvis is noted to be lower on the elevated leg, then the abductor muscles are weak or the hip that is weight-bearing is painful. This result is referred to as the Trendelenburg sign.

A careful neurologic examination and lumbar spine examination are essential to assessing the possibility of spine pathology producing pain radiating to the hip. Patients with significant arthritic disease in the hip also commonly have spine pathology. Hip arthritis and restriction in hip range of motion can exacerbate spine pathology. The limited range of motion of the hip results in increased motion at the lumbosacral junction, which can aggravate degenerative facet arthropathy and lumbar stenosis. Replacement of the hip and improvement in the range of motion in the hip,

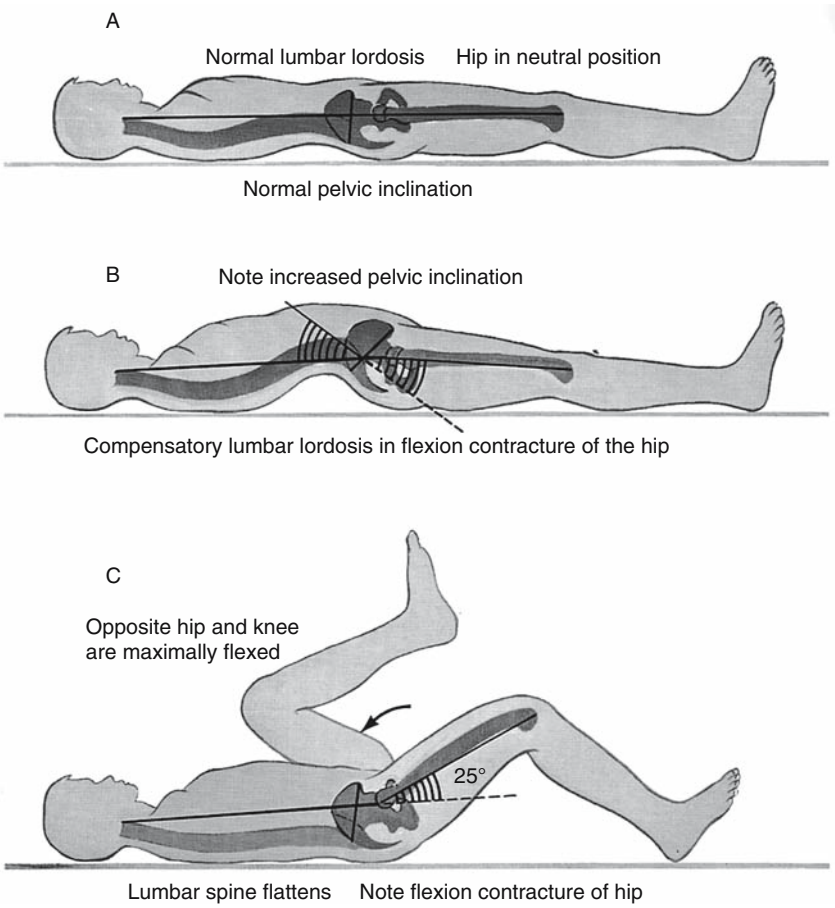


FIGURE 11-6. Diagrammatic representation of the Thomas test to assess hip flexion contracture. (Adapted from von Lanz T, Wachsmith W: Praktische Anatomic. Berlin, Julius Springer, 1938, p 157.) (From Tachdjian MO: Pediatric Orthopaedics, ed 2. Philadelphia, WB Saunders Company, 1990, p 28. Reprinted by permission.)

however, can relieve stress from the lumbosacral junction and subsequently relieve the patient's pain.

In addition, the pulses should be palpated in the foot and ankle. Significant reduction may indicate vascular insufficiency and may require further evaluation. Vascular compromise may impair wound healing or may lead to acute vascular crisis in the early postoperative period if this is not recognized and treated before any elective hip procedure. In addition, if any significant vascular reconstruction has been done in the area of the involved hip, care must be taken at the time of surgery to avoid damage to the previous reconstruction.

Radiographic Evaluation

Routine radiography of the pelvis and hips is the most useful study in evaluating hip pathology. Standard anteroposterior (AP) radiography of the pelvis will reveal the lower lumbar spine, sacroiliac joints, innominate bone, pubic symphysis, hip joint, and proximal femurs. Frequently, in unilateral disease, the normal side can be used for comparison (Fig. 11-7). Lateral views of the proximal femurs can also be helpful in defining pathology and in determining the size and location of a pathologic lesion. Four pelvic oblique views can be obtained to further evaluate the pelvis and acetabulum, particularly in cases of trauma: the inlet, outlet, and Judet views. Judet views are 45 degree pelvic oblique views, which are useful for examination of the acetabulum. The obturator oblique is a 45 degree internally rotated view of the pelvis (Fig. 11-8). The obturator foramen is roughly perpendicular to the beam and the iliac crest is in line with the beam. This view clearly demonstrates the anterior column and posterior rim of the acetabulum. The iliac oblique view is a 45 degree externally rotated view of the pelvis and acetabulum (Fig. 11-9). The iliac wing is perpendicular to the beam and the superior and inferior pubic rami are parallel to the beam. This view clearly demonstrates the anterior rim and the posterior column of the acetabulum.

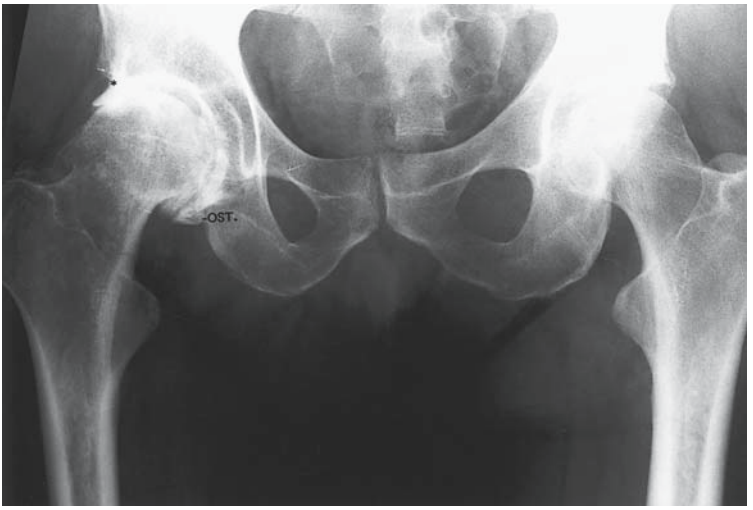


FIGURE 11-7. A 75-year-old patient with severe right hip pain. The radiograph reveals a normal left hip and advanced arthritic changes in the right hip. The right hip demonstrates a lateral femoral neck osteophyte, subchondral sclerosis of the subchondral bone, and a subchondral cyst in the femoral head.

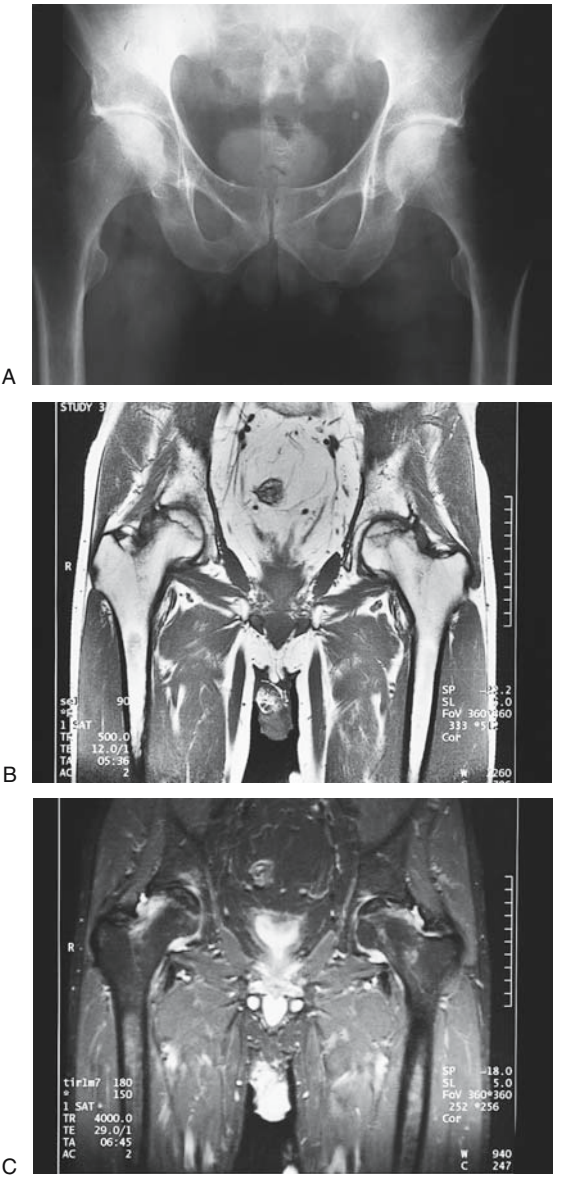


FIGURE 11-8. A 34-year-old man with a history of 4 months of increasing bilateral hip pain. (A) Anteroposterior (AP) pelvic radiograph is essentially normal. (B) T_1-weighted magnetic resonance image (MRI) of the pelvis and hips demonstrates a line of decreased signal intensity across the superior one-third of the femoral head, which represents the new bone laid down at the periphery of the lesion that serves to wall off the lesion. (C) T_2-weighted image demonstrates the same line of decreased signal intensity across the femoral head. However, this image also demonstrates a zone of increased signal intensity, consistent with the fibrovascular response to the necrotic bone.

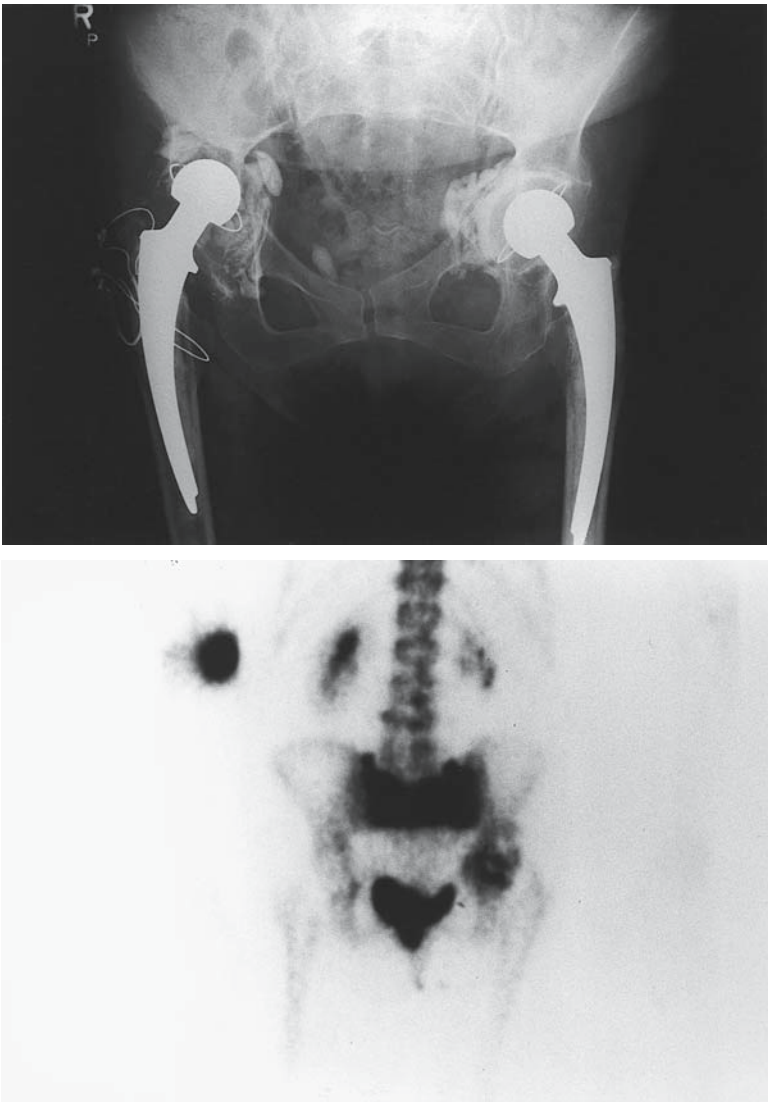


FIGURE 11-9. This 84-year-old woman presented with severe hip pain after a car ride. The patient had bilateral hip replacement approximately 15 years before presentation. (A) AP pelvic radiograph demonstrates a patient with significant diffuse osteopenia and two hip replacements. Both hips appear to have some loosening of the acetabular components but demonstrate no acute changes. (B) Delayed image from a Tc 99-MDP bone scan demonstrates significant uptake in the left acetabulum. However, there is diffuse marked increase uptake throughout the sacrum. This pattern of uptake is consistent with a sacral insufficiency fracture.

The inlet and outlet views are useful for patients with pelvic trauma to demonstrate translation of the involved hemipelvis (Fig. 11-10). The inlet view is taken with the beam oriented from cephalad to caudad 45 degrees to demonstrate the anterior or posterior translation of the involved hemipelvis. The outlet view is taken with the beam oriented 45 degrees from

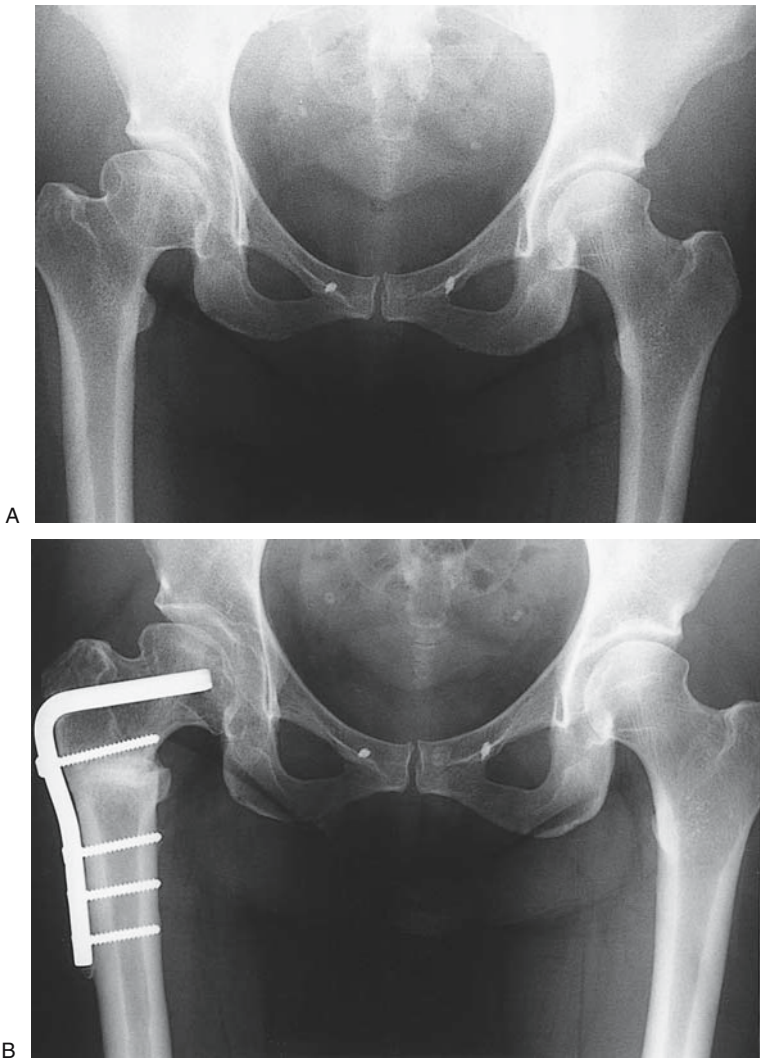


FIGURE 11-10. A 37-year-old woman with 1 year of increasing right hip pain. (A) Initial AP radiograph demonstrates a large femoral head with a shortened femoral neck, most likely the late result of Perthe's disease of the hip. (B) The patient underwent an osteotomy of the proximal femur to address her hip pain.

caudad to cephalad, providing a true AP view of the sacrum. Also, this view can clearly demonstrate any superior or inferior translation of the hemipelvis.

Computerized tomography (CT) of the pelvis is most helpful in evaluating trauma. In some centers this modality has replaced and certainly augments the use of oblique pelvic radiography. CT imaging is particularly helpful in demonstrating fractures in the posterior pelvis and sacrum, which may be poorly visualized in routine radiography. Fractures to the acetabulum are well visualized on CT scan images. CT images can clearly delineate the extent of the fracture as well as demonstrate any intraarticular fragments that may be present. The CT can also be converted into a three-dimensional image to more clearly demonstrate the fracture pattern. CT imaging can also be utilized to demonstrate other nontraumatic pathology. For example, anterior osteoarthritis, which may be subtle on the plain radiographs, can readily be appreciated on CT images. Avascular necrosis may also be evaluated with this technique. CT images can augment plain radiography in demonstrating early collapse, which may affect the treatment options available to the patient.

Magnetic resonance imaging (MRI) of the hips is indicated in patients in whom a periarticular lesion is suspected or to evaluate for the presence of avascular necrosis of the femoral heads (see Fig. 11-8). MRI is a very sensitive and specific tool for the evaluation of AVN as it can readily demonstrate the avascular segment before changes are seen on the plain radiographs. MRI can also be helpful in demonstrating a tear in the acetabular labrum, which is best demonstrated by the use of MR arthrography. MR contrast material is injected intraarticularly and an MR of the hip is obtained; the contrast outlines the labrum and any defect in labrum can be identified.

The Tc 99-MDP bone scan can be helpful in evaluating pelvic pathology. The bone scan can be used as a sensitive indicator of osseous pathology in the pelvis. Metastatic disease, occult fractures, infection, or osteomyelitis can be identified (see Fig. 11-9). The bone scan is most helpful as a general skeletal screening tool for metastatic disease. The bone scan is very sensitive but is not specific. Therefore, other studies such as MR or CT may be necessary to fully evaluate the nature and extent of any identified pathology.

Hip aspiration and arthrography can be helpful in the evaluation of pathology. Aspiration can be helpful in evaluating hip sepsis in both a native hip as well as after hip arthroplasty. Aspiration is best performed under fluoroscopic guidance. An arthrogram can then be utilized to confirm the intraarticular position of the needle. Arthrography can also be utilized to assess loosening of a hip prosthesis. The contrast material can be noted flowing around the loosened implant, demonstrating the separation of the implant, cement, and bone. Not infrequently patients present with a history of both hip and spine pathology. Injection of local

anesthetic with or without a corticosteroid medication into the hip under fluoroscopic guidance can be helpful in differentiating the pain coming from the hip with that coming from the spine. If the intraarticular local anesthetic results in significant relief of pain, the pain is most likely intraarticular in origin. If the local anesthetic agent does not alter the pain, extraarticular pathology or spine disease should be investigated. Aspiration of the hip should be performed under fluoroscopic guidance.

The patient's history and physical examination direct the use of these radiographic techniques. The appropriate use of these diagnostic tests can result in cost-effective and accurate diagnosis and properly directed treatment.

Hip Pathology

A variety of soft tissue conditions can affect the hip. Although these conditions are not uniformly associated with trauma or injury, an injury can be the inciting event. Trochanteric bursitis is a common condition of the hip. The pain results from inflammation within the trochanteric bursa, which is located over the lateral aspect of the greater trochanter under the fascia lata. It is associated with pain over the lateral aspect of the hip in the region of the greater trochanter. The pain is a deep ache centered over the greater trochanter with radiation both proximally to the pelvic brim and distally occasionally all the way to the knee. The pain is exacerbated by adduction of the hip with the knee extended. No pathologic changes are noted on either plain radiographs or MRI. The treatment consists of stretching the fascia lata and iliotibial band and the use of nonsteroidal antiinflammatory medications. If these conservative measures are unsuccessful, the patient may benefit from physical therapy with the use of local modalities such as ultrasound and iontophoresis. These modalities can be augmented with a corticosteroid injection into the bursa. If these nonoperative modalities fail to relieve the pain, the bursa can be surgically excised. However, this option is rarely required.

The iliotibial band and the trochanteric bursa can also be involved in the snapping hip. The iliotibial band snapping over the trochanteric bursa and the greater trochanter causes this condition, which is not always painful. The treatment is similar to that for trochanteric bursitis. Snapping in the hip can also occur anteriorly. The iliopsoas tendon can snap over the anterior aspect of the hip where the tendon exits the pelvis over the anterior pelvic brim, resulting in an anterior snap with flexion and extension. The amount of pain associated with the snap is variable. Treatment is directed toward alleviation of the pain. Nonsteroidal antiinflammatory medications can be helpful in alleviating the pain. Stretching of the iliopsoas with hip extension can also help to reduce the symptoms.

Another cause of a snapping hip is a tear in the acetabular labrum. The acetabular labrum is a dense fibrocartilaginous structure that is attached

to the acetabular rim which can be injured similarly to a meniscal injury in the knee. The labrum is more prone to injury in patients with acetabular dysplasia. In this condition, the acetabulum is shallow and the labrum hypertrophies and is weight-bearing. A tear in the acetabular labrum presents clinically with pain in the hip anteriorly, particularly with internal rotation; this is also commonly associated with a click noted when the hip is flexed and extended. The diagnosis can be confirmed with an MRI obtained after the injection of intraarticular contrast dye. The accuracy of this assessment is approximately 85%; without the intraarticular contrast, the accuracy is only 50% to 60%. When a tear is identified, no treatment is necessary if the pain is mild. If, however, the patient has pain or the click is activity limiting, then the tear should be excised or repaired; this can be done either arthroscopically or with an open hip arthrotomy.

Intraarticular loose bodies can occur either as a result of trauma or as a result of synovial chondromatosis. In synovial chondromatosis, the synovium develops osteochondral loose bodies that are free in the articular space. In the knee, these loose bodies cause a great deal of mechanical symptoms such as locking. In the hip, there is not enough free space for the loose body to cause locking. However, these loose bodies can restrict motion and cause pain. Synovial chondromatosis can be difficult to diagnose. The plain radiographs are usually normal or demonstrate the very subtle stippled calcifications of the osteochondral fragments. The MRI or CT scan can be helpful in demonstrating the loose bodies and the expansion of the synovial space and effusion. The treatment is surgical: an arthrotomy is performed and the fragments removed. Synovectomy can be performed, although care should be taken to preserve the vascularity of the femoral head.

Avascular necrosis (AVN) is a condition that most commonly affects the femoral head. However, this condition can also affect the proximal humerus, knee, and talus. The specific mechanism causing AVN is unclear. Several factors have been associated with increased risk of developing this condition. The most common factors are trauma to the femoral head or neck, systemic corticosteroid administration, and excessive alcohol intake. In addition to these factors there is a long list of other less common factors such as hemoglobinopathies, metabolic conditions, and inflammatory conditions that can cause AVN. However, in as many as one-third of patients with nontraumatic AVN no specific etiology can be identified, and thus these cases are identified as idiopathic AVN.

In all cases of AVN there is compromise of the blood supply of the femoral head, which most commonly occurs in the anterosuperior portion of the femoral head, leading to necrosis of a portion of the subchondral bone. If the avascular segment is large and in a weight-bearing area, the stability of the subchondral bone will be compromised as the necrotic trabeculae weaken. This process occurs over 6 to 24 months. Although a Tc 99-MDP bone scan can demonstrate the lesion early, plain radiographs are

frequently normal after the segment becomes avascular. Over time the round femoral head weakens and then develops an area of collapse. At this point the joint is no longer round and congruent, and without intervention the condition frequently progresses to degenerative arthritis.

The lesion of AVN has a very typical pathologic and radiographic pattern. The lesion is most commonly in the anterior and superior subchondral bone of the femoral head and has several distinct zones to the lesion. The outer zone is an area of increased vascularity and inflammation that develops in response to the necrotic segment. The next layer is a dense area of sclerotic bone, which is laid down around the necrotic segment in an attempt to heal the lesion. However, this response simply serves to wall off the lesion and prevents vascular invasion and healing of the lesion. Inside the sclerotic bone is the necrotic bone with the trabecular structure relatively intact. Histologically, the necrosis of the bone is demonstrated by trabecular bone with empty lacunae. Closer to the subchondral bone is the area of collapse of the trabecular bone. The outer layer is composed of the subchondral bone and articular cartilage. Radiographically, a subchondral radiolucent line that is referred to as a crescent sign demonstrates this region. Frequently, after collapse of the subchondral bone there is a defect through the cartilage and the subchondral bone that allows articular fluid to enter the necrotic area; this will further impair healing of the lesion.

In early cases, before collapse of the femoral head, attempts can be made to save the femoral head and restore viability to the necrotic bone. These techniques are surgical. There are several variations; however, all involve drilling a core tract into the avascular portion of the femoral head in an attempt to restore vascularity to the necrotic bone and possibly heal the lesion. Several techniques have been described to augment this procedure: autologous cancellous bone grafting, bone graft substitutes, allograft cortical or cancellous bone, or using one of the patient's fibulae on a vascular pedicle to place vascularized bone into the lesion.

Of patients who have documented AVN that is untreated, 70% will require a total hip replacement with in 5 years. Patients who have had a core decompression-type procedure will require a total hip replacement in 30% to 35% of cases by 5 years. The results are an improvement compared to the natural history; however, the success rate is less than we would prefer. Vascularized fibular grafting has demonstrated an improvement in the survivorship of the involved hip. However, there can be significant weakness in foot and ankle function on the involved side after harvesting the fibula.

For patients with small lesions that have already undergone subchondral collapse, an osteotomy may be done to rotate the necrotic collapsed segment out from under the weight-bearing area of the hip. However, commonly the lesion is extensive and not enough viable bone remains to allow the necrotic segment to be rotated away from the weight-bearing area of the hip. As the AVN progresses and the hip becomes severely degenerated,

hip replacement offers the most reliable means of restoring function and relieving pain. Many of the patients are relatively young to receive a total hip replacement. The average age of patients with AVN is approximately 35 to 45 years. The results of cemented arthroplasty in this population have not been as successful as in patients with osteoarthritis. Noncemented fixation does appear to have less loosening compared to cemented fixation in this population. However, the rate of other complications such as dislocation, infection, and hematoma are increased in this population regardless of the method of fixation of the components.

Hip Arthritis

A wide variety of arthritic conditions can affect the hip joint. While the medical therapy can vary based upon the specific diagnosis, the operative treatments fall into several broad categories and are discussed as such. Arthritis is defined as any condition that results in articular cartilage damage with resulting pain and limitation of the motion of a joint. Hip arthritis can be divided into several broad categories (Table 11-1).

The clinical presentation of hip arthritis is a gradual increase in pain and limitation of motion. Frequently patients complain of a reduction in their ability to walk for distances. Patients also notice a marked stiffness in the joint when they have been sitting for a period of time and then stand. The joint feels out of place or stiff, although this symptom usually resolves after a few steps. As the arthritis progresses and the joint begins to lose motion, patients will also notice a reduction in their ability to care for their own toenails and difficulty with activities such as putting on socks or stockings and tying their shoes. A limp also commonly occurs in patients with hip arthritis, particularly after long walks or at the end of the day.

Table 11-1. Classification of hip arthritis.

Category	Examples	Etiology
Osteoarthritis	Primary osteoarthritis	Idiopathic
	Secondary osteoarthritis	Congenital
		Developmental
		Avascular necrosis
		Posttraumatic
Inflammatory arthritis	Rheumatoid arthritis	Immunogenic
	Ankylosing spondylitis	
	Psoriatic arthritis	
	Systemic lupus	
Infectious	Pyogenic	*Staphylococcus aureus, S. epidermidis,* gonococcal
	Lyme disease	*Borrellia*
	Nonpyogenic	*Mycobacterium*
Other	Crystals	Gout, pseudogout
	Hemophilia	Hemosiderin deposition

Radiographic and etiologic criteria can assist in dividing the patients into two broad categories, osteoarthritis and inflammatory arthritis, based upon the history and the radiographic appearance of the hip joints. Osteoarthritis has four classic features on plain radiography: localized joint space narrowing, subchondral sclerosis, osteophyte formation, and subchondral cysts. In rheumatoid arthritis, as a classic example of an inflammatory arthritis, the radiographic features are periarticular osteopenia, diffuse or global joint space narrowing, and occasionally subchondral cysts. In inflammatory arthritis of the hip, protrusio deformity of the femoral head beyond the ilioischial line can be noted as well. In most cases of arthritic disease in the hip no additional studies other than plain radiography are necessary for the evaluation.

The nonoperative treatment varies based upon the specific diagnosis. Osteoarthritis, whether primary or secondary, is treated in a similar fashion. The treatment for the majority of patients with osteoarthritis is nonoperative. There are five primary interventions in the nonoperative management of the patient with osteoarthritis (Table 11-2).

These five interventions can be used in isolation or in combination based upon the specific clinical situation in which the patient presents. Nonsteroidal antiinflammatory drugs (NSAIDs) can be very effective in reducing the pain and improving function. However, there is a large individual variation in the efficacy and side effects with each of these agents. Therefore, patients should be tried on several NSAIDs from different chemical classes before abandoning this limb of therapy. The principal side effect of NSAIDs is gastrointestinal (GI) intolerance with the possibility of ulcer formation. NSAIDs can also affect renal and hepatic function, and in the long-term, use of these agents renal and hepatic function should be followed. In addition, these medications can affect platelet function and may have an adverse effect on bleeding times. These medicines should not be used in patients requiring anticoagulation therapy or within 5 to 7 days preceding any surgical intervention.

The cyclooxygenase 2 (COX-2) inhibitors may offer lesser side effects compared to the nonspecific cyclooxygenase inhibitors that represent the majority of the NSAIDs on the market; however, this benefit needs to be demonstrated in large clinical trials. The COX-2 inhibitors also have less effect on platelet function and may be safe to use for patients on anticoagu-

TABLE 11-2. Primary interventions in the nonoperative management of osteoarthritis.

Nonsteroidal antiinflammatory medications
Physical therapy
Intraarticular injection of corticosteroids
Assistive devices
Modification of activities

lation therapy. The efficacy of these medicines for pain relief will probably be similar to that noted with traditional NSAI medications. However, their safety is currently being investigated as they may be associated with an increase in cardiac disease.

Intraarticular corticosteroid injections are helpful for the treatment of an acute exacerbation in pain. Intraarticular injections are more beneficial in the treatment of shoulder and knee and knee pathology compared to the hip. They have not been as widely utilized for arthritis of the hip, in part because of the difficulty ensuring the injection is in fact intraarticular. Fluoroscopy is helpful in confirming proper placement of the needle. Injection of the hip with local anesthetic can be helpful in differentiating referred back pain from intraarticular hip pathology. Also, there are patients who have a strong referred pain from the hip to the knee; in these patients, an intraarticular hip injection will relieve the knee pain and confirm its site of origin. However, injections are limited in their ability to provide long-term relief of symptoms. Corticosteroid injection for arthritis should not be done more than three times per year. If the patient requires more-frequent injections for pain control, other therapeutic measures or surgery should be considered. Repeated injection of the joint is not indicated because this will result in acceleration of articular cartilage degeneration and increase the risks of complications such as infection.

Physical therapy can be beneficial in reducing pain and improving range of motion for osteoarthritis involving the knee or shoulder; however, limited benefit has been found for the treatment of osteoarthritis involving the hip. If this modality is to be utilized it should be done early in the course of osteoarthritis. As the arthritis progresses, therapy will only serve to exacerbate an already painful joint. However, all patients should be encouraged to maintain aerobic fitness to maintain their joint function as well as their general health. Activities such as swimming and cycling have minimal repetitive impact and are excellent for aerobic fitness. Activities such as running and racquet sports can further damage an arthritic joint and should be discouraged in a patient with hip arthritis. As the arthritis progresses the patient is able to do less and less and becomes more sedentary. As this occurs, the symptoms also will increase in severity.

Assistive devices including crutches, cane, and a walker can be quite effective in the relief of stress across the joint surface with ambulation in patients with osteoarthritis involving the lower extremities. A cane used in the contralateral hand of a patient with isolated hip arthritis can reduce the joint reaction force by as much as 30%. However, the use of these devices is associated with a significant change in a patient's perception of themselves and their global health status. So, although this modality can be helpful in relieving symptoms and maintaining mobility, it will commonly meet resistance from the patient.

Modification of activities is one of the most significant aspects in the nonoperative management of arthritis, which includes modification in a

patient's activities of daily living and self-care. Modification of car-parking and obtaining devices to assist in putting on shoes and socks, for example, can be very helpful for patients with limitations caused by hip arthritis. Reduction in certain activities such as running or racquet sports can improve the joint symptoms. However, this change will result in a gradual progressive decrease in the patient's quality of life. The level of social interaction and activities in which the patient can comfortably participate can become markedly reduced. Modification of activities should also address patients who are overweight. Reduction in weight can significantly improve a patient's symptoms, increase their mobility, and improve their global health status. In addition, reduction in weight will reduce the stress placed upon the joint replacement if they require surgery.

The nonoperative management of a patient with osteoarthritis involves all the aforementioned therapies. However, as the arthritis progresses, pain and limitation of activities continue to increase. When the patient fails to achieve acceptable symptomatic relief with the nonoperative regimen, joint replacement should be discussed. No significant change in the complexity of the surgery or outcome will be noted in patients with hip arthritis who delay operative intervention with nonoperative treatment. Therefore, the timing of the surgical intervention is based entirely upon the patients and their pain and limitations.

Surgical Management

Most hip pathology can be managed with one of several options: these include arthroscopy, osteotomy, arthrodesis, and arthroplasty (hemi-arthroplasty or total hip arthroplasty). Each option has specific indications and contraindications, discussed in the next few sections.

Arthroscopy

Hip arthroscopy is in its infancy compared to this technique in the knee. The indications for hip arthroscopy are to remove loose bodies from the hip joint, to address acetabular labral pathology, and to identify articular cartilage defects. The technique requires the use of special equipment because of the more extensive soft tissue envelope around the hip compared to the knee. The soft tissue envelope also limits the mobility of the arthroscope within the hip. In addition, the hip capsule is quite thick and the articular space quite small. Frequently traction is required to gain visualization of the hip joint. The portals must be opened with care to avoid injury to the neurovascular structures surrounding the hip. These issues have significantly slowed the widespread use of this technique in practice today.

Arthrotomy

Arthrotomy involves surgical opening of the hip joint. Many of the indications for hip arthroscopy are also indications for hip arthrotomy, such as removal of loose bodies and addressing acetabular labral lesions. However, hip arthrotomy can also address the drainage of hip sepsis and hip synovectomy. The hip joint can be exposed and opened from either the anterior aspect or the posterior aspect. Anterior approaches are more commonly utilized as this approach is less likely to injure the blood supply to the femoral head, which arises from the medial femoral circumflex vessels along the posterior intertrochanteric line.

The hip joint is then opened usually from the acetabular edge with care taken to preserve the acetabular labrum. If the labrum is torn it can either be excised or repaired, depending upon the condition and nature of the tear. Traction may need to be applied to the leg to allow inspection of the hip joint. Any loose bodies or fragments can be removed. If the indication for arthrotomy is synovectomy, it may be necessary to open the hip both from the posterior as well as the anterior aspect. This requirement does increase the risk of postoperative avascular necrosis; however, the synovium of the hip cannot be removed from a single approach.

Osteotomy

Osteotomy involves redirecting the articular surface to move damaged cartilage from the weight-bearing areas of the joint and place a less-damaged area of the articular surface in the weight-bearing area of the hip joint (see Fig. 11-10). Osteotomy can also reduce joint forces by realigning the bone of the pelvis or proximal femur to yield a larger area of contact to distribute the force of weight-bearing. During osteotomy, the bone of the pelvis or femur is transected, redirected, and then fixed rigidly. If the arthritis is localized to only one region of a joint, by performing an osteotomy the damaged cartilage can be moved away from the weight-bearing area, and undamaged articular surfaces are transferred into the high-stress area. The result is reduced pain and prolongation of the functional life of the patient's native joint. Prerequisites for an osteotomy are that the patient has an adequate range of motion of the joint, that the joint is stable, and that the articular damage involves only a limited area of the joint. If extensive arthritis or an inflammatory arthritis is present, an osteotomy will not be successful.

In properly selected patients, hip osteotomies can have a success of greater than 80% at 8 to 10 years follow-up. For young patients with focal articular damage, osteotomy can provide an acceptable result and allow them to retain their own hip joint; this can delay or possibly eliminate the need for replacement with artificial materials, which can wear or become loose. Acetabular osteotomy for developmental dysplasia of the hip can

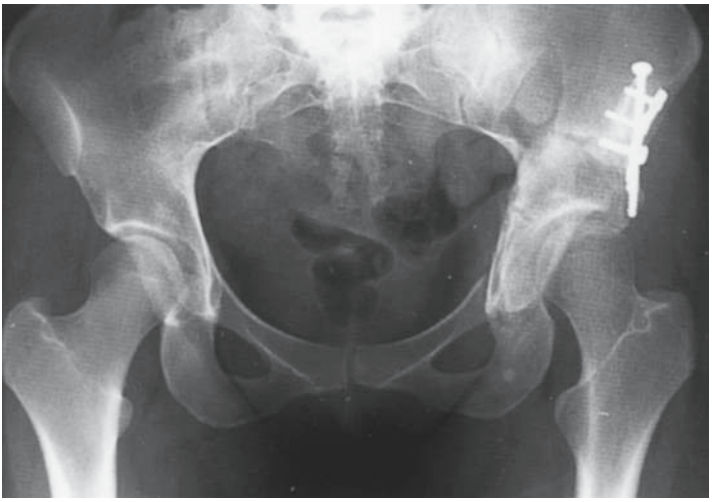


FIGURE 11-11. Anteroposterior radiograph of a 26-year-old female 6 months after a left pelvic osteotomy was performed to deepen her acetabulum and improve coverage of the femoral head. Her primary diagnosis was developmental dysplasia of the hip, which left her with a shallow left acetabulum.

make subsequent total hip arthroplasty easier by redirecting the acetabular bone stock and providing better coverage for an acetabular component (Fig. 11-11). However, osteotomy of the proximal femur can make a future hip replacement more difficult by altering the anatomy of the proximal femur; this may require an additional osteotomy to reconstruct the femur at the time of total hip replacement.

Arthrodesis

Arthrodesis involves the fusion of the proximal femur to the pelvis, which can provide a strong, stable, painless lower extremity. The patient can return even to heavy labor without the risk of loosening or damage to the arthrodesis. Arthrodesis is indicated in patients who are young with unilateral hip disease with no symptoms or disease involving the lumbar spine, contralateral hip, or ipsilateral knee. Patients with an inflammatory arthritis or nontraumatic AVN are relatively contraindicated for arthrodesis, as these diseases are frequently bilateral. Several studies of the long-term results of arthrodesis have found good results lasting greater than 20 years.

However, the hip is stiff, and after 15 to 20 years the arthrodesis can result in low back pain and pain in the ipsilateral knee. Several reports have noted between 50% and 60% of patients complaining of pain in the back or knee at 25 to 50 years follow-up. If the pain is severe, the fusion

can be taken down surgically and a total hip replacement performed. The outcome of this surgery depends upon the functional status of the hip abductor muscles. If the surgical arthrodesis involved the removal of the insertion or origin of the hip abductors, the patient will have an increased rate of dislocation, pain, and limp after conversion to total hip replacement. These complications can be minimized if the technique used for the arthrodesis spares the hip abductor muscles. The return to a mobile hip can relieve the patient's low back pain; however, they may experience pain in the hip that they did not have with the arthrodesis.

Hip Replacement Surgery

Total hip replacement (THR) is a common operation today. Approximately 250,000 replacements are performed each year. The primary goal of hip replacement is to relieve pain, which can be accomplished in more than 95% of patients. The results of THR can last approximately 15 years or more. In fact, one study found that more than 90% of THRs survived a minimum of 30 years.

In total hip replacement, both the socket (acetabulum) and the ball (femoral head) are replaced with metal and plastic parts. The socket is replaced with either a plastic cup cemented onto the bone or by a metal shell impacted into the prepared acetabular space with a removable liner (Fig. 11-12). The ball is replaced by a metal ball attached to a stem that goes inside the canal of the femur. Two principal types of implants are used

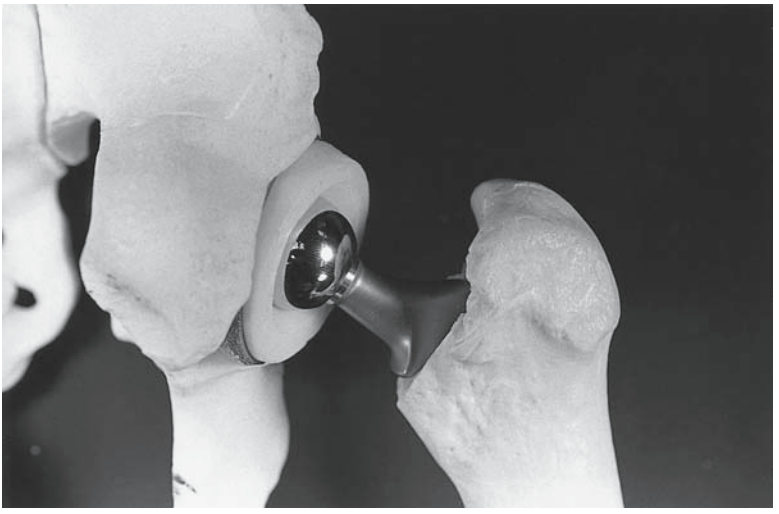


FIGURE 11-12. Total hip arthroplasty with the acetabular component press-fit onto the pelvis and the femoral component inserted into the femoral canal, with the femoral head articulating with the acetabular polyethylene liner.

today: those inserted with bone cement and those inserted without cement and designed to allow bone to grow onto or into a porous metal surface. Both techniques have excellent long-term follow-up data supporting their effectiveness.

The principal advantage of utilizing bone cement is that immediate rigid fixation is obtained. The bone does not need to respond to the implant to obtain fixation. In patients with an average age of 65 years, excellent survival of 30 years or greater has been noted. The patients can fully weight-bear immediately after the surgery, which facilitates their rehabilitation. In addition, the implants are simpler to manufacture and are correspondingly less expensive. Noncemented fixation requires the bone to respond to the implant to provide rigid long-term fixation. The implant has a surface that allows the bone to grow into or onto to stabilize the implant. Many surgeons keep the patient on restricted weight-bearing for the first 6 weeks postoperatively to allow for bone ingrowth. If the bone does stabilize the implant as the bone remodels over time, rigid fixation should be maintained over the long term.

Noncemented fixation is compromised by the presence of thigh pain, which is a mechanical pain that occurs over the anterior thigh. It is mechanical in nature, increasing with weight-bearing and usually relieved by rest. Usually thigh pain can be controlled with NSAIDs or mild narcotic analgesics. In a small number of patients, 1% to 2%, the pain can be severe. In these cases stem revision is indicated. Thigh pain is present in 5% to 15% of patients. Thigh pain is not uniformly associated with loosening of the stem. Thigh pain usually peaks by 6 months postoperatively, but it can persist for up to 18 to 24 months. In a small number of patients, it can persist indefinitely. Thigh pain is only rarely seen in cemented fixation and is usually associated with loosening.

Total hip arthroplasty is performed from either an anterior, posterior, transtrochanteric, or minimally invasive (MIS) approach. The transtrochanteric approach utilizes an osteotomy of the greater trochanter to mobilize the abductors to gain access to the hip joint; this has the advantage providing excellent exposure by lifting the abductors superiorly, allowing visualization of both the anterior and posterior column of the acetabulum. In addition, advancing the trochanter distally to tighten the abductors and reduce the risk of postoperative dislocation can increase the stability of the total hip. However, historically there has been a trochanteric osteotomy nonunion rate of 5% to 15%. Trochanteric nonunion will result in a persistent limp and an increased rate of hip dislocation postoperatively. The transtrochanteric approach is currently used primarily for revision procedures where additional exposure is required.

The posterior approaches are the most commonly used for total hip replacement. The dissection is carried posterior to the trochanter. The short external rotators are divided and a posterior capsule is opened; this creates a defect in the posterior capsule. The hip is dislocated posteriorly

by flexion, adduction, and internal rotation. The posterior approach provides an excellent extensile exposure to the pelvis, hip, and femur. In addition, the gluteus medius and minimus are preserved, optimizing the function of the hip abductors postoperatively. However, postoperatively the patients are most at risk for a posterior dislocation with flexion, adduction, and external rotation. The rate of instability after a posterior approach is 2% to 5% in primary total hip replacement.

Anterior approaches to the hip are also commonly employed for total hip replacement. These approaches enter the hip from in front of the greater trochanter by detaching a portion of the gluteus medius and minimus. The anterior capsule is then opened. The hip is extended, adducted, and externally rotated to dislocate the femoral head and the arthroplasty completed. This approach can yield extensile exposure proximally and distally; this leaves the posterior capsule intact, protecting the patient from a posterior dislocation. The rate of instability is 1% to 2% in most series. Thus, the rate of instability is less with the anterior approach compared to the posterior approach. However, by detaching a portion of the gluteus medius from the trochanter, the muscle is weakened, which can lead to a greater incidence of limp and pain in the postoperative period. Further, if the repair of the detached gluteus medius pulls off the trochanter, the patient may be left with a persistent Trendelenburg limp.

Currently there is a great deal of interest in minimally invasive approaches for hip replacement; these can be done from either a single incision of 4 inches or less or from two 2-inch incisions. Also, there are minimally invasive anterior and posterior approaches. The single-incision approaches are an evolution of what we have done in the past. The two-incision MIS approach requires the use of fluoroscopy for implant placement. Because the surgeon cannot fully visualize the femur during implantation, the excess cement cannot be adequately removed after cementing a stem in place. Thus, the surgeon is limited to the use of noncemented implants with a two-incision MIS approach. The two-incision approaches are new and need additional research to demonstrate safety and durability.

All approaches can provide good exposure and a successful arthroplasty. However, there is a trade-off in terms of stability and function. The posterior approach does not violate the abductors and has a low incidence of limp postoperatively. However, the posterior capsule is opened and the rate of instability is increased, whereas the anterior approaches leave the posterior capsule intact with a correspondingly lower rate of instability. The abductor mechanism is partially detached and repaired, which may leave the abductors weak and yield an increased rate of limp postoperatively.

The patient is mobilized to a chair the day of surgery and begins physical therapy. If the femoral component is cemented, the patient may fully weight-bear on the operative leg immediately. If porous ingrowth fixation is utilized, some surgeons allow only restricted weight-bearing for 6 weeks to allow for bone ingrowth. The best exercise in the postoperative period

is walking. With a posterior approach, hip abduction exercises may be done as well. However, if an anterior approach was utilized, the active abduction exercises may be delayed to allow the gluteus medius repair to heal.

Patients need to be careful not to flex the hip beyond 90 degrees and to keep their legs abducted and neutrally rotated for the first 6 weeks to prevent the femoral head from dislocating out of the acetabular component. The rate of instability and the position of greatest instability vary with the approach used for the arthroplasty. With anterior approaches, the greatest instability is with extension and external rotation. The patients usually report a dislocation occurring while they are standing and pivoting or while they are supine in bed with the legs adducted and the feet externally rotated. In contrast, posterior instability occurs when the hip is in a flexed, adducted, and internally rotated position. Patients report instability when they are getting out of a chair, off the toilet, or out of an automobile. The rate of dislocation is greatest in the first 6 weeks postoperatively. If a dislocation does occur with in the first 6 weeks, the rate of recurrent instability is approximately 30%, with the majority having a single event. However, if the first dislocation occurs after the first 6 months, the rate of recurrent instability increases to 60%, with the majority of patients having recurrent instability that often requires revision surgery to address the problem.

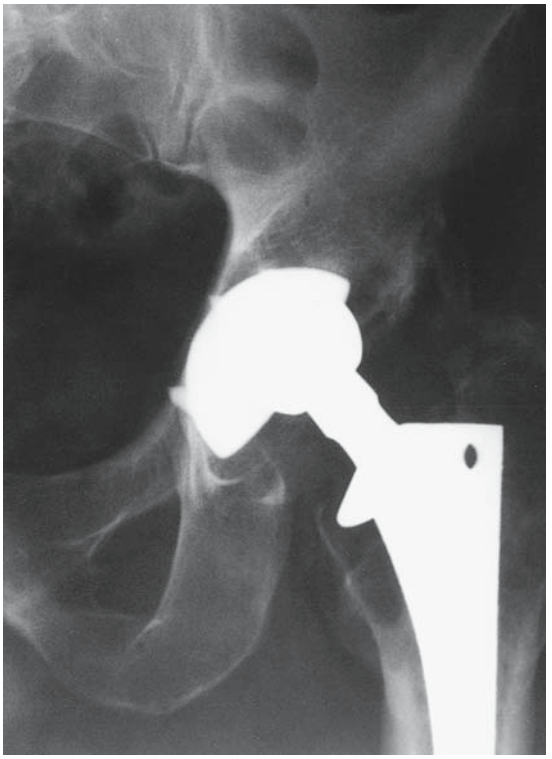
The treatment of a dislocated hip is to first reduce the hip, usually with conscious sedation; occasionally a general anesthetic may be required. The patient is placed into a brace for a period of 6 weeks. The patients can weight-bear as tolerated. If the patient does have recurrent instability, revision may be necessary. Before revision, it is helpful to determine the precise position of the components. Plain radiography can accurately determine the vertical inclination of the component; however, it is the degree of anterior rotation of the component that is a greater factor in instability after total hip replacement. Accurate assessment of the anterior rotation of the component can be best assessed by the use of CT imaging. If CT scan imaging cuts are also taken through the femoral condyles, the rotation of both the femoral and acetabular components can be determined. This information is important to aid in identifying the cause of the recurrent instability and to plan appropriate reconstructive surgery to correct the problem.

Aseptic loosening of the implant from bone occurs at a low rate with modern techniques. A recent study reviewed the minimum 20-year follow up of patients after cemented total hip arthroplasty revealed approximately 90% of patients had retained their original implant until they had died or reached their minimum 20-year follow-up evaluation. Revision surgery had been performed on 15% of the surviving patients; 11% of the revisions were for aseptic loosening. The rate of loosening of the femoral component was found to be 3% and 10% for the acetabular component in the surviving patients; 85% of the patients who survived a minimum of 20 years had

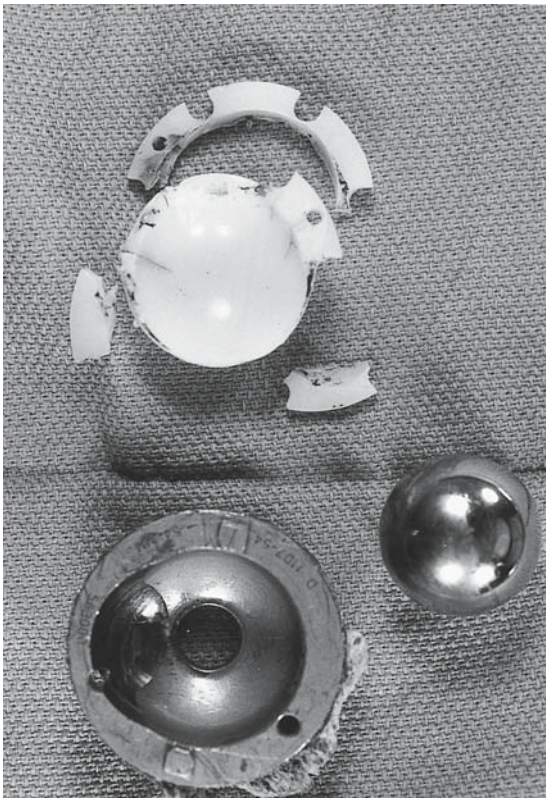
retained their initial implants. Another study demonstrated the rate of femoral loosening is greater in the first 5 years and that the rate decreases after 5 years. Acetabular loosening, however, was noted to increase over time when cemented components were used. A rate of cemented acetabular revision or radiographic loosening was noted to be approximately 50% at more than 10 years. The use of modern cementing techniques has decreased the rate of early failure of cemented stems. Modern techniques, however, have not resulted in any significant change in the rate of acetabular loosening.

The survival of cemented implants in patients less than 50 years of age is less than that noted in older patients, most likely related to the higher demands and higher activity level in this younger group of patients. In an attempt to reduce the rate of aseptic loosening after THR, surgeons have tried to achieve implant fixation directly to bone; this can be achieved through the use of porous surfaces made of small beads or wires sintered onto the base stem. If this surface is closely approximated to bone and essentially no motion occurs at the interface, bone trabeculae will interdigitate into the porous surface and secure the implant. The rate of early loosening of the porous ingrowth femoral implants is comparable in most series to cemented stems. The rate of loosening appears to vary with the stem design for the porous ingrowth devices. Therefore, data should be analyzed individually for each implant. Porous ingrowth hemispherical acetabular components, however, appear to have a lower rate of loosening compared to cemented acetabular components. Although fixation of the metal shell to bone was maintained, some early designs developed problems with the interface between the polyethylene liner and the metal shell. Motion and wear would occur at this interface as well as the articulating interface, leading to the development of wear debris and failure of the metal-polyethylene liner and the need for revision surgery. In addition, the importance of high-quality, thick polyethylene liners for the noncemented acetabular components was not appreciated early, which resulted in a number of patients having early failure because of wear-through or fragmentation of the polyethylene liners (Fig. 11-13). The current recommendations are for a polyethylene thickness of at least 8 mm.

Modern liner shell interfaces should be conforming, with the polyethylene liner supported by the metal shell across the entire nonarticulating surface. The liner should not bear stress on the rim only but be uniformly supported. Most designs limit the holes in the metal shell. The holes in the shell can provide a direct conduit for wear debris to the implant–bone interface. This debris can lead to an osteolytic reaction and subsequent loosening of the acetabular shell. Early designs had many holes in the metal shell for the use of ancillary fixation screws to fix the shell to bone before bone ingrowth. Currently, most surgeons press-fit the metal shell on the bone by underreaming the acetabular bed and then inserting a slightly larger metal shell into the acetabular bed; this can provide an excellent



A



B

FIGURE 11-13. (A) Anteroposterior radiograph of the left hip of a 52-year-old man 5 years after a noncemented total hip arthroplasty demonstrates a markedly eccentric position of the femoral head within the acetabular component. (B) Photograph of retrieved acetabular component and femoral head of this patient. The polyethylene is fragmented and was found displaced within the shell, allowing the femoral head to articulate with the metal acetabular shell.

initial stability and eliminate the need for screws and screwholes in many cases.

At the present time, a "hybrid" total hip arthroplasty is recommended for the majority of patients receiving THR, which includes the use of a cemented femoral stem and a porous ingrowth acetabular component. This arthroplasty takes advantage of the excellent long-term fixation of the cemented femoral stems and the improved fixation with modern cementing as well as the very encouraging results with the use of porous ingrowth acetabular components.

Loosening appears to be primarily related to the generation of polyethylene wear debris from the articulation. Several new technologies have been developed to reduce wear from the articulation in a total hip replacement. The first new concept was to improve the polyethylene, which was accomplished by cross-linking the polymer strands within the material. Think of a polymer as a bowl of cold spaghetti. If you pull out a strand of spaghetti, you can tease the whole strand from the bowl. If you cut some of the strands and then link these shorter strands to other strands, it will make it more difficult to pull out a strand and also more difficult to pull out a long strand. This logic applies to cross-linked polyethylene. The wear rate is reduced by 10 fold and the debris produced is of much smaller particles.

However, even with cross-linking, the plastic is the weak link, and the debris produced is from the polyethylene. Two other alternatives are now available, referred to as hard-on-hard interfaces. Both metal-on-metal and ceramic-on-ceramic are currently available. By using much harder materials for the articulation, the wear rate and debris production can be reduced as much as 1000 fold. With less debris and less wear, we hope to see a much longer functional life for these articulations. These new articulations, however, also have some limitations. Metal on metal involves the use of a cobalt-chromium femoral head on a cobalt-chromium acetabular liner. This articulation has been in clinical use for approximately 30 years. Early designs failed early as a result of design problems. The early heads were made of equal dimension to the acetabular opening. These would result in binding of the head within the acetabulum and the component would loosen. Current designs have reduced the size of the head relative to the acetabulum by a very small amount, which allows for lubrication of the interface and less friction; this eliminated the problem of acetabular loosening. However, it has been demonstrated that patients with metal-on-metal hip articulations have a very low level of metal detectable in their blood and urine. The long-term effects of this are unknown, but looking at the long-term follow-up of early implant designs there was no detrimental effect.

Ceramic on ceramic is the other hard-on-hard interface. This interface has been used in Europe for many years. Ceramic on ceramic results in the least amount of wear debris of all the currently used articulation for

total hip arthroplasty. However, it is limited by the strength of the ceramic material. Ceramic implants can be prone to fracture. When a ceramic implant fails, it results in a catastrophic failure. The ceramic fragments are very hard and abrasive, resulting in rapid extensive wear of the metallic implants that are attached to the bones. Frequently, the metal components that are attached to the bones and the ceramic articulation all need to be removed after a fracture. For other materials, you can change only the articulation.

Currently, wear and loosening are the most worrisome complications. We are trying to address these with improvements in materials and designs. However, the current devices work so well that to determine if new technology is truly an improvement we need at least a 10-year clinical follow-up. All the new devices need to be evaluated for not only their benefits but also the real and potential limitations.

Complications

The most frequent complication after THR is thromboembolic disease, including deep venous thrombosis and pulmonary embolism. Early in the history of THR the rate of fatal pulmonary embolism was 1% to 2%. However, at that time patients were kept at bed rest for as long as 2 to 3 weeks and kept as long as 6 weeks in the hospital. Early mobilization of patients has undoubtedly contributed to the significant reduction in the rate of fatal pulmonary embolism. However, significant reduction has also occurred through the use of anticoagulant prophylaxis, regional anesthesia, shorter operating times, and less blood loss. In the United States, THR is considered a significant risk factor for thromboembolic disease (TED) and therefore the routine use of medical and/or mechanical prophylaxis has been recommended. At present, the rate of TED ranges between 5% and 20%. The rate of fatal pulmonary embolism is low, approximately 0.01%.

The principal methods of prophylaxis are low-dose Coumadin, aspirin, low molecular weight heparin, and pneumatic compression stockings. Coumadin has the greatest volume of data supporting its use. Coumadin is started the evening preceding surgery or on the day of surgery. It is recommended that the therapy be continued for 6 weeks postoperatively. The medication needs to be monitored closely to keep the level within a safe range. The prothrombin time (PT) is held between 16 and 18 and the INR (international normalized ratio) at 1.25 to 1.5. It has been shown in many studies to be a safe and effective method of prophylaxis. The monitoring of Coumadin is of particular concern. Occasionally, patients have a dramatic elevation of their PT and INR with the first dose, which will lead to a risk of postoperative bleeding and hematoma at the operative site. As the length of stay in the hospital has decreased to 3 to 4 days or less, this has made the use of Coumadin increasingly difficult; 5 to 7 days are frequently required

to equilibrate a patient on a steady dose of Coumadin, and this is more difficult to accomplish in the outpatient setting. Currently, this is managed with the use of home nursing services and frequent monitoring.

Low molecular weight heparin formulations were developed in part to provide safe effective prophylaxis against thromboembolic disease. Subcutaneous unfractionated heparin has been used historically in the general surgical population; it has not been found to be effective in the orthopedic population. Intravenous unfractionated heparin is effective prophylaxis and treatment of thromboembolic disease. However, it requires even greater monitoring when used intravenously as it fully anticoagulates the patient immediately. If this occurs with in the first 3 days postoperatively, the incidence of wound hematoma is greater than 50%; thus, this is infrequently used in the postoperative orthopedic patient. Low molecular weight heparin is more selective in the interruption of the coagulation cascade; this results in a more controlled effect and patients do not require monitoring. The current protocols are for 2 weeks of therapy. Most studies demonstrate efficacy comparable with Coumadin for total hip replacement.

Aspirin has been used for DVT prophylaxis historically. Aspirin irreversibly inhibits platelet function and theoretically reduces the rate of formation of DVT. Few data directly support its routine use in THR; however, several studies demonstrate acceptable prophylaxis with the use of aspirin and hypotensive epidural anesthesia (HEA). HEA is an excellent anesthesia technique for THR; however, it requires careful patient monitoring and a dedicated anesthesia team. This form of anesthesia results in reduced blood loss while maintaining blood flow in the lower extremities. This approach reduces the need for transfusion postoperatively, which has been shown to increase the risk of DVT. In addition, the reduction in blood loss results in less activation of the coagulation cascade, again minimizing the risk of DVT. Although this technique has been shown to be very effective, it has not been widely applied because of concerns about the reduction of mean arterial pressure in elderly patients, which may result in stroke, renal failure, or myocardial infarction.

Dislocation of the prosthetic femoral head from the acetabular component occurs in 2% to 5% of patients after THR. As discussed previously, the incidence and direction vary with the operative approach. Postoperatively patients are instructed to not bend their replaced hip beyond 90 degrees and to keep their legs abducted and in neutral rotation. These restrictions should be followed closely for the first 6 to 8 weeks following surgery. After this time the patient should have formed a sufficient pseudocapsule to protect against dislocation. However, a replaced hip is always at greater risk for dislocation compared to a native hip joint. The majority of patients who dislocate their hip in the early postoperative period can be reduced without additional surgery and protected with a hip abduction brace for 6 weeks to allow healing of the pseudocapsule. The risk of recur-

rent instability after an early dislocation is approximately 30%. In addition to patient compliance, the other etiologies for dislocation are component malposition, excessive soft tissue laxity, and impingement of the prosthetic or osseous structures, resulting in levering of the femoral head out of the acetabulum. If a patient recurrently dislocates, revision surgery may be indicated.

The most devastating complication after THR is deep sepsis. Early postoperative infection occurs in approximately 0.3% to 0.5% of cases after primary THR. Late infection resulting from hematogenous spread can occur in 1% to 2% of patients. If detected within the first 2 weeks postoperatively, aggressive open debridement and synovectomy combined with intravenous antibiotics may be successful. However, if the infection recurs after debridement or is detected beyond 2 weeks, treatment must include removal of the prosthetic components and all cement. The prosthesis is left out for at least 6 weeks. An antibiotic-impregnated spacer may be placed at the time of debridement; this will provide a local depot of antibiotic at the site of the infection.

Recent work has demonstrated the effectiveness of a prosthesis covered in antibiotic-impregnated cement inserted at the time of the debridement to maintain the articular space and soft tissue tension and to provide stability to the soft tissues to promote healing. The success of this technique also raises the question of the role of one-stage reconstruction for an infected total hip replacement. Early data from Europe had demonstrated a success rate of 80% with this technique. However, more study is required to define the role of these techniques in the management of the infected arthroplasty. If the pathologic organisms are highly virulent and resistant to antibiotic therapy, reimplantation should be delayed for more than 12 months. Serum bactericidal titers (SBT) should be determined and a titer of at least 1:8 maintained during the 6-week course of therapy. During the antibiotic therapy, patients may be mobilized as tolerated with the use of a walker. Reimplantation can proceed when the wound is sterile if sufficient bone stock and soft tissue integrity remain. The use of antibiotic-impregnated cement for the femoral component is recommended at the time of reimplantation. If the SBT was maintained at greater than 1:8 for 6 weeks, reimplantation of a new prosthesis will be successful in more than 90% of cases. Recent data have demonstrated a higher rate of recurrence for patients reimplanted without cement.

Heterotopic ossification (HO) can form around a THR in 5% to 25% of cases. Heterotopic bone is histologically bone tissue, which forms within the muscle around the hip after arthroplasty. A metaplasia occurs, forming a bone matrix that becomes calcified over the first 6 to 12 months after the surgery. Most commonly the presence of HO will not compromise the clinical result. Associated risk factors are patients with hypertrophic osteoarthritis, male, over the age of 65, HO formation after previous surgery, and ankylosing spondylitis.

Heterotopic ossification is graded according to Brooker. Grade one consists of isolated islands of bone within the soft tissue between the femur and pelvis; grade two is bone protruding from the proximal femur or pelvis with greater than 1 cm of separation; grade three consists of bone protruding from the femur and or pelvis with less than 1 cm between the bones; and grade four is radiographic ankylosis, with no visible space between the bone protruding from the femur and pelvis. Grades one and two are rarely symptomatic. Grade three patients usually have stiffness and mild pain, and patients with grade four usually have marked stiffness and can be very symptomatic.

Patients who are at high risk for this complication can receive prophylaxis using indomethacin for 6 weeks or low-dose radiation therapy. Once HO forms the patients should be encouraged to maintain range of motion and activity, but passive stretching and passive range of motion should be avoided. Surgical intervention is indicated in patients with significant restriction of motion and pain, which occurs most commonly in patients with grade three and four HO. Surgery should be delayed until the HO is mature; this usually takes 12 to 24 months and is indicated by mature appearance on plain radiography, uptake similar to the uninvolved bone of the pelvis on a Tc 99-MDP bone scan, and normal serum alkaline phosphatase level. When the bone is mature, it can be surgically excised. Attempts to remove the bone before maturity have an increased rate of recurrence. After the bone is excised, the patient should receive prophylaxis to prevent recurrence either with indomethacin or by radiation therapy. Radiation therapy is preferred in most patients; it is usually a one-dose regimen of 700 to 800 cGy that can be administered either immediately preoperatively or within the first 2 or 3 days postoperatively. In this way, the entire treatment regimen is delivered in a controlled setting, compared to indomethacin, which is administered for 6 weeks. The rate of recurrence after excision and prophylaxis is approximately 5% to 20%.

The limitations to the long-term fixation of a total hip arthroplasty are loosening and wear. The primary articulation in total hip arthroplasty is a metal ball in a polyethylene socket. The rate of wear is variable; however, it is between 0.01 and 0.1 mm/year. The rate of wear is affected by the surface roughness of the femoral head, the quality of the polyethylene, the thickness of the polyethylene, the method of sterilization of the polyethylene, and stress applied to the articulation by the patient. As the implant, particularly the polyethylene liner, wears, the debris that is produced is released into the local tissues. The body has no mechanism to digest or eliminate the polyethylene debris. However, the local macrophages in the area recognize the material as a foreign substance and try to eliminate the debris. The macrophages ingest the material and try to digest it with catabolic enzymes and superoxides, which fails to alter the material. As the debris accumulates within the cell, it breaks down, releasing the polyeth-

ylene, enzymes, and oxides into the local environment. The result is a local bone lysis that creates cysts in the bone and dissects along the fixation of the implant or cement and bone. If allowed to continue, the lysis leads to loosening. In addition, failure can occur if the polyethylene is thin at the time of implantation. Thin polyethylene results in increased stress within the polyethylene with weight-bearing and a significantly increased rate of wear, which in turn leads to failure of the polyethylene liner and the need for revision of the implant.

Loosening can also result from mechanical failure of the implant–bone interface. The cement mantle can fragment or fracture, leaving the implant loose. In noncemented fixation, the implant can also loosen because the implant never actually bonds to the bone with bone ingrowth; a fibrous tissue forms instead, and this fibrous tissue may not be sufficient to maintain stable fixation of the implant. The implant will then migrate slowly, which is best appreciated on serial radiographs. Revision will be required to provide a stable implant.

Similar to the indications for primary arthroplasty, these are elective surgeries. However, in the revision setting it is important to follow the patient closely with plain radiographs. If an accelerated pattern of bone loss is noted, revision surgery should be performed before the loss of an extensive amount of bone. The greater the loss of bone at the time of revision, the greater the difficulty in obtaining stable fixation for the revision components. This loss may also lead to a higher rate of repeated revision for aseptic loosening.

Summary

As noted initially, disorders involving the hip and femur are manifested by alteration in the patient's ability to ambulate. These conditions can be diagnosed and treated by obtaining a careful history, thorough physical examination, and the appropriate use of radiographic studies. When the proper diagnosis is made for most nontraumatic disorders, it is usually best to begin with a nonoperative approach. If the nonoperative treatment alternatives are not successful, then operative intervention is indicated, which will result in an excellent outcome in the majority of patients.

Suggested Readings

Brooker AF, Bowerman JW, Robinson RA, Riley LH. Ectopic ossification following total hip replacement: Incidence and a method of classification. J Bone Joint Surg 1973;55(A):1629–1632.

Callaghan JJ, Templeton JE, Liu SS, et al. Results of Charnley total hip arthroplasty at a minimum of thirty years: a concise follow-up of a previous report. J Bone Joint Surg 2004;86:690–695.

Collier JP, Sutula LC, Currier BH, et al. Overview of polyethylene as a bearing material: comparison of sterilization methods. Clin Orthop Relat Res 1996; 333:76–86.
Evans BG, Salvati EA, Huo MH, Huk OL. The rationale for cemented total hip arthroplasty. Orthop Clin N Am 1993;24(4):599–610.
Evans BG. Late complications and their management. In: Callaghan JJ, Rosenberg AG, Rubash HE, (eds) The Adult Hip. New York: Lippincott-Raven, 1998: 1149–1161.
Garvin K, Evans BG, Salvati EA, Brause B. Palacos gentamicin for the treatment of deep periprosthetic hip infections. Clin Orthop Relat Res 1994; 298:97–1054.
Healy WL, Lo TCM, DeSimone AA, Rask B, Pfeifer BA. Single-dose irradiation for the prevention of heterotopic ossification after total hip arthroplasty: a comparison of doses of five hundred and fifty and seven hundred centigray. J Bone Joint Surg 1995;77A:590–595.
Hoagland FT, Steinbach LS. Primary osteoarthritis of the hip: etiology and epidemiology. J Am Acad Orthop Surg 2001;9:5.
Jazarawi LM, Kummer FJ, DiCesare PE. Alternative bearing surfaces for total joint arthroplasty. J Am Acad Orthop Surg 1998;6:198–203.
Steinberg ME. Early diagnosis, evaluation and staging of osteonecrosis. Instruct Course Lect 1994;43:513–518.
Trousdale RT, Ekkernkamp A, Ganz R, Wallrichs SL. Periacetabular and intertrochanteric osteotomy for the treatment of osteoarthrosis in dysplastic hips. J Bone Joint Surg 1995;77A:73–85.
Wedge JH, Cummiskey DJ. Primary arthroplasty of the hip in patients who are less than twenty-one years old. J Bone Joint Surg 1994;76A:1732–1742.
Wiklund I, Romanus BA. Comparison of quality of life before and after arthroplasty in patients who had arthrosis of the hip joint. J Bone Joint Surg 1991; 73A:765–769.
Willert HG, Bertram H, Buchhorn GH. Osteolysis in alloarthroplasty of the hip, the role of ultra-high molecular weight polyethylene wear particles. Clin Orthop 1990;258:95–107.
Woo RYG, Morrey BF. Dislocation after total hip arthroplasty. J Bone Joint Surg 1982;64A(9):1295-1306.

Questions

Note: Answers are provided at the end of the book before the index.

11-1. The femoral head receives 80% of its blood supply from:
   a. Artery of the ligamentum teres
   b. Obturator artery
   c. Superior gluteal artery
   d. Small vessels within the synovial retinaculum
   e. Internal iliac artery

11-2. The primary internal rotator of the hip is the:
   a. Iliopsoas

b. Rectus femoris
c. Gluteus medius
d. Gluteus maximus
e. Piriformis

11-3. Osteotomy of the hip joint is contraindicated in which of the following conditions:
a. Osteoarthritis
b. Rheumatoid arthritis
c. Developmental dysplasia of the hip
d. Avascular necrosis of the femoral head
e. Coxa vara

11-4. The most frequent complication of total hip arthroplasty is:
a. Loosening
b. Fracture
c. Infection
d. Deep venous thrombosis
e. Dislocation

11-5. Dislocation after total hip replacement can result from:
a. Impingement on an anterior osteophyte
b. Soft tissue laxity
c. Malposition of the components
d. Poor patient compliance
e. All the above

11-6. Patients with high risk for developing heterotopic ossification after a total hip replacement can be treated with which of the following treatments to reduce the risk?
a. Coumadin
b. Antibiotics
c. Calcium channel blockers
d. Radiation therapy
e. Chemotherapy

11-7. Fractures of the femoral neck can commonly result in which complication?
a. Infection
b. Avascular necrosis of the femoral head
c. Rheumatoid arthritis
d. Lengthening of the leg
e. Dislocation of the hip

11-8. During the anterior approach to the hip for a total hip replacement, which muscle is partially detached from the greater trochanter?
a. Gluteus medius
b. Gluteus maximus
c. Tensor fascia lata
d. Piriformis
e. Quadratus femoris

11-9. Deep periprosthetic infection after total hip replacement is:
   a. An easy complication to treat
   b. Can be managed without surgery with antibiotics alone
   c. A devastating complication requiring several surgeries and long courses of intravenous antibiotics
   d. Associated with good range of motion
   e. Less frequent in patients taking oral corticosteroids

11-10. A coxalgic gait pattern has which two components?
   a. Increased stance phase and abductor lurch
   b. Decreased stance phase and adductor lurch
   c. Normal stance phase and swing phase
   d. Decreased stance phase and abductor lurch
   e. Increased stance phase and late toe-off

12
The Knee

Brian G. Evans

This chapter discusses the anatomy, biomechanics, and pathology of the knee. The function of the knee is provided primarily by the soft tissue. Therefore, injury to these soft tissue structures has significant impact upon the stability of the knee.

Anatomy

The osseous anatomy of the knee consists of the proximal tibia, distal femur, and the patella (Fig. 12-1). The distal femur consists of the medial and lateral condyles, the medial and lateral epicondyles, the femoral trochlear groove, and the intercondylar notch. The medial condyle is larger and extends slightly distal compared to the lateral condyle. Both condyles are covered with articular cartilage. The trochlear groove lies on the anterior aspect of the distal femur between the medial and lateral femoral condyles. This surface is also covered by articular cartilage and serves as the site of articulation of the patella. The lateral rim of the trochlear groove is frequently more prominent than the medial side to allow for proper patellar tracking along the femur.

The epicondyles serve as the site of insertion of several important structures. The deep and superficial medial collateral ligaments (MCL) attach to the medial epicondyle. The proximal margin of the medial epicondyle is enlarged and serves as the site of insertion of the adductor magnus (the adductor tubercle). The lateral or fibular collateral ligament (LCL) attaches to the lateral epicondyle. Inferior to the attachment of the LCL is the insertion of the popliteal muscle at the junction of the lateral condyle and epicondyle. The medial and lateral heads of the gastrocnemius muscle originate from the medial and lateral posterior femoral condyles. The intercondylar notch is the site of the femoral attachment of the cruciate ligaments. The anterior cruciate ligament (ACL) attaches in the posterolateral aspect of the notch, and the posterior cruciate ligament (PCL) attaches in the anteromedial aspect of the notch.

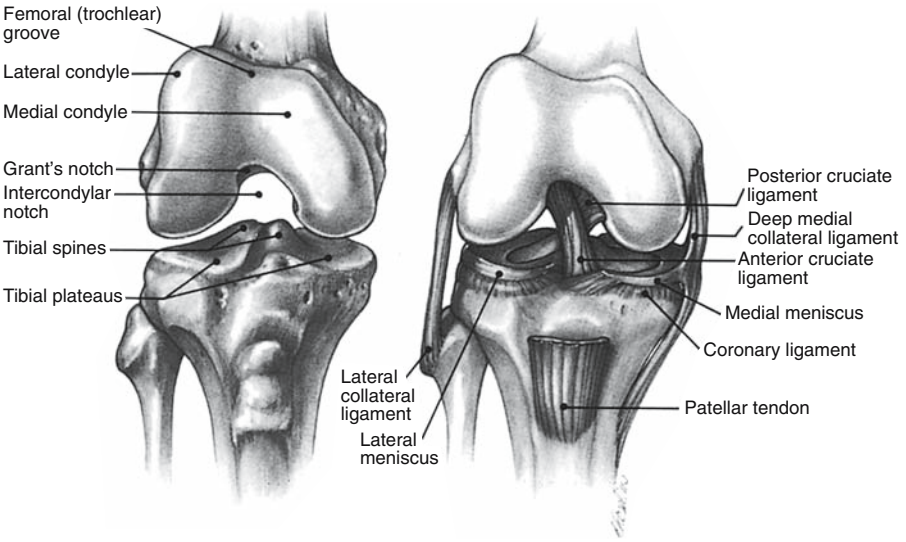


FIGURE 12-1. Bony anatomy and major ligamentous structures of the flexed knee joint (anterior view).

The proximal tibial surface is composed of the medial and lateral plateaus and the intercondylar eminence. The medial plateau is larger and extends further posterior compared to the lateral plateau. The surface of the medial plateau is relatively flat. The lateral tibial plateau is, in fact, slightly convex. Both the tibial plateaus are covered with articular cartilage. The intercondylar eminence is the site of attachment menisci and the cruciate ligaments.

The patella is a sesamoid bone within the tendon of the quadriceps mechanism. There are two major facets on the patella, the medial and lateral facets. There is significant variability in the size and orientation of these facets. However, normally the lateral facet is broader and the medial facet is more acutely oriented to the femoral trochlea.

The osseous anatomy of the knee provides little to the stability of the knee. Stability and function are therefore provided by the complex soft tissue envelope around and in the knee (Figs. 12-2, 12-3). The soft tissue components of the knee can be divided into several components: static restraints (ligaments), dynamic restraints (muscles and tendons), and the menisci. The static restraints are represented by the medial collateral ligament (MCL), lateral collateral ligament (LCL), anterior cruciate ligament (ACL), and posterior cruciate ligament (PCL). These structures resist valgus and varus stress as well and anterior and posterior translation of the

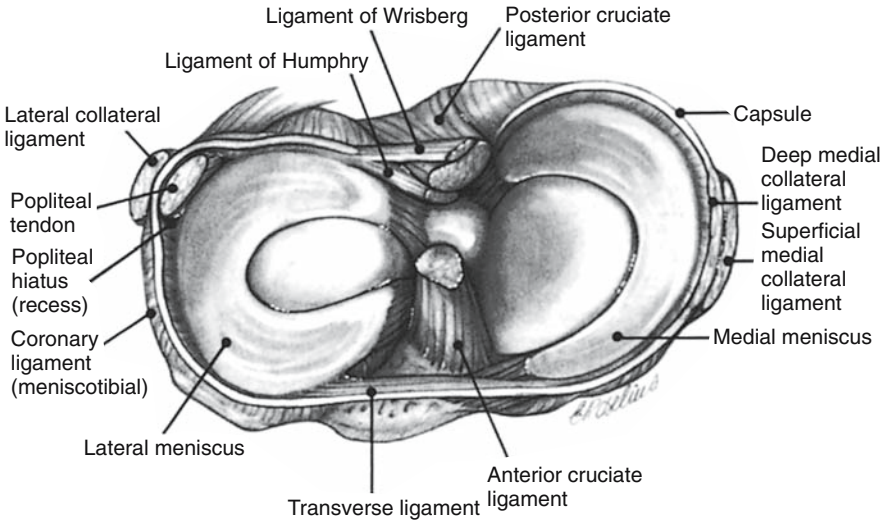


FIGURE 12-2. Cross section of the knee demonstrating the menisci and associated ligaments.

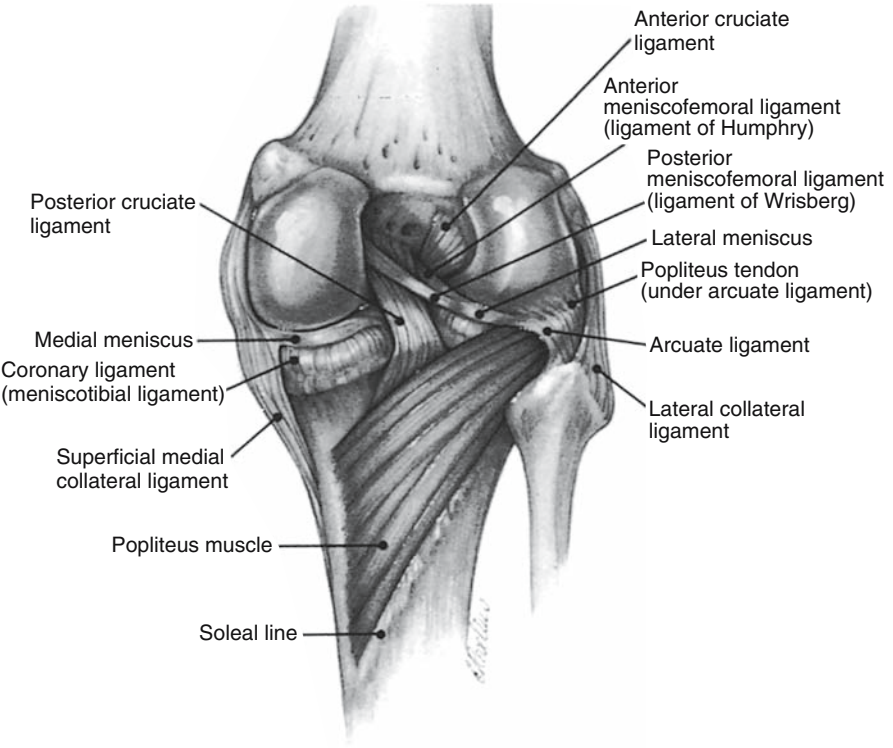


FIGURE 12-3. Posterior aspect of the knee joint.

tibial relative to the femur. The MCL consists of two layers. The deep MCL spans from the medial epicondyle of the femur to the proximal tibial border just below the medial tibial plateau. The superficial MCL has the same femoral origin; however, the ligament has a broad tibial insertion extending 6 to 10 cm below the tibial plateau along the posteromedial border of the tibia. The LCL is a more-discrete band along the lateral aspect of the knee. It spans from the lateral epicondyle to the fibular head.

The anterior cruciate ligament resists the anterior translation of the tibia relative to the femur. The ligament runs from the anterior aspect of the tibial eminence to the posterolateral aspect of the femoral notch. The posterior cruciate ligament resists posterior translation of the tibia relative to the femur and resists hyperextension of the knee. The ligament extends from the posterior aspect of the intercondylar eminence and proximal tibia in the midline to the anteromedial aspect of the femoral intercondylar notch.

The dynamic restraints in the knee are the muscles and tendons that cross the knee joint. These muscles are broadly divided into those that act to extend the knee and those which act to flex the knee. The extensor muscles are the quadriceps femoris and the tensor fascia lata. The quadriceps is a group of four muscles, all inserting onto the patella and patellar tendon, which in turn inserts on the anterior tibial tubercle. The muscles that make up the quadriceps are the rectus femoris, vastus lateralis, vastus medialis, and vastus intermedius; these are all supplied by the femoral nerve. The tensor fascia lata originates on the pelvic brim and inserts at Gerdy's tubercle on the proximal anterior lateral tibia. The tensor fascia lata is innervated by the superior gluteal nerve.

The primary flexors of the knee are the hamstring muscles—the semimembranosus, semitendinosus, and the biceps femoris—and the sartorius and gracilis. The hamstring muscles originate on the ischium and insert on the posteromedial and posterolateral proximal tibia. They receive their innervation from the sciatic nerve; all are innervated by the tibial division of the sciatic nerve, except the short head of the biceps, which is innervated by the peroneal division of the sciatic nerve. The sartorius originates from the anterosuperior iliac spine and the gracilis originates from the pubis. Both these muscles with the semitendinosus insert into the proximal medial tibia in the pes anserine (goose's foot, relating to the appearance of the three tendons inserting together). The sartorius is innervated by the femoral nerve and the gracilis by the obturator nerve.

The other muscles that serve to flex the knee are the gastrocnemius and popliteus, which extend from the posterior aspect of the femoral condyles to the calcaneus and proximal tibia, respectively.

The menisci are two crescent-shaped cartilaginous structures attached to the proximal tibial surface. These structures serve two purposes in the knee. They increase the surface area for weight-bearing, therefore reducing the peak stress in the articular cartilage, and they also provide a small

degree of stability to the knee by changing the flat tibial articular surface to a cupped surface. The menisci are composed of dense organized cartilage tissue.

Biomechanics of the Knee

The mechanical axis of the lower extremity extends from the center of rotation of the hip to the center of the ankle joint. This axis normally crosses the knee joint in the lateral third of the medial tibial plateau. The normal anatomic alignment of the knee is in 7 degrees of valgus. When the knee is loaded, the medial compartment experiences 60% and the lateral compartment 40% of the weight-bearing stress. This difference in the applied load in the normal knee is the reason the medial tibial plateau and medial femoral condyle are larger than the lateral side. Patients with significant angular deformity in the knee have altered weight-bearing, which results in increased stress in the medial (with varus or bowlegged deformity) or lateral (with valgus or knock-knee deformity) compartment. The increased stress frequently results in early arthritis in the overused compartment of the knee.

The highest joint forces, however, are found in the patellofemoral articulation. Forces as high as five- to eightfold body weight can be noted for activities such as stair climbing and jumping. The function of the patella has been controversial; however, most now recognize the role of the patella in providing a mechanical advantage to the quadriceps tendon. The patella moves the line of pull of the quadriceps further away from the center of rotation, therefore acting as a lever and reducing the force required to extend the knee. Patients who have had the patella removed because of arthritis or trauma are noted to have approximately 30% reduction in the force in the quadriceps compared to patients with a patella.

Evaluation of the Painful Knee

History

The history should begin with the chief complaint and how long the patient has noticed the problem. The specific location of pain, any radiation, the nature of the pain (ache, burning, stabbing, etc.), and any exacerbating or ameliorating factors are included. In particular, the relationship of the pain to activity and rest are important to note. Commonly, pain in the musculoskeletal system is relieved with rest. Severe pain that is present at rest suggests a septic process or neoplasm, which may be primary or metastatic.

Knee problems frequently begin with an injury. A detailed history describing the injury can be very helpful in determining the structures that are injured. The nature of any external force contacting the knee and the

position of the knee at the time of injury should be elicited. Did an audible or palpable pop occur at the time of the injury? Shifting or abnormal movement of the knee may also have been noted at the time of injury. The degree and nature of any swelling around the knee is important to record. In addition to a description of the injury, it is helpful to inquire about the patient's ability to use the knee after the injury: Was the patient able to weight-bear? Was the onset of pain or swelling immediate or delayed? Could the patient flex or extend the knee after injury? These are important questions to ask the patient after a knee injury.

In addition to pain, patients with knee problems complain of mechanical problems in the knee. Patients may note an inability to fully bend or straighten the knee, which is referred to as locking of the knee. Locking can be a result of a loose body in the knee becoming lodged between the femoral condyle and tibial plateau, similar to a wedge "doorstop." The patients who note intermittent locking of the knee are usually able to relieve the locked knee by gently moving the knee without weight-bearing. This maneuver allows the loose fragment to be released from between the femur and tibia, and motion will be restored. However, inability to fully flex and extend the knee can also be noted in patients with large effusions and in patients with ligament injuries.

Instability is another frequent complaint of patients with knee injuries. Patients observe that their knee shifts or buckles with particular activities. Instability can result from two general etiologies. The first are ligamentous injuries. As noted previously, the stability of the knee is a result of the ligaments that cross from the tibia to the femur. Disruption of the ligaments will result in alteration of knee function; the knee may shift or sublux with activity. The second common cause of a knee buckling or giving-way are problems in the patellofemoral joint. Instability of the patella in the trochlear groove will result in a giving-way sensation as the patella subluxes. Damage to the articular surfaces of the patella or the trochlear groove will result in pain as the patella tracks over the trochlea; this can occasionally lead to a sharp acute pain that leads to the quadriceps releasing its contraction while the patient is weight-bearing on the leg as a result of a primitive reflex arc. The patient notes a giving-way or buckling sensation in the knee, and a few patients may actually fall as a result.

The majority of knee complaints are aggravated by activities. The specific problems the patient has encountered are important to note. Patients commonly have difficulty ascending and descending stairs. Frequently, descending stairs will be the most symptomatic as this places high stress across the patellofemoral joint. Bicycling can also aggravate the patellofemoral joint. Activities that involve quadriceps contraction with the knee in flexion may result in subluxation in patients with patellar instability. Patients with meniscal tears have difficulty squatting and may notice snapping or pain when rising from a chair or ascending stairs. Activities that involve stopping and turning or cutting will result in the knee

shifting or giving-way if there is insufficiency in the collateral or cruciate ligaments.

Physical Examination

Physical examination of the patient with a knee complaint begins with inspection. Observation of the alignment of the lower extremity should demonstrate a normal 7 degree valgus (knock-knee) angle at the knee when a patient is standing. Deformity of the leg in varus or valgus beyond 7 degrees can be associated with either a ligamentous or osseous deficiency. Any swelling, bruising, or ecchymosis should be recorded.

Next, the evaluation should focus on the patient's gait. Normal gait involves range of motion from 0 to 65 degrees of flexion. The gait should have a smooth cadence, with the length of each step being equal on the left and right sides. The knee should not demonstrate any sudden shift to either the lateral or medial side. If abnormal lateral motion is noted, this is recorded as a medial or lateral thrust.

The knee should then be examined with the patient sitting with the legs over the edge of the examining table. The position of the patella should be anterior and symmetrical. The patellar tracking can then be followed by asking the patient to flex and extend the knee with the examiner palpating the patella. There should be little lateral movement. Crepitus may also be noted as a grinding sensation between the patella and the femoral trochlear groove.

The knee should then be examined with the patient supine. For all aspects of the examination, the contralateral knee can be used as a normal control. Effusion or fluid within the knee can be assessed by placing both hands on the knee, with one below the patella and one above the patella. Any fluid in the knee can then be displaced and palpated proximally and distally. The knee can be palpated to determine the specific site of maximum tenderness. The range of motion of the knee is measured with the knee in straight extension as 0 degrees of flexion; normal full flexion is approximately 135 degrees.

The collateral ligaments are then assessed by stabilizing the thigh with one hand and placing a varus or valgus stress on the knee with the other hand. A normal knee has a small amount of medial and lateral laxity in the collateral ligaments. However, any laxity that is excessive, or causes pain to be elicited, should be noted. The cruciate ligaments can also be assessed. The anterior cruciate ligament is best assessed using the Lachman test. The examiner stands by the patient's feet and stabilizes the femur with one hand holding the distal medial thigh. The tibia is held with a thumb at the lateral joint line. The examiner then attempts to displace the tibia forward in relation to the femur. Translation less than 5 mm should be noted, and the anterior cruciate ligament should be felt to "snap taut." Injury to the posterior cruciate ligament can be demonstrated by noting

the degree of recurvatum (back-knee), which can be obtained passively compared to the contralateral knee. Also, with both knees flexed 60 to 90 degrees and the patient supine, the tibia on the deficient side will be noted to sag posteriorly compared to the uninjured leg when viewed from the side. Comparison to the contralateral knee is very important for examination of the collateral and cruciate ligaments.

The menisci are examined by palpation of their outer margin along the joint line at the proximal tibial articular surface. In addition, meniscal tears can be detected by the McMurray maneuver; this is done by flexing the knee internally and externally rotating the tibia and then extending the knee with a valgus force applied. If a reproducible snap is palpated or pain elicited at the joint line, this is suggestive of a tear. Patients with meniscal tears also report pain when asked to squat down with the knees flexed.

Imaging

All the available imaging techniques have been utilized in the evaluation of patients with knee problems. Plain radiographs are the most commonly obtained studies (Fig. 12-4). Plain radiographs are helpful in the evaluation of fractures and subluxation of the joint; in addition, the condition of the articular surfaces can be investigated. The standard series of routine X-

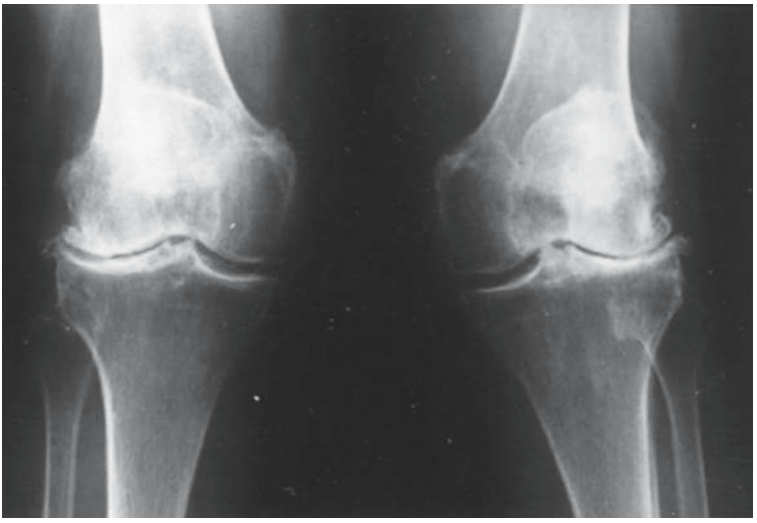


FIGURE 12-4. Standing anteroposterior (AP) radiograph of both knees in a 70-year-old woman with osteoarthritis of both knees with a valgus (knock-knee deformity) of both knees. Note the asymmetrical space between the medial and lateral femoral condyles and the tibial surface.

rays of the knee should include a standing anteroposterior (AP) radiograph of both knees, a lateral view and a merchant or "sunrise view." The sunrise view is a view taken with the knee in 45 degrees of flexion with the beam directed inferiorly and parallel to the patellar articular surface. There should be a space of 5 to 10 mm between the end of the femoral condyles and the tibial surface and beneath the patellar surface and the femoral trochlea. This "clear space" is in fact occupied by articular cartilage.

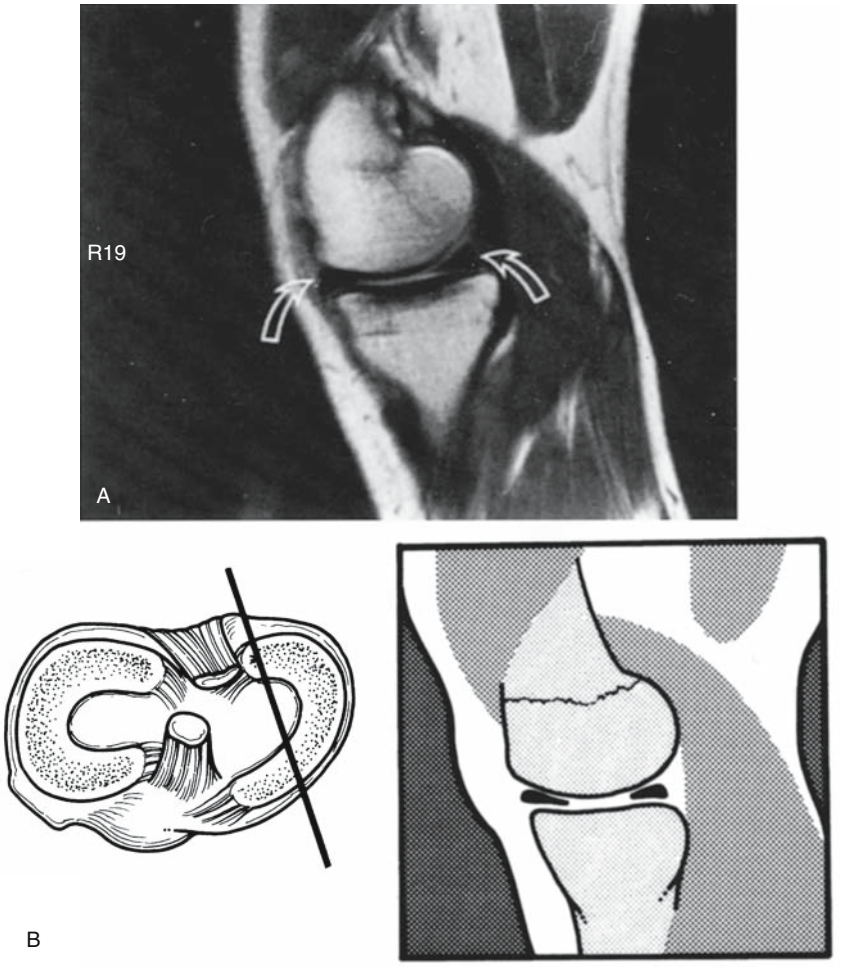


FIGURE 12-5. (A) Normal T_1-weighted magnetic resonance imaging (MRI) sagittal image of the medial meniscus. (B) Schematic illustration showing the section cut of (A).

Routine radiography is an excellent tool for the evaluation of the knee for trauma, arthritis, and alignment. Plain radiographs, however, only demonstrate the osseous structures. As mentioned earlier, the soft tissues provide the stability and allow the knee to function. Arthrography has been used in the past to evaluate the knee for meniscal pathology. However, this technique is inaccurate and invasive. The development of arthroscopy is a technique that allows the direct visualization of the structures within the knee with a minor surgical procedure. However, this technique is also invasive, and although arthroscopy is accurate, the procedure is relatively expensive compared to an imaging modality alone. Nuclear medicine studies are of limited use in the knee. These studies are sensitive; however, the specificity of these studies is limited. Magnetic resonance imaging (MRI) has provided a dramatic step forward in our ability to diagnose soft tissue injury to the knee. MRI provides accurate and noninvasive evaluation of all the soft tissue structures within the knee (Fig. 12-5). MRI is currently the study of choice for the evaluation of intraarticular pathology within the knee.

Knee Pathology

Soft tissue injury is common in the knee. A knee with a bloody effusion after an injury has an incidence as high as 80% of significant soft tissue injury. The differential diagnosis of a posttraumatic bloody effusion in the absence of an intraarticular fracture are meniscal tear, ACL tear, or a patellar dislocation.

Meniscal Tears

Tears of the meniscus can occur in two settings. One is as the result of a specific injury, which usually involves a twisting injury with the knee in some flexion. Swelling and pain are noted immediately after the injury. There is increased pain with attempts at movement, and there is a limitation in the range of motion. Pain with squatting down or arising from a chair is commonly reported. The torn meniscus can block motion. Occasionally the knee can be gently manipulated to reduce the torn meniscal fragment, and motion will be restored. However, the fragment will frequently redisplace, and intermittent locking may occur. This form of a tear is usually in younger patients with stout meniscal tissue.

In older individuals, the meniscal tissues soften and the edge becomes frayed. As this occurs, the frayed edges can become entrapped between the edges of the bone, initiating a tear that can extend into the meniscal substance. This tear can occur with little or no trauma with minimal swelling and pain initially. The diagnosis is made by joint line pain, effusion, and rarely locking. Patients with locking frequently require arthroscopic

surgery to debride the torn portion of the meniscus. In older patients, if the meniscal tear does not cause locking, frequently these can be treated with nonsteroidal antiinflammatory (NSAI) medications and an intraarticular corticosteroid injection. These treatments will reduce the effusion and pain. With continued activity, the soft meniscal tissue can be worn down and a stable edge reestablished.

Ligament Injuries

Injury to the ligamentous structures are manifest by instability in the knee. In addition to pain and swelling, patients report a sense of the knee shifting or giving way, which may occur only with specific activities such as descending stairs or when turning on the loaded extremity. The initial management of these injuries is rest, ice, and elevation. A splint or knee immobilizer can also be helpful to protect the knee. As the initial pain subsides, it is important to begin to work on restoring range of motion, using a brace to protect the injured ligament. As the pain further decreases, strengthening is begun. If after the strengthening program is completed the knee remains unstable, the patient may be a candidate for surgical reconstruction.

Patellofemoral Pathology

The patellofemoral joint is one of the most common areas of pain in the knee. Common complaints are anterior knee pain, which is aggravated by activities involving high loads on a flexed knee such as stair climbing or bicycling. This pain can be the result of degenerative changes in the patellofemoral articulation or a result of maltracking of the patella within the trochlear groove. A grinding or snapping sensation may also be noted. Pain is usually relieved by rest; however, if the patient is sitting for a prolonged period of time with the knee flexed, such as in a theater, on a plane, or during a long car ride, anterior knee pain will result. Frequently patients try to change the position of the knee to relieve their discomfort. This symptom is referred to as movie sign and is indicative of degenerative changes in the patellofemoral joint. Softening of the articular surface is referred to as chondromalacia patella; this can be a primary problem or it may be secondary to excessive trauma to the joint caused by maltracking of the patella within the trochlear groove.

The treatment of these conditions is primarily nonoperative. Improving the patellar tracking can be done through a series of exercises to retrain the quadriceps and through patellar mobilization exercises. The exercise program need to be maintained for a minimum of 6 to 8 weeks to demonstrate benefit. The symptoms frequently recur. If the symptoms are recurrent and do not respond to the nonoperative regimen, and patellar maltracking is evident, operative intervention may be indicated. Operative

intervention is directed at correcting the patellar tracking and maximizing the quadriceps function with postoperative physical therapy.

Arthritis

The management of arthritic symptoms within the knee is similar to management elsewhere in the body. The nonoperative management of arthritis within the knee consists of a five-modality approach. The first line of therapy is the use of NSAI agents, which will reduce the pain and swelling associated with the knee. Although all the NSAI drugs (NSAIDs) function in a similar fashion, there is wide variation in individual patient response. Therefore, minimally two or three different NSAIDs should be tried. The most common side effect of this course of treatment is dyspepsia.

The second line of treatment of arthritis, the selected use of intraarticular corticosteroid medication, can be effective in patients who have an acute exacerbation of the arthritic pain. The injection can quiet their pain and restore them to a baseline level of discomfort. The injection should not be utilized for the control of baseline pain. If the injection is required at a frequency of greater than one every 6 to 8 weeks, some other course of treatment should be initiated, such as surgery. If the knee is injected more frequently than two to three times per year, the corticosteroid may have a detrimental effect on the articular cartilage.

Physical therapy can be very helpful in the treatment of arthritis of the knee. As the soft tissue sleeve is very important to the function of the knee, by optimizing the function of the soft tissues the symptoms of arthritis can be reduced. Physical therapy should be directed at maintaining the range of motion of the knee and optimizing the strength of the quadriceps and the hamstring muscles. In the late stages of degenerative arthritis, physical therapy may worsen the patient's symptoms and should be limited to the patient's tolerance.

Assistive devices such as a cane or crutch may be helpful in the management of arthritis of the knee. These aids can limit the stress across the painful knee and improve the patient's walking tolerance. The final approach to the management of arthritis of the knee is modification of the patient's activities, such as sports, the work environment, and possibly arranging special parking for the patient the patient's car. Frequently, patients with significant knee arthritis are also overweight. Weight loss in these patients can significantly reduce symptoms and the need for other treatment modalities.

Surgical Reconstruction for Arthritis

When all nonoperative measures have failed to relieve the symptoms of knee arthritis, surgical intervention should be contemplated. The surgical

correction of knee arthritis can be separated into treatments that retain the patient's articular surfaces and knee replacement. Nonreplacement options include the use of arthroscopy to "clean out" the knee; this procedure can remove the small cartilage fragments that accumulate in arthritic joints and debride any loose articular fragments. The pain relief from this procedure, however, is short lived, lasting only 3 to 6 months. Patients should be informed preoperatively that if extensive arthritis is noted during arthroscopy, the pain may be worse after surgery. In that setting, the patient is a candidate for knee replacement.

Patients with osteoarthritis of the knee frequently develop angular deformities. The most common deformity is varus angulation of the knee, which results from erosion of the medial compartment of the knee. As the deformity progresses, a greater portion of the weight-bearing stress is concentrated in the medial compartment of the knee. Osteotomy is a procedure to realign the articulation. The proximal tibia is transected, and a wedge of bone is removed from the lateral aspect. When the two new surfaces are brought together, the varus deformity is corrected. This procedure redistributes some of the weight-bearing stress to the lateral compartment and can result in improved symptoms in the knee. The result is generally successful for 5 to 10 years. Osteotomy is contraindicated in knees that are stiff or unstable. When the symptoms return, knee replacement surgery is indicated.

Arthrodesis or fusion of the knee is an option for the management of young active patients, particularly physical laborers. Fusion results in a stiff straight knee that will allow the patient to ambulate and stand for long periods of time without difficulty. However, significant limitations also exist. The gait pattern is significantly abnormal. In addition, patients will have difficulty sitting, particularly in confined spaces such as public transportation and theaters. Resection arthroplasty is a procedure in which the articular surfaces are resected and a fibrous pseudoarthrosis forms within the joint space. Pain may be decreased; however, the knee is significantly unstable, requiring a brace for ambulation. Arthrodesis and resection arthroplasty are not commonly performed. Currently, these procedures are reserved for the management of a failed total knee replacement.

Total knee replacement (TKR) is commonly utilized to relieve the symptoms of knee arthritis and restore function (Fig. 12-6). Approximately 200,000 arthroplasties are performed annually in the United States; the average age of patients receiving a TKR is 70 to 74 years. Successful results can be obtained in more than 95% of patients, with survivorship at 10 to 15 years of 90%. All components are currently fixed with polymethylmetacrylate (PMMA) bone cement. Noncemented components, those used with porous ingrowth surfaces for bone ingrowth, have been associated with a higher incidence of loosening and pain.

The proximal tibia is cut perpendicular to the long axis of the shaft, and the femoral articular surface is cut using specific guides to remove the

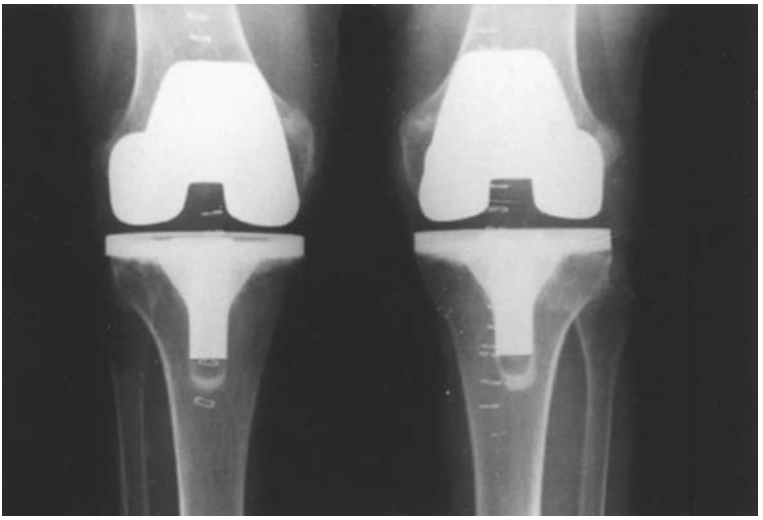


FIGURE 12-6. Standing AP radiograph of both knees 2 weeks after one-stage bilateral knee replacements in the 70-year-old female patient whose preoperative radiograph is shown in Figure 12-4.

femoral trochlea and distal and posterior femoral condyles. The ACL is removed; however, the PCL can be resected or retained depending on the design of implant chosen. For proper function of the arthroplasty, the MCL, LCL, and, if retained, PCL must be carefully balanced. The components are then fixed to the surfaces of the tibia and femur with bone cement. The patella is normally resurfaced as well after resecting the articular surface parallel to the anterior surface.

The patient is mobilized into a chair on the first postoperative day, and full weight-bearing may be allowed immediately. However, a knee immobilizer should be utilized to protect the knee from acute flexion while walking, and this is continued until the quadriceps function returns. The critical element of the postoperative therapy is the restoration of motion. If the motion is not restored within the first 3 to 6 weeks, maturation of the scar tissue will prevent major gains in motion after that point. Many patients can be safely discharged at 3 to 4 days after surgery.

Frequently, however, these patients require home physical therapy to continue to work on range of motion and ambulation in the first few weeks after surgery. The total rehabilitation period after total knee replacement is between 3 and 6 months, although patients are functionally mobile after 2 to 3 weeks. Knee replacement can be performed bilaterally in one stage in medically healthy patients (see Fig. 12-6). The initial increase in debilitation postoperatively is offset by a reduction in the overall period of rehabilitation after sequential unilateral TKR.

Aseptic loosening of the implants after TKR occurs at a low rate. Several studies have documented a 15-year survivorship of greater than 90% and less than 0.5% per year rate of aseptic loosening after cemented TKR. If a TKR is noted to be loose earlier than 5 years postoperatively, it should be evaluated for deep infection. Deep sepsis is associated with early loosening after TKR. Young age, marked obesity, and high demand also negatively impact upon the long-term survival of the replacement. To date, the best data indicate noncemented TKR are equal to the cemented replacement. Several studies suggest poorer results when cement is not used, particularly for fixation of the tibial component. Increased tibial loosening and pain have been noted with these devices. At present. because of the generally increased cost for the noncemented porous-coated implants and poorer clinical results, the use of these devices is difficult to justify.

The majority of the complaints after cemented TKR are from the patellofemoral joint, which can be the result of poor soft tissue alignment at the time of arthroplasty and may lead to painful subluxation or dislocation of the patellar component. If inadequate bone is resected from the patella at the time of resurfacing, a marked increase in the patellofemoral stress can be noted, which may become painful. Several authors have advocated not resurfacing the patella. However, several studies now demonstrate a higher rate of patellofemoral complaints after TKR without patellar resurfacing. If significant patellofemoral arthritis exists at the time of arthroplasty, patients with weight greater than 60 kg and height greater than 160 cm will have more pain postoperatively if the patella is not resurfaced.

The most common complication after TKR is thromboembolic disease (TED). The rate of deep venous thrombosis ranges from 25% to 50% of cases in patients evaluated with venography or duplex Doppler analysis. Similar to patients receiving total hip replacement (THR), currently it is recommended that all patients receive some form of prophylaxis against TED. Mechanical methods such as the pneumatic compression stockings appear to have a greater benefit after TKR compared to THR. Low-dose Coumadin and aspirin are currently the most commonly utilized medications. The efficacy of low molecular weight heparin is currently under investigation.

Deep infection occurs at a rate of approximately 1% after TKR for osteoarthritis over the life of the implant. The most common organisms are skin flora, primarily *Staphylococcus aureus* and *Staphylococcus epidermidis*. In particular to knee replacement, the relatively thin soft tissue envelope at the inferior aspect of the skin incision can lead to wound dehiscence and allow entry of the flora into the joint. Any area of skin breakdown after TKR should be treated aggressively to prevent deep infection, particularly in patients with prior incisions and in those with diabetes or significant vascular disease.

If a deep infection is established, the only way to eradicate the infection is to remove the implants and cement and then thoroughly debride the

joint. A cement spacer is then placed into the joint space, and the patient should receive 6 weeks of intravenous antibiotics. The serum bactericidal titers (SBT) again should exceed 1:8. After 6 weeks, the knee can be reimplanted if adequate soft tissue and bone remains. However, as a result of the inevitable scarring the clinical result is compromised.

Occasionally, after TKR range of motion of the knee does not progress well. If the patient is less than 2 to 6 weeks past surgery, a gentle manipulation of the knee in the operating room under anesthesia may be beneficial. If the motion cannot be restored, particularly if the patient is beyond 6 weeks after replacement, additional surgery may be necessary to restore functional range of motion.

Summary and Conclusions

The knee is a complex joint with function provided by the combination of osseous and soft tissue structures. The soft tissue envelope plays a significant role in the pathology of the knee and in the management of these conditions. With careful history, physical examination, and appropriate use of the available diagnostic modalities, knee pathology can be accurately determined and successful treatment instituted. Successful management of knee pathology includes treatment of the specific etiology, but optimal management of the soft tissue envelope with directed physical therapy is essential to an optimal outcome.

Suggested Readings

Heck DA, Murray DG. Biomechanics in the knee. In: Evarts CM (ed) Surgery of the Musculoskeletal System, 2nd ed. New York: Churchill Livingstone, 1990: 3243–3254.

Rand JA, Ilstrup DM. Survivorship analysis of total knee arthroplasty: cumulative rates of survival of 9200 total knee arthroplasties. J Bone Joint Surg 1991;73A: 397–409.

Stern SH, Insall JN. Posterior stabilized prosthesis: results after follow-up of nine to twelve years. J Bone Joint Surg 1992;74A:980–986.

Windsor RE, Bono JV. Infected total knee replacements. J Am Acad Orthop Surg 1994;2:44–53.

Questions

Note: Answers are provided at the end of the book before the index.

12-1. The posterior cruciate ligament limits which motion of the knee?
   a. Posterior translation of the tibia relative to the femur
   b. Anterior translation of the tibia relative to the femur
   c. Valgus opening of the knee

d. Varus opening of the knee
e. Hyperflexion of the knee

12-2. Which ligament is removed in all modern knee replacement surgeries?
a. Anterior cruciate ligament
b. Posterior cruciate ligament
c. Medial collateral ligament
d. Lateral collateral ligament
e. Patellar ligament

12-3. The most common complication after total knee replacement is:
a. Stiffness
b. Infection
c. Instability
d. Deep venous thrombosis
e. Neurovascular injury

12-4. A valgus closing wedge osteotomy is indicated for the treatment of:
a. Valgus osteoarthritis with isolated lateral compartment narrowing
b. Varus osteoarthritis with isolated medial compartment narrowing
c. Isolated patellofemoral osteoarthritis
d. Rheumatoid arthritis
e. Tricompartmental osteoarthritis

12.5. On postoperative day 3 after a total knee replacement, the patient is noted to have an open area of the wound with a black necrotic edge. The most worrisome complication of this clinical situation is:
a. Deep venous thrombosis
b. Infection
c. Poor scar appearance
d. Nerve injury
e. Medial collateral ligament rupture

12-6. If a total knee replacement becomes loose before 5 years after implantation, it should be evaluated for what other complication:
a. Osteoporosis
b. Stiffness
c. Fracture
d. Neurovascular injury
e. Infection

12-7. Resection arthroplasty of the knee is indicated for the treatment of:
a. Osteoarthritis
b. Rheumatoid arthritis
c. Chronic knee instability
d. Salvage of the multiply operated failed total knee replacement
e. Ankylosing spondylitis

12-8. When recommending arthroscopy of the knee for a patient with osteoarthritis, the surgeon should inform the patient that:
   a. The results are highly successful
   b. The long-term success is excellent for pain relief
   c. The patient may have more pain postoperatively
   d. Arthroscopy is necessary before total knee replacement
   e. Arthroscopy can delay the need for total knee replacement

12-9. Nonoperative management of osteoarthritis of the knee includes:
   a. Nonsteroidal antiinflammatory medications
   b. Careful use of intraarticular corticosteroid injections
   c. Physical therapy
   d. Use of a cane and weight loss
   e. All the above

12-10. Patients with chondromalacia of the patella have which of the following symptoms?
   a. Anterior knee pain with prolonged sitting
   b. Anterior knee pain when descending stairs
   c. Buckling or giving way of the knee with ambulation
   d. Crepitus in the anterior aspect of the knee
   e. All the above

13
The Foot and Ankle

Scott T. Sauer and Paul S. Cooper

An overview of orthopedics would not be complete without an understanding of the foot and ankle. This area of the body is often forgotten in the scheme of things, and yet it is one of the most common sources of complaints in any physician's office. Painful feet are seen in emergency rooms and family practitioners' offices. Ankle discomfort is seen in medical clinics and on the sidelines of recreational sporting activities. This chapter is intended familiarize the student of medicine, whether an actual medical student, resident, or practitioner, with the anatomy, diagnostic tools, and some common conditions that affect the foot and ankle.

Bones and Joints

The bony anatomy of the foot and ankle consists of the distal tibia and fibula in the leg and the 26 major bones that compose the foot. The tibia distally terminates into the metaphyseal plafond with its medial malleolus. The lateral surface of the distal tibia has a sulcus to accommodate the adjacent fibula, forming the distal tibiofibular joint. The distal fibula, which lies laterally and slightly posterior to the tibia, is held there by the inferior tibiofibular ligaments. The fibula forms the lateral malleolus of the ankle joint. The relationship of the fibula to the tibia is not static. With ankle dorsiflexion, the fibula laterally translates, proximally migrates, and externally rotates.

The ankle is a diarthrodial joint (Figs. 13-1, 13-2). It consists of an articulation between the talus and the mortise of the tibia and fibula. Dorsiflexion of the ankle joint is coupled with eversion of the foot, and plantarflexion is combined with inversion. The distal fibula provides a static buttress over the talus laterally and also bears one-sixth of the transmitted weight during the stance phase of gait. The foot is composed of 7 tarsals, 5 metatarsals, and 14 phalanges.

Three anatomic groupings are defined for descriptive purposes: the hindfoot, the midfoot, and the forefoot (see Fig. 13-3). The hindfoot

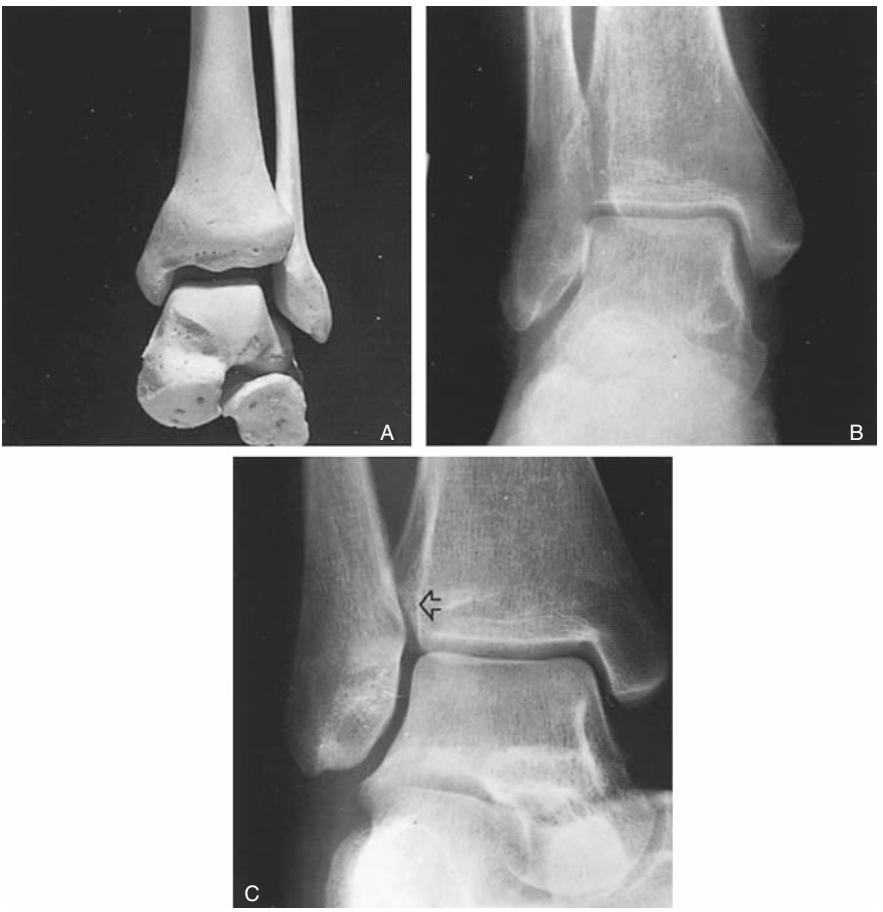


FIGURE 13-1. (A, B) Photographic, diagrammatic, and radiologic anatomy of the normal ankle in anteroposterior views. (C) Note equal width of cartilage spaces and alignment of lateral talus with posterior cortex (*arrow*) on mortise view. (From Weissman BNW, Sledge CB. Orthopedic Radiology. Philadelphia: Saunders, 1986. Reprinted with permission.)

consists of the talus and calcaneus bones, and the talus consists of a body, neck, and head. Two-thirds of the talus is covered by articular cartilage. There are no muscle or tendon attachments on this bone. The talar dome is the superior portion of the body that forms the mortise with the tibia and fibula. The dome is wider anteriorly, which allows for stability in the mortise during dorsiflexion. Posteriorly, a sulcus is formed between the posterolateral and posteromedial tubercles to accommodate the flexor hallucis longus (FHL) tendon. The inferior surface of the talus articulates

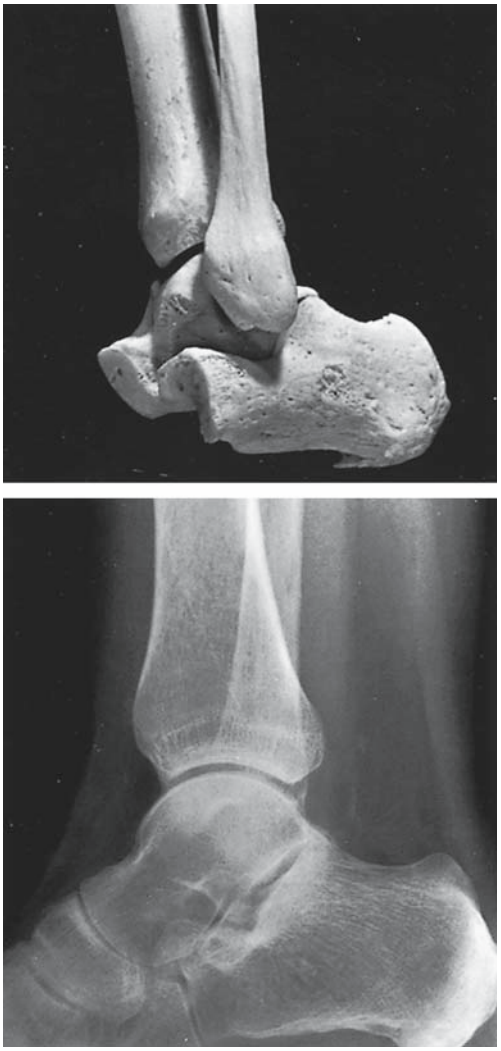


FIGURE 13-2. Photographic (A) and radiologic (B) anatomy of the normal ankle in lateral projection. (From Weissman BNW, Sledge CB. Orthopedic Radiology. Philadelphia: Saunders, 1986. Reprinted with permission.)

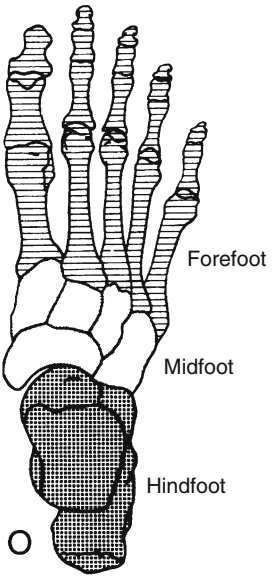


FIGURE 13-3. Anatomic regions of the foot. (From Weissman BNW, Sledge CB. Orthopedic Radiology. Philadelphia: Saunders, 1986. Reprinted with permission.)

with the corresponding facet of the calcaneus to create a subtalar joint. The calcaneus is the largest bone in the foot, with its longitudinal axis directed dorsally and laterally. Its superior surface articulates with the talus and three facets—anterior, medial, and posterior—to form the subtalar joint (Fig. 13-4). The large posterior facet articulates with the corresponding articular facet on the inferior surface of the talus. The middle facet overlies the sustentaculum tali (a dense, medial projection of the calcaneus that contains a groove to accommodate the FHL tendon sheath) and is often merged with the anterior facet. The middle and anterior facets articulate with the undersurface of the talar head.

The midfoot consists of the navicular, cuboid, and three cuneiform bones. The tarsonavicular bone articulates with the talar head and lies medially to the cuboid bone. It functions as a keystone for the medial longitudinal arch of the foot. The distal surface is composed of three facets that articulate with the medial, middle, and lateral cuneiform bones, respectively; this is also the insertion site for the posterior tibial tendon. In 10% of people, an unfused accessory navicular bone may be present. The cuboid bone forms an articulation with the calcaneus proximally and the fourth and fifth metatarsals distally. Laterally, a groove accommodates the peroneus longus tendon as it courses plantarly. Three cuneiform bones have distal articulations with the first, second, and third metatarsals and contribute to the formation of part of the tarsometatarsal, or Lisfranc's

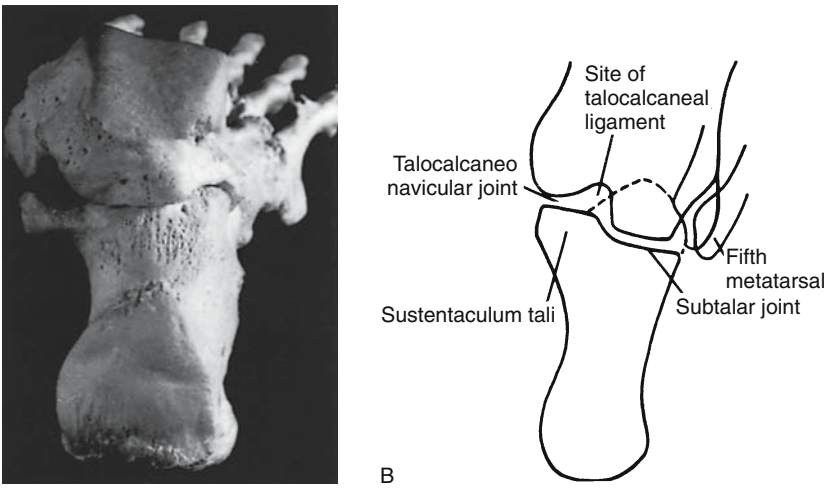


FIGURE 13-4. Photographic (A) and diagrammatic (B) anatomy of the normal ankle in tangential calcaneal (Harris) projection. (From Weissman BNW, Sledge CB. Orthopedic Radiology. Philadelphia: Saunders, 1986. Reprinted with permission.)

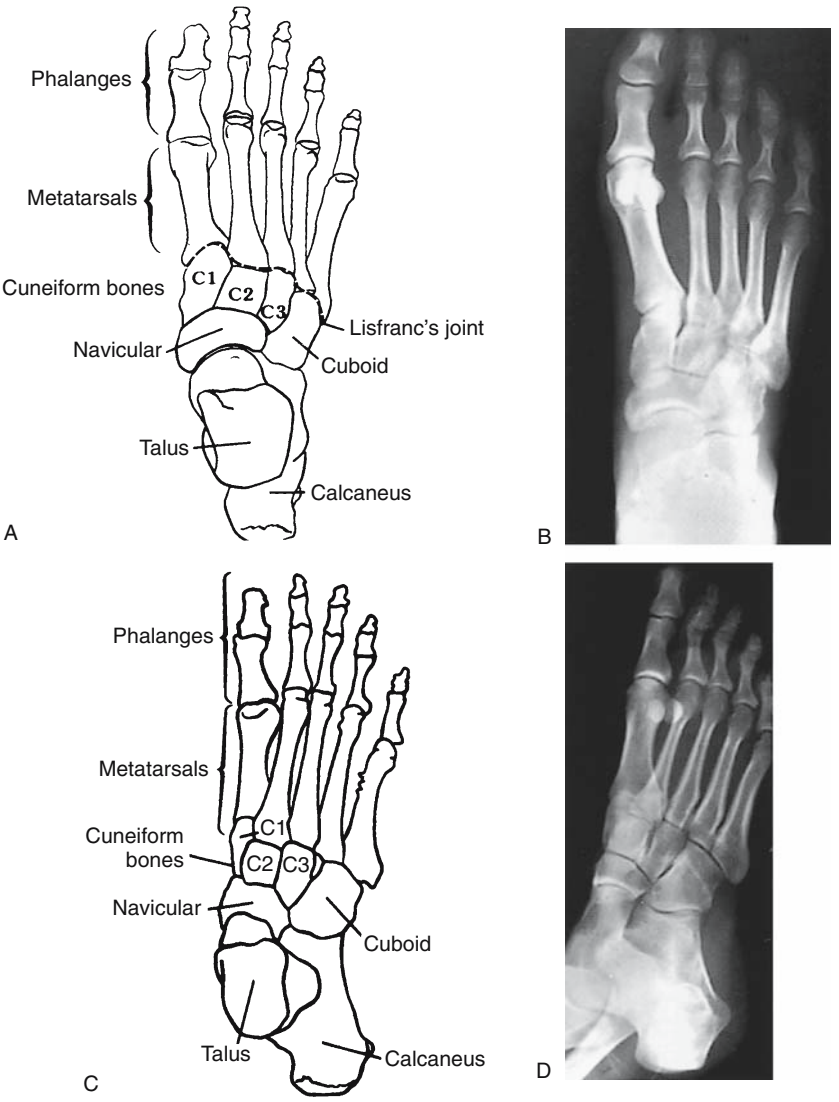


FIGURE 13-5. Photographic, diagrammatic, and radiologic anatomy of the normal foot in posteroanterior (A, B) and internal oblique (C, D) projections. (From Weissman BNW, Sledge CB. Orthopedic Radiology. Philadelphia: Saunders, 1986. Reprinted with permission.)

joint (Fig. 13-5). The middle cuneiform bone is shorter axially, adding to greater stability in the second tarsometatarsal joint; this is also known as the keystone.

The forefoot consists of the metatarsal and phalangeal bones. Five metatarsals terminate distally with articulations to the proximal phalanges

creating metatarsal phalangeal (MTP) joints. The fifth metatarsal is a prominent styloid process proximally to which the peroneus brevis attaches. Each of the lesser toes, two through five, has three phalanges—a proximal, middle, and distal phalanx—and the hallux has only two phalanges, proximal and distal. Each distal phalanx terminates in a tuft of bone and serves as an anchor for the toe pad. Underlying the first MTP joint are the two sesamoid bones. Tibial (medial) and fibular (lateral) sesamoid bones are encased by the flexor hallucis brevis tendon (FHB), which inserts at the base of the proximal phalanx.

Ligaments

The ligamentous structures of the ankle joint (Fig. 13-6) include the medial deltoid ligament complex and the lateral ankle ligament complex. The deltoid ligament medially has both superficial and deep components

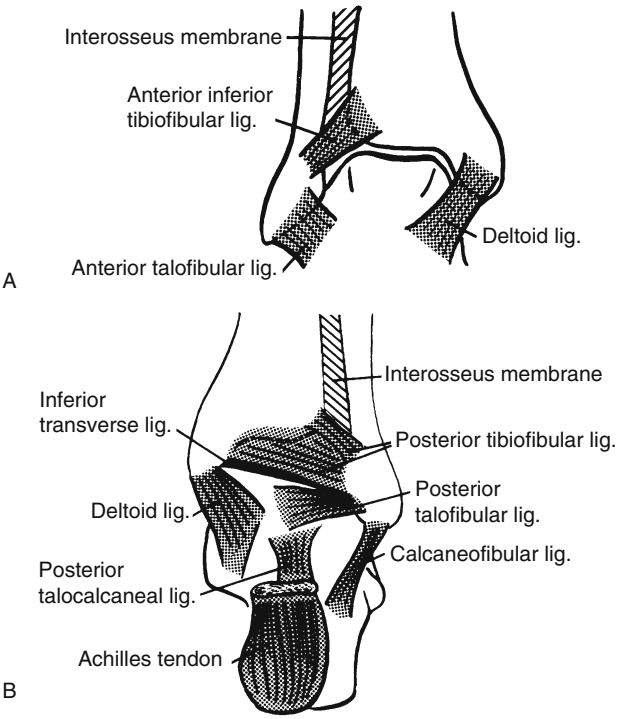


FIGURE 13-6. The tibiofibular syndesmosis. The syndesmosis consists of the interosseous membrane, the anterior and the posterior inferior tibiofibular ligaments, and the inferior transverse ligament. (A) Anterior view; (B) posterior view. (From Weissman BNW, Sledge CB. Orthopedic Radiology. Philadelphia: Saunders, 1986. Reprinted with permission.)

and is the primary contributor to medial stability of the ankle joint. The lateral ligament complex consists of three major ligaments including the anterior talofibular ligament (ATFL), the calcaneofibular ligament (CFL), and the posterior talofibular ligament (PTFL); these contribute to lateral stability of the ankle joint.

Ligaments of the ankle syndesmosis include the anterior tibiofibular, posterior tibiofibular, and interosseous ligaments. Injuries to these ligaments may occur with hyperdorsiflexion and external rotation, creating a "high-ankle sprain" that is seen especially in athletes. Ligamentous support of the subtalar joint is contributed by the CFL, the ligaments of the anterior capsule, the posterior subtalar joint capsule, the interosseous talocalcaneal ligaments, and the ligaments of the tarsal canal. The midfoot joints are stabilized by multiple ligaments as well as the intrinsic bony architecture of the wedge-shaped cuneiform bones. Little motion occurs through the midfoot. Stabilizing ligaments include the bifurcate ligament, a V-shaped structure composed of the lateral calcaneonavicular and medial calcaneocuboid ligaments, which insert on the anterior process of the calcaneus, navicular, and cuboid bones, respectively. Superficial and deep plantar ligaments span from the calcaneus to the cuboid bone and metatarsals; these serve as static stabilizers of the longitudinal arch. Another important structure is the plantar aponeurosis (or plantar fascia). This thick fibrous structure runs from the plantar surface of the calcaneus to distally insert into the metatarsals; it stabilizes the arch during gait (Fig. 13-7). There is

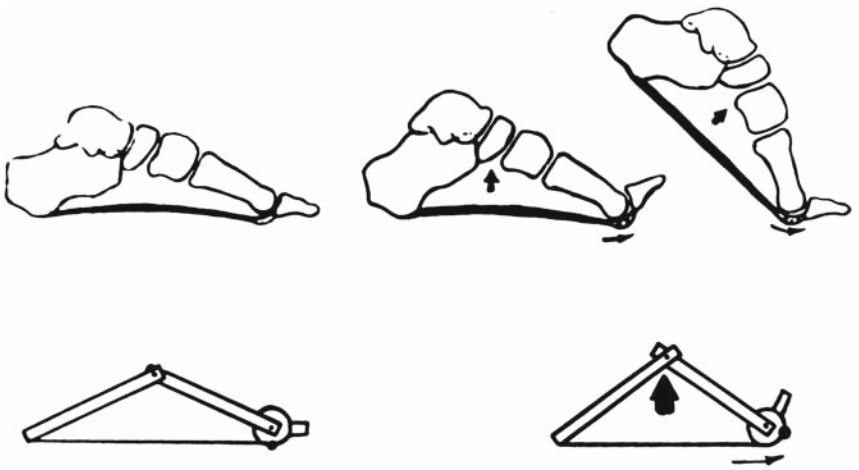


FIGURE 13-7. Plantar aponeurosis and windlass mechanism provide stability to the longitudinal arch of the foot when the first metatarsophalangeal joint is forced into dorsiflexion and it secondarily plantarflexes the first metatarsal. (From Mann RA. The great toe. Orthop Clin N Am 1989;20(4):520. Reprinted by permission.)

no true transverse interosseous ligament between the first and second metatarsal bases. Instead, there is an oblique plantar ligament that connects the first cuneiform bone to the second metatarsal; it is known as Lisfranc's ligament. Stabilizing the MTP joints are a deep transverse metatarsal ligament as well as medial and lateral collateral ligaments.

Muscles

The muscles of the leg are encased in four leg compartments: the superficial and deep posterior compartments, the lateral compartment, and the anterior compartment. The superficial posterior compartment includes the gastrocnemius, the plantaris, and the soleus muscles. This compartment houses the main plantarflexors of the ankle (Fig. 13-8), which are innervated by the tibial nerve. The tendon fibers of the soleus merge with the gastrocnemius tendon fibers to firm the tendo calcaneus or Achilles tendon. The Achilles tendon rotates 90 degrees to insert on the posterosuperior tuberosity of the calcaneus. The deep posterior compartment contains three muscles that invert the foot and serve as secondary plantarflexors: the tibialis posterior muscle, the flexor digitorum longus muscle, and the flexor hallucis longus muscle. The lateral compartment, innervated by the superficial peroneal nerve, contains the peroneus longus (FDL) and peroneus brevis muscles, the main evertors of the foot. The deep peroneus longus muscle courses distally underneath the cuboid to insert on the base of the first metatarsal and medial cuneiform bone. The peroneus brevis inserts on the base of the fifth metatarsal. The anterior leg compartment contains the tibialis anterior, the extensor hallucis longus (EHL), and the extensor digitorum longus (EDL) muscles. These muscles serve as the primary dorsiflexors of the ankle and foot; they are innervated by the deep peroneal nerve.

The intrinsic muscles of the foot are arranged in four plantar layers. The EDB is innervated by the deep peroneal nerve. The first superficial layer of the intrinsic plantar muscles includes the flexor digitorum brevis (FDB), the abductor hallucis, and the abductor digiti minimi (ADM) muscles. The second layer contains the muscles for toe motion and includes the quadratus plantae and lumbrical muscles as well as the tendons of the FHL and FDL. The third layer includes the flexor hallucis brevis, abductor hallucis, and the adductor hallucis (ADH) tendon. These muscles assist in first and fifth toe function. The fourth and deepest layer of intrinsic muscles contains the seven interosseous muscles and the insertions of the peroneus longus and anterior and posterior tibial tendons. The interossei are divided into two groups with four dorsal interossei and three plantar interossei. The dorsal interossei are involved in toe adduction, and the plantar interossei are involved in toe abduction.

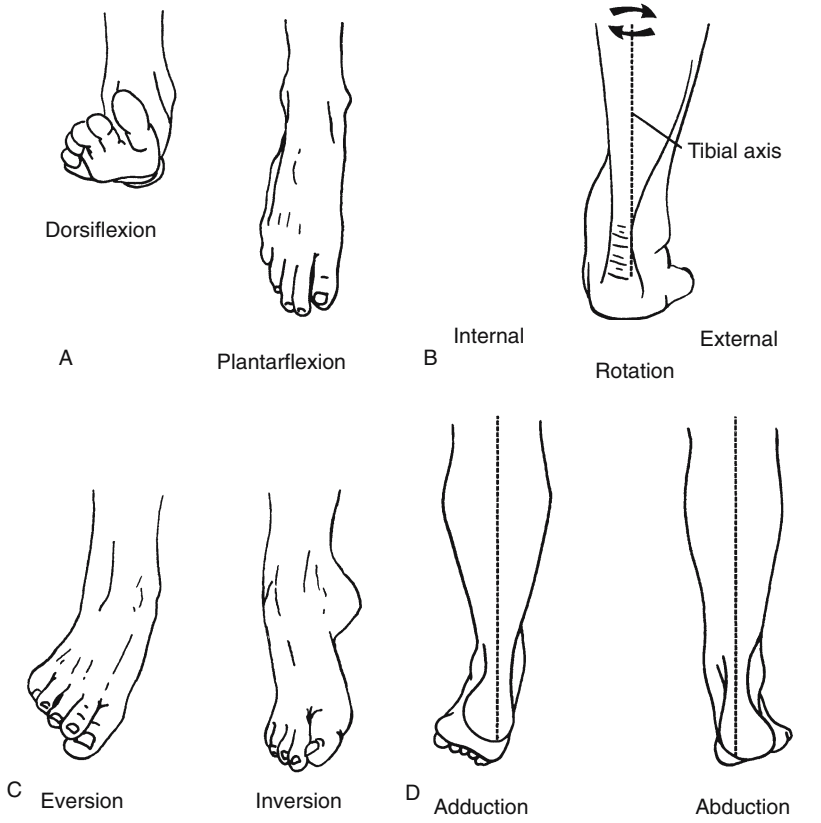


FIGURE 13-8. Motions of the foot and ankle. (A) *Plantarflexion* and *dorsiflexion* refer to movement of the foot downward or upward. *Supination* and *pronation* refer to rotation of the foot internally or externally around the longitudinal axis of the foot. (B) *Internal* and *external rotation* of the foot refer to motion around the vertical axis of the tibia. (C) *Eversion* directs the sole laterally, whereas *inversion* refers to rotation of the foot until the sole is directed medially. (D) *Adduction* and *abduction* describe motion of the forefoot toward or away from the midline. (From Weissman BNW, Sledge CB. Orthopedic Radiology. Philadelphia: Saunders, 1986. Reprinted with permission.)

Nerves and Vessels

The neurovascular structures of the foot and ankle include five major nerve branches and three arteries. The tibial and common peroneal nerves are terminal branches of the sciatic nerve, which arises from the lumbosacral plexus. The common peroneal nerve from L5 branches into the superficial peroneal nerve and deep peroneal nerve. The superficial peroneal nerve courses through the lateral compartment and exits the lateral compartment

approximately 10 to 15 cm above the lateral malleolus through a fascial defect and continues subcutaneously to provide sensory innervation of the dorsal aspect of the foot and toes. The deep peroneal nerve courses through the anterior compartment with the anterior tibial artery, continues into the foot with the dorsalis pedis artery to provide innervation to the intrinsic foot muscles, including the EDB and EHB muscles, and terminates as a cutaneous nerve in the first web space. The tibial nerve, a branch of S1, travels through the popliteal fossa into the deep posterior compartment. It courses medial to the Achilles tendon, enters the tarsal tunnel just posterior to the medial malleolus, and divides into the median and lateral plantar nerves. The medial and lateral plantar nerves supply motor and sensory function to the plantar aspect of the foot. The sural nerve is a sensory branch of the tibial nerve and provides sensation to the posterolateral hindfoot and lateral border of the foot. The saphenous nerve courses along the anteromedial aspect of the lower limb posterior to the greater saphenous vein and provides sensation to the medial side of the ankle.

Vascular supply to the foot and ankle is derived from the anterior and posterior tibial arteries and peroneal arteries. The anterior tibial artery becomes the dorsalis pedis in the foot. The posterior tibial artery divides into the medial plantar artery and lateral plantar artery to supply the plantar structures in the foot. The peroneal artery branches from the posterior tibial artery and travels posterior to the interosseous membrane, deep to the FHL muscle, terminating at the distal tibiofibular joint.

The major structures of the venous system of the leg include the greater saphenous vein and the lesser saphenous vein. The greater saphenous vein courses anteromedial to end in the femoral vein; it drains the dorsum of the foot. The lesser saphenous vein runs posterior to the fibula and drains the lateral foot and arch.

Gait Cycle

The gait cycle consists of one heel strike to the next heel strike of the same foot. It is traditionally divided into a stance phase that comprises 62% of the cycle and the swing phase which constitutes the remaining 38% of the cycle. At initial heel strike, the lower extremity is in internal rotation. The ankle joint is plantarflexed and the subtalar joint is everted. The transverse tarsal joint is unlocked to allow shock absorption. Anterior compartment muscles are active in helping decelerate the limb. At foot flat, the lower extremity externally rotates, the ankle joint dorsiflexes, and the subtalar joint begins to invert; this increases stability throughout the midfoot in anticipation of push-off. Anterior compartment muscles become inactive, intrinsic muscles of the foot become active, and the posterior compartment calf muscles are contracting. At pre-swing, the ankle joint is in plantarflexion.

Clinical Evaluation of the Foot and the Ankle

History and Physical Examination

A complete medical and surgical history, the mechanism of injury, and the duration of the symptoms should be elicited. The location and quality of pain should be documented. Existing systemic disorders should be ruled out, with an emphasis on diabetes and gout. Musculoskeletal history involving the spine and lower extremities is helpful. A physical examination should be done with both stockings and shoes removed. Gait patterns should be determined with the patient walking both toward and away from the examiner. The stance phase or station should be examined with emphasis placed on the relationship of the hindfoot with the forefoot and longitudinal arch. Once inspection has been completed, examination of the bony and soft tissue structures follows. The area should be examined for the presence of edema, effusion, skin temperature changes, and previous sites of surgery or trauma. Systemic examination can be divided into the ankle, hindfoot, midfoot, and forefoot subgroups. When examining the ankle, note any effusion. Range of motion of the ankle is normally 20 degrees of dorsiflexion and 40 to 50 degrees of plantarflexion. Loss of ankle dorsiflexion may be associated with a tight Achilles tendon, posterior capsular contracture, or bony impingement. Limitation of dorsiflexion with the knee in full extension that improves passively with the knee flexed to 90 degrees indicates a contracture of the gastrocnemius muscle. Ligamentous laxity should be evaluated in comparison with the contralateral ankle joint, and palpation of the tendons should be performed to note evidence of subluxation or dislocation. Midfoot examination involves selective palpation of the bony anatomy to isolate specific joint or joint involvement. Forefoot examination should include MTP joint motion with any documentation of subluxation and pain.

Radiology of the Foot and Ankle

Radiographic studies of the foot and ankle require weight-bearing X-rays when possible. Important views involve the anteroposterior (AP), lateral, and oblique views of the foot, and AP, lateral, and mortise views of the ankle. The AP view of the foot can be used to assess forefoot and midfoot pathology. The lateral view of the foot shows the relationship of the talus and calcaneus to that of the midfoot, forefoot, and ankle joint. The medial oblique view is used to evaluate the lateral tarsometatarsal joints. Other studies are available to assess the sesamoids, the calcaneus, or the subtalar joint. The sesamoid view involves the X-ray beam directed tangential to the plantar surface of the sesamoid region while the patient's toes are in hyperextension. The Harris axial heel view is used to assess the calcaneal tuberosity and is important in calcaneus fractures or tarsal coalitions.

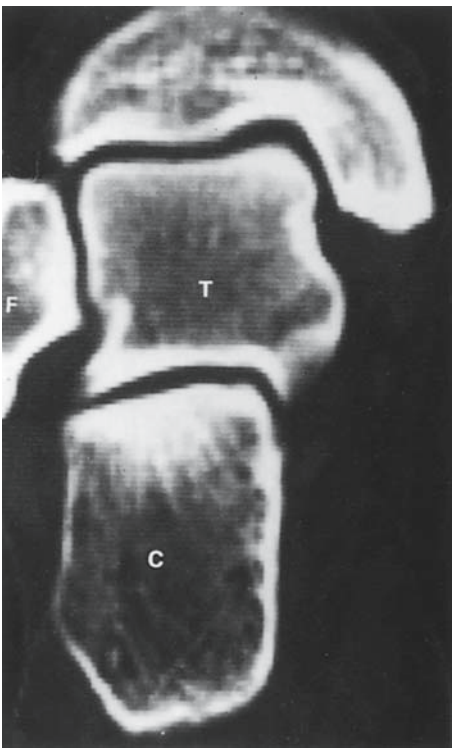


FIGURE 13-9. Normal anatomy seen on computerized tomography: coronal section through the ankle and subtalar joint. *C*, calcaneus; *F*, fibula; *T*, talus. (From Weissman BNW, Sledge CB. Orthopedic Radiology. Philadelphia: Saunders, 1986. Reprinted with permission.)

Ancillary radiographic studies include computed tomography (CT) (Fig. 13-9), magnetic resonance imaging (MRI), and radionuclide studies. MRI can be used to assess soft tissue structures such as soft tissue tumors, osteomyelitis, avascular necrosis, bone tumors, chondral lesions, and tendon abnormalities.

Diseases of the Foot and Ankle

This overview discusses the pathologic states that affect the foot and the ankle by diagnostic category. It is not meant to be an exhaustive catalogue of every affliction, but rather a representative sampling of the more common disease states that mandate medical care.

Trauma

Ankle

Injuries of the ankle mortise include pilon fractures, ankle fractures, and syndesmotic injuries.

Pilon Fractures

Pilon fractures involve the intraarticular fractures of the tibial metaphysis that extend to the weight-bearing portion of the tibia. There is often extensive comminution. Nondisplaced pilon fractures may be treated nonoperatively with immobilization in a cast; however, because these are often displaced injuries, treatment consists of some type of operative fixation. Initially and temporarily, an ankle-spanning external fixator may be applied to maintain length and ankle joint reduction until soft tissue swelling subsides, within 1 to 2 weeks. At that point, open reduction and internal fixation using screws and a plate can be done. In high-energy injuries with soft tissue compromise, external fixation may be the definitive treatment.

Ankle Fractures

Ankle fractures are discussed in Chapter 2.

Syndesmosis Injuries

With disruption of the syndesmotic ligaments, a diastasis, or separation, of the distal tibia and fibula can occur. This injury is often associated with higher grades of ankle fractures when medial stability is compromised by a medial malleolar fracture or a deltoid tear. Definitive diagnosis of a syndesmotic injury can be made with stress X-rays, which show a diastasis at the distal tibial and fibular joint. If this exists, reduction and stabilization of the syndesmosis are achieved with screw placement across the tibial and fibular joint or tibial and fibular syndesmosis. The screw should remain in place for a minimum of 10 to 12 weeks and is then removed.

Fractures to the Hindfoot

Fractures of the hindfoot involve the calcaneus, talus, and navicular bones.

Talus Fractures

The talus articulates with the ankle, calcaneus, and navicular bones and is covered by articular cartilage on 60% of its surface (Fig. 13-10). Because most of the talus is covered by articular cartilage and there are no muscle or tendinous attachments, there is limited space for blood vessels to enter this bone. Therefore, the blood supply is tenuous. The blood supply enters the talus at the neck and travels retrograde into the body and the dome (Fig. 13-11). Fractures of the talus, depending on the severity, can often disrupt this blood supply. Fractures of the talus typically occur through the neck and result from an acute dorsiflexion injury. Standard radiographs with CT scans are usually adequate to demonstrate the nature of the fracture. Treatment is tailored to restore normal talar anatomy. If nondisplaced, conservative nonsurgical treatment can be used. If displaced, often

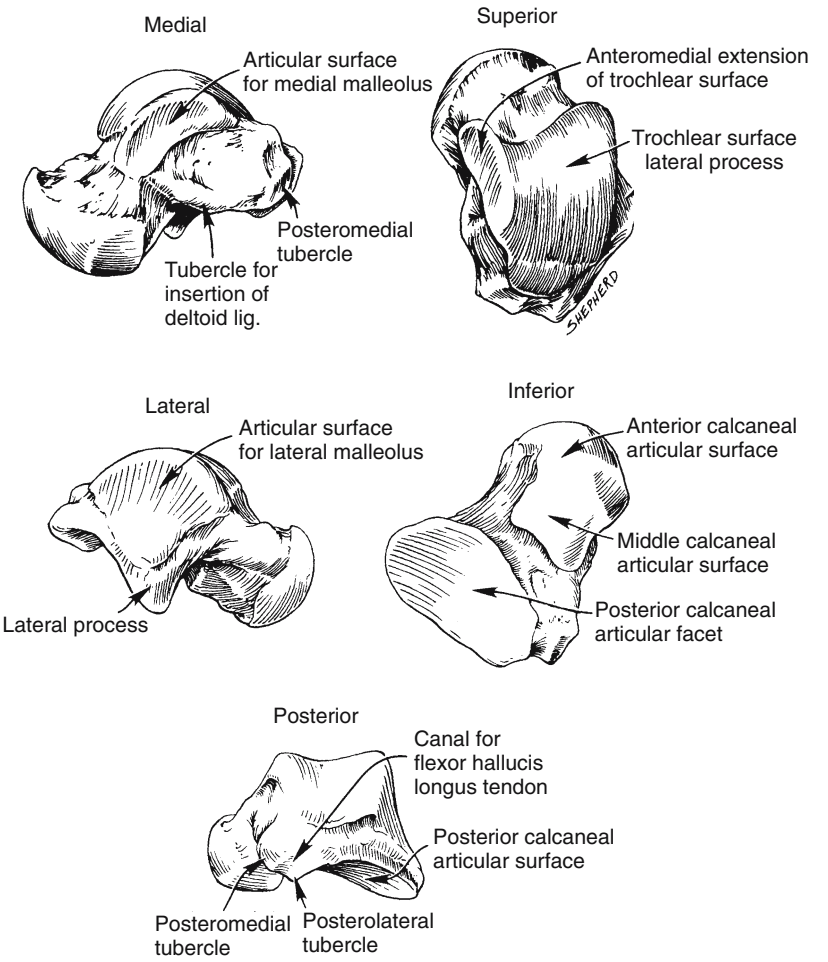


FIGURE 13-10. Important anatomic structures of the talus. (From Adelaar RS. The treatment of complex fractures of the talus. Orthop Clin N Am 1989;20(4):692. Reprinted by permission.)

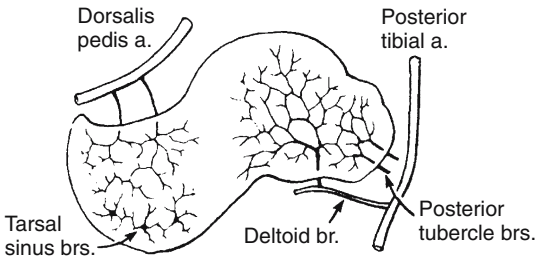


FIGURE 13-11. Extraosseous and intraosseous circulation of the talus. (From Adelaar RS. The treatment of complex fractures of the talus. Orthop Clin N Am 1989;20(4):693. Reprinted by permission.)

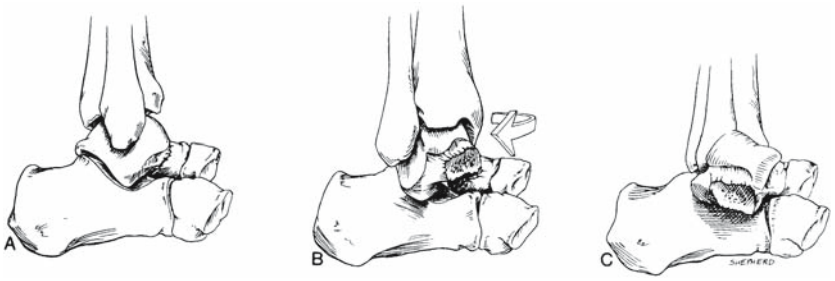


FIGURE 13-12. Classification of talus neck fractures: (A) Class I; (B) class II; (C) class III. (Modified from Hawkins LG. Fractures of the neck of the talus. J Bone Joint Surg 1970;52A:991–1002; and from Adelaar RS. The treatment of complex fractures of the talus. Orthop Clin N Am 1989;20(4):696. Reprinted by permission.)

anatomic reduction and rigid fixation is the best approach; this is done in an effort to prevent avascular necrosis, which can result as a disruption of the tenuous blood supply. Hawkins' classification of talar neck fractures categorizes these fractures into three patterns (Fig. 13-12): type I is a nondisplaced fracture of the neck, type II is a displacement of the neck fracture with subluxation or dislocation of the talar body from the subtalar joint, and type III is a neck displacement fracture with subluxation or dislocation of the body from both the ankle and the subtalar joints. A fourth pattern, which has been described, involves a displaced neck fracture that includes dislocation of the talonavicular joint. The incidence of avascular necrosis increases significantly with each increase in type.

Calcaneus Fractures

The calcaneus is the most commonly fractured tarsal bone. Fractures are classified as intraarticular or extraarticular. Calcaneus fractures are often seen when an axial load is applied to the foot, resulting from falls or motor vehicle accidents. Patients typically present with severe pain and swelling. Radiographs including the axial heel view in addition to CT scanning can fully define the injury. Closed treatment of these fractures is reserved for nondisplaced fractures or poor surgical candidates with severe soft tissue compromise or complicated medical conditions. Open reduction and internal fixation is indicated for displaced intraarticular fractures and significantly displaced extraarticular fractures. Surgical intervention should not proceed until the soft tissues and excessive swelling have stabilized. Assessment of this can be done by observation of wrinkling of the lateral hindfoot soft tissues. If soft tissues are not amenable to open reduction and internal fixation, other techniques including percutaneous fixation and external fixation may be utilized. Despite anatomic reduction and adequate treatment, these patients often develop subtalar stiffness and osteoarthritis.

Injury to the Midfoot

The midfoot injuries include those of the tarsonavicular, cuboid, cuneiform, and tarsometatarsal joints. Injuries to the Lisfranc (tarsometatarsal) joints include subtle sprains to frank fracture dislocations. Bony architecture is similar to that of a Roman arch and designed for stability. The keystone of the arch is the second metatarsal, which has a wedge-shaped base that is recessed between the medial and lateral cuneiform bones. Strong plantar interosseous ligaments provide the main support for the tarsometatarsal joints. There is an absence of an intermetatarsal ligament between the first and second metatarsal joint, which makes this area susceptible to injury. The "Lisfranc ligament" spans the plantar lateral aspect of the medial cuneiform bone and the medial base of the second metatarsal and resists lateral translation of the lesser metatarsals. Mechanisms of Lisfranc injury include a direct crush injury to the midfoot and an indirect twisting-type injury when an axial load is applied to the heel with the foot in fixed equinus, as in motor vehicle accidents or sporting activities. Up to 20% of these injuries are missed on initial evaluation because of the potential subtle nature of these injuries. It is important to obtain standard three-view radiographs of the injured foot and look for the appropriate signs of injury.

Treatment involves conservative nonsurgical treatment for stable injuries versus anatomic reduction of the involved joints with rigid fixation via percutaneous method or open reduction internal fixation for unstable injuries. Patients often develop posttraumatic arthrosis and stiffness.

Ankle Sprains

Ligamentous disruptions, partial and complete, are common about the ankle. The most common ligament to be injured is the anterior talofibular ligament (Fig. 13-13). Inversion stress testing can elicit pain and demonstrate instability on radiographs (Fig. 13-14). Partial injuries can be treated with either a cast or fracture boot or a brace. A complete ligament disruption, particularly of the deltoid, may require surgical repair.

Injuries of the Forefoot

Fractures of the sesamoid bones occur relative to direct trauma or use or both injuries, associated with hyperdorsiflexion of the first metatarsal phalangeal joint. Bipartite sesamoid bones (congenital separation of the two poles of the sesamoid) occur in approximately 25% of individuals, the majority involving the tibial sesamoid bone. Management is mostly conservative. Phalangeal fractures may be either displaced or nondisplaced and angulated. Closed manipulation is often needed under local anesthetic; then the affected toe is taped to the adjacent toe as a splint mechanism, or "buddy taping" is done with wearing of a stiff-soled shoe or sandal.

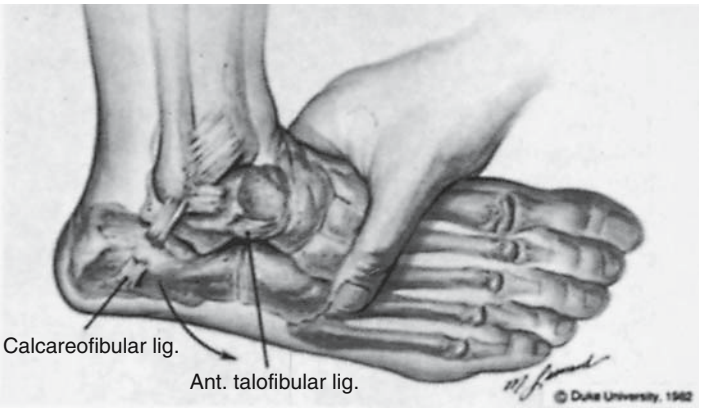


FIGURE 13-13. Inversion stress testing, or the talar tilt. (From Lasseter TE Jr, Malone TR, Garrett WE Jr. Injury to the lateral ligaments of the ankle. Orthop Clin N Am 1989;20(4):631. Reprinted by permission.)

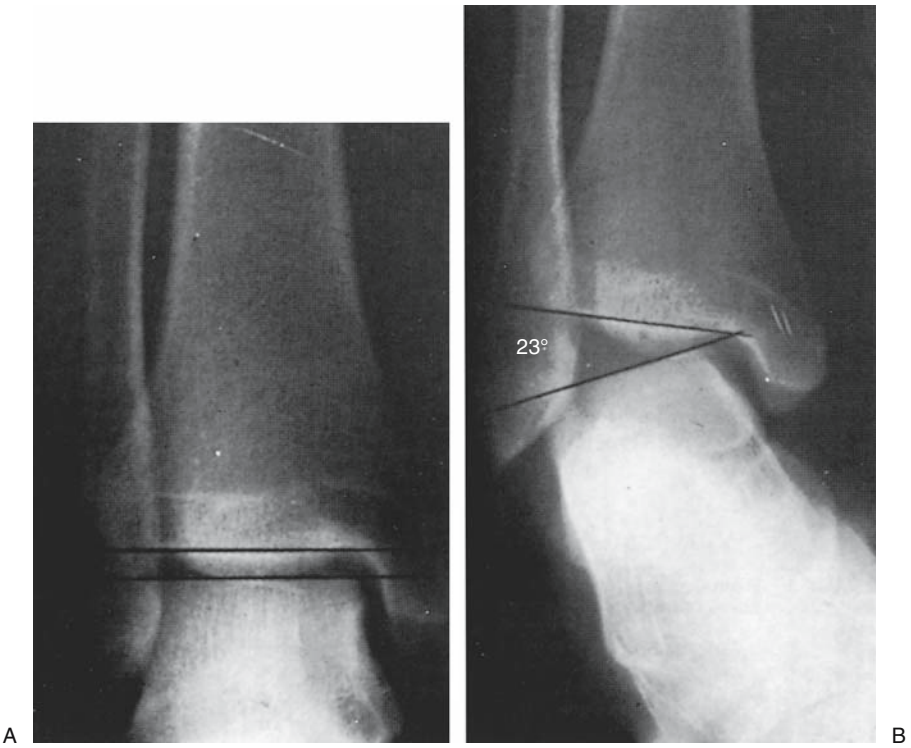


FIGURE 13-14. (A) Anteroposterior view of the ankle prestress. (B) Anteroposterior view of the ankle with inversion stress reveals marked lateral ligament injury. (From Lasseter TE Jr, Malone TR, Garrett WE Jr. Injury to the lateral ligaments of the ankle. Orthop Clin N Am 1989;20(4):632. Reprinted by permission.)

Acquired Deformities of the Foot and Ankle

Deformities of the Forefoot

Hallux Valgus

Hallux valgus is a condition of medial prominence of the first MTP joint with lateral drifting of the big toe (Fig. 13-15). It is almost exclusively related to shoe wear. Radiographically, it is defined as a MTP joint angle of more than 15 degrees and an angle between the first and second metatarsals that is more than 9 degrees. Symptoms include pain, swelling, and inflammation over the medial first MTP joint related to shoe wear. Range of motion of the first MTP joint should be assessed, and AP and lateral radiographs are taken to determine the degree of hallux valgus deformity, the associated metatarsus primus varus, joint congruity, and degenerative changes, as well as position of the sesamoids. Treatment of hallux valgus deformity in the early stages is conservative and includes shoe modification

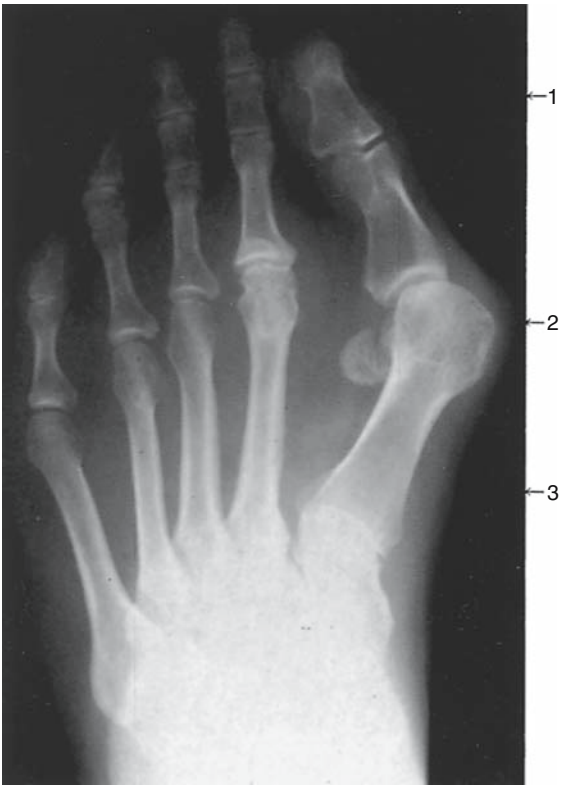


FIGURE 13-15. Classic abnormalities in a bunion: *1*, hallux valgus; *2*, the exostosis; and *3*, metatarsus primus varus. (From Mann RA. The great toe. Orthop Clin N Am 1989;20(4):524. Reprinted by permission.)

to a high, wide toe box and a soft leather upper portion of the shoe. Orthotic devices can be helpful. When conservative measures are not successful, surgical procedures are recommended; these include a simple exostectomy, soft tissue repair, proximal metatarsal osteotomy, distal metatarsal osteotomy, resection arthroplasty, proximal phalangeal osteotomy, and arthrodesis. Contraindications to surgery include generalized spasticity, ligamentous laxity as seen in Marfan's and Ehlers–Danlos' syndromes, and vascular skin insufficiency.

Hallux Varus

Hallux varus is a medial deviation of the great toe at the MTP joint. Causes include complications to hallux valgus surgery or rupture of the conjoined tendon as seen in rheumatic conditions.

Hallux Rigidus

Hallux rigidus is painful loss of motion at the first MTP joint (Fig. 13-16). Patients present with an enlarged, warm, and swollen first MTP joint, with a decreased range of motion, predominantly in dorsiflexion. Shoes with elevated heels tend to increase pain. Initial treatment is conservative with orthotic devices and shoe modifications to reduce the stress across the first MTP joint. Surgical intervention includes resection arthroplasty, cheilectomy, metatarsal or phalangeal osteotomy, or arthrodesis.

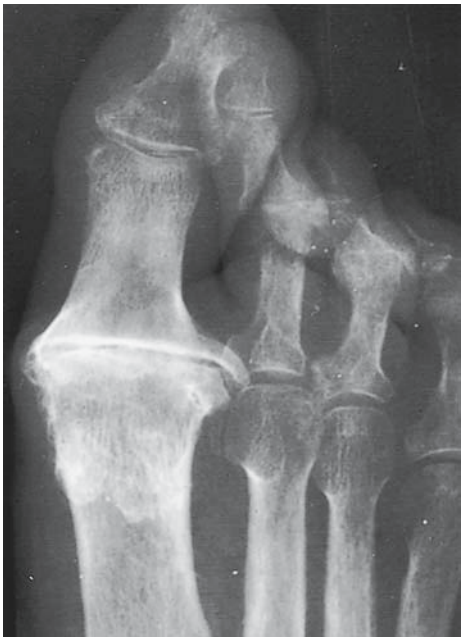


FIGURE 13-16. Hallux rigidus. The posteroanterior view of the great toe metatarsophalangeal joint show the marked cartilage loss, flattening of articular surfaces, and hypertrophic lipping that resulted in severe loss of motion. (From Weissman BNW, Sledge CB. Orthopedic Radiology. Philadelphia: Saunders, 1986. Reprinted with permission.)

Injuries of the Tendons of the Foot and Ankle

Tendonitis is a nonspecific term for a variety of pathologic conditions of tendons. Tendonitis is the inflammatory process of the connective tissue structure surrounding a tendon. Tendonosis is intratendinous degeneration. Management is often conservative, with rest and immobilization with antiinflammatory medications. Common disorders of tendons are those involving the peroneal tendon complex, the anterior tibial tendon, the Achilles tendon, the posterior tibial tendon, and the FHL tendon.

Peroneal Tendon Pathology

Peroneal tendon disorders include injury and degeneration of the peroneus brevis or longus and instability of the peroneal tendon complex. Peroneal brevis tendon injuries may manifest as tenosynovitis, a longitudinal split in the tendon, and subluxation or frank dislocation of the tendon. The patient may have a history of an inversion supination sprain. Radiographic studies are often normal. Indications for operative treatment are persistent pain and failure of conservative treatment with cast immobilization for 2 to 3 weeks and physical therapy. Goals of surgery are to reconstruct the superior peroneal retinaculum, perform a tenosynovectomy when applicable, and to repair any tendon injury.

Anterior Tibial Tendon Pathology

Injuries of the anterior tibial tendon are rare. Tendosynovitis may result from irritation by shoe wear, but is often attributed to an underlying rheumatic condition. Surgery is indicated for a young, active individual with an acute rupture.

Achilles Tendon Disorders

Disorders of the Achilles tendon include peritendonitis, tendinosis, partial and complete rupture, and insertional tendonitis with retrocalcaneal bursitis. Achilles tendonitis is painful inflammation and degeneration of either the surrounding peritenon (peritendonitis) or tendon (tendinosis) or both that occurs proximal to the insertion site of the Achilles in the calcaneus. This condition is often seen in runners with tight Achilles tendons and poor flexibility. Treatment is often conservative, with a period of immobilization to allow inflammation to subside, followed by physical therapy and stretching of the Achilles tendon daily. When conservative measures fail, debridement of the Achilles tendon can be done surgically. When tendonitis occurs at the Achilles tendon insertion onto the posterior aspect of the calcaneus, it is called insertional Achilles tendonitis. Often, there is an enlarged posterior superior calcaneal process called a Haglund's defor-

mity. This tendonitis is also associated with a retrocalcaneal bursitis, which is inflammation of the bursa directly anterior to the Achilles tendon at its insertion. Conservative treatment includes a period of immobilization, heel lifts to shorten the Achilles tendon and take the pressure off the insertion, stretching exercises through physical therapy, and modification of shoe wear. When conservative measures fail, surgery, with debridement of the insertion and removal of the Haglund's deformity as well as a reattachment of the Achilles tendon, is done.

Ruptures of the Achilles tendon can be acute or chronic. These ruptures commonly occur in middle-aged men at the hypovascular zone of the Achilles tendon approximately 3 to 5 cm above its insertion site. Ruptures occur because of forceful eccentric contraction of the elongating tendon; they rarely result from direct trauma. Symptoms include severe pain at the back of the calf. Patients often describe being hit in the back of the leg and an audible "pop." Diagnosis is made by a palpable defect above the Achilles insertion with the patient in a prone position. Two findings are consistent with rupture of the tendon. The first is loss of passive resting tension in comparison to the opposite extremity, which causes the foot to be at a right angle to the remainder of the lower extremity. The second finding is performing the Thompson test, which is done with the patient's foot hanging over the edge of the examination table in a prone position. The midcalf is squeezed. If the tendon is intact, the ankle passively plantarflexes. If the tendon is ruptured, no plantarflexion occurs. In difficult cases, MRI or ultrasound can confirm the diagnosis. Treatment of an acute rupture of the Achilles tendon can be conservative or surgical. Nonoperative management includes immobilization in a plantarflexed position, nonweightbearing, for approximately 3 months; this should be reserved for elderly, less active patients with a medical history that makes surgery dangerous. Disadvantages of conservative management include a higher rerupture rate than surgical repair. Surgical repair includes direct repair of the ends of the Achilles tendon. Advantages include a lower rerupture rate than conservative treatment. Disadvantages include wound complications, infection, and sural nerve injury. Treatment of chronic neglected ruptures includes bracing with an ankle-foot orthosis and other complex surgical reconstructions including flexor hallucis longus tendon transfer.

Posterior Tibial Tendon

Overuse of the posterior tibial tendon causes conditions that range from mild tendonitis to complete rupture and asymmetrical flatfoot deformity. Posterior tibial tendon dysfunction etiologies include trauma, inflammatory arthropathies, or nutritional degenerative conditions. Predisposing factors include hypertension, obesity, diabetes, steroid exposure, and prior surgery or trauma. Early stages include pain, swelling, and fullness localized to the posterior and medial hindfoot. As the tendon continues to

deteriorate and becomes incompetent, a progressive asymmetrical flatfoot deformity develops with lateral hindfoot impingement.

Clinical examination may show tenderness and swelling over the posterior medial hindfoot posterior to the medial malleolus, a secondary Achilles tendon contracture, and weakness in inversion. Patients are unable to perform a single heel-toe rise and often show a "too-many-toes sign" when visualizing the foot from behind when a patient is in a standing position. Too-many-toes sign refers to an advanced collapse of the arch with the heel in significant valgus. The toes are abducted more on the affected foot than the unaffected foot and show more prominently on exam. Weight-bearing X-rays may show uncovering of the talar head by the navicular as the forefoot and midfoot abduct. The lateral view may show talonavicular sagging. MRI can confirm tendinosis and peritendonitis. Treatment options are determined by the stage of dysfunction and presentation. Stage I, which is very mild tendon weakness without flatfoot deformity, can be addressed with orthotics, antiinflammatory medicines, and physical therapy. Sometimes immobilization is needed to allow a decrease in inflammation. Stage II, which involves posterior tibial tendon disruption and the presence of a flatfoot deformity with a flexible hindfoot, can be treated conservatively with orthotics or surgically, which involves reconstruction of the posterior tibial tendon using a flexor digitorum longus tendon transfer and calcaneal osteotomy. There are other surgical options available, and the decision is based on the clinical presentation of the patient. Stage III, which involves posterior tibial tendon dysfunction or disruption, with advanced arthritis and a rigid hindfoot, can be treated conservatively with orthotics or surgically with the appropriate joint fusions. Typically, a triple arthrodesis, or a fusion of the subtalar joint, talonavicular joint, and calcaneocuboid joints, is preferred.

Heel Pain

Plantar heel pain is one of the most common and most disabling conditions of the foot. There are many causes including tumors, infection, stress fractures, inflammatory arthropathies, and neuropathies. The most common cause of plantar heel pain is associated with chronic injury of the plantar fascial origin. This heel pain syndrome is also known as heel spur syndrome and plantar fascitis. Typical pain occurs at the plantarmedial aspect of the heel. Onset is insidious, and often patients recall no trauma. Classic pain and stiffness occurs when arising from bed and taking the first step on the floor in the morning. Symptoms often decrease after prolonged walking. High-heeled shoes typically alleviate symptoms, whereas barefoot walking and wearing flat shoes may increase symptoms. Physical examination shows point tenderness on the plantarmedial heel. Often there is a tight Achilles tendon complex with limited ankle dorsiflexion; occasionally, fat pad or heel pad atrophy is present. Radiographs include a lateral

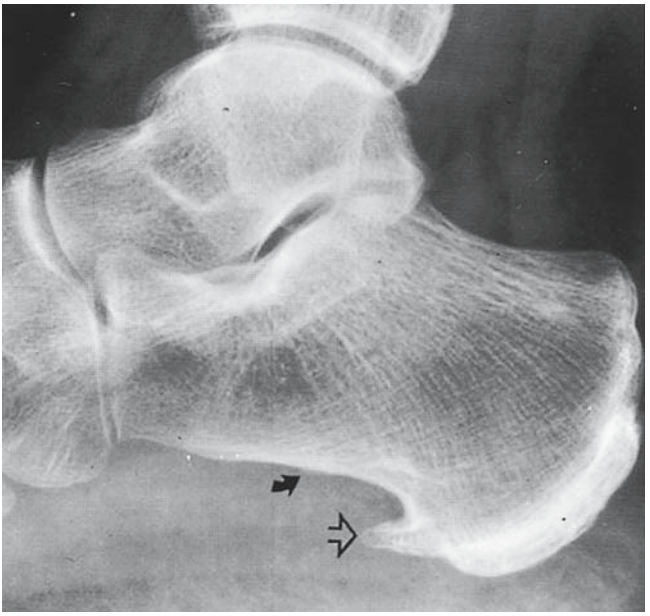


FIGURE 13-17. Calcaneal spurs. The normal plantar spur (*open arrow*) has smooth margins, no sclerosis or erosion, and no adjacent soft tissue swelling. Very small spurs are present at the insertions of the long plantar ligament (*arrow*) and the Achilles tendon. (From Weissman BNW, Sledge CB. Orthopedic Radiology. Philadelphia: Saunders, 1986. Reprinted with permission.)

X-ray, which may show a plantar heel spur (Fig. 13-17); this is often associated with a flexor digitorum brevis origin and can signify a chronic fascitis. It is important to rule out a calcaneal stress fracture and tumor via X-rays. Treatment is almost always conservative, consisting of rest, antiinflammatory medication, orthotic devices, and aggressive stretching. Isolated stretching of the gastrocnemius–soleus complex and plantar fascia is important. Surgery, typically reserved for chronic conditions that have lasted more than 6 six months to a year, involves partial release of the plantar fascial origin.

Arthritic Conditions of the Foot and Ankle

Causes of ankle joint degeneration include primary osteoarthritis, posttraumatic arthritis, avascular necrosis, osteochondritis dissecans, synovial chondromatosis, and other rheumatologic conditions. Conservative management includes antiinflammatory medications, bracing, and intraarticular cortisone injections. Surgical management is dependent on the extent and location of the arthrosis. Options range from joint debridement,

arthroscopic versus open, ankle arthrodesis (fusion), or a total ankle replacement. It is important to note that in extensive arthritis of the ankle the standard surgical treatment is arthrodesis (fusion). Total ankle replacement, although available and helpful in patients with a low-demand lifestyle, has not proven effective in long-term management of the osteoarthritic ankle.

Rheumatoid Arthritis

Rheumatoid arthritis is a systemic disease that commonly involves the foot because there are many joints lined with synovium (Fig. 13-18). It affects both the synovial lining of the joint and the tendons of the foot and ankle.

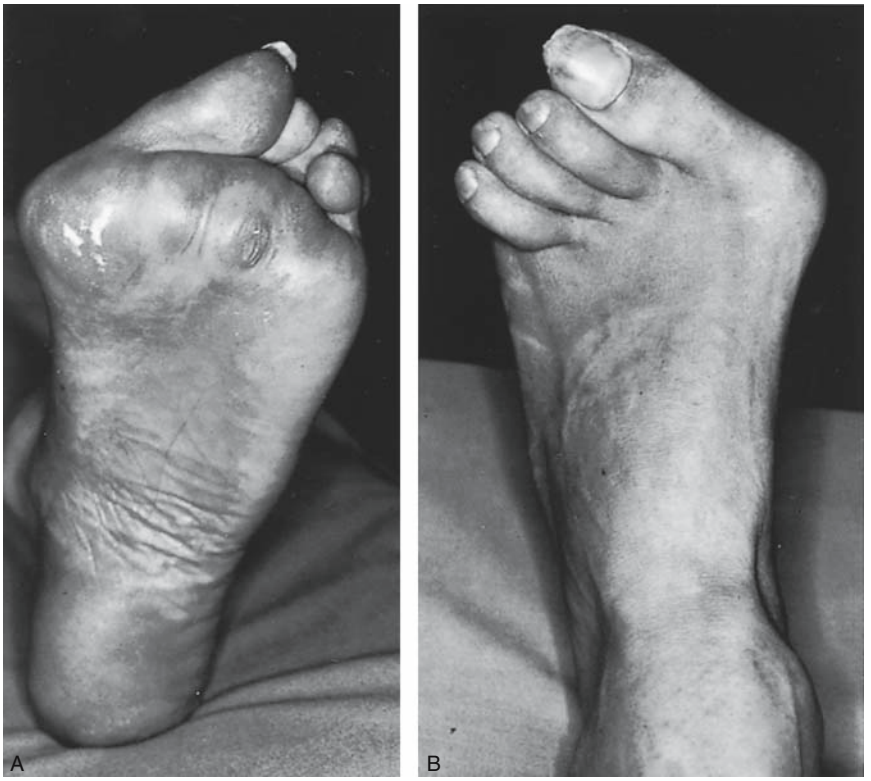


FIGURE 13-18. Plantar (A) and dorsal (B) views of the foot of a patient with rheumatoid arthritis with characteristic dislocation of all toes, which tend to drift off into marked hallux valgus with dorsal displacement of the phalanges onto the metacarpals. The metacarpal heads become very prominent in the sole of the foot, and large, painful callosities are common. (From Bogumill GP. Orthopaedic Pathology: A Synopsis with Clinical and Radiographic Correlation. Philadelphia: Saunders, 1984. Reprinted with permission.)

Physical examination shows an antalgic gait, generalized swelling, and decreased motion in the joints of the foot. Weight-bearing radiographs of the foot and ankle are essential for showing deformity and often show a valgus angulation of either the ankle or subtalar joint. Treatment options include conservative management, such as patient education, activity modification, intermittent steroid injections, optimizing medical management, shoe modifications, and the use of an ankle-foot orthosis. Surgical options include simple synovectomy, arthrodesis, and total ankle arthroplasty.

Infections

Both the bones and joints of the foot can be involved in musculoskeletal septic processes such as osteomyelitis and septic arthritis.

Puncture Wounds

Puncture wounds in the foot can be caused by many things, including glass, nail, and plant and animal parts. Typically, the puncture occurs through the sole of the shoe or sneaker and enters the foot (Fig. 13-19). Because the insole of a sneaker can be colonized with the *Pseudomonas* organism, care should be taken to treat the patient with an infection from a puncture wound for this organism. Patients frequently present late with a swollen cellulitic foot. A complete blood count (CBC) and sedimentation rate can

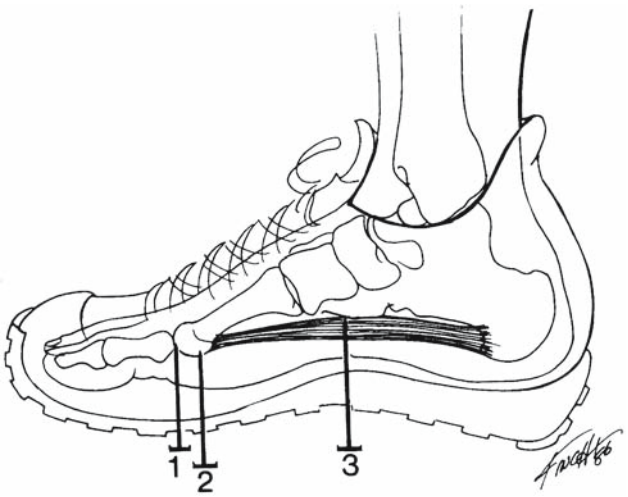


FIGURE 13-19. Puncture injury sites: *1*, metatarsophalangeal joint; *2*, cartilage of metatarsal head; *3*, plantar fascia. (From Clinton JE. Puncture wounds by inanimate objects. In: Gustilo RB, Gruninger RP, Tsukayama DT (eds) Orthopaedic Infection: Diagnosis and Treatment. Philadelphia: Saunders, 1989. Reprinted by permission.)

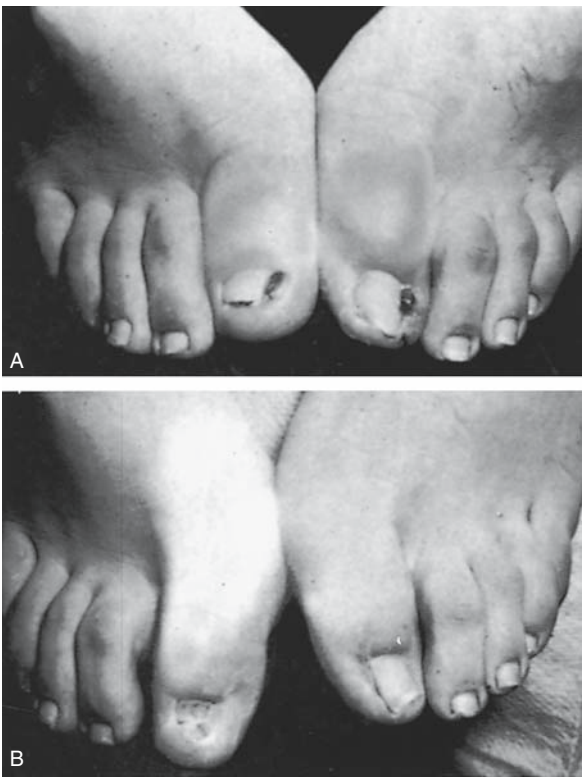


FIGURE 13-20. (A) Bilateral infected ingrowing of both edges of the big toenails. The toenail of the right big toe was practically completely separated from its bed and was avulsed. The operation, which was performed under a local anesthetic, consisted of bilateral resection of all onychogenic tissue in the longitudinal grooves. (B) Sixteen months after surgery. (From Lapidus PW. The toenails. In: Jahss M (ed) Disorders of the Foot, vol I. Philadelphia: Saunders, 1982. Reprinted with permission.)

occasionally be abnormal. Standard radiographs and a bone scan can confirm the diagnosis. When bone or joint involvement is extensive, aggressive surgical debridement is mandatory for satisfactory resolution. Appropriate antibiotic coverage is required until the infection has resolved.

Paronychia

A paronychia is an infection of the medial or lateral nail fold, often seen in the great toe (Fig. 13-20). Paronychiae are often seen in an abnormally growing nail, which penetrates the skin of the lateral nail fold, introducing bacteria. A soft tissue abscess forms and a paronychia develops. Decom-

pression of the abscess is done under local anesthesia, and removing the lateral portion of the nail often allows temporary relief. With more chronic paronychial infections, more aggressive nail excisions may be required.

Diabetic Foot Infections

People with diabetes can develop a sensory neuropathy that prevents them from protective sensation. Because of this, cutaneous defects and ulcerations can form that allow bacterial inoculation and infection to develop. Typical scenarios in which this can happen are after a pedicure or from the abrasions of a poorly fitting shoe (Figs. 13-21, 13-22). With abscesses and ulcers, both acute and chronic septic arthritis and osteomyelitis are frequently the end result. Aggressive treatment of any infection in the diabetic foot is mandatory for salvage. Medical management of the diabetes is crucial, and the patient must be under strict diabetic control. Intravenous antibiotics are almost always necessary in the acute scenario. Antibiotics are often broad spectrum because of the polymicrobial nature of these infections.

Tumors

A complete discussion of soft tissue and bone tumors is beyond the scope of this chapter; however, a few specific lesions are mentioned here.

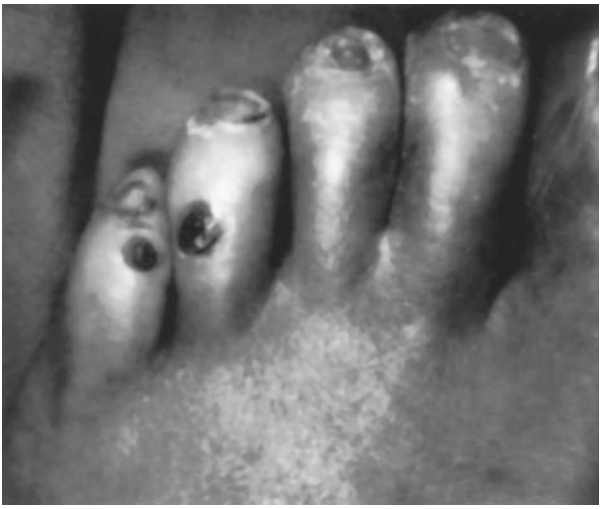


FIGURE 13-21. This diabetic patient had recently obtained new shoes. The two small, dorsal ulcers were exquisitely painful. Note the blanching of the toes distal to the ulcers. (From Harrelson JM. Management of the diabetic foot. Orthop Clin N Am 1989;20(4):606. Reprinted by permission.)

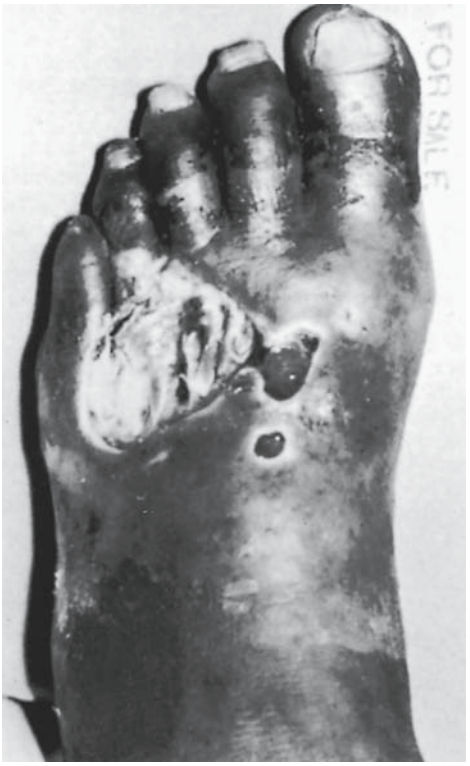


FIGURE 13-22. One day of new shoe wear produced the ulcers seen over the fifth metatarsal head and lateral sides of the fourth and fifth toes. (From Harrelson JM. Management of the diabetic foot. Orthop Clin N Am 1989;20(4):606. Reprinted by permission.)

Soft Tissue Lesions

The anterolateral ankle is the common site for the development of a ganglion cyst as well as soft tissue lipomas. These are both benign lesions, and excision can be performed if symptoms warrant. Thickening of the plantar fascia on the plantar surface of the foot can be palpated on some patients. Sometimes, these thickenings are large, firm nodules known as plantar fibromas. They are benign and should at all costs be treated conservatively.

Bone Tumors

Common bone tumors include enchondroma, a benign cartilage tumor that can occur in the short tubular bones such as the phalanges. The chondromyxoid fibroma (Fig. 13-23) is another benign cartilage tumor that can affect the bones of the foot. It is usually managed by curettage of the lesion. Occasionally, a bone cyst can form in the calcaneus. Pathologic fracture through this can occur and may, in fact, be the chief complaint at a patient's presentation. Treatment usually requires curettage and bone grafting. It is uncommon to have metastatic disease to the small bones of the foot.

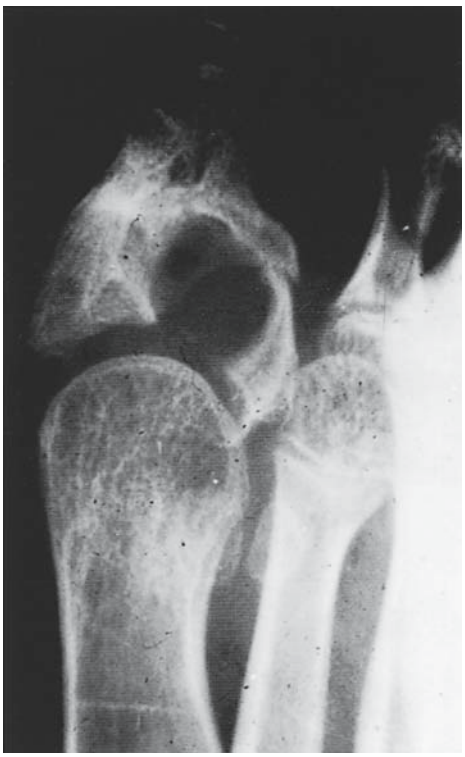


FIGURE 13-23. Chondromyxoid fibroma. This lesion has a tendency for localization in the small bones of the hands and feet. A sharply circumscribed defect in the proximal phalanx of the great toe is shown here. (From Bogumill GP. Orthopaedic Pathology: A Synopsis with Clinical and Radiographic Correlation. Philadelphia: Saunders, 1984. Reprinted with permission.)

When seen, one should suspect the lung as the primary site of the patient's disease.

Complex Regional Pain Syndrome

This disabling disorder of unknown pathophysiology has a variable symptom complex with many hypothesized causes and mechanisms. Renamed from the limited descriptive term reflex sympathetic dystrophy, Complex Regional Pain Syndrome (CRPS) is more common in women than men and more common in adults than children. It can occur after a minor injury with no nerve involvement, or after a significant injury with nerve involvement. Patients present with disproportionate extremity pain, swelling, autonomic symptoms (e.g., changes in sweating, skin discoloration), and motor symptoms (e.g., weakness). Diagnosis of any obvious, treatable causes of pain should be done before definitively selecting CRPS as the diagnosis. Treatment involves extensive therapy and pain relief with desensitization through medication or nerve blockade.

Summary and Conclusions

Numerous conditions affect the foot and ankle, and foot pain remains a very common presenting complaint. A knowledge of anatomy and common foot and ankle problems can provide the diagnostician adequate tools to treat patients. The last three figures in this chapter provide algorithms that can assist in the diagnosis and treatment of foot and ankle pain. Figure 13-24 can assist in the diagnosis and treatment of patients with foot and ankle complaints resulting from an acute injury. Figure 13-25 provides steps to evaluate and treat patients who have foot and ankle pain without a history of an acute injury but do have radiographic evidence of deformity or pathology. Figure 13-26 should provide some structure to the diagnosis and treatment of patients with foot and ankle complaints without injury and no radiographic evidence of deformity or pathology. These algorithms

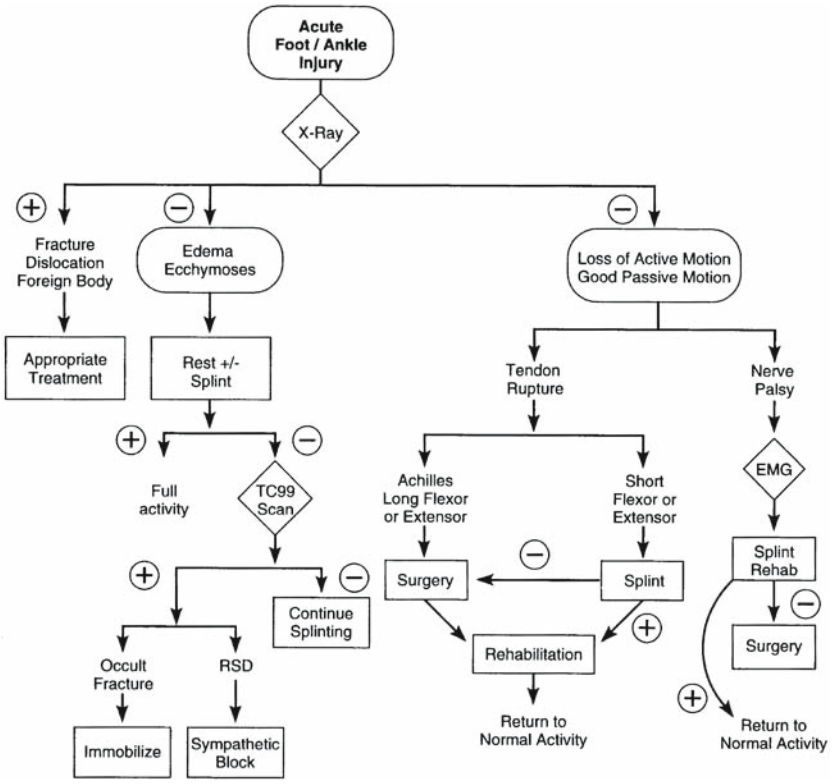


FIGURE 13-24. Algorithm for diagnosis and treatment of foot and ankle pain with acute injury.

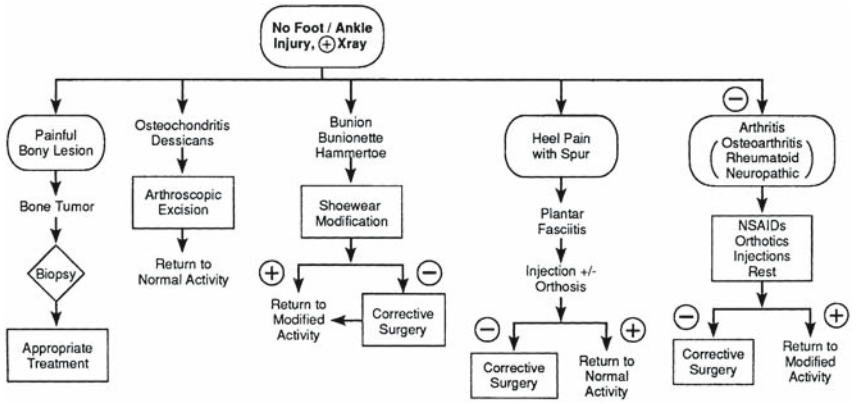


FIGURE 13-25. Algorithm for diagnosis and treatment of foot and ankle pain with no injury and positive radiograph.

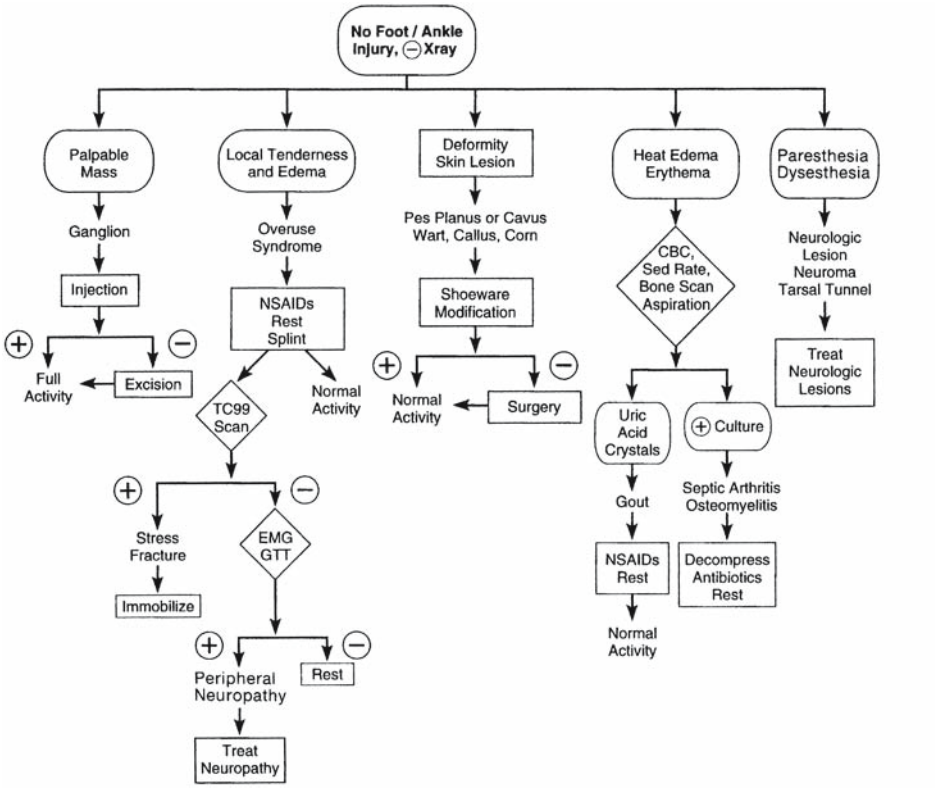


FIGURE 13-26. Algorithm for diagnosis and treatment of foot and ankle pain with no injury and negative radiograph.

are not comprehensive but should provide some guidance when encountering patients with foot and ankle complaints.

Suggested Readings

Cooper PS. The foot and ankle. In: Wiesel SW, Delahay JN (eds) Principles of Orthopaedic Medicine and Surgery. Philadelphia: Saunders, 2001:767–830.

Mann R, Coughlin M (eds) Surgery of the Foot and Ankle, 6th ed. Philadelphia: Mosby, 1993.

Myerson M (ed) Foot and Ankle Disorders. Philadelphia: Saunders, 2000.

Questions

Note: Answers are provided at the end of the book before the index.

13-1. The location of the distal fibula in relation to the distal tibia is:
- a. Directly lateral
- b. Lateral and slightly posterior
- c. Lateral and slightly anterior
- d. Directly medial
- e. Medial and slightly posterior

13-2. The trapezoidal geometry of the talus allows for more stability in ankle:
- a. Plantarflexion
- b. Inversion
- c. Eversion
- d. Dorsiflexion
- e. Neutral position

13-3. The largest bone in the foot is the:
- a. Talus
- b. First metatarsal
- c. Tibia
- d. Cuboid
- e. Calcaneus

13-4. Ligaments of the ankle syndesmosis include the:
- a. Deltoid
- b. Anterior talofibular
- c. Anterior tibiofibular
- d. Calcaneofibular
- e. Plantar calcaneonavicular

13-5. The major nerve branches that supply the foot and ankle include:
- a. Superficial peroneal
- b. Deep peroneal
- c. Tibial
- d. Sural
- e. All the above

13-6. When evaluating a painful foot, radiographs should include:
   a. An anteroposterior view
   b. An oblique view
   c. A lateral view
   d. Weight-bearing views
   e. All the above

13-7. A pilon fracture is:
   a. A fracture of the midfoot involving a disruption of the relationship among the first metatarsal, second metatarsal, and cuneiform bones
   b. A fracture of the calcaneus
   c. An intraarticular fracture of the distal tibial metaphysis extending into the plafond
   d. A displaced fracture of the talar neck, with dislocation of the subtalar joint
   e. A stress fracture at the base of the fifth metatarsal, between the metaphyseal and diaphyseal junction

13-8. Hallux valgus includes:
   a. A lateral deviation of the first toe
   b. Metatarsus primus varus
   c. Medial first metatarsal phalangeal joint exostosis
   d. Pronation of the first toe
   e. All the above

13-9. Puncture wounds through the sole of a sneaker are often associated with:
   a. *Escherichia coli*
   b. *Pseudomonas*
   c. *Staphylococcus*
   d. *Streptococcus*
   e. Polymicrobial infection

13-10. A painful flatfoot can be the result of a dysfunctional:
   a. Achilles tendon
   b. Peroneus brevis tendon
   c. Posterior tibial tendon
   d. Anterior tibial tendon
   e. Extensor digitorum longus tendon

Answers to Questions

Chapter 1

1-1. Answer: c

Osteoporosis results from net bone resorption. Therefore, there is net loss of bone. There is no change in the standard mineral to matrix ratio. Cortical diameter increases and bone mineral density (BMD) by dual-energy X-ray absorptiometry (DEXA) decreases.

1-2. Answer: e

Paget's is a disease of typically older males and results from increased bone turnover. Bone formation and bone resorption both increase.

1-3. Answer: d

The mechanical properties of bone depend largely on its unique integrated lamellar structure. Apatite is the primary mineral and the collagen is type I. (Remember, the word ONE is found in BONE.)

1-4. Answer: a

Without doubt, the common denominator in these and other similar diseases is muscle imbalance. This imbalance results in abnormal agonist–antagonist relationships, leading to joint contractures, fixed deformities, subluxation, and dislocation. In cerebral palsy (CP), the imbalance is spastic muscle versus more spastic muscle, in spina bifida the imbalance is largely weak muscle versus absent muscle, and in polio the imbalance is absent and weak muscle versus normal muscle. Nevertheless, the net result is the same: muscle imbalance.

1-5. Answer: c

Vitamin C deprivation causes the condition known as scurvy. Dilantin is toxic to liver microsomes, hence blocking normal pathways of vitamin D metabolism.

1-6. Answer: e

All are typical characteristics of hyaline cartilage.

1-7. Answer: b

Achondroplasia is an abnormality of the proliferating zone of the physis resulting primarily in short stature. Typically, these individuals have bowlegs, kyphotic spines, and are of normal intelligence.

1-8. Answer: e

Rheumatoid arthritis is a synovial disease characterized by hyperemia and hyperplasia of the synovium. There is NO repair attempt made; hence, all the changes around the joint are atrophic. Vascular hyperemia is the mechanism of resorption on both sides of the joint.

1-9. Answer: a

Gout produces typically focal changes around the joints as a result of the deposition of urate.

1-10. Answer: b

Polio does NOT affect the sensory nerves. It is purely a motor neuropathy; therefore, neuropathic joints are not seen.

1-11. Answer: e

All are typical of avascular necrosis (AVN). The talus, proximal femur, and scaphoid all have a retrograde blood flow, making them vulnerable to AVN.

1-12. Answer: c

Collagen is a linear protein molecule that is highly cross-linked at multiple sites in the triple helix called tropocollagen. Both cell populations can synthesize the molecule despite the fact that the amino acid sequence is different. Type I collagen is found in bone and type II collagen in cartilage. The primary mechanical role of collagen is to provide tensile strength to the tissue.

Chapter 2

2-1. Answer: e

Twisting-type forces, which cause torsional loading to bone, produce spiral fractures. These fractures appear as an oblique fracture in both anteroposterior and lateral radiographs.

2-2. Answer: b

Axonotmesis is an anatomic disruption of the axon in its intact sheath. In neuropraxia, the nerve is anatomically intact and physiologically nonfunctional. Neurotmesis is an anatomic disruption of the nerve itself (axons and sheath).

2-3. Answer: b

In the metabolic phase of fracture healing, the soft callous is reworked by a number of specific cellular elements to produce a firm, hard callous satisfactory for meeting the mechanical demands placed upon the fracture in the early phase. This process usually begins 4 to 6 weeks after the injury.

2-4. Answer: h

All the above answers are documented complications of fractures. See the chapter for more detail.

2-5. Answer: c

Midshaft radius and ulna fractures, or "both bone forearm fractures," require anatomic reduction and rigid fixation to allow early range of motion and less stiffness. The remaining fractures can all be treated conservatively and nonsurgically, with reasonable expectation for regaining excellent function of the extremity.

2-6. Answer: b

The middle column includes the posterior half of the vertebral body and the posterior longitudinal ligament. The anterior column includes the anterior half of the vertebral body and the anterior longitudinal ligament. The posterior column includes the pedicles and the lamina (see Figure 2-15).

2-7. Answer: c

An open fracture of the pelvis with injury to the bowel and the urogenital system still carries with it a mortality rate of 50%. Great care in evaluating the patient is essential. A rectal and vaginal examination is required to assure that the fracture is not open through those soft tissue structures.

2-8. Answer: c

These fractures occur through an area below the lesser trochanter and do not heal quite as rapidly as the intertrochanteric injuries. In the younger population, subtrochanteric fractures usually follow the severe trauma of motor vehicle accidents. In the elderly, they are caused by severe osteoporosis or a pathologic process in the subtrochanteric area.

2-9. Answer: c

This injury is the result of very severe trauma. True dislocation of the knee is a very serious injury notable for producing arterial damage to the popliteal vessels. The popliteal artery is fixed anatomically at the level of the proximal tibia by the interosseous membrane and, therefore, is placed at great risk when the knee dislocates.

2-10. Answer: d

All displaced ankle fractures should be treated surgically.

Chapter 3

3-1. Answer: c

The involucrum refers to an area of new or reactive bone growth around a sequestrum or focus of necrotic bone.

3-2. Answer: d

Staphylococcus aureus is by far and away the most common organism found in pediatric osteomyelitis.

3-3. Answer: b

Plain radiographs rarely demonstrate evidence of changes within the bone until 10 days to 2 weeks.

3-4. Answer: b

Staphylococcus aureus is the most common isolate from an adult septic joint.

3-5. Answer: c

It is the phenotypic alterations in the bacteria encased in the slime layer that most directly renders the antibiotic resistance.

3-6. Answer: a

Hematogenous inoculation is the most common cause of osteomyelitis in the pediatric population.

3-7. Answer: d

All the above are known risk factors for the development of a septic arthritis.

3-8. Answer: b

Soft tissue swelling is the earliest radiographic change that may be evident on plain films; this is particularly important in the distal aspect of the extremities where these soft tissue changes may be readily detectable.

3-9. Answer: d

In general, wounds associated with open fractures should be carefully inspected and then dressed in preparation for an emergent operative debridement. There is little or no reason to obtain predebridement cultures.

3-10. Answer: c

This would be considered a grade 1 open fracture. It is recommended that a first-generation cephalosporin alone be used in this setting.

Chapter 4

4-1. Answer: d

Both answers a and b describe benign or benign aggressive bone tumors, and answer c describes sarcomas of the soft tissues. Osteosarcoma and Ewing's sarcoma are the two most commonly diagnosed primary bone sarcomas in patients less than 30 years of age.

4-2. Answer: a

Sarcomas tend to grow in a centripetal manner and push and compress the surrounding tissues. This tendency is important in that limb-sparing surgeries can typically take place due to this "buffer zone" with few or any malignant cells noted. It is very rare for sarcomas to be found in adjacent lymph nodes.

4-3. Answer: d

A large open biopsy can cause contamination of the surrounding soft tissues, making a limb-sparing procedure impossible. Although staging studies are crucial in diagnosing a sarcoma, one should always perform a core biopsy under CT guidance if there is a question of malignancy. Multiple cores are usually obtained and provide an accurate diagnosis in more than 95% of all patients.

4-4. Answer: d

Any and all of these characteristics can be displayed by an osteosarcoma.

4-5. Answer: a

The distal femur, proximal tibia, and proximal humerus are the most common anatomic sites, in descending order. Tumors arising in the proximal femur and pelvis are less common. The spine is the most common site of metastatic carcinomas, usually after the age of 40 years.

4-6. Answer: d

Each of these diagnoses is seen in older adults; they are commonly found in the flat bone of the pelvis and may result in a pathologic fracture.

4-7. Answer: b

Batson's plexus is a venous system (plexus) surrounding the spine (vertebral bodies) and arises from the abdominal and thoracic cavity structures. There are no valves within this system, thus permitting blood carrying tumor cells to travel 'backward' away from the heart during valsalva type of breathing and seed the spine. This is thought to be the primary physical mechanism for carcinoma metastases to the spine. The brachial plexus is the correct name for the answer given in a.

4-8. Answer: d

Benign bone tumors do not metastasize but often require treatment for all the reasons in answers a–c; for example, benign UCBS often present with a fracture, osteoid osteomas are always painful and require removal, and cartilage tumors as well as GCTS may become malignant.

4-9. Answer: d

Surgery, chemotherapy, and radiation therapy are all utilized for high-grade soft tissue sarcomas. Surgery and radiation therapy given postoperatively are almost always required. Chemotherapy, either preoperative (called induction chemotherapy) or postoperative, is recommended for high-grade soft tissue sarcomas that are more than 5 cm in size and are deep, that is, occurring below the deep fascia.

4-10. Answer: b

A lipoma characteristically appears homogeneous and bright on T_1 sequence on an MRI. The signal looks identical to the surrounding subcutaneous fat, whereas most sarcomas are dark on T_1 and bright on T_2.

Chapter 5

5-1. Answer: b

Most are hereditary and are characterized by generalized skeletal abnormalities. The face is commonly involved, and typically there is genu varum or genu valgum.

5-2. Answer: d

It is multifactorial with environment and genetics playing a role. The reason that the left hip is much more frequently involved is the subject of speculation.

5-3. Answer: a

The child's periosteum has an inner cambial or osteogenic layer. The structure is of great mechanical significance as a dense fibrous membrane usually assisting in fracture reduction and maintenance.

5-4. Answer: e

Achondroplasia is a physeal dysplasia with the proliferating zone being most affected.

5-5. Answer: b

Slipped capital femoral epiphysis (SCFE) is common in obese adolescents, presenting as a painful limp. It is classified based on the ability of the child to bear weight on the limb: stable or unstable (cannot bear weight).

5-6. Answer: d

Avascular necrosis (AVN) of the femoral head is the definition of Perthes' and a complication of the other two.

5-7. Answer: d

Because of the ligamentous laxity, typical in these children, the arch collapses and they have flatfeet.

5-8. Answer: a

Fracture of the parietal bone is the most common skull fracture and rarely indicates battery. Rather, suspicion should be raised if the fracture is not typical: frontal, temporal, etc.

5-9. Answer: e

Osteolysis of the metaphysis is a radiographic hallmark of leukemia.

5-10. Answer: c

A Trendelenburg gait results from putting the Trendelenburg sign into motion. The Trendelenburg sign is caused by either weakness of the abductor muscles or shortening of the lever arm over which they act. When the patient is asked to stand on the affected side, because of inability to stabilize the pelvis the iliac crest on the contralateral side is seen to drop. Put into motion, the child throws the upper body over the affected hip to prevent falling.

5-11. Answer: 3

Displacement alone is the most forgiving, especially in the younger age groups.

5-12. Answer: e

The Pavlik harness has become the worldwide standard for the management of developmental dysplasia of the hip (DDH) in infants. If, however, the position is extreme (especially in abduction), avascular necrosis can occur. Overall, the device is capable of normalizing the hip in about 90% of affected.

Chapter 6

6-1. Answer: c

Type I collagen is the major constituent of tendon, comprising 86% of its dry weight. It is the high concentration of collagen in combination with its parallel orientation that gives it high tensile strength.

6-2. Answer: d

Dancing is most commonly associated with an overuse of the flexor hallicus longus tendon. This is a classic finding specific to this activity. Other tendonopathies are sport specific and can be found in Table 6-1.

6-3. Answer: d

A grade III ligamentous injury is best characterized by complete ligamentous rupture without any structural integrity remaining. A common example is that of a complete rupture of the anterior cruciate ligament that results in increased translation of the tibia to anteriorly directed force.

6-4. Answer: b

Muscular strains most commonly occur with passive stretching and lengthening that occur during eccentric muscular contractions.

6-5. Answer: a

The proteoglycan component of articular cartilage makes it most effective in resisting compression across a joint.

6-6. Answer: e

The meniscus has a poor blood supply, limited largely to the peripheral one-third of its structure. The potential for meniscal tears to heal is based primarily on the location of the tear as well as the morphology. Tears best associated with potential to heal with repair are red–red longitudinal tears of the meniscus.

6-7. Answer: c

Injury patterns in sports medicine are best described as either microtraumatic or macrotraumatic. Microtraumatic injuries include overuse injuries. Of those injuries listed, the only injury not caused by a single episode of trauma is a stress fracture of the hip.

6-8. Answer: b

Achilles tendonitis represents an overuse injury. Initial management of all overuse injury involves activity modification; this is an essential component to management of all entities that involve an overuse component. Often, this requires cessation of the sport in question.

6-9. Answer: d

At their attachments to bone, the transition from ligament to bone occurs gradually in a series of distinct phases. These phase range from ligament to fibrocartilage, from fibrocartilage to mineralized fibrocartilage, and from mineralized fibrocartilage to bone. The size of each zone varies from ligament to ligament and is related to its structural properties. Collagen fibers, known as Sharpey's fibers, run in continuity throughout this zone of transition and have an important role in securing the ligament to bone.

6-10. Answer: a

Collagen chains are linked together to form fibrils that in turn are bound together by a proteoglycan matrix to form a fascicle, the primary unit in tendon structure. Fascicles in turn are bound by the endotenon, a layer of elastin-containing loose connective tissue that supports the blood, lymphatic, and neural supply to the tendon unit. It is the endotenon that is contiguous with both the muscle fibers and the periosteum at the musculotendinous and tendo-osseous junctions, respectively.

Chapter 7

7-1. Answer: e

Any or all of the above may be seen in a patient with cervical myelopathy. Abnormality of gait, particularly a broad-based and shuffling gait, is the hallmark abnormality of cervical myelopathy, but any of the above can be seen.

7-2. Answer: c

The triceps reflex is innovated by C7, and a diminished triceps reflex would be seen in a C7 radiculopathy.

7-3. Answer: a

Cervical myelopathy results in upper motor neuron findings for spasticity including hyperreflexia of the lower extremities, up-going toes, and, depending on the level of the spinal cord compression, hyperactivity in the upper extremities.

7-4. Answer: a

Spondylosis of the cervical (or lumbar) spine includes disk degeneration. The first and most striking finding in disk degeneration is a decrease in water content of the nucleus pulposus. All the other abnormalities are indeed seen in cervical and lumbar spondylosis.

7-5. Answer: d

In a relatively healthy, middle-aged patient, the presence of cervical myelopathy represents a fairly clear-cut indication for surgical treatment. The presence of chronic severe axial neck pain is usually treated nonoperatively. Patients with a herniated disk, even with evidence of radiculopathy, are usually treated nonoperatively, and that is certainly the first line of treatment in most cases.

7-6. Answer: a

All the above patterns of instability, including mixed patterns involving C1–C2, the occipitocervical junction, and the subaxial spine can be seen. Instability at C1–C2, however, is the most common pattern of instability seen.

7-7. Answer: d

It has been estimated that between 60% and 80% of adults in the United States will have at least one episode of significant low back pain in their lifetime.

7-8. Answer: d

The extensor hallucis longus is innervated by L5; weakness of this muscle would be evidence of an L5 radiculopathy.

7-9. Answer: c

Spondylolysis is believed to be a stress or fatigue fracture of the pars interarticularis occurring because of repetitive shear stresses from repetitive hyperextension in individuals with a hereditary predisposition. It occurs most commonly at L5, is more common in boys than in girls and in athletes, particularly gymnasts.

7-10. Answer: d

Urinary retention results from lower motor neuron bladder dysfunction seen in cauda equina compression (CEC) syndrome. Patients with CEC syndrome may also present with severe back pain, saddle anesthesia, pain down the back of lower extremities, or even foot drop, but the most typical and most important manifestation is bladder dysfunction.

Chapter 8

8-1. Answer: c

The scapula and posterior thorax articulate through a number of bursae, but there is no articular surface.

8-2. Answer: b

The anterior band of the inferior glenohumeral ligament complex is the main stabilizer of the humeral head when it is abducted and externally rotated.

8-3. Answer: a

Central erosion of the glenoid is more common in inflammatory arthropathy. In glenohumeral osteoarthritis, posterior glenoid wear is more common.

8-4. Answer: e

The spinal accessory nerve is the 11th cranial nerve and innervates the trapezius muscle.

8-5. Answer: c

The deltoid muscle is critical for elevation and abduction of the shoulder girdle, but it is not part of the rotator cuff.

8-6. Answer: a

Although all the above regions can produce referred pain into the shoulder, the cervical spine is the most common origin of shoulder pain that does

not emanate from the shoulder girdle. Most patients with cervical spine pathology presenting as shoulder pain localize the pain to the trapezial and posterior scapular regions.

8-7. Answer: d

Total shoulder arthroplasty and humeral head replacement are the most common surgical procedures used to treat end-stage osteoarthritis of the glenohumeral joint. Arthroscopic debridement of the glenohumeral joint is also a reasonable alternative in some patients with osteoarthritis of the glenohumeral joint. Glenohumeral fusion is an option for the treatment of osteoarthritis but is not generally recommended because of the severe restriction in motion that occurs.

8-8. Answer: e

The MRI scan is currently the gold standard for noninvasive evaluation of the rotator cuff tendons.

8-9. Answer: a

Adhesive capsulitis is initially treated with physical therapy for capsular stretching and NSAIDs. Corticosteroid injections into the glenohumeral joint are also helpful for pain relief. Arthroscopic adhesiolysis and manipulation under anesthesia are both options for patients who fail nonoperative treatment.

8-10. Answer: e

Most rotator cuff tears are degenerative in nature. The presence of rotator cuff tears has been documented by MRI scans in normal patients, and, in this asymptomatic population, the incidence of rotator cuff tears increases with the age of the patient.

Chapter 9

9-1. Answer: c

The thenar musculature is supplied by the recurrent motor branch of the median nerve, so it is never involved in isolated cubital tunnel syndrome. It is a late finding in carpal tunnel syndrome. The other signs are all common in cubital tunnel syndrome.

9-2. Answer: e

Treatment of lateral epicondylitis should focus on conservative management with rest, activity modification, modalities, bracing, physical therapy, and injections. When all else fails, arthroscopic and open surgical options are available.

9-3. Answer: d

The musculocutaneous nerve innervates the coracobrachialis, the biceps brachii, and the brachialis.

9-4. Answer: b

This term has been coined to describe the pathologic tissue in lateral epicondylitis based on its microscopic appearance. It has little, if any, inflammatory component.

9-5. Answer: d

For fractures around the elbow, it is critical to obtain good alignment and begin early motion. The only way to achieve this for the fracture described is through rigid internal fixation.

9-6. Answer: c

The brachioradialis is a powerful elbow flexor when the forearm is pronated.

9-7. Answer: a

The arcade of Frohse is a ligamentous band between the two heads of the supinator. It can compress the posterior interosseous branch of the radial nerve but not the ulnar nerve.

9-8. Answer: e

The above-mentioned muscles encompass the motor innervation of the anterior interosseous branch of the median nerve.

9-9. Answer: At this time, arthroscopic or endoscopic techniques are not indicated for median nerve release at the elbow. All the other procedures have been described by authors with reasonably good results when done arthroscopically.

9-10. Answer: e

MRI can be helpful for all the conditions listed.

Chapter 10

10-1. Answer: d

Aside from skin cancer, such as squamous cell carcinoma, malignancies in the hand are extremely rare. The most common ones are epithelioid sarcoma, synovial cell sarcoma, and malignant fibrous histiocytoma.

Isolated metastatic disease to the bones of the hand are particularly uncommon conditions.

10-2. Answer: e

Although most patients who develop carpal tunnel syndrome have no known underlying causative factor, several medical conditions can contribute to the onset of this disease. All of the diagnoses mentioned as well as other conditions such as amyloidosis or antiinflammatory arthropathies can contribute to compression of the median nerve at the wrist.

10-3. Answer: b

When a patient presents with a radial aplasia such as a radial clubhand or thumb deficiency, evaluation by the appropriate pediatric subspecialist should be performed for visceral anomalies: these includes vertebral anomalies, imperforate anus, tracheoesophageal problems, thrombocytopenia, and other potentially life-threatening problems. It is uncommon for the other anomalies mentioned to have significant visceral involvement.

10-4. Answer: a

Osteoarthritis of the hand and wrist is a very common condition that markedly diminishes a patient's hand function. Commonly involved joints include the thumb CMC joint, the scaphotrapeziotrapezoid joint, the PIP joints, and the DIP joints. The MP joints of the index through small finger are most commonly spared until very late in the disease process.

10-5. Answer: d

Forced ulnar deviation of the thumb and wrist causing severe pain over the first dorsal compartment is a positive Finkelstein's test. It is indicative of de Quervain's tenosynovitis. One of the chief conditions in the differential diagnosis is thumb CMC arthritis, which is further differentiated by a CMC grind test.

10-6. Answer: c

The small finger receives nearly all its sensory function from the ulnar nerve and, as such, carpal tunnel syndrome rarely causes isolated small finger numbness. Patients often have a sensation of global numbness and until specifically tested do not realize their small finger is spared.

10-7. Answer: d

Open hand wounds should almost never be explored on initial evaluation. They should be covered with a sterile dressing, and a careful documenta-

tion of nerve, tendon, and vascular function distal to the injury should be obtained before applying an anesthetic block. After this evaluation, definitive management can be performed either in the emergency room, if appropriate, or in the operating room, if necessary.

10-8. Answer: e

Human bite wounds are fairly common injuries usually caused by the patient punching another person in the mouth. Many different bacteria can be involved. *Staphylococus aureus* is the most common infectious agent in this situation, but one must cover *Eikenella corrodens* as well, because it is a common bacterium in the human mouth.

10-9. Answer: e

Scaphoid fractures, although the most common fractures of the carpal bones, are often difficult to diagnose and treat because of the poor blood supply. Nonunion and osteonecrosis occur at relatively high rates. One should maintain a high index of suspicion when patients present with radial-sided wrist pain and anatomic snuff box tenderness, even if initial X-rays are negative.

10-10. Answer: c

Bone destruction is a very uncommon finding in suppurative flexor tenosynovitis. The remaining four options constitute Kanavel's four signs, which are pathognomonic for the disease process.

10-11. Answer: d

Gamekeeper's thumb is an ulnar collateral ligament rupture of the thumb MP joint. It can be associated with a Stener lesion, in which the ruptured ligament button-holes into the adductor aponeurosis and becomes incarcerated there.

Chapter 11

11-1. Answer: d

The artery of the ligamentum teres, a branch of the obturator artery, only supplies approximately 10% to 20% of the blood supply to the femoral head. The majority of the blood supply comes from the small retinacular vessels that run in the synovial space. They are supplied by the medial and lateral femoral circumflex vessels from the profunda femoris artery. The internal iliac artery and the superior gluteal artery do not contribute to the femoral head.

11-2. Answer: c

The primary internal rotator of the hip is the gluteus medius muscle. The anterior one-third of that muscle runs from the iliac wing to the anterior greater trochanter. The iliopsoas and piriformis are external rotators. The rectus femoris and iliopsoas are hip flexors. The gluteus maximus is a hip extensor.

11-3. Answer: b

Rheumatoid arthritis is an inflammatory arthritis. Inflammatory arthritis results from an autoimmune attack of the articular cartilage, which results in involvement in the entire joint. Therefore, there is no preserved cartilage to rotate into a weight-bearing area. Inflammatory arthritis is a contraindication to osteotomy. The other conditions listed are indications for osteotomy.

11-4. Answer: d

The rate of deep venous thrombosis (DVT) is between 10% and 20%. DVT is the most common complication after hip replacement. The rate of loosening is approximately 0.5% to 1% per year, of perioperative fracture is approximately 1%, and of infection is approximately 0.1% to 0.4%. The rate of dislocation after total hip replacement is between 1% and 5%.

11-5 Answer: e

All the listed factors alone or in combination can be responsible for the dislocation of a total hip replacement.

11-6. Answer: d

Patients at high risk for the formation of heterotopic ossification after total hip replacement can be treated with 700 to 800 cGy radiation therapy to reduce the risk of bone formation; this is usually administered as a single dose of therapy. The other treatment that has been shown to be successful is the use of NSAI medications.

11-7. Answer: b

A fracture of the femoral neck can result in disruption of the small retinacular vessels that lie in the synovial space; this will destroy the blood supply of the femoral head and result in avascular necrosis even if the fracture is repaired.

11-8. Answer: a

The anterior approach to the hip detaches a portion of the gluteus medius from the greater trochanter; this can result in a limp postoperatively if it

is not properly repaired. The tensor fascia lata is displaced anteriorly and does not attach to the trochanter. The quadratus femoris, piriformis, and gluteus maximus all are posterior.

11-9. Answer: c

Deep periprosthetic infection is a devastating complication that requires at least two surgeries and 6 to 8 weeks of intravenous antibiotics to treat. It will occur more frequently in patients taking oral corticosteroids. Antibiotics alone either orally or intravenously cannot be used to treat periprosthetic sepsis.

11-10. Answer: d

A coxalgic gait pattern results from a decreased stance phase and an abductor lurch. An antalgic or painful gait pattern is any gait with a reduced stance phase. The stance phase is reduced to decrease the time standing on a painful lower extremity. An abductor lurch results from weakened hip abductors. To compensate for the weakened abductors, the patient shifts the upper body over the affected hip to reduce to stress on the hip abductors, resulting in a lurch. Combining the two patterns results in a coxalgic gait pattern.

Chapter 12

12-1. Answer: a

Posterior translation of the tibia relative to the femur is primarily restricted by the posterior cruciate ligament. The quadriceps and the extensor mechanism are secondary restraints to posterior translation. The anterior translation of the knee is resisted by the anterior cruciate ligament. Varus and valgus opening are resisted by the lateral and medial collateral ligaments, respectively.

12-2. Answer: a

In all modern knee replacements, the anterior cruciate ligament is removed. The function of the ligament is replaced by the design of the implants for the arthroplasty. The posterior cruciate ligament can either be retained or taken for the arthroplasty. The implant design varies depending upon what is done with the ligament. The medial, lateral, and patellar ligaments are necessary for the proper functioning of a total knee replacement.

12-3. Answer: d

The most common complication after total knee replacement is infection. The rate of deep venous thrombosis is approximately 10%. The second

most frequent complication after total knee replacement is stiffness, occurring in approximately 2% of cases. The other listed complications occur at a rate of less than 0.5%.

12-4. Answer: b

Osteotomy of the knee is indicated for patients with osteoarthritis of the knee isolated to one part of the knee, that is, either the medial, lateral, or patellofemoral compartment. Valgus osteoarthritis is best treated with a varus osteotomy to correct the valgus deformity; this can be done on either the tibia or femur. Osteotomy is contraindicated in rheumatoid arthritis and in tricompartmental osteoarthritis. Patellofemoral osteoarthritis cannot be treated with either a varus or valgus osteotomy.

12-5. Answer: b

This patient is developing an early wound complication after total knee replacement. This is an urgent situation. If it is not rapidly addressed, the patient will quickly develop a deep wound infection, which can require multiple surgeries to correct and long courses of antibiotic. Infection is the most feared complication after a joint replacement arthroplasty.

12-6. Answer: e

If a knee replacement becomes loose before 5 years after implantation, it should be considered infected until proven otherwise. Stiffness and neurovascular injury will occur early after the surgery. Fracture can occur at any time after the surgery and is associated with osteoporosis. Osteoporosis is not associated with loosening after total knee replacement.

12-7. Answer: d

Resection is a salvage procedure used to treat a multiply operated knee that has failed. This procedure is also best reserved for minimally active sedentary patients. Patients with chronic instability and arthritis are best treated by reconstruction or replacement.

12-8. Answer: c

The patient with osteoarthritis may experience more pain after the procedure than they had before. The results of arthroscopy for osteoarthritis are not highly successful and do not have a good long-term success. The ability of arthroscopy to delay total knee arthroplasty is unproven, and it is not necessary to do it before total knee replacement.

12-9. Answer: e

All the measures are important in the nonoperative management of knee osteoarthritis. There is never a rush to surgery. All patients should be tried in a good conscientious course of conservative management before total knee replacement.

12-10. Answer: e

All the listed symptoms are commonly seen in patients with chondromalacia of the patella. Pain with prolonged sitting is also referred to as movie sign.

Chapter 13

13-1. Answer: b

The distal fibula lies laterally and slightly posterior to the tibia and is held there by the inferior tibiofibular ligaments. The lateral surface of the distal tibia has a sulcus to accommodate the adjacent fibula, forming the distal tibiofibular joint.

13-2. Answer: d

The talar dome is the superior portion of the talar body that articulates with the mortise of the tibia and fibula. The dome is wider anteriorly, which allows for stability in the mortise during dorsification.

13-3. Answer: e

The foot is composed of 7 tarsals, 5 metatarsals, and 14 phalanges. Three anatomic groupings are defined for descriptive purposes: the hindfoot, the midfoot, and the forefoot (see Figure 13-3). In the hindfoot lies the largest bone in the foot, the calcaneus.

13-4. Answer: c

Ligaments of the ankle syndesmosis include the anterior tibiofibular, posterior tibiofibular, and inerosseous ligaments.

13-5. Answer: e

The tibial and common peroneal nerves are terminal branches of the sciatic nerve, which arises from the lumbosacral plexus. The common peroneal nerve from L5 branches into the superficial peroneal nerve and deep peroneal nerve, which terminally supply sensation to the dorsal foot and first web space, respectively. The tibial nerve, a branch of S1, travels through the popliteal fossa into the deep posterior compartment. The sural

nerve is a sensory branch of the tibial nerve and provides sensation to the posterolateral hindfoot and lateral border of the foot.

13-6. Answer: e

Radiographic studies of the foot and ankle require weight-bearing X-rays when possible. Important views involve the anteroposterior (AP), lateral, and oblique views of the foot, and AP, lateral, and mortise views of the ankle.

13-7. Answer: c

Pilon fractures involve the intraarticular fractures of the tibial metaphysis, which extend to the weight-bearing portion of the tibia; a is a Lisfranc fracture-dislocation, and e is also known as a Jones fracture.

13-8. Answer: e

All the above answers define a hallux valgus, or bunion, deformity. Answers a, c, and d may be observed clinically. Answers a, b, and c may be seen radiographically.

13-9. Answer: b

Because the insole of a sneaker can be colonized with the *Pseudomonas* organism, care should be taken to treat the patient with an infection from a puncture wound for this organism.

13-10. Answer: c

Overuse of the posterior tibial tendon causes conditions that range from mild tendonitis to complete rupture and asymmetrical flatfoot deformity. As the tendon continues to deteriorate and becomes incompetent, a progressive asymmetrical flatfoot deformity develops with lateral hindfoot impingement.

Case Studies

Degenerative Spondylolisthesis

William C. Lauerman

History

E.D. is a 72-year-old woman with a 2-year history of progressively worsening back pain, with radiation of pain into the buttocks, posterior thighs, and more recently into her legs bilaterally. The pain is worse with walking and is relieved when she stops to sit down. She denies any bowel or bladder changes. She notes that it is significantly easier walking in a grocery store pushing a cart than it is to walk in a mall. Her past medical history is positive for adult-onset diabetes mellitus. Past medical history, family history, and social history are otherwise unremarkable. Review of systems is noncontributory.

On physical examination, she has a normal gait. She tends to stand in a forward flexed position, and she has limited extension of the lumbar spine, with pain on extension. Pulses are palpable in both feet. Neurologic examination demonstrates normal motor and sensory function. Her deep tendon reflexes are symmetrically diminished at the knee and ankle. Her toes are down-going. Straight leg raising is negative. (See Figs. 1, 2.)

Treatment

The patient had previously been treated with physical therapy, including Williams flexion exercises, which improved her symptoms for several months but did not give her long-lasting or adequate relief. She underwent a trial of lumbar epidural steroids. Each injection led to good relief of her symptoms but that relief lasted only 2 to 3 weeks. Having failed nonoperative treatment, she elected surgery and underwent a decompressive laminectomy at L4–L5 with posterolateral fusion, utilizing pedicle screw instrumentation and iliac crest autograft. (See Fig. 3.)

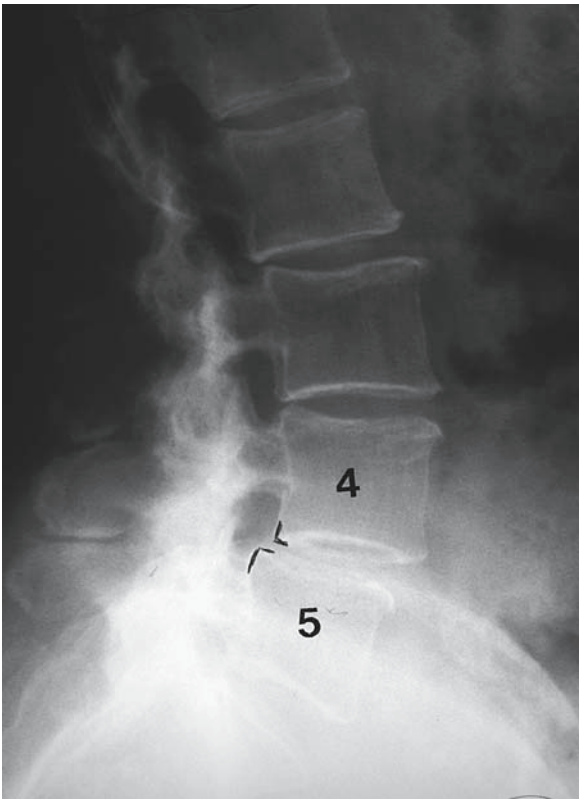
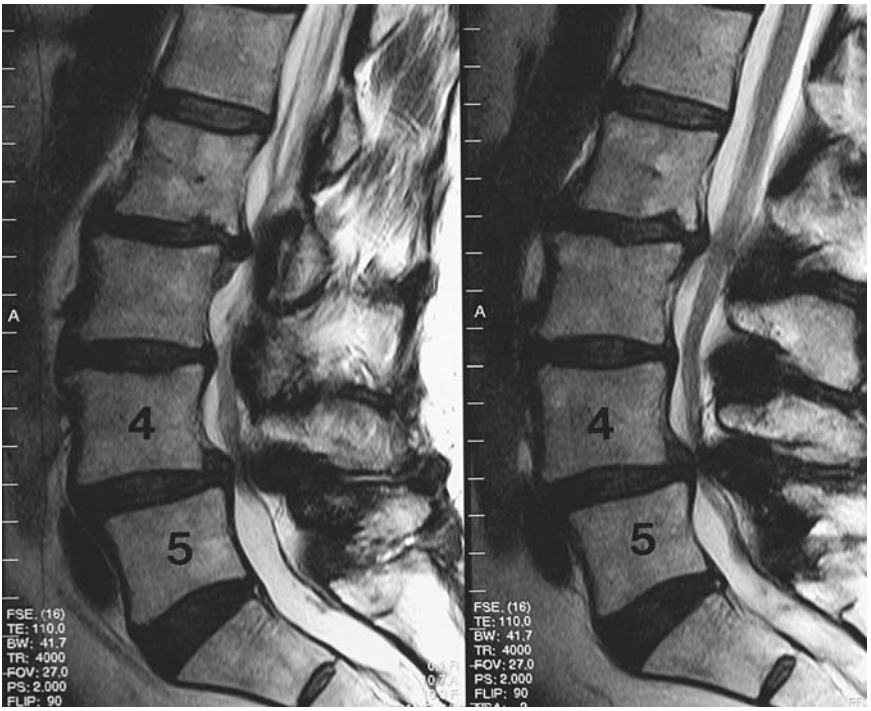


FIGURE 1. Lateral radiograph demonstrates a grade 1 degenerative spondylolisthesis at L4–L5.

Discussion

Degenerative spondylolisthesis is common and increases in prevalence with increasing age. It is more common in women than in men, in blacks than in whites, and is found with increased frequency in patients with diabetes. Degeneration of the disk and facet joints, most commonly at L4–L5, leads to anterior slippage of the cephalad vertebrae (L4 in this case) on the level below (L5). It is common to see spinal stenosis in association with degenerative spondylolisthesis, and this patient's symptoms, including back pain and stiffness with aching pain into the buttocks, thighs, and legs, are common. A common complaint is pain with walking that is often relieved by stopping and sitting down. Patients frequently note that they can walk farther in a grocery store pushing a cart than they can in a mall.

In spinal stenosis, positions of flexion, such as pushing a grocery cart or sitting down, are more comfortable than extension, and the most common



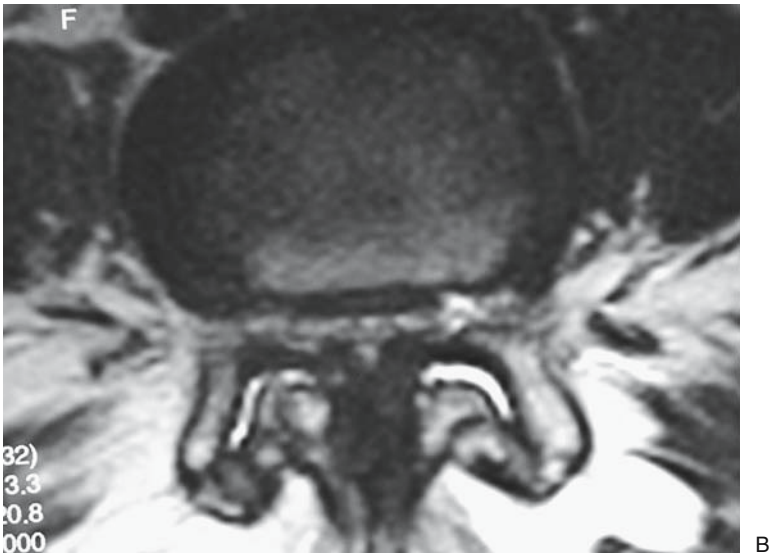


FIGURE 2. Sagittal (A) and axial (B) magnetic resonance (MR) images. The sagittal view demonstrates the spondylolisthesis, as well as the significant thecal sac narrowing at L4–L5. The axial view demonstrates enlargement and arthritic change in the facet joints bilaterally, thickening of the ligament flavum, and severe central and lateral recess stenosis.

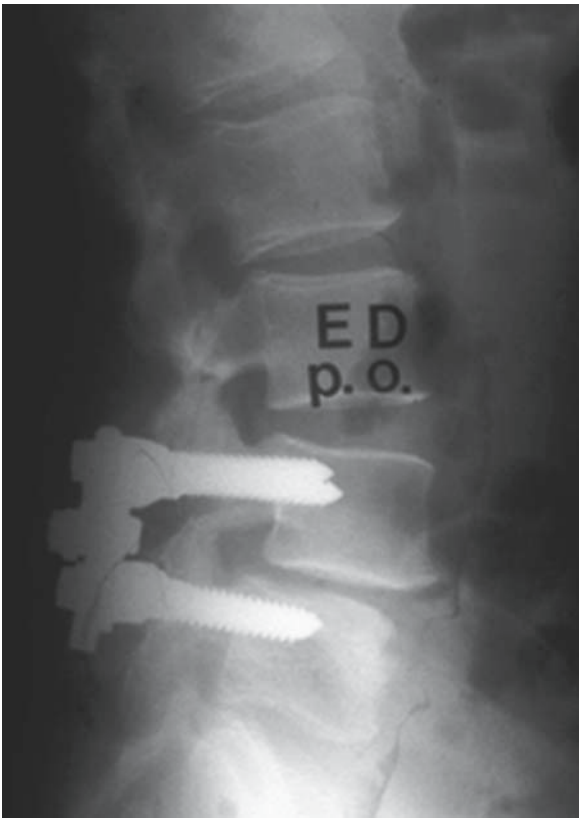


FIGURE 3. Decompressive laminectomy at L4–L5 with posterolateral fusion, utilizing pedicle screw instrumentation and iliac crest autograft.

physical finding is limited extension of the lumbar spine with pain on extension. Treatment options include nonoperative measures such as a daily back exercise regimen, flexion exercises, physical therapy modalities, nonsteroidal antiinflammatory medications, or epidural steroid injections. When nonoperative measures fail, surgery is often indicated, usually with good results. The primary goal of the surgical treatment of spinal stenosis is decompression of the affected nerve roots and/or thecal sac. In cases of degenerative spondylolisthesis, because of the risks of further slippage, concomitant fusion is routinely employed.

Hallux Valgus

Scott T. Sauer

History

A 52-year-old woman presents with worsening bilateral forefoot pain over the last three years. She describes pain in the left foot that is greater than the right foot. It is an achy, sometimes sharp intermittent pain over the medial aspect of both first metatarsophalangeal (MTP) joints. She rates the pain as 4 of 10 with 10 being the worst pain she has ever felt. The pain she feels is worse with shoe wear and walking and is relieved by wearing sandals. She also reports having to wear multiple layers of socks to keep her shoes from rubbing on the medial aspects of her forefeet. She describes no pain with arising, no swelling, no loss of sensation, no joint stiffness, and no flatfoot. Her past medical history is significant for breast cancer, for which she has had a mastectomy. Currently, the only medication she is taking is tamoxifen. She has no known drug allergies. She is a nonsmoker, and her review of systems is noncontributory.

Physical Examination

This is a well-developed, well-nourished female in no apparent distress. She is 5 feet 3 inches in height and weighs 118 pounds. She walks with a normal-appearing gait. Her station shows bilateral hallux valgus with normal-appearing arches and heels in slight valgus positioning. She is able to double-toe heel rise with minimal tenderness in her bilateral first MTP joints, plantar and medial. Examination of her right foot and ankle shows a moderate hallux valgus formation with a medial protuberance noted. No skin lesions or edema. Dorsalis pedis and posterior tibial artery pulses are palpable. There is tenderness to palpation over the medial and plantar medial aspect of the first MTP joint. There is no pain plantarly over the medial or lateral sesamoid, no lesser toe pain, and no medial midfoot or hindfoot pain. No ankle pain noted. Ankle range of motion is 5 degrees of dorsiflexion, 40 degrees of plantar flexion, 10 degrees of inversion, and

5 degrees of eversion. First MTP joint range of motion is approximately 30 degrees of extension and 20 degrees of flexion with no ligamentous instability. Ankle dorsiflexion, plantarflexion, inversion, eversion, and toe extensor and flexion strength are 5/5. Sensation is intact on the dorsal, medial, lateral, and plantar aspects of the foot.

Examination of the left foot and ankle shows a moderate hallux valgus with protuberance medially noted. No skin lesions or edema noted. Dorsalis pedis and posterior tibial artery pulses are palpable. There is tenderness to palpation over the medial first MTP joint, as well as plantar medially in the same region. There is no sesamoid pain noted. No medial midfoot or hindfoot pain is noted. No ankle pain noted. Ankle range of motion is 5 degrees of dorsiflexion, 40 degrees of plantar flexion, 10 degrees of inversion, and 5 degrees eversion. First MTP joint range of motion is 30 to 40 degrees of extension and 20 degrees of flexion with no ligamentous instability noted. Ankle dorsiflexion, plantarflexion, inversion, eversion, and toe extension and flexion strength are 5/5. Sensation is intact in the dorsal, medial, lateral, and plantar aspects of the foot.

X-Rays

Weightbearing anteroposterior (AP), lateral, and mortise views of her bilateral feet show bilateral mild hallux valgus deformities with slight subluxation laterally of the sesamoids with congruent first MTP joints. Medial exostosis present. First MTP joint appears without degenerative change. First and second intermetatarsal (IM) angle on the left foot is 12 degrees with a hallux valgus angle of 20 to 25 degrees. No other bony abnormalities noted.

Treatment

Surgical correction of left hallux valgus using distal chevron bunionectomy, which includes distal metatarsal osteotomy with exostectomy and medial first MTP joint capsule tightening.

Discussion

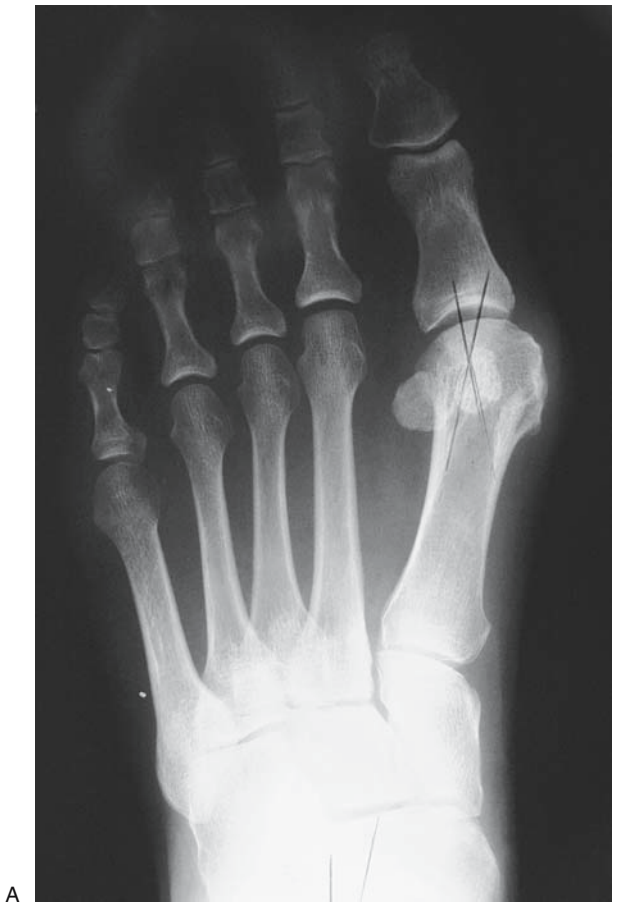
This patient has a symptomatic hallux valgus deformity; the left foot is clinically worse than the right foot. Clinically, hallux valgus can be problematic in that it makes shoe wear difficult. With the progressive valgus deformity of the toe, extra strain is placed on the medial structures of the first MTP joint, and this area becomes more prominent. With shoe wear, the inner aspect of the shoe pushes on the medial aspect of the first MTP

joint, which can cause friction and pain. With this repetitive stress, as well as progression of the bunion deformity, bony buildup can occur on the medial aspect of the first metatarsal head; this perpetuates continued discomfort as the exostosis enlarges. As the bunion deformity progresses, it can affect the lesser toes, creating hammer toes, which have hyperextension at the MTP and DIP joints and hyperflexion of the PIP joints.

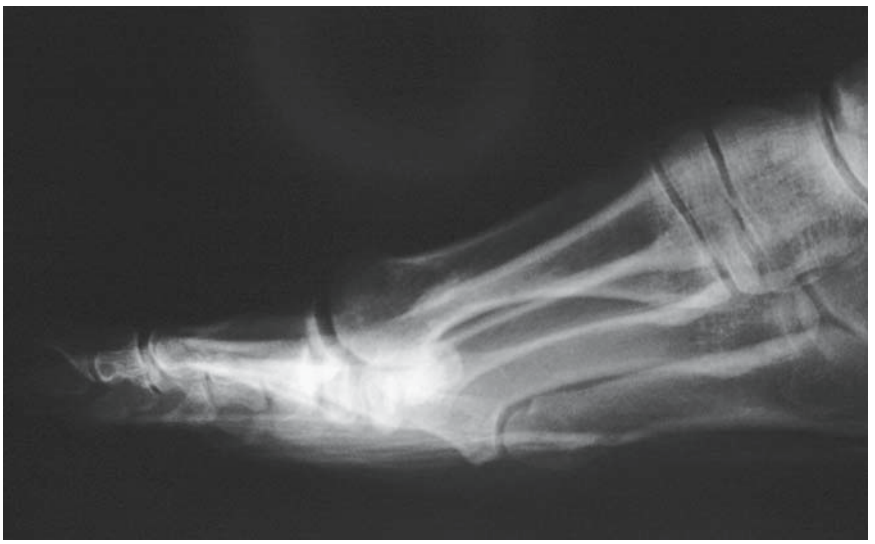
Treatment is aimed at relieving pain, which can be done conservatively and nonsurgically in early stages of hallux valgus by shoe wear modification utilizing a wider toe box to prevent rubbing or friction. Toe spacers, which keep the first toe in a straight orientation in relation to the other toes, can also be used, as well as physically altering the shoe with shoe stretching or cutting out the medial side of the forefoot toe box to accommodate the bunion deformity. When these modifications are unsuccessful, surgical options can be helpful. Surgical treatment goals include removing the exostosis, correcting the hallux valgus deformity, and straightening the toe, as well as relocating the sesamoid complex to be congruent with the underside of the first metatarsal head.

Many surgical options are available for bunion correction and are dependent on the degree of severity of the bunion deformity. The severity is typically measured radiographically with weight-bearing X-rays. The first and second IM angle, and the hallux valgus angle, the angle between the proximal phalanx and the first metatarsal, are measured. Treatment parameters for hallux valgus generally include whether the first MTP joint is congruent. An incongruent joint is one in which the proximal phalanx articular surface does not line up with the metatarsal head articular surface because of extreme hallux valgus. A normal hallux valgus angle is less than 20 degrees. Generally, when it approaches 30 degrees and is symptomatic, it requires correction. The IM angle is generally about 9 degrees. When the IM angle is less than 12 to 13 degrees, a distal corrective osteotomy may be done in the first metatarsal. With an IM angle greater than 13 degrees, one should consider a proximal first metatarsal osteotomy with distal soft tissue balancing. One final consideration is the sesamoids. Typically, they are subluxed laterally, and surgery should be tailored to make these bones congruent in their articulations with the base of the first metatarsal.

In this case, because of the IM angle, hallux valgus angle, and slight incongruence, a distal first metatarsal osteotomy was performed, and the distal aspect of the metatarsal was moved laterally to reduce the sesamoids. The medial capsule was imbricated and tightened, allowing for adequate stability of the first toe, as well as holding a corrected position. Postoperative management included weight-bearing as tolerated in a postoperative shoe for 6 weeks, as well as a first–second toe spacer for 3 months. See the preoperative, immediate postoperative, and late follow-up pictures (Figs. 1, 2, 3, respectively) for details and radiographic results.

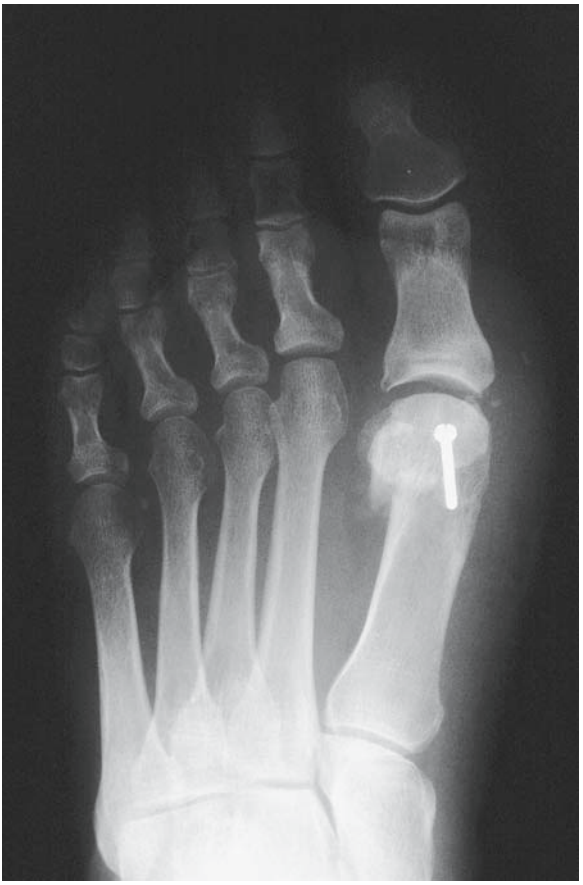


A

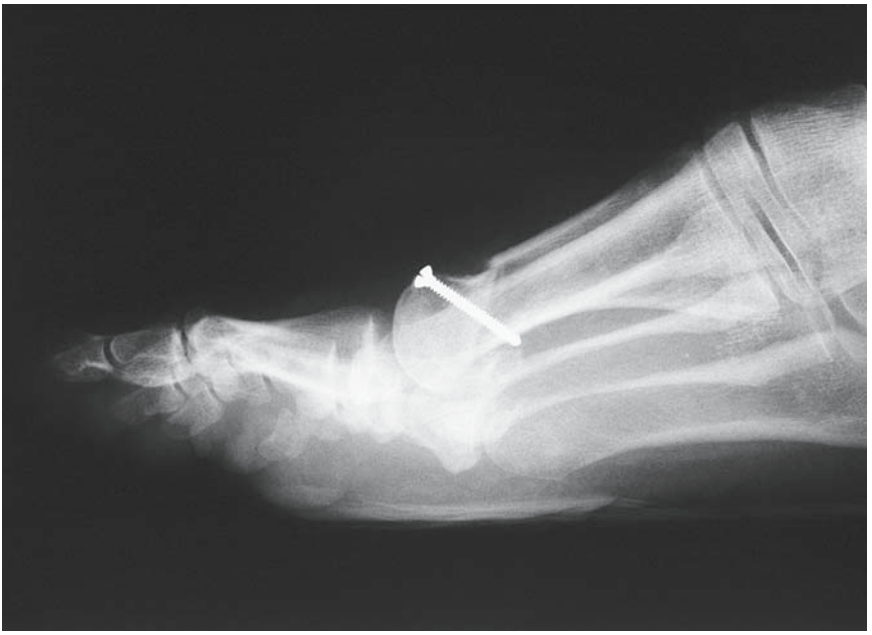


B

FIGURE 1. Preoperative radiographs with radiographic evidence of hallux valgus.

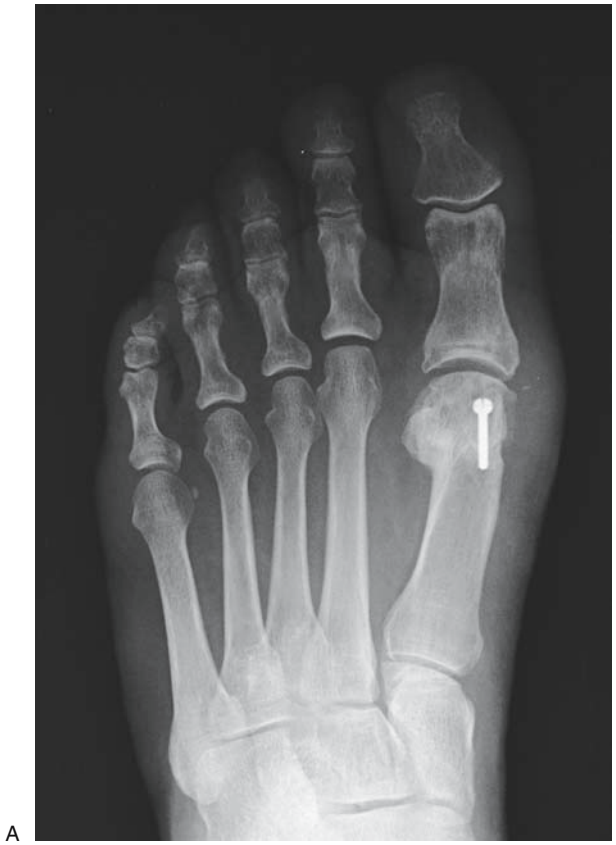


A

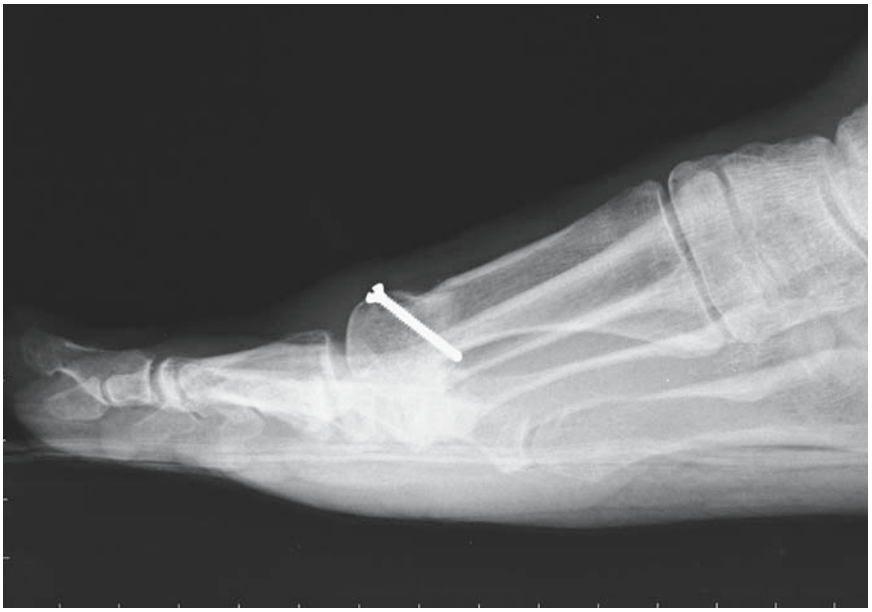


B

FIGURE 2. Immediate postoperative radiographs with corrective osteotomy and hardware in place.



A



B

FIGURE 3. Postoperative radiographs with healed first metatarsal osteotomy.

Trauma: Open Tibia Fracture

Scott T. Sauer

History

A 58-year-old woman was at a social event in the early morning hours. She fell down a flight of stairs and injured her right lower extremity. She presented to an emergency room with extreme pain in her right lower extremity, with some bloody drainage by report. She had no reports of numbness or tingling in the leg itself and no other injuries. She did not lose consciousness at the time of her fall. She describes an achy sharp pain in the right lower extremity just below the knee. She reports the pain as a severity of 9 of 10, with 10 being the worst pain she has felt, and nothing relieves her pain. She has no significant past medical history. She has a past surgical history that includes an open-reduction internal fixation of the right forearm many years ago, as well as strabismus surgery on the right eye in the past 5 years. She takes no medications. She has no drug allergies. Social history includes moderate alcohol consumption, and she is a nonsmoker. Family history and review of systems are noncontributory.

Physical Examination

This is a well-developed, well-nourished female in a moderate amount of distress. She is alert and oriented times three. She is approximately 5 feet 3 inches and 150 pounds. Temperature is 98.7°F. Blood pressure is 125/80, pulse is 95, and respiratory rate is 20. Airway, breathing, and circulation exams are within normal limits. Her secondary survey includes a moderately swollen right lower extremity below the knee, with a small laceration over the anteromedial aspect of the lower leg midtibial region that measures approximately 1 cm. Further examination of her right lower extremity shows good palpable dorsalis pedis and posterior tibial artery pulses, and tenderness over the midshaft of the tibia and proximal fibular region. There is no other tenderness in the knee or hip area or ankle area. Range of motion of the knee and ankle is limited secondary to pain in the midtibial

region. Hip range of motion internal–external rotation is 45 to 50 degrees without pain. No obvious evidence of ligamentous instability. Ankle dorsiflexion, plantarflexion, inversion, and eversion strength is 4+/5. Sensation is intact on the dorsal, medial, lateral, and plantar aspects of the foot. No pain with passive range of motion of the foot and toes.

X-Rays

Anteroposterior (AP) and lateral radiographs of her right tibia and fibula, AP, lateral, and mortise view radiographs of her right ankle, and AP and lateral radiographs of her right knee show a spiral fracture of the middle shaft to distal third of the tibia with a proximal fibular fracture with moderate displacement. No obvious deformity or fracture is seen in the ankle mortise or around the distal femur.

Laboratory Values

Laboratory values, EKG, and chest X-ray are within normal limits.

Assessment

Right open tibia and fibular fracture with spiral fracture of the midshaft distal third tibia, proximal fibular fracture; no signs of neurologic injury or compartment syndrome.

Treatment

Discussion of the clinical and radiographic findings was done with the patient in regard to the nature of the fracture itself with the small skin opening. The patient was given intravenous antibiotics and was taken immediately to the operating room for irrigation and débridement of the open tibial wound with intramedullary nail fixation. Her postoperative course was uncomplicated. Her wound healed uneventfully with no signs or symptoms of infection and, over the next 3 to 4 months, her tibia fracture healed with excellent results and alignment. Preoperative, postoperative, and healed X-rays are shown in Figures 1, 2, and 3, respectively.

Discussion

This woman presented with isolated right lower extremity trauma after a fall. However, it is important not to be distracted by her presenting symptoms. Patients that are brought to an emergency room who have question-

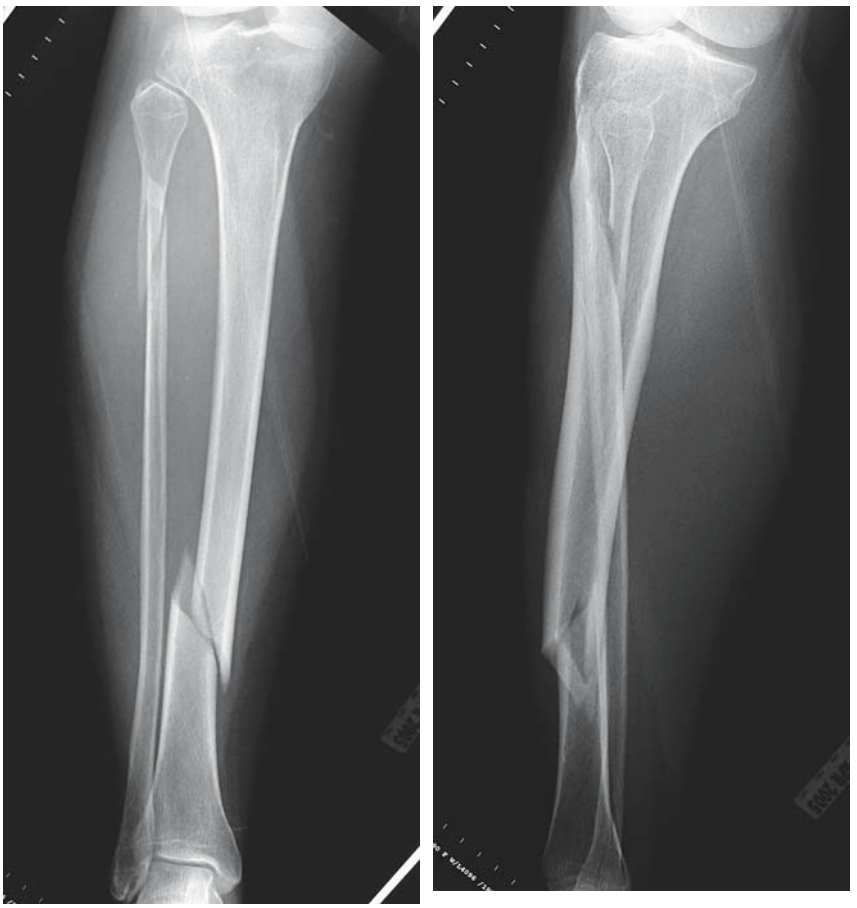


FIGURE 1. Preoperative radiographs show spiral tibia fracture with proximal fibular fracture.

able consciousness or are obviously inebriated should be treated as a multitrauma victim before focusing on an obvious injury. It is important to obtain as complete a history as possible from these patients or family members or friends who have brought the patient to the emergency room to determine exactly the events surrounding the circumstances bringing the patient to the emergency room. In this case, there was alcohol involved, which may cloud the history or judgment of the patient. It is important to go through the advanced trauma life support (ATLS) protocol, which starts with evaluating the airway, breathing, and circulation. When these parameters are deemed stable, then a secondary survey may be performed. In this patient's case, although alcohol was involved, her neck was stabilized with a collar appropriately

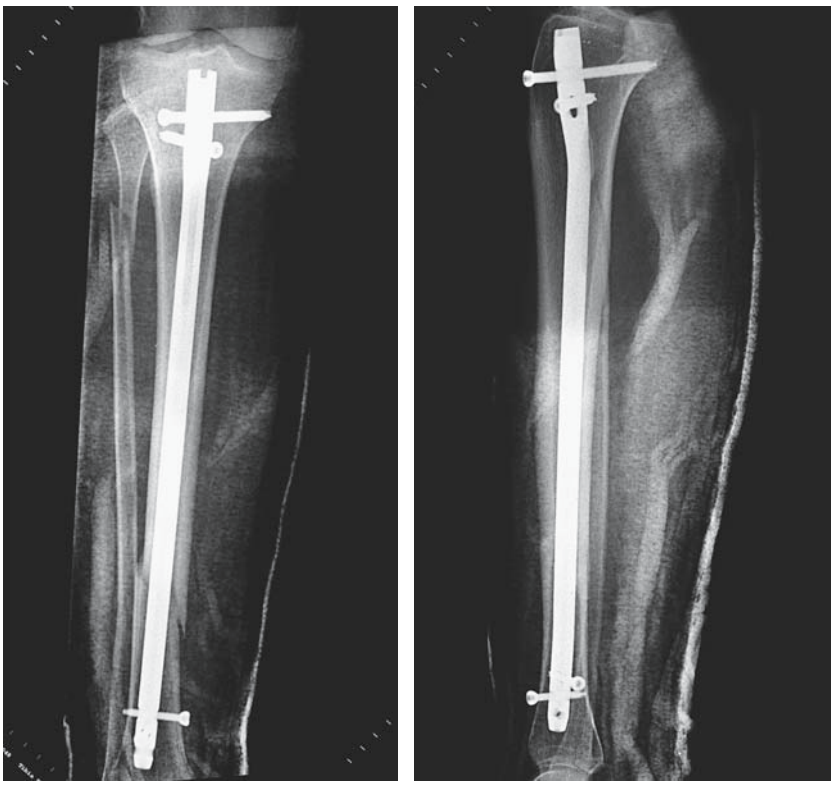


FIGURE 2. Immediate postoperative radiograph shows intramedullary nailing.

until she was not intoxicated, which was postoperatively the next day. She was then cleared from the clinical and radiographic standpoint. However, while maintained in the collar, a secondary survey was performed with no obvious other injuries noted and further trauma ruled out with appropriate radiographs, namely of the chest and pelvis, in conjunction with her C-spine radiographs, which had been done on admission.

Once the secondary survey was performed and the isolated injury was identified, in her case an open tibia fracture, appropriate treatment could be applied. In most cases, tibia fractures, if minimally displaced, well aligned, and without evidence of open injury, may be treated conservatively: a long leg cast for 6 to 8 weeks converting to a short leg cast after healing and beginning of weight-bearing between 8 and 12 weeks. In this case, an open injury made it necessary to operatively wash out the wound to prevent infection. Intravenous antibiotics were given immediately in conjunction with the size of the wound. Typically wounds 1 cm or less

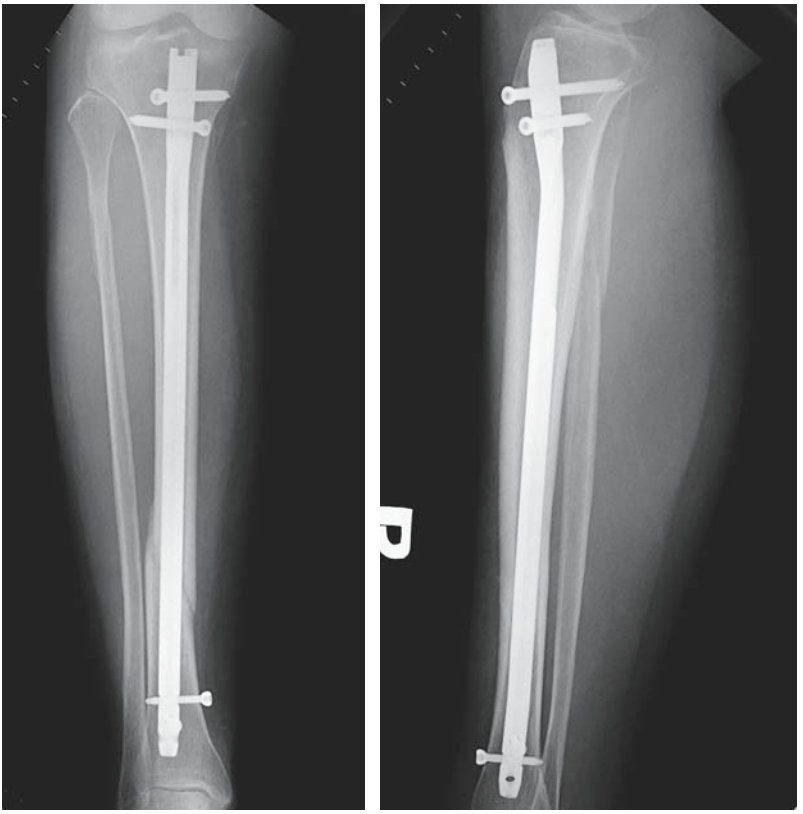


FIGURE 3. Radiographs of the tibia after healing.

require a cephalosporin, whereas larger wounds may require broader coverage, including gram-positive and gram-negative organisms. With appropriate antibiotics, the patient was taken to the operating room where her wound was irrigated fully. If the wound is small, extending the proximal and distal ends to provide adequate exposure for irrigation may be necessary. These extensions may then be closed after surgery. However, the initial wound should be left open to drain. Treatment in this case included tibial intramedullary nailing with 24 to 48 hours of intravenous antibiotics, namely a gram-positive-covering cephalosporin. She tolerated her procedure well, and the postoperative course was uneventful.

Herniated Nucleus Pulposus

Sam W. Wiesel

History

A 34-year-old lawyer arose with the hope of taking an early-morning run. As he began, he felt sudden back pain to the point where he had to stop running. Walking, the back pain became less intense, but he noticed pain down the leg all the way into the foot with paresthesia (numbness and tingling) into the foot. He had trouble walking and came into the office for an evaluation.

Physical Examination

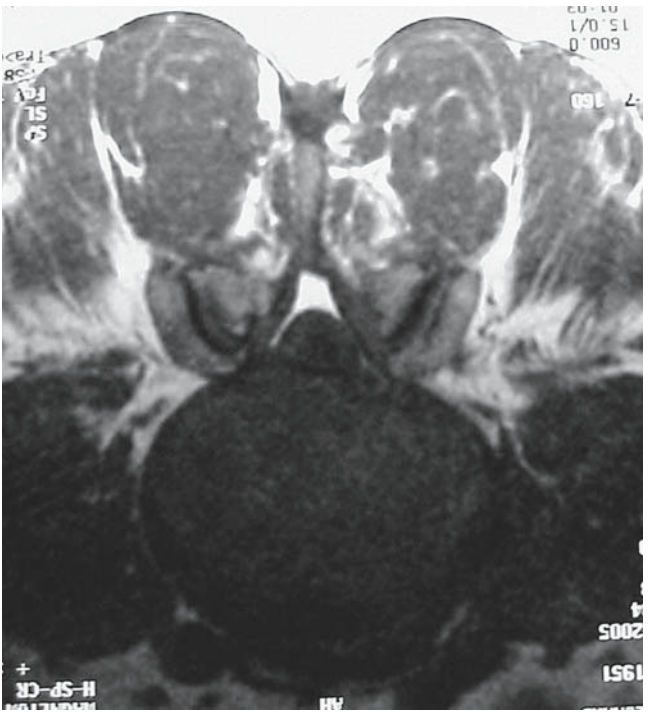
The patient is a well-nourished young man in moderate distress. He had decreased range of motion of the lumbosacral spine with no palpable spasm. His straight leg raising test was positive in that it produced pain all the way down the leg. He had a weak extensor hallioxic longus (EHL). His hip examination was normal.

Laboratory Studies

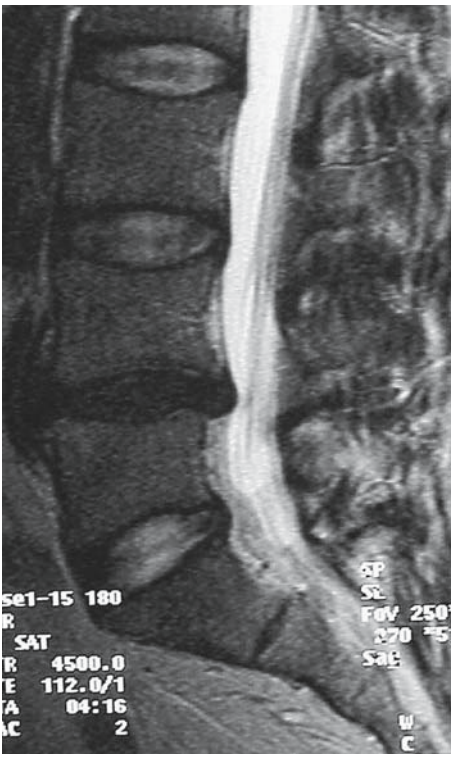
A magnetic resonance image (MRI) was obtained (see Fig. 1) that demonstrated a herniated nucleus pulposus at L4–L5.

Treatment

The patient was initially placed on antiinflammatory medication as well as decreased physical activity and some wet heat for comfort. Over a 2- to 4-week period, the patient improved about 30%, but still demonstrated a positive straight leg raising test and a weak EHL. At this point the patient was given epidural steroids, which gave him about 50% overall relief. At



A



B

FIGURE 1. (A, B) Magnetic resonance imaging (MRI) demonstrates herniated nucleus pulposus (HNP) at the L4–L5 level.

the 10-week mark, because the patient was really unable to function, it was recommended that he have a laminectomy with removal of the herniated disk at L4–L5. Patient underwent the procedure, and postoperatively his pain and paresthesias disappeared. He was placed in a rehabilitation program and 1 year later was doing well.

Discussion

This is a classical history for a herniated nucleus pulposus. It generally occurs in the second and third decades of life. This patient had a positive straight leg raising and a positive neurologic in the form of an EHL that coincided with his herniated disk between L4 and L5 involving the L5 nerve root. Conservative treatment was instituted because the simple fact of a neurologic deficit such as a weak EHL does not mandate surgical intervention. If the patient can get good subjective pain relief using nonoperative measures, it is preferred. The patient was treated nonoperatively for a total of 10 weeks. The recommendation is that if one cannot get satisfactory pain relief within 3 months and there is a correlation between the physical examination and an MRI, surgery is indicated. This patient did well with the laminectomy between L4 and L5 and was able to resume all his activities.

Osteomyelitis

Steven C. Scherping, Jr.

History

The patient is an 18-year-old man who is referred to the office for evaluation of a painful and swollen left knee. Two weeks before presentation he suffered a minor twisting injury to the knee while playing soccer. This injury was not associated with any significant pain at the time, and he was able to continue his routine activities, including playing soccer. Over the ensuing 4 to 5 days, the knee and the distal thigh became progressively more painful with some swelling noted in the knee. He denies any giving-way or locking of the knee. The pain is present at all times, only slightly worsened with weight-bearing activities. He denies any prior history of injury to the extremity. He denies pain at any other site. He has no history of recent illness other than a laceration to his foot that occurred 3 weeks ago and which was complicated by a local wound infection requiring treatment with oral antibiotics. The laceration subsequently healed without event, and he has no residual swelling or pain in the foot. His past medical history is otherwise benign. On review of symptoms, he has noted a mild sense of fatigue, in association with a sense of a low-grade fever, although he has not taken his temperature and denies any frank rigors or chills.

Physical Examination

This generally healthy-appearing young adult male is afebrile. Gait is antalgic with restricted motion through the left knee. His left knee is swollen in appearance with an effusion. Tenderness is appreciable over the distal femur, more so of the medial condyle. Range of motion of the knee is from 0 to 120 degrees in association with some discomfort. No mechanical block or instability is detected. His neurovascular examination is normal in the extremity. No adenopathy is appreciated in the groin or popliteal fossa. Range of motion of his ankle and hip is painless and symmetrical with the uninvolved extremity.

Radiographic and Laboratory Evaluation

Plain radiographs of the knee demonstrated no bony lesions, only an effusion. A bone scan was remarkable for intense uptake in the medial condyle of the femur on all images including the delayed-phase bony images. The reminder of the skeleton was normal on all phases of the bone scan. A magnetic resonance imaging (MRI) scan of the knee showed no evidence of any intraarticular pathology. It did, however, demonstrate an area of hypointensity on T_1-weighted images and hyperintensity on T_2-weighted images in the medial condyle of the femur. No area of frank cortical disruption or soft tissue involvement was detected. (See Figs. 1 through 6.)

Laboratory studies were notable for a normal white blood cell count but a markedly elevated erythrocyte sedimentation rate (ESR) of 83.

Treatment

Upon presentation to the office, an arthrocentesis was performed to rule out the possibility of septic arthritis. The joint fluid was consistent with an aseptic effusion, and follow-up cultures were unremarkable. After evaluation of the bone scan and MRI of the knee, a presumptive diagnosis of

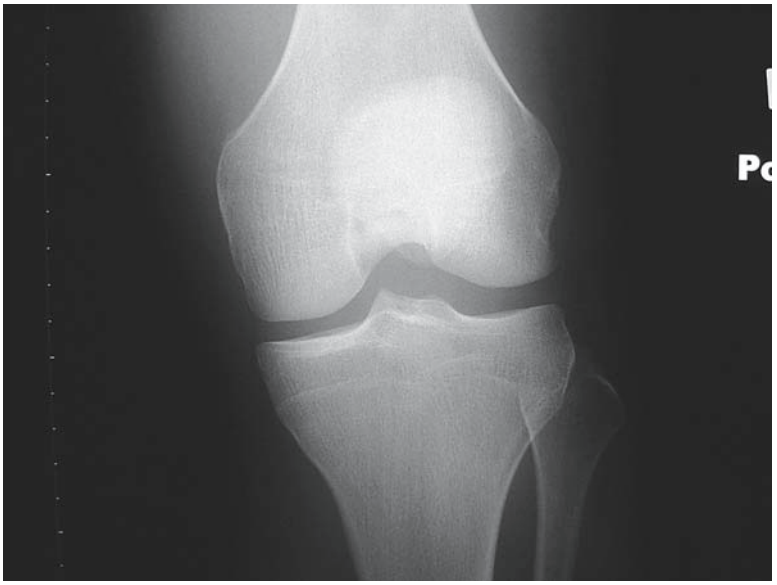


FIGURE 1. Anteroposterior (AP) radiograph of the knee.

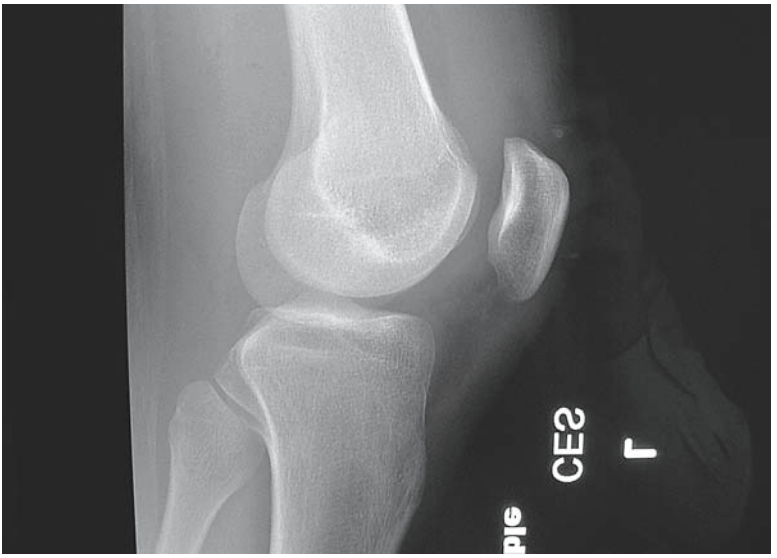


FIGURE 2. Lateral radiograph of the knee. An effusion is evident.

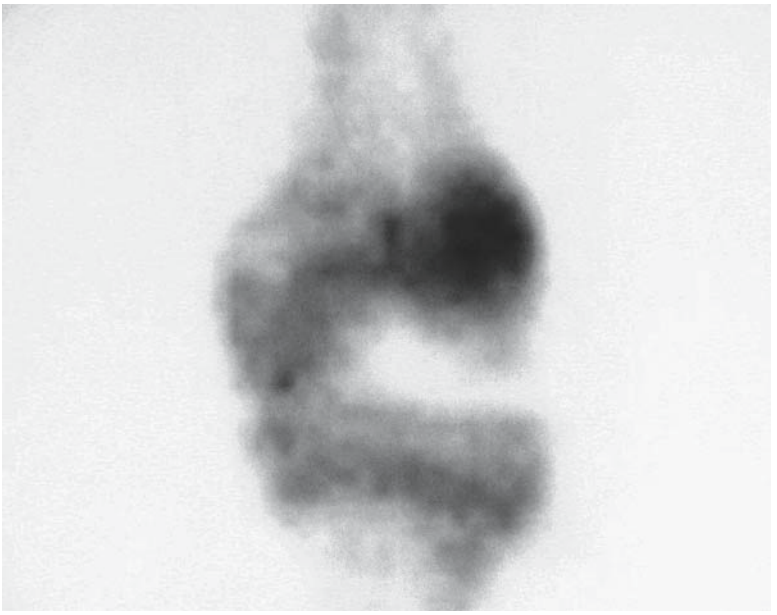


FIGURE 3. Delayed-phase bone scan demonstrating intense uptake in the medial condyle of the femur.

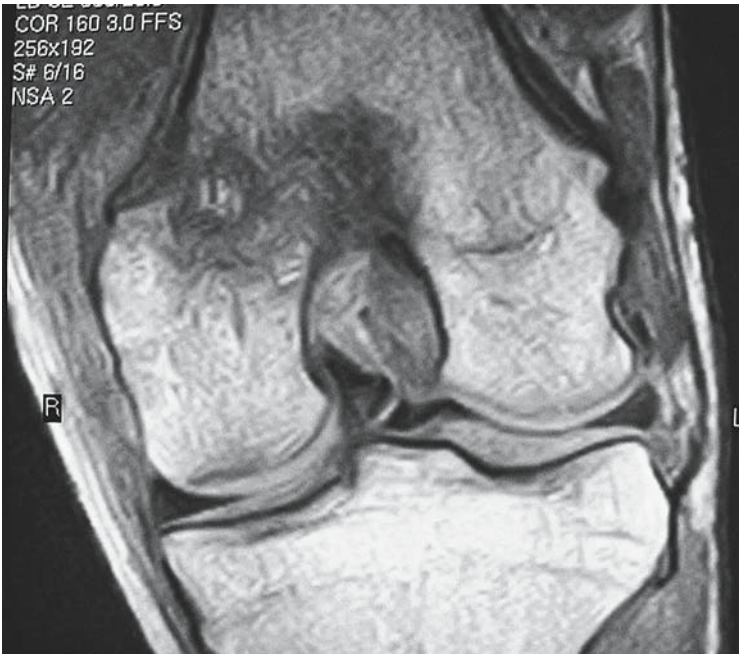
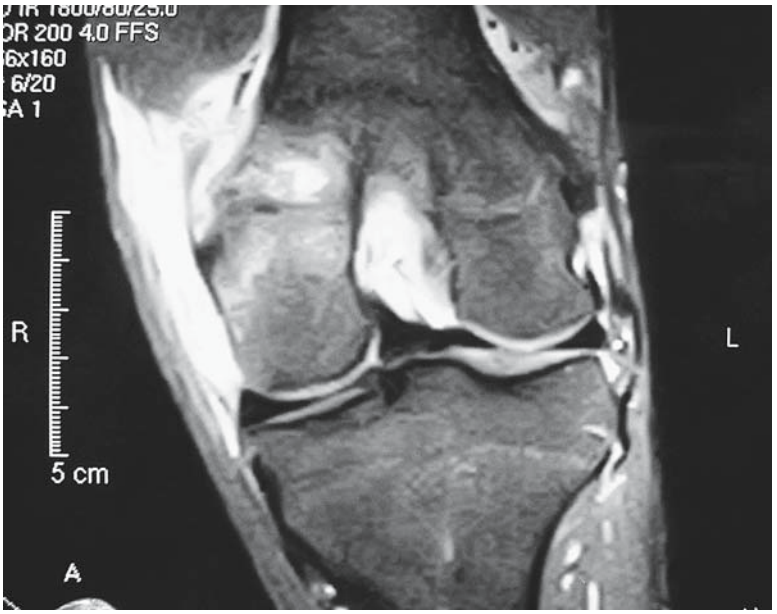
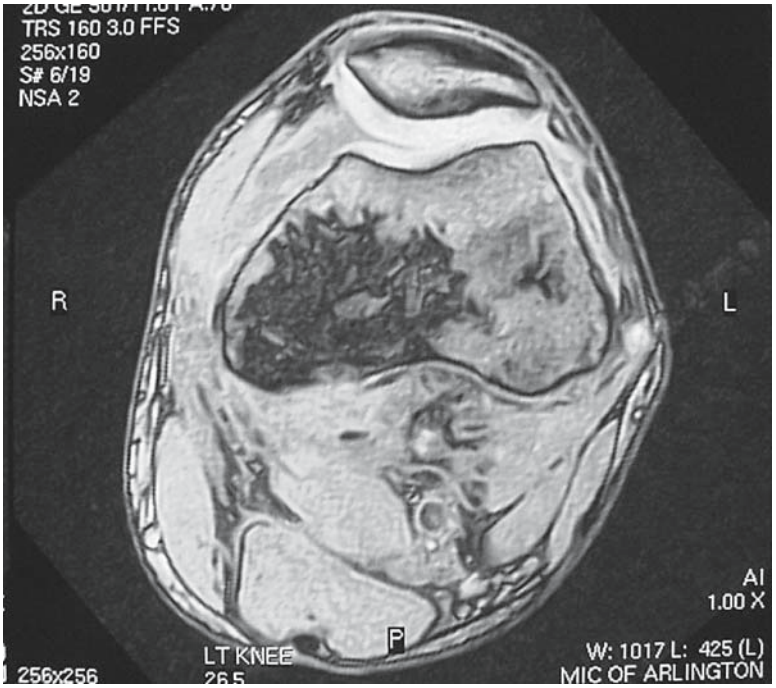


FIGURE 4. T_1-weighted coronal of the left knee. Hypointense signal is evident in the medial condyle.



FIGURES 5. T_2-weighted images demonstrate hyperintensity in the medial condyle consistent with edema.



FIGURES 6. Axial T1-weighted MRI demonstrating signal change in the medial femoral condyle.

osteomyelitis was made. Blood cultures were obtained and noted to be unremarkable. The patient was then taken to the operating room where, through a limited medical incision, a small cortical window was made into the medial femoral condyle and several specimens obtained for pathologic and microbiologic evaluation. Intraoperative findings included a small area of inflammatory change and patchy necrosis consistent with osteomyelitis. No areas of frank purulence were encountered. Intraoperative cultures grew *Staphylococcus aureus*. The patient was started on a 6-week course of intravenous antibiotics with resolution of all clinical symptoms and normalization of all laboratory data with presumptive cure of osteomyelitis.

Discussion

Osteomyelitis arises from one of two pathways: hematogenous spread or direct inoculation. A common source of direct inoculation is an open fracture, particularly one with gross contamination or inappropriate initial management. In this case, the development of the osteomyelitis was

undoubtedly from transient bacteria related to the superficial foot infection. If found early, before the development of an abscess or a bony sequestrum, osteomyelitis is generally be successfully treated with appropriate antibiotic therapy alone, which is why the timely diagnosis of a bone infection plays a critical role in minimizing the morbidity of treatment. In some instances, however, surgical treatment, or at a minimum a biopsy, will be necessary to precisely define the bacteriologic origin and thereby allow a specific course of antibiotic therapy. In this case, as the presumed osteomyelitis was of uncertain origin, the biopsy and limited debridement were performed to refine the selection and course of antibiotic therapy. In most instances of a confirmed osteomyelitis, a minimum of 6 to 8 weeks of treatment is necessary.

Hip Osteoarthritis

Brian G. Evans

History

This patient is a 65-year-old woman who has had a long-standing history of pain in the right groin. The pain has been gradually getting more severe, resulting in the patient limping when she walks for more than 10 to 15 minutes. The pain began approximately 6 to 7 years ago. Initially, she thought the pain was caused by a groin pull. She tried treating it on her own with nonsteroidal antiinflammatory medications such as ibuprofen, which provided good symptomatic relief. Over the past 1 to 2 years, however, the pain has become much more pronounced. She has pain at night when she turns over and significant pain and stiffness in the morning when she first gets up out of bed. Also, with prolonged sitting, such as during a car ride or if she goes out to dinner, after approximately 30 to 40 minutes, she has significant pain in the hip that requires her to get up and move about to alleviate the pain. If she has been sitting for more than 10 to 15 minutes, when she arises from the sitting position she also has a significant degree of stiffness when she first starts walking. Initially, this pain was well treated with ibuprofen; however, currently she is having a significant degree of pain and discomfort, even when taking 600 to 800 mg ibuprofen three times a day. She has also had increasing difficulty putting on her socks and tying shoes. She has been unable to clip her toenails for several years, particularly on the right side. She has a history of some mild hypertension, but otherwise she is in good health and feels quite limited by her right-sided groin pain. She denies any numbness, tingling, or weakness in the leg. She has not had any buckling. The pain does not worsen with coughing or sneezing, and she has no pain in the buttock or posterior thigh.

Physical Examination

The patient walks with a significant coxalgic gait consisting of a reduced stance phase and a Trendelenburg lurch. When she stands, she stands with the right knee slightly flexed with her weight on the left side. She does have

stiffness and a limp when she moves from a chair in the examination room to sit on the examination table.

When examining the lower extremities, she has 5/5 motor strength in the extensor hallucis longus, tibialis anterior, gastrocnemius-soleus, and quadriceps muscles. She has no decrease in sensation to light touch over both lower extremities. With the patient supine, both legs have equal limb lengths. On assessing range of motion, on the right side she has flexion to approximately 85 degrees, extension to the table, internal rotation to 0 degrees, and external rotation of approximately 45 degrees, and adduction of 5 degrees and abduction of approximately 30 degrees. All range of motion is limited to pain. On assessing for flexion contracture with the Thomas test, she has a 15 degree flexion contracture on the right hip and none on the left. On the left side she has flexion to 105 degrees, full extension, internal rotation of 15, external rotation of 70, and adduction of 20 and abduction of 45 degrees. She has no pain with range of motion of her knees or ankles. She has no exacerbation of her pain with extension or flexion or lateral bending of the lumbar spine.

Radiographs

Figure 1 is an anteroposterior (AP) radiograph of the pelvis showing both hips that demonstrates a normal left hip with a well-maintained articular space and no osteophyte formation. The right hip, however, has extensive osteoarthritic changes. There is no articular space, extensive osteophyte

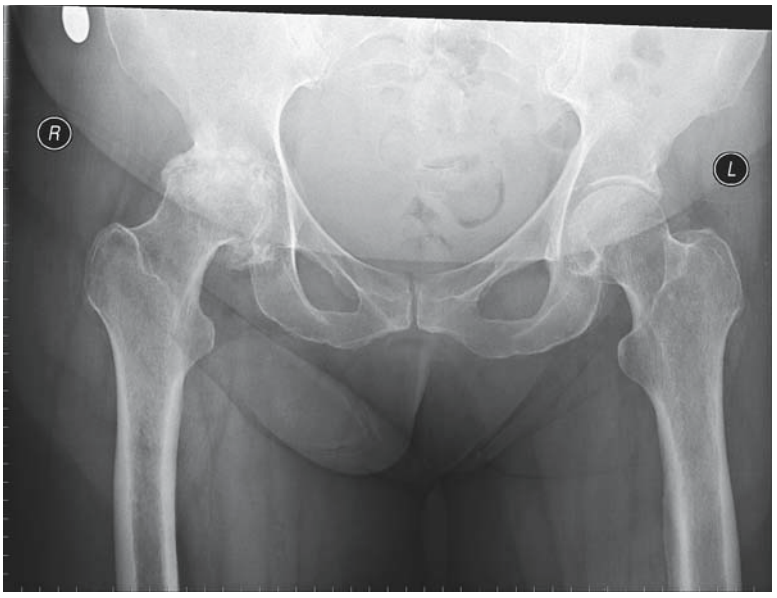


FIGURE 1. Anteroposterior (AP) radiograph of the pelvis showing both hips.

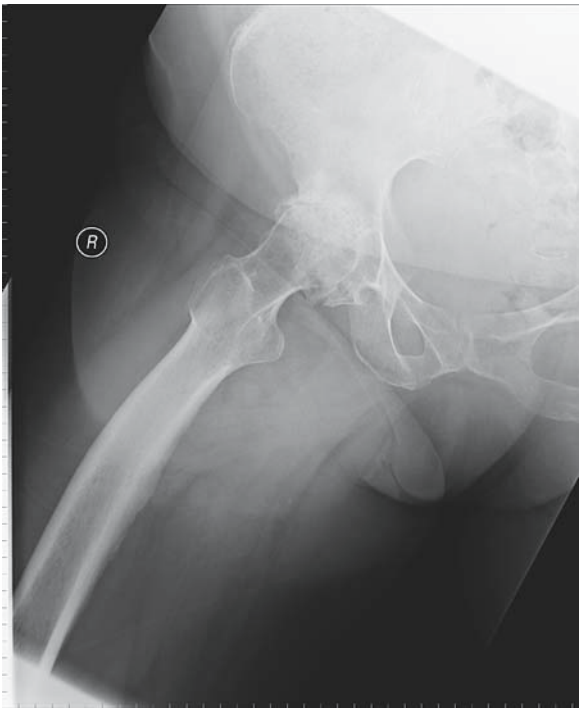


FIGURE 2. Lateral radiograph of the right hip demonstrates extensive osteoarthritis of the hip, with no articular space, subchondral sclerosis, and osteophyte formation.

formation is noted, and sclerosis or increased density in the bone is noted both in the femoral head as well as on the acetabular side. Figure 2, a lateral radiograph of the right hip, again demonstrates extensive osteoarthritis of the hip, with no articular space, subchondral sclerosis, and osteophyte formation.

Diagnosis

A patient with substantial osteoarthritis of the right hip, which is significant clinically in terms of pain and reduction in function and radiographically in terms of marked changes on the plain radiographs.

Treatment

The treatment alternatives for this patient are either to continue with current medications, with stronger antiinflammatories, and with reduction in activities or use of a cane. The other treatment alternative would be a total hip arthroplasty. The benefit of total hip arthroplasty would be relief

of pain and restoration of ambulatory function and ability. The risks of the surgery, as indicated in Chapter 11, are the risks of bleeding, thromboembolic disease, dislocation, and loosening of the components. These possibilities were reviewed with the patient in detail, and the patient elected to proceed with total hip arthroplasty.

Figure 3 shows the patient after having had a right hybrid total hip replacement. This replacement consists of a cemented femoral stem with a noncemented acetabular component. The components appear to be well fixed and well aligned. There is good interdigitation of the bone cement into the femoral cortex, and the overall limb alignment and anatomy have been restored.

The patient did well subsequent to the surgery. She returned to the office at 2 weeks postoperatively, able to ambulate with only the use of a cane with no pain, taking no pain medications. She returned again 6 weeks after the surgery and was ambulating freely without the use of a cane, crutch, or walker. She was able to ambulate for 40 to 60 minutes with no difficulty whatsoever and had no limp in her gait and no pain with routine activities. She was also able to put a sock on her right foot, clip her right toenails, and tie a shoe on her right foot without difficulty.

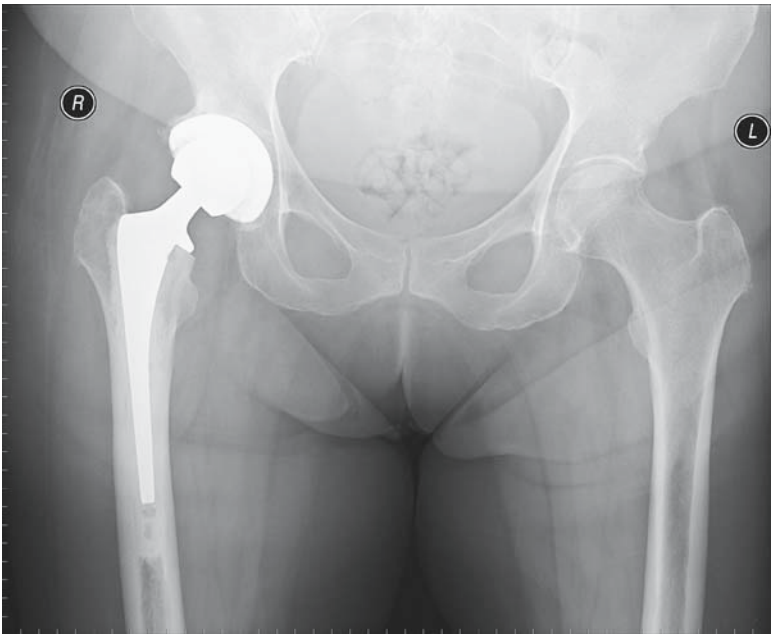
This patient has done well after a total hip arthroplasty. She should enjoy continued success with the arthroplasty for approximately 15 to 20 years.

Discussion

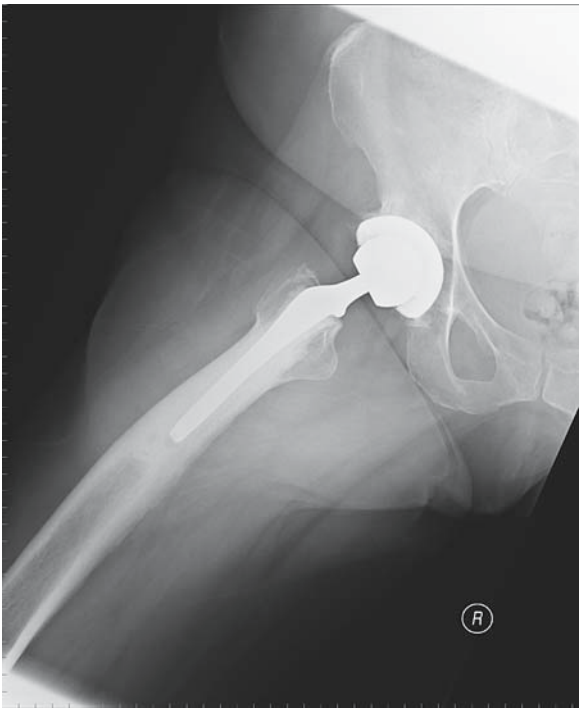
The treatment of osteoarthritis of the hip is based upon exploring nonoperative management as long as possible. Nonoperative management includes NSAIDs, physical therapy, the use of a cane, and, if appropriate, weight loss. In the end, however, the arthritis becomes increasingly symptomatic. As the pain and limitation of mobility become more severe, the next step in treatment is total hip replacement, done after nonoperative management fails. The timing for total hip replacement is elective; it is based solely upon the patient's pain and the impact of the pain upon their life and activities.

Total hip replacement is an excellent surgical option. It has an extremely high success rate, and after recovery the patient moves and ambulates completely normally, which allows a near-complete return to normal activities. However, the patients should not participate in running or cutting activity such as jogging and racquet sports after total hip replacement as these activities may result in early loosening and wear of the implanted devices. They are encouraged to keep aerobically fit with nonimpact aerobic activities such as cycling and swimming.

Total hip replacement commonly results in excellent functional return. Some patients, years after surgery, may have to stop and think which hip they had replaced. That is the definition of a good result.



A



B

FIGURE 3. Right hybrid total hip replacement consists of a cemented femoral stem with a noncemented acetabular component.

Slipped Capital Femoral Epiphysis

John N. Delahay

History

V.C. is a slightly overweight 11-year-old Caucasian girl who presented with the chief complaint of leg pain and limp for a period of 3 months. The pain began somewhat insidiously and without antecedent trauma. The pain was dull and aching in character and without significant radiation. The pain was relieved by rest and accentuated by standing and walking. She had actually attempted to play soccer during this period but had to stop because of the pain.

Her past medical history was entirely negative. However, of note, her brother had previously been diagnosed with slipped capital epiphysis and had been operated upon sequentially for bilateral disease.

Physical Examination

Pertinent findings were confined to the musculoskeletal system. Observation of gait demonstrated an antalgic limp on the right side. She was, however, able to walk without an assistive device and in fact was able to stand only on the affected side with the opposite leg off the ground.

In the resting position (hip extended), the leg tended to lie in the externally rotated position. When evaluating range of motion (ROM), the hip was noted to flex up in the externally rotated position. Attempts to internally rotate the hip in flexion or extension demonstrated the inability to do so as well as guarding because of pain. The flexion–extension range was normal. Leg lengths were equal, and the neurovascular status of the limb intact.

Laboratory and Radiographic Evaluation

Complete blood count (CBC), sedimentation rate, C-reactive protein (CRP), thyroid hormone assays, and renal function studies (BUN, creatinine, UA) were all within normal limits.

Initial radiographs are shown in Figures 1 and 2. Figure 1 is an anteroposterior (AP) view of the pelvis and both hips. Figure 2 is a "frog leg" lateral of both hips. As is often the case, the radiographic findings are most pronounced on the frog leg lateral view.

1. Kline's line is a line drawn along the superior neck of the femur. Normally, it should intersect a small portion of the capital femoral epiphysis. It can be seen in Figure 2 that if one were to draw this line it would not intersect the epiphysis but rather go above it.
2. Physeal widening can also be seen in Figure 2 and to a lesser degree in Figure 1.
3. Cystic changes are seen in the metaphysis in both figures but again are more apparent in the frog leg lateral view.

Careful review of those radiographs also shows similar changes on the opposite (left) unaffected and presumptively "normal" side.

Diagnosis is bilateral slipped capital epiphysis.

Treatment

Although these slips were considered stable, the patient was placed on crutches to restrict weight-bearing while arrangements were made for surgical treatment. She was taken to the operating room in a timely fashion

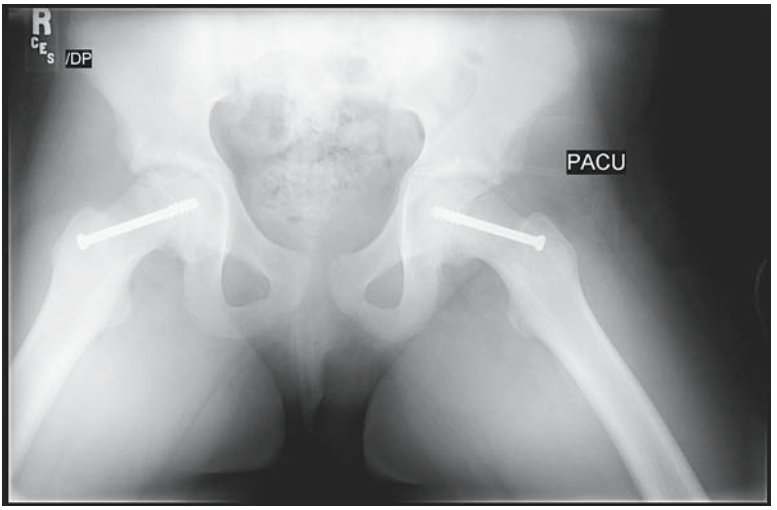


FIGURE 1. An anteroposterior (AP) view of the pelvis and both hips.

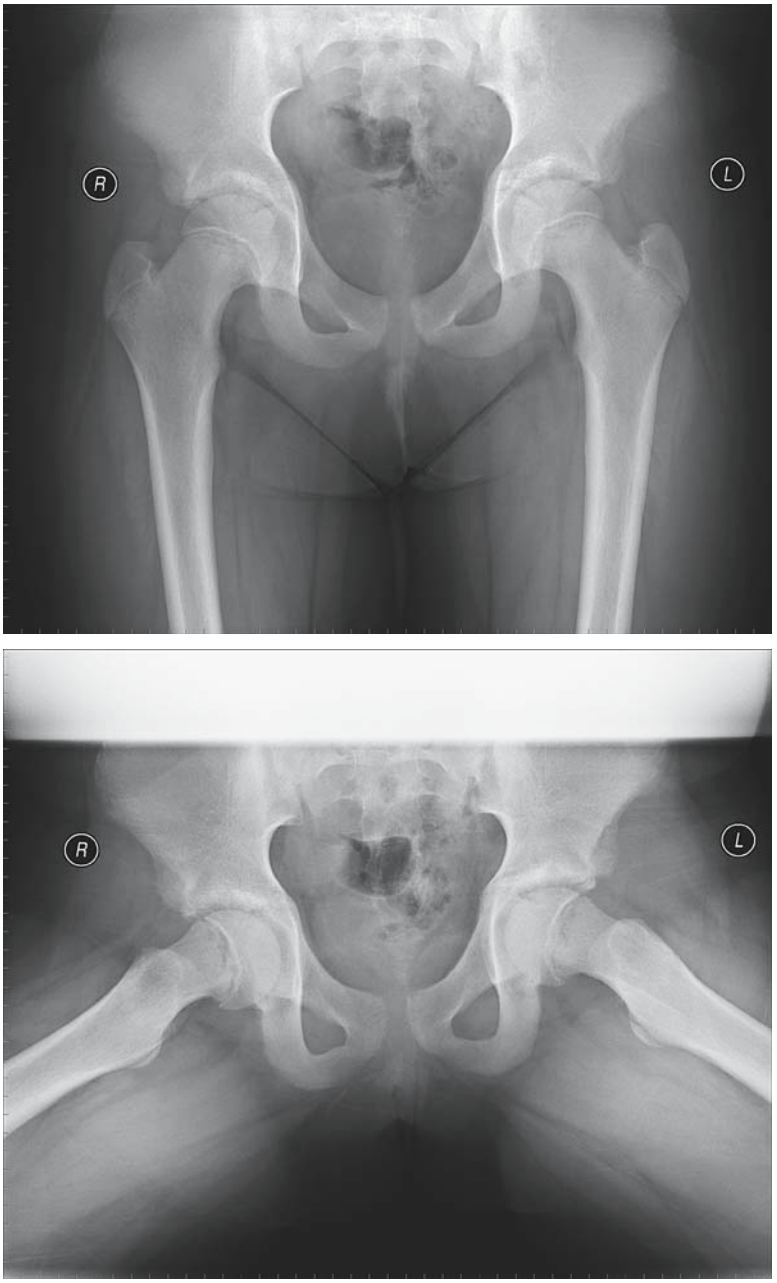


FIGURE 2. A “frog leg” lateral view of both hips.

(2 days after presentation) and underwent bilateral percutaneous pinning in situ using 7.3-mm cannulated screws. One screw was used on each side. No attempt was made to reduce the slips. Postoperatively, she was discharged home on crutches. Her weight-bearing status was slowly advanced, and the crutches were discontinued when the adductor spasm had resolved. No plans exist to remove hardware. Follow-up X-rays are planed at 6-month intervals until growth completion.

Discussion

Slipped capital femoral epiphysis (SCFE) is a relatively common cause of hip pain and limp in the preadolescent population. Typically, however, it affects Afro-Americans more commonly than Caucasians and males more commonly than females. Typically the patient is somewhat overweight and has had the pain and limp for several months at the time of presentation. The incidence of bilaterality is somewhat debated, but most texts report it to be about 25%. There is rarely a family history (as is the case here), and that of course raises the question of genetic association (which has never been demonstrated).

Because the patient was a female and Caucasian with a strong family history, the other issue to be considered is an endocrine etiology, and this was the rationale for obtaining thyroid and renal function studies. One other area to be considered would be growth hormone abnormalities.

Her presenting complaints were rather typical. The pain was more localized to the thigh; this phenomenon is usually explained as referral along the course of the obturator nerve. The pain was mechanical and relieved by rest. The limp was antalgic with a shortened stance time on the affected limb.

The X-rays were diagnostic, showing the most typical findings: positive Kline's line on the right and arguably the left, and physeal widening and metaphyseal cysts on both sides. Additional imaging studies are not needed in this patient. Occasionally, when the diagnosis is in question, a magnetic resonance imaging (MRI) scan or a Tc-99 bone scan may provide confirmation of the diagnosis, although some authors question the efficacy of either. There are many who believe that if a child presents with the classic history and physical findings, they should be considered as having "pre-slips" and treated as such.

This girl's treatment was the norm: restrict weight-bearing and pin the SCFE in situ in a timely manner. No attempt to reduce the slip should be made when the slip is stable as doing so increases the risk of vascular necrosis. A child with a stable slip can still bear weight on the limb and walk. The child with an unstable slip cannot bear weight on the extremity. Pinning in situ is the standard treatment for this condition; the goal of the

treatment is primarily to stop any further slipping and initiate or facilitate plate closure.

In this case, both hips were pinned because there was radiographic evidence of bilateral disease. This author and others routinely pin both sides whether or not there is evidence of bilaterality, the rationale being the relatively high incidence of bilaterality (this patient's brother had to have his pinned sequentially) and resultant leg length discrepancy that results from unilateral pinning. In the case of an 11-year-old girl, who would have about 3 years of growth left, one could expect a 1.8-cm discrepancy (6 mm × 3).

This girl's postoperative course was benign. The two major complications of SCFE are avascular necrosis (AVN) and chondrolysis. AVN is usually considered a complication of the treatment of the disease, resulting from aggressive manipulation to reduce the slip or osteotomies of the femoral neck. Chondrolysis is considered by most to be a complication of the disease itself. This loss of the articular cartilage is much more likely to be seen in African-Americans and can actually be seen at the time of presentation before treatment has been initiated.

Overall, the prognosis for SCFE is good. With early diagnosis and appropriate surgical treatment, most children can be restored to normal function rather quickly.

Cubital Tunnel Syndrome

Mustafa A. Haque

History

This patient is a healthy, 34-year-old woman who started to develop pain, numbness, and tingling in her dominant right hand 3 months ago. She points to the medial elbow as the source of her symptoms but notes radiation all the way to the tips of her ring and small finger. She is a laboratory medical researcher and has worsening of her symptoms while pipetting under a sterile hood. She is starting to have weakness with opening jars or grasping objects. She has no history of injury or trauma. Her remaining medical and surgical history are negative; in particular, she has no history of diabetes, hypothyroidism, or renal failure. She is not on any medications and has no allergies.

Physical Examination

The patient is a healthy, athletic-appearing female in no distress. Her upper extremities and left hand have no deformity and full active range of motion. She is tender to palpation over the ulnar nerve just posterior to the medial epicondyle, and tapping over the nerve at that site creates tingling that radiates all the way to the small fingertip. Full elbow flexion for more than 30 seconds reproduces her symptoms. Elbow flexion greater than 90 degrees causes subluxation of the ulnar nerve on to the medial epicondyle. The patient is nontender over the medial and lateral epicondyle or over the wrist. Carpal tunnel compression and Phalen's test are negative, as is Tinel's testing at the wrist. Sensation to light touch is normal over the thumb through radial border of the ring finger and subjectively decreased over the ulnar border of the ring finger and all of the small finger. She has slight finger abduction weakness.

Radiographs and Laboratory Values

This patient's X-rays were completely normal. Her laboratory studies were also unremarkable; in particular, serum glucose and thyroid function tests were within normal limits.

Diagnosis and Treatment

This patient has compression of the ulnar nerve at the elbow, more commonly known as cubital tunnel syndrome. She was treated with nonsteroidal antiinflammatory drugs (NSAIDs), a custom-molded night splint to avoid elbow flexion greater than 30 degrees, ergonomic workstation adjustments, and therapy. Her symptoms unfortunately worsened over the next 3 months despite these interventions, and she developed significant finger abduction weakness. She was then surgically treated with an anterior subcutaneous transposition of the ulnar nerve. Within a few weeks her symptoms resolved, and by 3 months after surgery, she had regained completely normal hand and elbow function.

Discussion

Cubital tunnel syndrome results from compression of the ulnar nerve around the elbow. Patients classically present with medial elbow pain and paresthesias in an ulnar nerve sensory distribution (the ulnar half of the ring finger and all the small finger). As the condition progresses, patients can develop weakness to finger abduction. Tinel's sign, or tapping on the nerve dorsal to the medial epicondyle, causes paresthesias radiating to the small finger. A positive elbow flexion test reproduces the patient's symptoms after 60 seconds of maximal elbow flexion. Another classic late finding is the Froment's sign, in which attempts at key pinch result in flexion of the thumb interphalangeal (IP) joint as the extensor pollicis longus (EPL) and flexor pollicis longus (FPL) compensate for adductor weakness.

The differential diagnosis includes medial epicondylitis, cervical radiculopathy, thoracic outlet syndrome, carpal tunnel syndrome, and ulnar tunnel syndrome, and several of these conditions can occur concurrently. History and physical examination are the keys to making the correct diagnosis, but EMG and nerve conduction studies are helpful. The electrical criteria for confirming cubital tunnel syndrome includes a drop in conduction velocity of 11 m/s or greater across the elbow compared to below the elbow. Lesser velocity decreases, however, do not rule out the disease.

Treatment is usually conservative with nighttime extension splinting, NSAIDs, and rest. Occasionally, hand therapy with nerve and tendon gliding exercises can be helpful. If a patient's symptoms do not resolve after 3 months of this management, one can consider surgical intervention. The options include in situ decompression, medial epicondylectomy, and anterior transposition of the ulnar nerve. The anterior transpositions include subcutaneous, intramuscular, and submuscular techniques. It is important to completely release the arcade of Struthers (see Fig. 1), the medial intermuscular septum (see Fig. 2), the fascia over the groove dorsal

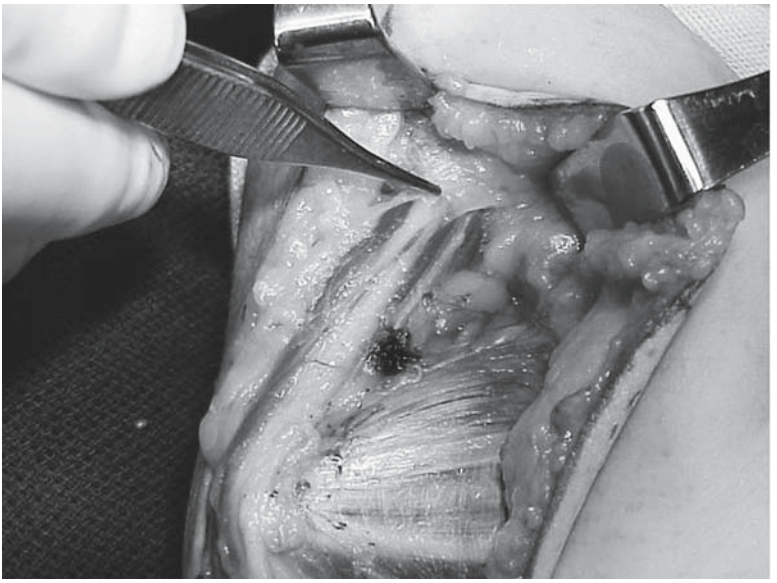


FIGURE 1. Medial exposure to the ulnar nerve prior to transposition. The nerve can be seen subluxating over the medial epicondyle at the bottom of the picture. The forceps point to the arcade of Struthers, the most proximal site of compression in cubital tunnel syndrome.

FIGURE 2. The arcade of Struthers has been released. The intermuscular septum has been dissected away from the nerve and is held in the forcep.

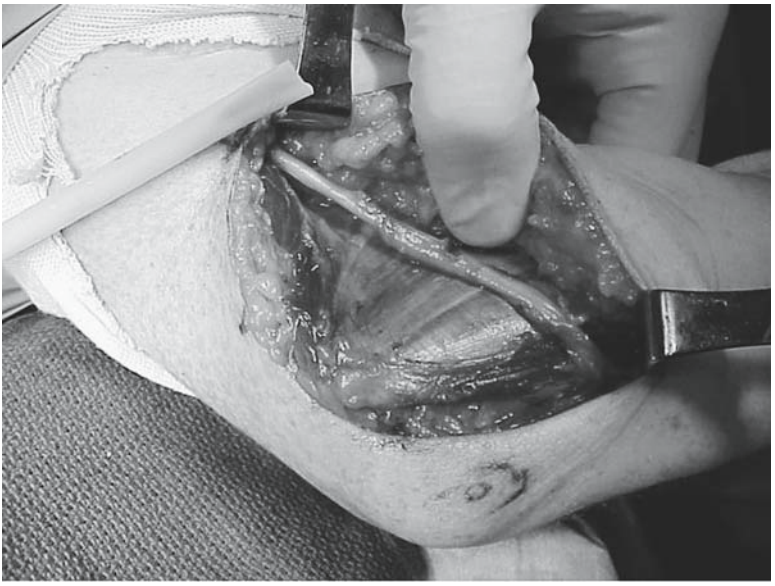


FIGURE 3. The decompression and anterior transposition of the ulnar nerve have been completed.

to the medial epicondyle, the ligament of Osborne (the fascial band between the ulnar and humeral heads of the flexor carpi ulnaris), and the exit of the nerve from the flexor carpi ulnaris. The nerve should be completely free at the end of the release and transposition (see Fig. 3).

Flexor Tendon Avulsion

Mustafa A. Haque

History

This patient is a healthy, 27-year-old man who was playing flag football 2 days ago. While trying to grab an opponent's flag, his nondominant left hand became caught in the other player's belt. He felt a "pop" in his ring finger, and he noted moderate pain in this digit. He soon developed mild swelling of the digit and has been unable to flex it ever since. He has no other injury or history of trauma. His remaining medical and surgical history are negative. He is a first-year medical student with aspirations of becoming an orthopedic surgeon.

Physical Examination

The patient is a healthy-appearing male in no distress. His left hand has an extension deformity of the ring finger with inability to actively flex the distal interphalangeal joint (DIP) joint and loss of the normal hand flexion cascade (see Fig. 1). He has full passive range of motion, but he is painful with full extension of the wrist and finger. He is tender over the flexor tendon sheath at the level of the proximal phalanx shaft with a small area of fullness there. He is also tender at the base of the distal phalanx, and he has mild ecchymosis in this area.

Radiographs and Laboratory Values

This patient's X-rays and laboratory studies were completely normal.

Diagnosis and Treatment

This patient has an avulsion of the flexor digitorum profundus (FDP) tendon. He was treated with surgical repair the next day by approaching the retracted tendon through a volar zigzag (Bruner) incision, passing it

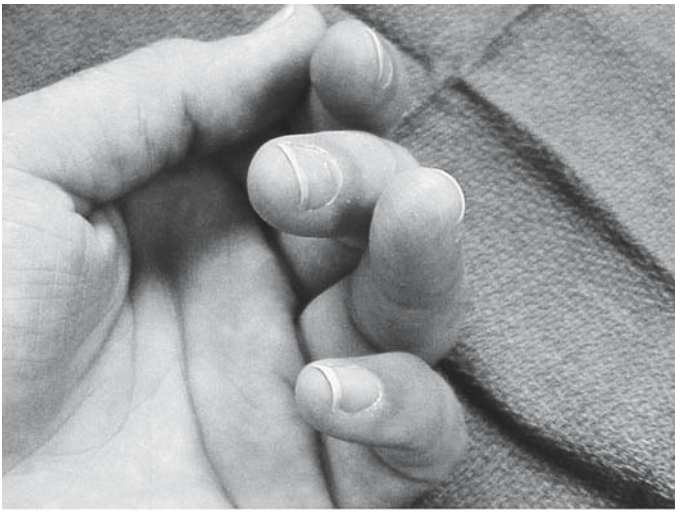


FIGURE 1. This is a typical extended posture of the ring finger after an FDP tendon avulsion or laceration.

back through the pulley system (see Fig. 2), and reattaching it to bone with a pull-out suture going through the distal phalanx and tied over a button on the dorsum of the nail (see Figs. 3, 4). He started a passive flexion range

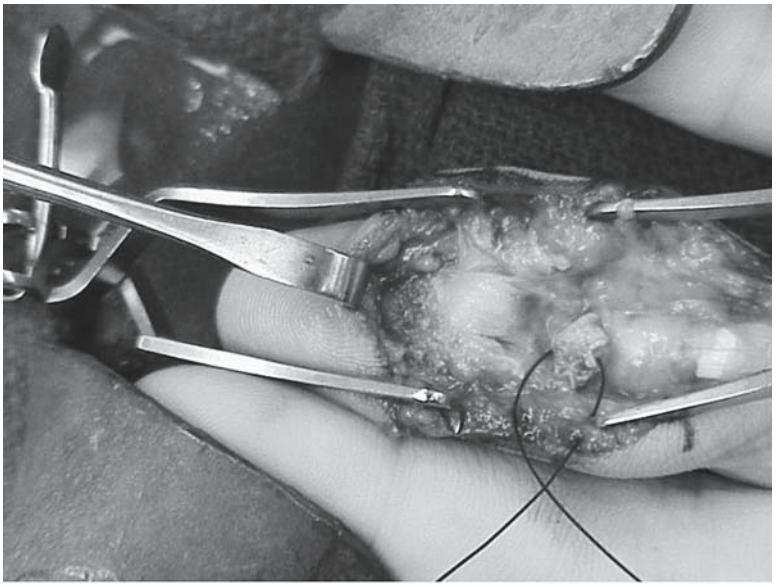


FIGURE 2. Surgical exposure: The avulsed tendon (with a suture attached) has been mobilized through the pulley on the right and is ready for reattachment to the bony bed of the distal phalanx on the left.

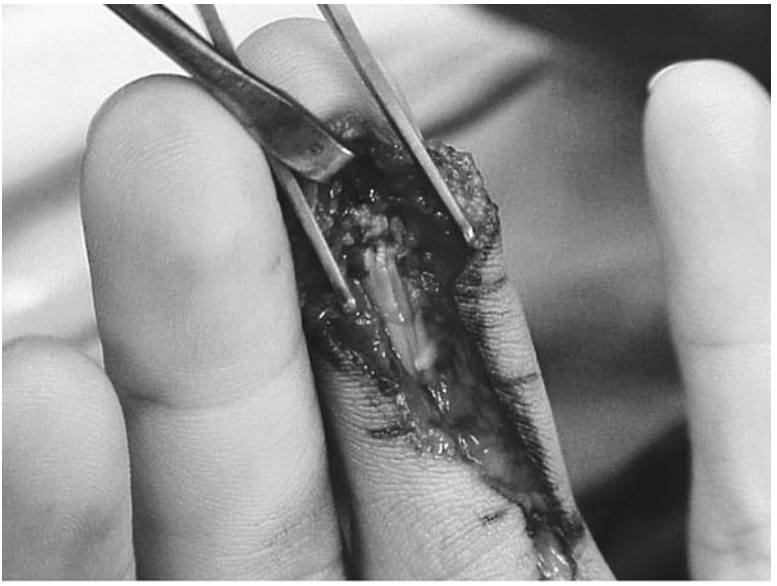


FIGURE 3. The reattached tendon.

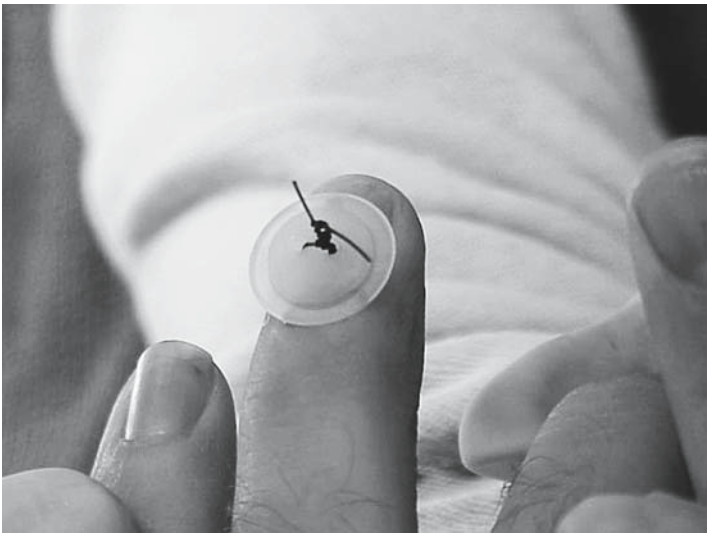


FIGURE 4. The pullout suture is tied dorsally over an acrylic button after being passed throught the distal phalanx and the nail.

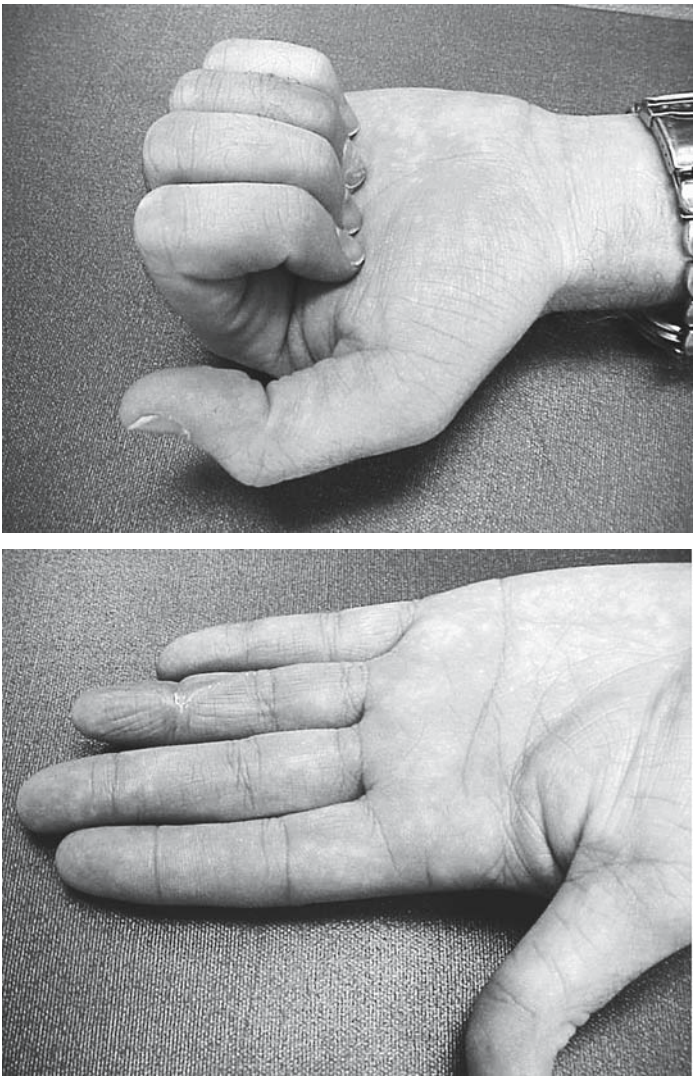


FIGURE 5. The active range of motion 3 months after surgery.

of motion protocol with therapy on postoperative day 1, and he advanced to full use of the finger (including sports) over 3 months. His final result was excellent with only a slight flexion contracture of the DIP joint and full flexion of the digit (Fig. 5).

Discussion

Avulsions of the flexor digitorum profundus (FDP) tendon are also known as jersey fingers because they frequently occur when patients are trying to grasp an opponent's jersey to make a tackle. The eccentric extension load on the actively flexing digit leads to failure of the FDP tendon insertion into the distal phalanx. The Leddy and Packer classification categorizes these injuries by the level of retraction of the tendon and the presence or absence of a distal phalanx fracture. The treatment of choice is surgical fixation, either through reattachment of the tendon to bone using a pull-out suture through bone, a bone anchor, or newer tendon repair systems. This repair is optimally done within a few days of injury to limit retraction and scarring of the tendon. After flexor tendon repairs, early protected motion and an extensive therapy protocol are necessary to avoid severe problems with stiffness.

Acute Anterior Cruciate Ligament Rupture with Strain of the Medial Collateral Ligament

John J. Klimkiewicz

History

This patient is a 20-year-old college football player who sustained an injury to his left knee. He is a lineman and stated another player had fallen on the lateral aspect of his left knee. He stated that his knee was extended at the time of the injury and described a "pop" within his knee. He was unable to continue playing, and required assistance off the field. He stated that his knee subsequently swelled over the next few hours and is currently unable to bear weight without significant discomfort. He denies any prior injury to his knee.

Physical Examination

His height is 6 feet 3 inches and his weight 245 lbs. He is unable to ambulate without crutches. His knee shows no signs of bruising or ecchymoses. His range of motion is 5 degrees to 90 degrees of flexion. He has a significant effusion (see Fig. 1). There is no patellar tenderness and no crepitation with range of motion, and no patellar apprehension. Patient has tenderness over the medial epicondyle of the distal femur and over the lateral joint line. There is no medial joint line tenderness. McMurray sign is positive for pain at 90 degrees of flexion over the lateral joint line. He is stable to varus stress maneuvers at both full extension and 30 degrees of flexion. Although stable to valgus stress maneuvers in full extension, at 30 degrees the patient has 1+ laxity with pain during this maneuver. He has a grade II Lachman with no endpoint, and also has grade II laxity to anterior drawer maneuvers at 90 degrees of flexion. There is a positive pivot shift. There is no increased laxity to posterior drawer maneuver at 90 degrees of flexion. His neurologic examination and vascular examination are unremarkable.

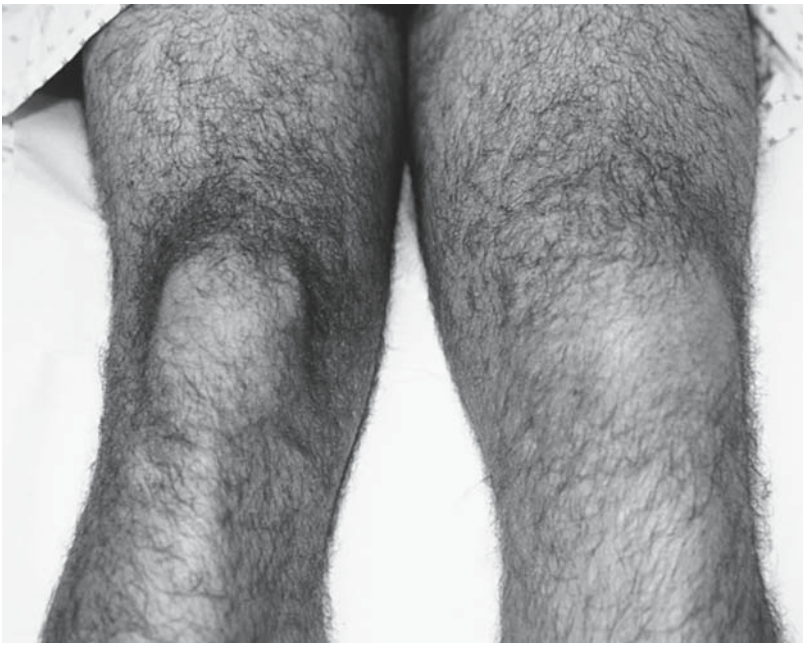


FIGURE 1. Acutely swollen knee after injury.

Radiographic Evaluation

Posteroanterior weight-bearing and lateral radiographs demonstrate no abnormality (see Figs. 2, 3). Magnetic resonance imaging (MRI) demonstrates disruption of the anterior cruciate ligament (see Fig. 4), in combination with partial injury of the medial collateral ligament (see Fig. 5). There is also a tear of the lateral meniscus.

Treatment

This patient has sustained a complete rupture to the anterior cruciate ligament (ACL) associated with a grade II strain of the medial collateral ligament (MCL) and lateral meniscal tear. As the patient is young and athletic, the preferred treatment would include initial physical therapy to regain full motion, followed by surgical reconstruction of the anterior cruciate ligament and lateral menisectomy versus repair (see Figs. 6, 7). This intervention is usually performed after 4 to 6 weeks of physical therapy to allow the medial collateral ligament to heal and for the patient to regain full

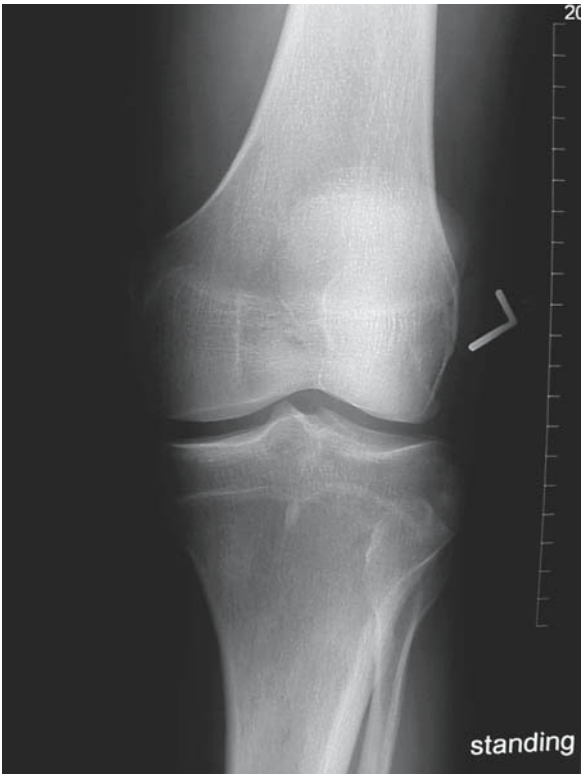


FIGURE 2. Posteroanterior radiograph of knee.

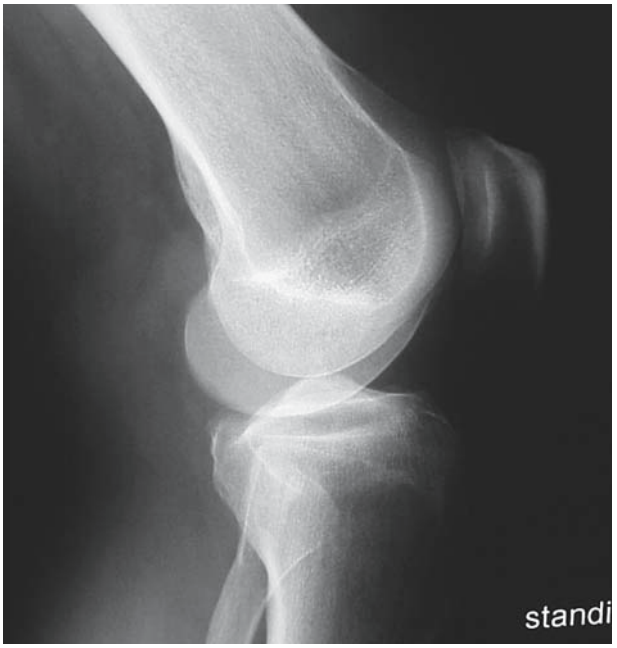


FIGURE 3. Lateral radiograph of knee.

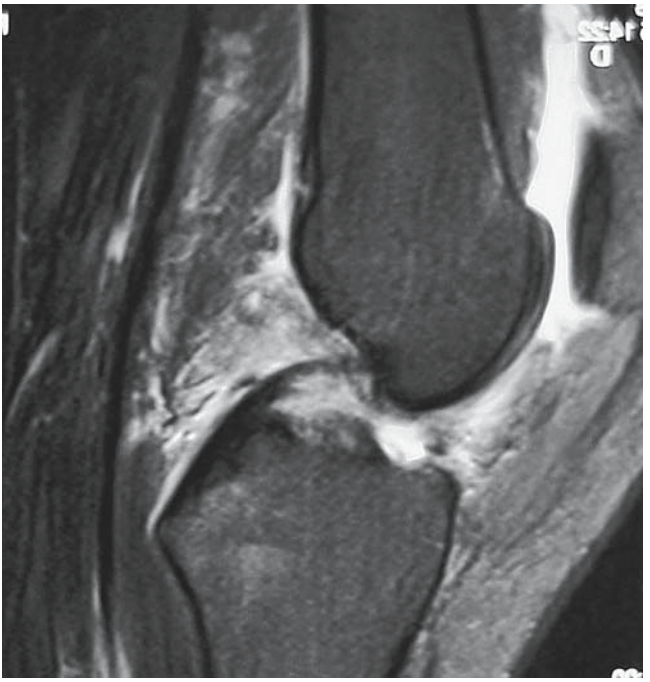


FIGURE 4. Magnetic resonance image (MRI) of knee demonstrating anterior cruciate ligament (ACL) injury.

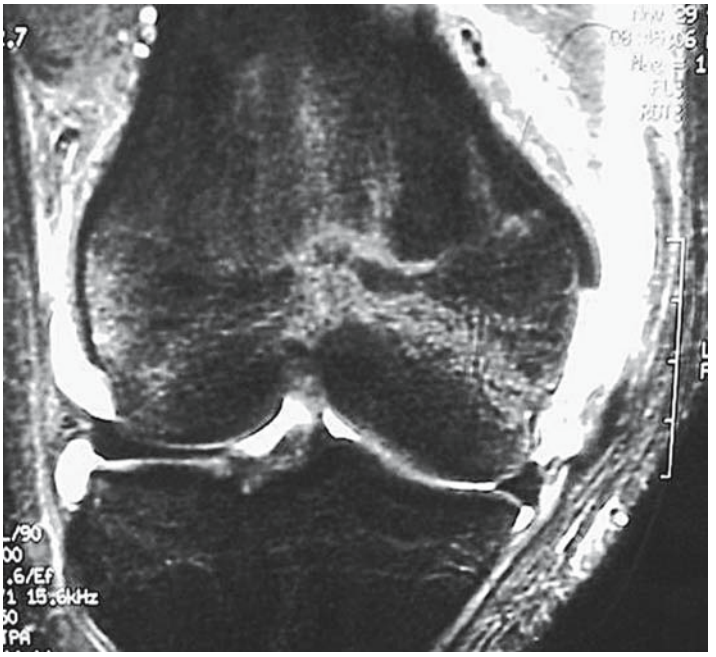


FIGURE 5. MRI of knee demonstrating medial collateral ligament (MCL) injury.

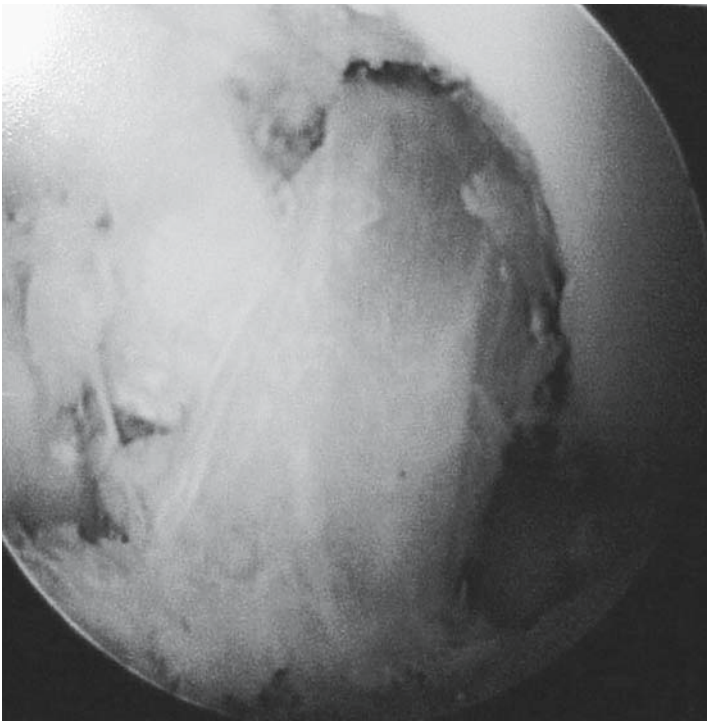


FIGURE 6. Arthroscopic view of ACL reconstruction using patellar tendon autograft for reconstruction.

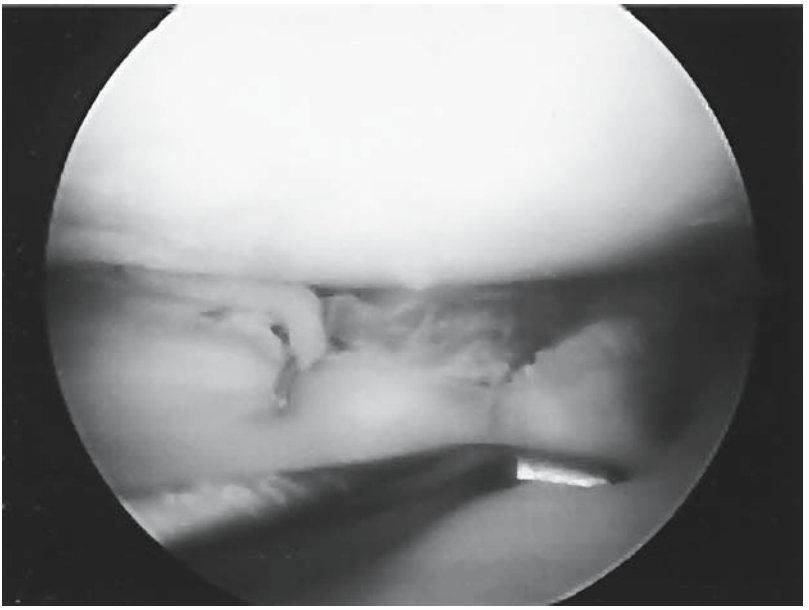


FIGURE 7. Arthroscopic view of lateral meniscal repair.

range of motion. Although different graft options exist to reconstruct the anterior cruciate ligament, a central third patellar tendon autograft was chosen. Intense physical therapy is necessary postoperatively to allow a return to sport at 6 months after the procedure.

Discussion

This patient suffered an injury to the ACL, MCL, and lateral meniscus. The mechanism for this injury involved a valgus load to the extended knee. The patient often recalls hearing a pop that is shortly followed by significant swelling. There is often an immediate inability to ambulate or a significant antalgic (painful) gait. These injuries can also be associated with injuries to the collateral ligaments and injuries to the menisci or articular cartilage. This patient suffered the triad of injuries that include: an ACL rupture, strain or rupture of the MCL, and a lateral meniscal tear.

This patient's examination is significant for increased laxity to anterior stress tests including the Lachman exam at 30 degrees and anterior drawer at 90 degrees. These tests are categorized by grades based on the degree of translation. Grade I injuries are those with laxity 0 to 5 mm greater than the contralateral side, grade II, 5 to 10 mm, and grade III, more than 10 mm. There is also a positive pivot shift that results when a valgus load is applied to the knee through a range of motion, and there is a palpable shift at 30 degrees to full extension when the tibia translates from an unreduced position secondary to ACL disruption to a reduced position in full extension. This is pathognomonic for an ACL rupture. This patient also demonstrates a partial injury to his MCL with pain at its origin (medial epicondyle). Grade I injuries involve a strain with no increased laxity on exam, grade II injuries involve increased laxity with an endpoint of this structure, and grade III injuries involve increased laxity of this structure with no endpoint present, thus representing a complete tear. This was the case for this patient. The presence of lateral joint line tenderness with a positive McMurray test is consistent with the lateral meniscal tear.

Current treatment for anterior cruciate ligament injuries involves an initial period of physical therapy to emphasize range of motion and modalities to decrease swelling. After this initial period of rest, a reconstruction is the recommended form of treatment to allow the patient to return to cutting sports. Conservative modification of activity and bracing can be considered for less active individuals. Reconstruction can be performed with the patient's own tissue (autograft) or through the use of cadaveric tissue (allograft). At the time of surgery, associated injuries to the articular cartilage or meniscus are also addressed. This patient sustained a tear of the lateral meniscus in the vascular zone of this structure, making meniscal

repair the preferred surgical technique, as compared to menisectomy. Return to sport is possible with this technique at 6 to 9 months. Long-term results are dictated by not only providing the patient with a stable reconstruction but also through preserving the patient's meniscal structures as well as articular cartilage.

Shoulder Osteoarthritis

Raymond M. Carroll

History

A 57-year-old man presents to your office with a chief complaint of right shoulder pain. On further questioning, the patient reports that the pain began a few years ago with sharp pain in the shoulder with various activities such as reaching overhead and out to the side. He denies trauma or injury. He notes that the pain has become constant and dull at rest. With activity, the pain is sharp and is becoming unbearable. He reports that he is unable to use the extremity because of the pain and loss of motion. Nonsteroidal antiinflammatory medications alleviated the pain in the past but have minimal effect at this time. He denies any systemic symptoms. He has no significant past medical history other than hypertension, which is controlled with diet and exercise.

Physical Examination

In general, the patient is mildly overweight. His cervical spine motion is within normal range and is pain free. His right shoulder girdle reveals a loss of the normal contour of the anterior aspect relative to the left shoulder girdle. He has no scars, wounds, or localized atrophy. He has tenderness diffusely on the anterior and posterior joint lines. There is no fluctuance or induration noted on palpation. His active range of motion is as follows: forward elevation to 100 degrees with sharp pain at the end range of motion, external rotation is limited to 15 degrees, also painful, and internal rotation is limited to the buttock region. His passive range of motion is similarly affected. He has no focal motor or sensory deficits in the upper extremity. He has a strong and symmetrical radial pulse.

Differential Diagnosis

There are a number of important aspects to consider in this patient when formulating a differential diagnosis. The age of the patient is critical. Common diagnoses in this age group include rotator cuff disease and osteoarthritis. Also, it is important to note that there is no history of trauma or prior surgery. The documentation of a loss of active and passive motion in the shoulder suggests arthropathy or capsular adhesion as is seen with adhesive capsulitis. The most likely diagnoses are osteoarthritis or adhesive capsulitis (idiopathic). Although the patient may have a degenerative rotator cuff condition, the loss of passive motion indicates that the rotator cuff is not likely to be the culprit. Patients can develop secondary adhesive capsulitis following shoulder injuries such as a traumatic rotator cuff tear, but this patient does not have a history that is consistent with such an event.

Laboratory Results and Studies

Because of the lack of systemic or additional joint involvement, there is no indication to obtain any laboratory studies. A radiographic shoulder series including anteroposterior (AP), lateral, and axillary views is the next diagnostic step.

Imaging

The first image is an AP radiograph of the shoulder (see Fig. 1). The radiograph shows a loss of the glenohumeral joint space, subchondral sclerosis, and osteophyte formation at the inferior aspects of the humeral head and glenoid, and subchondral cysts are easily identified. The second image is an axillary view of the shoulder (see Fig. 2). The findings are similar to those noted on the AP radiograph. There is mild wear on the posterior aspect of the glenoid, which is commonly seen in osteoarthritis of the glenohumeral joint.

Treatment

Treatment for osteoarthritis of the glenohumeral joint includes activity modification, rest, and antiinflammatory medication. Corticosteroid injections may be used sparingly but are often not helpful in alleviating pain. Patients with osteoarthritis who have pain that is not responsive to these modalities may require narcotic pain medicine for relief of their symptoms.

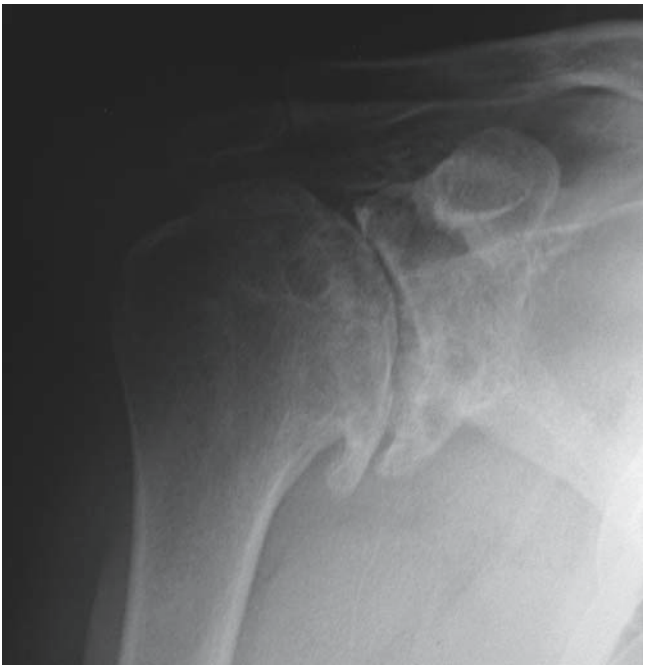


FIGURE 1. Anteroposterior (AP) radiograph of the shoulder.

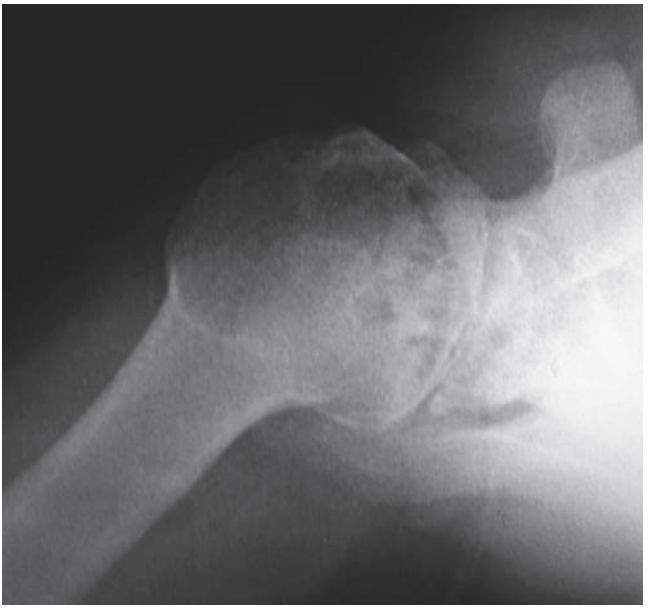


FIGURE 2. Axillary view of the shoulder.

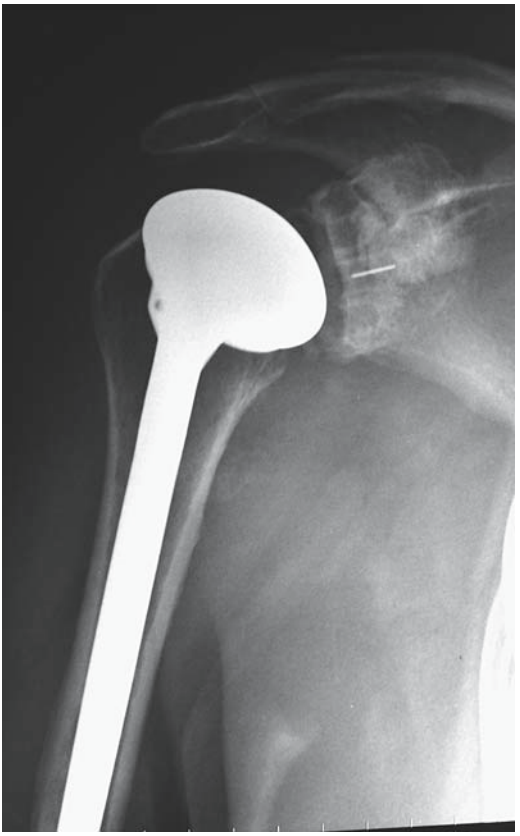


FIGURE 3. AP view of the shoulder after total shoulder arthroplasty.

Patients with osteoarthritis who require pain medicine for relief of symptoms are good candidates for joint replacement. The patient in this vignette has pain that is not responsive to standard nonoperative modalities. This fact in conjunction with the radiographic evidence of end-stage osteoarthritis makes him a good candidate for total shoulder arthroplasty. The third image is an AP view of the shoulder after total shoulder arthroplasty (see Fig. 3). The metallic humeral head replacement is obvious. The radiopaque horizontal line in the glenoid is evidence of the polyethylene glenoid component that has been cemented into the glenoid.

Glossary

abscess: a collection of purulent material which usually consists of bacteria, both alive and dead, and the byproducts of local infection including viable and nonviable neutrophils, lymphocytes, and lysosomal enzymes. The presence of neutrophils within an abscess often results in a localized inflammatory reaction which can become systemic and life threatening if allowed to persist.

acute osteomyelitis: bacterial colonization of bone or bone marrow with signs of acute inflammation and periostitis. Radiographic changes are usually present within the first 6 weeks.

adjuvant therapy: therapy which is administered to assist in the treatment of a neoplasm. Adjuvant therapy can include radiation therapy or chemotherapy and usually is utilized to improve the results of a primary type of treatment (i.e., surgery).

allograft: tissue for transplantation which is acquired from donated cadaveric sources. Musculoskeletal allografts are generally processed by either deep freezing or dehydration utilizing freeze-drying techniques. Sterilization is generally performed with either gamma radiation, aseptic acquisition in an operating room setting, or treatment with ethylene oxide.

ankylosis: spontaneous bony fusion of a joint.

antalgic gait: a type of limp characterized by shortening the stance phase of gait, in an attempt to relieve pain on weight-bearing.

apophysis: secondary ossification center which develops in response to tension, and ultimately forms a process for muscular attachment.

arthrodesis: fusion performed surgically between two articulating bones by removal of the joint cartilage, removal of cortical bone, bone grafting, and immobilization.

arthrofibrosis: restricted joint motion due to formation of dense scar tissue around the articulation (contracture).

arthroplasty: an operation to improve function and relieve pain caused by arthritis in a peripheral joint. Joint resection or replacement, as well as interposition between joint surfaces, are forms of arthroplasty.

arthroscopy: a procedure to inspect, and operate on, the contents of a joint through a small portal utilizing a fiber-optic light source and specialized viewing and operative instruments.

benign: a neoplasm which has local capability for growth, with well-differentiated cells that are not capable of vascular or lymphatic invasion. Benign neoplasms can be either latent, with limited local growth, or aggressive, with growth proceeding in a destructive manner.

biopsy: the acquisition of material from a lesion, whether it be neoplastic or infectious, for diagnostic review. An adequate biopsy requires obtaining enough material for complete pathological review to arrive at a definitive diagnosis.

bone cement: polymethylmethacrylate (PMMA), used as a filler to enhance the fixation of total joint components.

bone graft: bone used to promote fracture healing, reconstruct a defect in bone, or enhance fusion by providing an organic matrix, osteoblasts, and hormonal factors that contribute to osteogenesis.

calcification: the deposition of calcium within a cartilaginous matrix. This occurs secondary to mineralization of an existing lobule of cartilage which may appear punctate, comma shaped, or popcorn-like on radiographs.

callus: reparative tissue at the site of a fracture that evolves and matures, leading to fracture healing.

cancellous bone: mature bone found in the epiphysis and metaphysis of long bones, and in flat bones, comprised of a three-dimensional lattice of trabecular bone that is less densely packed than cortical bone.

chondrocyte: cartilage matrix-producing cells which rely on nutrition from synovial fluid and not blood vessels. These cells are often arranged in lacunae which are arranged in rather distinct layers.

chronic osteomyelitis: a chronic infection of bone, usually involving the presence of an involucrum or sequestrum, in addition to radiographic changes within the bone. Sclerosis surrounding chronic sites of radiolucency on radiographs and a sinus tract may be present. Chronic osteomyelitis generally requires at least 6 weeks in order to demonstrate radiographic changes.

Codman's triangle: a region at the periphery of a bone tumor which is formed secondary to the deposition of reactive bone underneath the periosteum. As the periosteum lays down new bone in response to stress, the bony trabecular patterns in this region are usually at a right angle to the underlying cortical bone. A Codman's triangle usually represents a rapidly growing tumor or osteomyelitis, with elevation of the periosteum off of the bone secondary to neoplastic tissue, bone edema, or purulent material.

comminution: disruption of a fractured bone into more than two fragments.

compartment syndrome: an increase in the resting pressure in a contained fibro-osseous compartment, such as the forearm or leg, resulting sequentially in decreased lymphatic drainage, decreased venous drainage, loss of arterial inflow, and finally death to the muscle contained in the affected compartment. Sequelae include contracture, pain, and severe functional disability.

computerized axial tomography/computerized tomography (CAT/CT scan): an imaging modality which utilizes computer-generated analysis and imaging resulting from multi-planar exposure through either an extremity or the spine. These scans provide clinicians with excellent axial representation of body segments that were previously not available. Tissue density is graded based on Hounsfield units with dense structures being represented by a bright or white image.

contracture: fixed loss of motion in one direction caused by hypertrophy and shortening of periarticular soft-tissue structures such as tendon, ligament or capsule.

cortical bone: mature, organized, densely packed bone, making up the periphery of flat bones and the diaphysis of long bones.

crepitus: audible or palpable grinding, usually located in a peripheral joint, with motion.

curettage: the mechanical removal of neoplastic or infectious tissue from a primary site. This generally involves entering a lesion and scraping its contents from within its lesional cavity, and has the potential for leaving residual disease, at the microscopic level, in the periphery. This type of "intralesional resection" is generally utilized for benign neoplasms.

cyst: a fluid-filled cavity which results from the production of fluid from a surrounding glandular membrane. The majority of cysts in orthopaedic terminology, such as a simple bone cyst or aneurysmal bone cyst are not true cysts, since the fluid does not directly result from the surrounding mesenchymal tissue present in the wall lining, but from the passive accumulation of fluid within the marrow cavity of bone.

debridement: the removal of infected or devitalized bone, muscle, and skin. The purpose of debridement is to remove any material that can serve as a substrate which harbors bacteria and to enable antibiotics, via parental or local routes, to reach colonies of bacteria.

delayed union: failure of a fracture to heal within the desired and expected time frame, with the potential still present for eventual union.

developmental: pertaining to growth and differentiation.

diarthrodial joint: a joint which consists of connections between two rigid parts of the musculoskeletal system which is lined by synovial tissue, lubricated by synovial fluid, and demonstrates appreciable ranges of motion. The ends of bones in diathrodial joints are usually covered with hyaline cartilage.

diaphysis: the tubular midportion of a long bone, consisting primarily of cortical bone.

dislocation: loss of normal articular congruity of a joint, with no contact between opposing articular surfaces.

dysostosis: an isolated disruption of normal bone growth with no identifiable etiology.

dysplasia: intrinsic defect in normal bone growth, which may be localized or generalized.

dystrophy: alteration in bone growth due to extrinsic defect, typically an endocrine abnormality.

electromyography (EMG): recording of the variations of electric potential or voltage from skeletal muscle. The EMG/nerve conduction velocity test is useful in determining the site of injury of a peripheral nerve or nerve root, and in identifying peripheral neuropathy caused by metabolic abnormalities.

enchondral ossification: bone formation following the template of a cartilaginous matrix.

enchondroma: a benign tumor of bone, with a cartilaginous matrix, commonly occurring in the hand.

epiphysis: a secondary ossification center, adjacent to the physis, which develops in response to compression and is covered by articular cartilage.

external fixation: the use of an extracorporeal device to stabilize a part of the skeleton, usually following an open fracture.

fracture: a cortical disruption, ranging from incomplete and non-displaced to completely displaced.

fracture healing: the process of biologic repair of a fracture in response to hormonal, biochemical, and mechanical factors. Fracture healing encompasses the phases of inflammation, soft callus, hard callus, and remodeling.

free tissue transfer: one-stage transplantation of distant autogenous composite tissue from a donor site to a recipient site. Free tissue transfer can involve transplantation of muscle, fasciocutaneous tissue, or bone with or without attached soft tissue. This type of transfer requires immediate revascularization, utilizing microsurgical anastomosis of graft and recipient site arteries and veins.

frozen section: the preparation of pathological sections from fresh tissue, used primarily in the operating room for rapid diagnosis which may impact on surgical decision making.

ganglion: a soft, mucin-filled cyst arising from a tendon, tendon-sheath, or joint capsule. Most common about the hand and wrist, and more common in women.

gigantism (overgrowth): hypertrophy of a single digit or entire limb, primarily involving soft tissues. Causes include neurofibromatosis, tumor, or vascular anomaly.

haversian bone: cortical bone composed of vascular channels surrounded by mature (lamellar) bone.

herniated nucleus pulposus (HNP): Extrusion of gelatinous nucleus pulposus through the anulus fibrosus, into the spinal canal or neural foramen. When an HNP results in nerve root compression, radicular pain, numbness, or weakness may be seen. Herniated disc, ruptured disc.

hydroxyapatite: the calcium mineral crystal component of bone.

internal fixation: the use of an implant to stabilize the skeleton, usually after a fracture.

involucrum: newly formed reactive bone, usually occurring at the interface between diseased bone and healthy tissue. An involucrum consists of viable bone which is the opposite of a sequestrum, which is composed of dead bone.

joint reaction force: the force across a joint that results from a combination of weight bearing and muscular contraction.

kyphosis: forward bending of the spine, when viewed from the side, which is normal in the thoracic spine.

laminectomy: removal of a lamina from its superior to its inferior margin, performed as surgical treatment for spinal stenosis or HNP. Laminotomy or hemilaminectomy refer to partial removal of the lamina.

lordosis: backward bending, or "sway," of the spine when viewed from the side. Lordosis is normal in the neck and low back.

low back strain: nonspecific term referring to acute onset of pain in the low back, occasionally radiating into the buttocks, with associated muscle spasm. Low back sprain, lumbago.

magnetic resonance imaging (MRI): an imaging modality utilizing resonance phenomenon resulting in the absorption and/or emission of electromagnetic energy by nuclei or electrons in a static magnetic field. Magnetic resonance imaging requires unpaired electrons that are excited by exposure to a magnetic field with a particular signal being emitted once that field is removed. Differences in density of tissues are then represented on images as varying shades of gray, black, or white, depending on their concentration of hydrogen. The modality is extremely useful in the evaluation of musculoskeletal tumors, as well as disorders of the spine, knee, shoulder, and foot.

malignancy: a neoplasm consisting of undifferentiated or dedifferentiated cells which have the active capability of vessel invasion, transport, and establishment of a secondary site of neoplastic growth in a distant organ.

malunion: healing of a fracture in a nonanatomic position.

membranous bone formation: bone formation occurring directly from a fibrous, mesenchymal, connective tissue template.

metaphysis: the transition segment of a long bone from the enlarged end (epiphysis) to the tubular shaft (diaphysis). The funnel-shaped metaphysis is usually made up of abundant cancellous bone, and during growth, woven bone.

metastasis: the deposition to secondary sites of neoplastic cells from a primary neoplasm.

myelopathy: noninflammatory dysfunction of the spinal cord resulting in long-tract signs and symptoms, most commonly caused by mechanical compression in the cervical spine.

neoadjuvant therapy: the application of adjuvant treatment, usually chemotherapy or radiation, prior to a primary procedure in an attempt to facilitate surgical removal of the primary tumor.

neuroma: a nodule, frequently painful, developing in a nerve that has been partially or completely lacerated or traumatized.

nonunion: failure of a fracture to heal within the upper range of time expected, with sequential radiographic documentation of a lack of any progression towards healing.

nonsteroidal anti-inflammatory drugs (NSAIDs): these agents are in widespread use to treat arthritis as well as a variety of soft-tissue injuries and for pain relief. Gastrointestinal side effects are common.

open fracture: a fracture which has come into contact with the outside, extracorporeal environment. Implications primarily relate to an increased risk of infection and impaired fracture healing secondary to soft-tissue injury.

ossification: the deposition of mineral along osteoid matrix, produced by either normal (fracture healing) or malignant osteoblasts (osteosarcoma).

osteoarthritis: noninflammatory degeneration of a diarthrodial joint characterized by loss of articular cartilage, effusion, crepitus, deformity, and pain. Radiographic changes include loss of joint space, subchondral sclerosis, cyst formation, and periarticular osteophytes.

osteoblast: a type of differentiated mesenchymal cell that is essential for the process of osteogenesis or ossification. Osteoblasts alone can produce the organic intercellular substance or matrix which makes up bone tissue, called osteoid.

osteoclasis: to manually fracture a bone, usually to correct malposition.

osteoclast: bone resorbing cell.

osteocyte: histologically and possibly biochemically inert osteoblast, usually present in bone which is not undergoing any active remodeling or repair.

osteoid: organic component of bone.

osteomalacia: metabolic disorder of bone characterized by inadequate mineralization of normal osteoid. Less common than osteoporosis, causes include Ca^{++} deficiency and renal disease.

osteomyelitis: infection involving bone. (See acute and chronic osteomyelitis)

osteoporosis: pathologic condition of bone characterized by a decrease in bone matrix with normal mineralization of the matrix that is present. Causes include postmenopausal estrogen deficiency, steroid usage,

immobilization, and bed rest. Fractures of the spine, hip, wrist, and shoulder are common.

osteotomy: surgical cutting and realignment of bone to change the mechanical environment of adjacent joints, posture, or appearance.

pannus: hyperplastic, hypertrophic synovium seen in the inflammatory arthritides. Source of degradative enzymes.

paraesthesia: a "pins and needles" or "tingling" sensation in an extremity, typically along the distribution of a peripheral nerve or nerve root.

pathologic fracture: a fracture occurring in bone that is of abnormal quality, either from metabolic changes (e.g., osteoporosis), tumor, or infection.

periosteum: thick fibrous tissue covering of a bone.

physis (epiphyseal plate, growth plate): a highly specialized cartilaginous structure, at each end of long bones, through which longitudinal growth of the bone occurs. The physis regresses and closes at the end of active skeletal growth.

polydactyly: the presence of an extra digit, either partial or complete. Most common in the hand, polydactyly may occur on either the ulnar or radial side.

prosthesis: a mechanical replacement for a removed portion of either bone or soft tissue. Prostheses include endoprostheses, which are internal replacements (joints, valves, ect.), and exoprostheses as would be used following an amputation.

radial club hand: congenital absence of all or part of the radius, resulting in a near-normal hand attached to, but radially deviated on, the forearm.

radicular pain: pain traveling down the extremity in a dermatomal distribution, often associated with paraesthesia. Pain should typically extend distal to the elbow or knee to be considered radicular.

radiculopathy: noninflammatory dysfunction of a spinal nerve with abnormal neurologic findings, most commonly secondary to a herniated nucleus pulposus or spinal stenosis.

referred pain: sclerotomal pain in a region that shares a common embryologic origin with the diseased region, such as the trapezius and shoulders for cervical disc pathology or the buttocks and posterior thighs for the lumbar spine.

remodeling: continuous process whereby older bone is removed and replaced with new bone, usually in response to mechanical stresses.

rheumatoid arthritis: inflammatory arthritis characterized by morning stiffness, swelling of peripheral joints, subcutaneous nodules, pain, and deformity.

rheumatoid factor: a blood marker that is usually, but not always, present in patients with rheumatoid arthritis. Some patients who do not have rheumatoid arthritis may have a positive rheumatoid factor.

rotation tissue transfer: soft tissue, such as muscle, or bone which is transplanted for wound coverage from one local site to another without transecting the blood supply to the transplanted tissue.

scintigraphy: a sensitive but nonspecific imaging modality for the diagnosis and staging of various orthopaedic problems. The standard "bone scan" utilizes technetium 99m, a gamma-emitting radioisotope with a half-life of 6 hours, coupled with methylene diphosphonate, a bone-seeking mineral material. Positive bone scans usually demonstrate increased uptake in areas of bony repair or destruction caused by neoplasm, fracture, infection, inflammation, or arthritis.

sclerosis: a rim of host bone reaction around the periphery of a lesion, or in an area of degeneration, which appears white (radiopaque) on radiographs.

scoliosis: coronal plane curvature, typically associated with rotation, leading to asymmetric rib or flank prominence. Common etiologies are idiopathic, neuromuscular, and congenital.

segmental instability: abnormal motion pattern between adjacent vertebrae resulting in excessive motion under physiologic loads and causing, in some individuals, characteristic mechanical back or neck pain.

septic arthritis: the presence of bacteria or their by-products within a diarthrodial joint.

sequestrum: a microscopic or macroscopic island of necrotic bone found at the nidus of an infection within viable bone. Often, sequestered fragments are surrounded by purulent material and infected granulation tissue and occur secondary to devitalization of cortical bone.

spinal fusion: arthrodesis of two or more adjacent vertebrae for painful or unstable conditions of the spine including spinal deformity, trauma, or degenerative segmental instability. Bone graft or bone-graft substitute is utilized and internal fixation may be used. Fusion may be performed anteriorly (interbody) or posterolaterally (intertransverse).

spinal stenosis: narrowing of the spinal canal or neural foramen resulting in compression of the cord or nerve roots. Causes include congenital narrowing, degenerative changes, and spondylolisthesis.

spondylolysis: defect of the pars interarticularis, most commonly a stress fracture that occurs during childhood. May be associated with back pain and lead to spondylolisthesis.

spondylolisthesis: the forward slippage of a vertebrae on the one below it (most commonly L5 on S1). The most common types are isthmic (secondary to spondylolysis), degenerative (caused by degenerative instability of the disc and facet joints) or postsurgical.

sprain: partial or complete injury to ligament resulting from excessive stretching.

straight-leg raising (SLR) test: with the patient supine or seated, simultaneous hip flexion and knee extension places the sciatic nerve on stretch.

Reproduction of ipsilateral sciatica (not back pain) constitutes a positive SLR sign.

subluxation: partial dislocation of a joint, with some retained contact of the articular surfaces.

syndactyly: webbing of the fingers, usually resulting from congenital failure of formation, and commonly seen with other congenital abnormalities.

synostosis: congenital fusion, either partial or complete, of adjacent bones. Synostosis is far more common in the upper than in the lower extremity, and may involve the elbow, carpus, metatcarpals, or phalanges.

synovectomy: removal of the synovium (lining surface of a diarthrodial joint), for inflammatory conditions such as rheumatoid arthritis or infection.

synovial membrane: a soft glandular tissue which lines diarthrodial joints and produces synovial fluid. The synovial membrane has a rich capillary network and serves both in phagocytosis of foreign debris and the production of synovial fluid.

tension sign: a physical finding produced by placing the involved nerve root on stretch to assess for mechanical compression. A positive tension sign requires reproduction of pain, in a dermatomal distribution, down the extremity.

Trendelenburg gait: a type of limp, caused by ineffective hip abduction, marked by swaying the torso over the effected hip on weight-bearing.

Trendelenburg sign: an abnormal drooping of the pelvis, on single-leg stance, away from the effected side due to ineffective hip abduction secondary to neurologic or mechanical factors, or pain.

ulnar club hand: congenital absence of all or part of the ulna, resulting in a near-normal hand attached to, but ulnarly deviated on, the forearm.

valgus: malalignment of an extremity, in the coronal plane, with the apex of the deformity pointing to the midline ("knock-knees").

varus: malalignment of an extremity, in the coronal plane, with the apex of the deformity pointing away from the midline ("bow-legs").

volar: the palmar surface of the hand and forearm.

Wolff's Law: physiologic phenomenon whereby new bone forms in response to mechanical stress and resorbs in the absence of it ("form follows function").

woven bone: immature bone found in the embryo and newborns, fracture callus, tumors, and osteogenesis imperfecta or Paget's disease.

zone of transition: the boundary between what is perceived as normal bone and lesional tissue on radiographs. The zone of transition can be very sharply defined, indicative of a slow-growing process (benign tumor), or very poorly defined, indicative of an aggressive process (neoplasm or infection).

Index

M