UPDATE ON IMAGING OF ORTHOPEDIC INFECTIONS

Robert D. Boutin, MD, Joachim Brossmann, MD,
David J. Sartoris, MD, Donald Reilly, MD,
and Donald Resnick, MD

Just as a traveler should not begin a journey without a map nor a carpenter build a house without a blueprint, an orthopaedic surgeon should not take a patient into the operating room without a master plan. Without a plan, a well-trained and highly skilled surgeon must often struggle through unforseen difficulties to achieve the desired result, and the patient often suffers.[55]

The radiologic evaluation of musculoskeletal infections can be extremely helpful to the orthopedic surgeon in drafting a master plan for conservative or operative treatment. Although infections often are suspected clinically, imaging is used to confirm the presumed clinical diagnosis and to provide information regarding the exact site and extent of the infectious process. For example, differentiating among diagnosis of osteomyelitis, abscess, and cellulitis is crucial in selecting treatment options, such as operative intervention; percutaneous drainage; and (noninvasive) medical treatment. Furthermore, the early diagnosis of some infectious processes is essential in prompting aggressive treatment, often allowing calamitous complications to be avoided.

Substantial gains in both medical and operative treatment of musculoskeletal infections have been realized during this century. In the medical realm, antibiotics have become widely available and increasingly sophisticated since they were first introduced over 50 years ago. In orthopedic surgery, numerous techniques have come into use to address the problem of musculoskeletal infections, including modern operating room design,[22] the use of muscle flaps for covering large cavitary lesions with exposed bone or metal,[124] and the use of antibiotic-impregnated methylmethacrylate spacers during two-stage replacement arthroplasties.[2]

With such advances, however, the types of infections that are encountered today have changed. Only a generation ago, physicians had never heard of large groups of patients who are at increased risk of infection, including intravenous drug abusers, patients with AIDS, and transplant patients with iatrogenic immunosuppression.[39,47,73,78,81,111] Furthermore, orthopedists today are confronted with the realization that most chronic infections of bone are associated with surgical procedures rather than the classical route of hematogenous dissemination.[47]

Just as chemotherapeutic and surgical techniques have become more sophisticated, so too have the radiologic techniques. Despite substantial improvements in radiologic technologies, however, the imaging diagnoses of various musculoskeletal infections are potentially

From the Department of Radiology (RDB) (DR), Harvard Medical School; the Department of Radiology (RDB), and the Department of Orthopaedic Surgery (DR), Beth Israel Deaconess Medical Center, Boston, Massachusetts; the Department of Diagnostic Radiology (JB), Christian-Albrects-Universitat zu Kiel, Kiel, Germany; the Department of Radiology (DJS) (DR), University of California School of Medicine; and the Department of Radiology (DR), Veterans Affairs Medical Center, San Diego, California

time consuming, expensive, and even misleading. Clearly, knowledge of the limitations and potential pitfalls of the various radiologic techniques helps in establishing the correct diagnosis.

Following a brief review of the most common routes by which musculoskeletal infections may occur, we focus on the diagnosis of osteomyelitis and soft tissue infections by conventional radiography and other imaging techniques. Finally, we consider specific situations that are especially topical or common, including the imaging evaluation of chronic recurrent multifocal osteomyelitis (CRMO), musculoskeletal infections in patients with the human immunodeficiency virus (AIDS), and pedal infections in diabetic patients.

CLASSIFICATION OF MUSCULOSKELETAL INFECTIONS

Although most serious infections are bacterial, on rare occasions viruses, fungi, and parasites may be the responsible pathogens. Infectious processes generally are designated as acute, subacute, or chronic. Orthopedic infections also are classified according to the site of involvement, and include osseous (osteomyelitis); articular (septic arthritis); bursal (septic bursitis); subcutaneous (cellulitis or abscess); muscular (infectious myositis or abscess); or tendinous (infectious tendinitis or tenosynovitis) varieties.

Regardless of the anatomic location, the mechanism of contamination occurs by only one of three routes: (1) hematogenous seeding, (2) spread from a contiguous source of infection, or (3) direct implantation of pathogens. Iatrogenic infections are notable in that they may be the result of any of these three mechanisms. Recognition that one of these three pathogenic pathways is operational in each patient with a musculoskeletal infection is of more than academic interest; it often is fundamental to the accurate interpretation of diagnostic imaging examinations.

ACUTE OSTEOMYELITIS

Hematogenous Spread of Infection

The pathologic and radiologic features of hematogenous osteomyelitis differ in the infant, the child, and the adult.[100] These differences are related, in part, to the particular vascular anatomy of the tubular bones that is evident in each of these three age groups (Figs. 1 and 2).

Vascular Anatomy. In infants (less than 1 year of age), diaphyseal vessels can penetrate the growth plate and reach the epiphysis, where they end in sinusoidal lakes. This situation provides a vascular connection between the metaphysis and the epiphysis, and explains the frequency of epiphyseal infections in neonates.

In children after the age of about 1 year, the capillaries of the metaphysis do not cross the physis but form large sinusoidal lakes in the metaphysis. The slow and turbulent blood

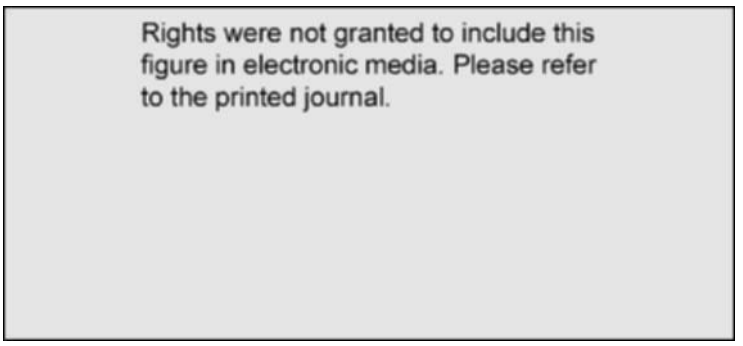

Figure 1. Normal vascular patterns of a tubular bone in the infant, the child, and the adult. *A*, In the infant, some metaphyseal vessels may penetrate or extend around the open growth plate, ramifying in the epiphysis. *B*, In the child, the capillaries of the metaphysis turn sharply, without violating the open growth plate. *C*, In the adult, with closure of the growth plate, a vascular connection between metaphysis and epiphysis is restored. (*Adapted from* Resnick D: Diagnosis of Bone and Joint Disorders, 3rd ed. Philadelphia, WB Saunders, 1995, p 2330; with permission.)

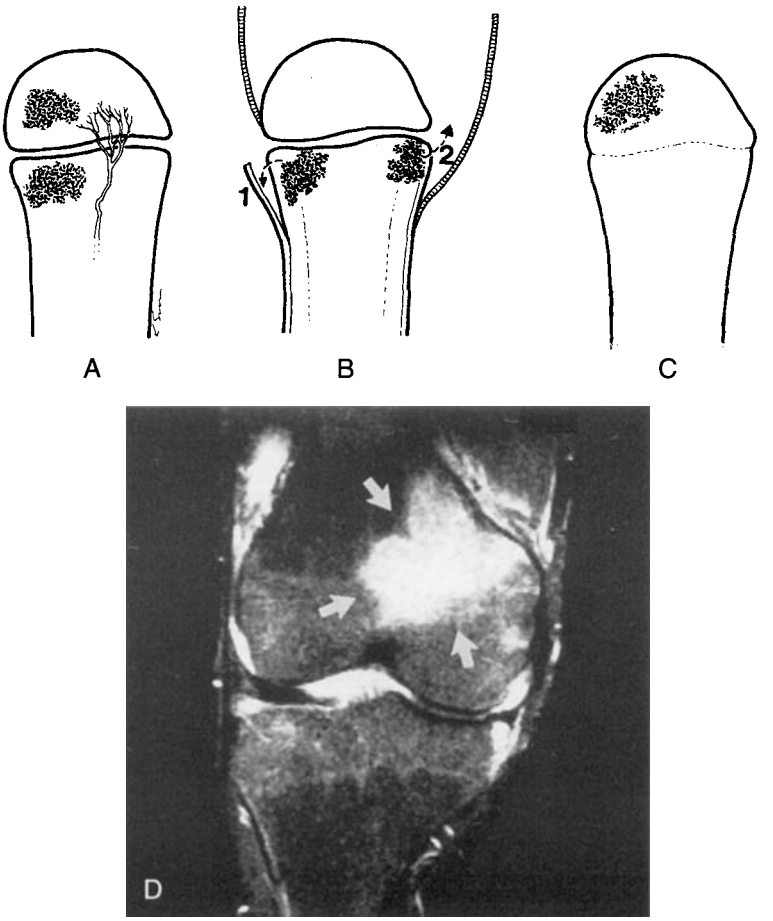

Figure 2. Sites of hematogenous osteomyelitis of a tubular bone in the infant, the child, and the adult. *A,* In the infant, a metaphyseal infection may be complicated by epiphyseal extension owing to the vascular anatomy in this age group. *B,* In the child, metaphyseal infection is common. From this site, cortical penetration can result in (1) a subperioseal abscess in those locations in which the growth plate is extra-articular or (2) a septic joint in those locations in which the growth plate is intra-articular. *C,* In the adult, a subchondral infection is not unusual, owing to the vascular anatomy in this age group. *D,* In an adult patient, a coronal STIR MR image demonstrates hematogenous osteomyelitis involving both the metaphyseal and epiphyseal portions of the distal femur (*arrows*). (*A* to *C Adapted from* Resnick D: Diagnosis of Bone and Joint Disorders, 3rd ed. Philadelphia, WB Saunders, 1995, p 2330; with permission.)

flow in these areas predisposes the metaphyses to hematogenous infection. A predilection also is shown for metaphyseal-equivalent locations adjacent to physeal cartilage in long bones (e.g., femoral trochanters) or other bones (e.g., calcaneal apophysis). In up to 25% of children with hematogenous osteomyelitis, infection is found in locations other than tubular bones, including the calcaneus and innominate bones.

In adults, the growth plate closes and vascular continuity between the epiphysis and metaphysis is restored. This facilitates spread of infection to the subchondral bone which, in turn, increases the risk of contamination of the adjacent joint. Nevertheless, hematogenous osteomyelitis of long bones in adults is relatively uncommon. Far more commonly, hematogenous osteomyelitis localizes to the spine, pelvis, and small irregular bones.[100]

Pathophysiology. Acute inflammation of bone is characterized by vascular engorgement, edema, cellular infiltration, and abscess formation. Increasing intramedullary pressure associated with osteomyelitis leads to spread of pathogens into the cortical bone, with intracortical extension facilitated by the haversian and

Volkmann's canals. Subsequently, the subperiosteal space typically becomes infected.

In infants and children, elevation of the periosteum is prominent because of the loose attachment of the periosteum to the bone. The elevated periosteum lays down bone to form an involucrum, especially in infants and children, which can completely surround the infected bone. Following thrombosis of metaphyseal vessels, extensive cortical necrosis and sequestration also can occur. Because septic arthritis occurs relatively commonly in pediatric patients with osteomyelitis, it is imperative that joint involvement be considered during the diagnostic work-up.[95] Other potential complications of epiphyseal and metaphyseal infections include damage to the physeal cartilage with subsequent growth disturbance.

In adults, owing to the firm attachment of the periosteum to the bone, lifting the periosteum by the infectious process is less pronounced. Sinus tracts, however, are more common in adults than in infants and children. Penetration of the infection through the periosteum can lead to abscess formation in the adjacent soft tissues. As cortical osteolysis progresses, a biomechanical stress riser puts patients (especially adult patients) at increased risk for pathologic fracture.[100]

Radiography. Radiography is well-suited for revealing several findings of osteomyelitis, such as permeative osteolysis, periosteal reaction, and sequestra.[1, 49, 100, 107, 116] The earliest radiographic signs may be subtle and consist of soft tissue swelling related to inflammatory and vascular changes. A few days later, regional hyperemia results in bone resorption. Frank osteomyelitis leads to further osteolysis and cortical erosion. With extension of infection through the cortex into the subperiosteal space, periostitis and involucrum formation may result. Even at that time, however, the degree of bone destruction seen with radiography usually is less than that found on pathologic examination. Bone mineral loss of approximately 30% to 50% is required for positive radiographic findings. Consequently, radiographic evidence of bone destruction by osteomyelitis may not appear for approximately 2 weeks after the onset of a hematogenous bacterial infection.[100]

The radiographic appearance of acute osteomyelitis, which classically exhibits a permeative pattern, is not specific. The features can resemble those associated with infiltrative round cell lesions of the bone and other malignant bone tumors. The osseous changes associated with osteomyelitis also occasionally simulate findings of healing fractures or neuropathic osteoarthropathy. Given these limitations, it is not surprising that the sensitivity and specificity of radiography in the diagnosis of osteomyelitis is 43% to 75% and 75% to 83%, respectively.[67, 71, 129]

Spread from a Contiguous Source of Infection

Although the most common means of acquiring osteomyelitis in skeletally immature patients is hematogenous, osteomyelitis in the appendicular skeleton of adults occurs more commonly by either spread of pathogens from a contiguous source of infection or direct implantation.

The direction of contamination for osteomyelitis resulting from a contiguous contaminated source is from the soft tissues inward into the bone (Fig. 3). This is the reverse of hematogenous osteomyelitis, whereby the infection starts in the medullary bone and progresses outward to involve the surrounding structures. Thus, the pathogenic sequence of events is (1) soft tissue infection (e.g., cellulitis); (2) infectious invasion of the periosteum and disruption of the cortex; and (3) dissemination of the pathogen via haversian and Volkmann's canals to the bone marrow.

The most common sites of this type of osteomyelitis are in the foot and hand. Particular problems associated with the diagnosis of osteomyelitis in the diabetic foot are discussed later in detail. Other common sites affected by this mechanism of infection include the skull, maxilla, and mandible; these osseous infections usually are related to sinus disease and poor dental hygiene, and are of limited interest to orthopedists.

Radiography. Radiography commonly reveals soft tissue swelling, a nonspecific finding. The initial radiographic manifestation specific for osteomyelitis occurs as a pathogen extends to involve the periosteum. Contamination of the subperiosteal space causes the periosteum to be lifted from the underlying bone (most dramatically in children) and periosteal new bone formation occurs. With progression in the infectious process, cortical disruption and medullary involvement ensue.

Although the sequence of events resulting in osteomyelitis from a contiguous source of infection is predictable, the early radiographic findings often are not specific. Periostitis may

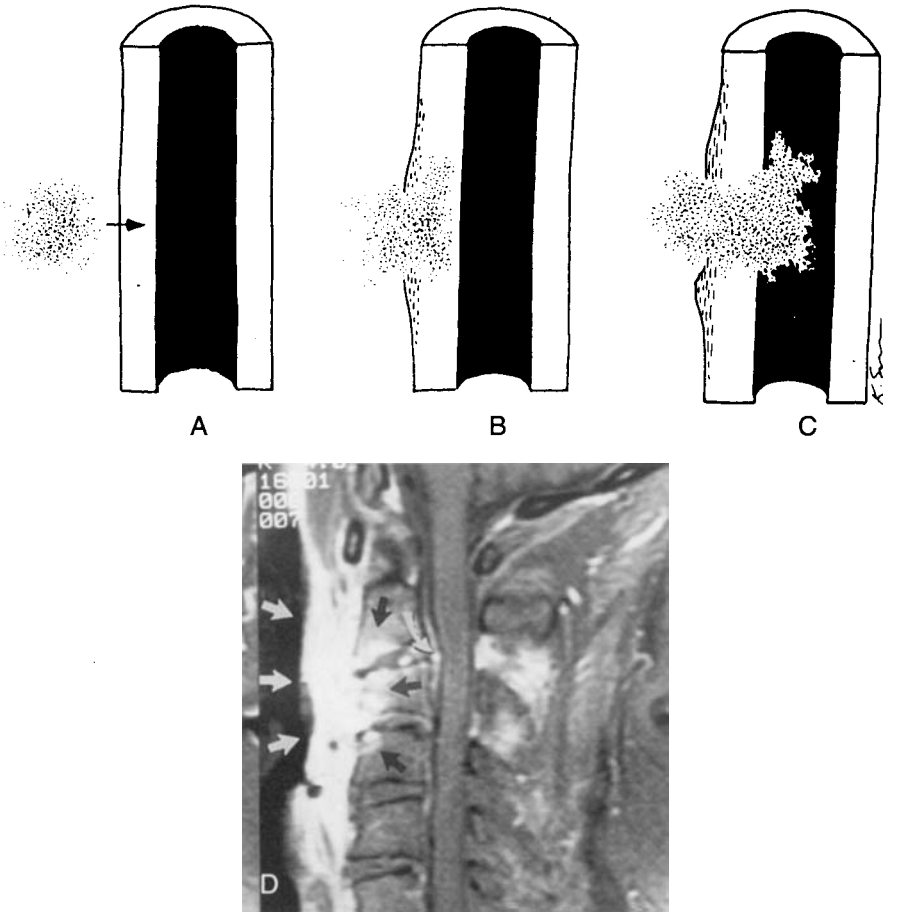

Figure 3. Osteomyelitis resulting from spread from a contiguous source of infection. A diagrammatic representation of the sequential steps of osteomyelitis. *A,* An infection of the soft tissues is present. Occasionally, such a soft tissue infection can irritate the underlying bone, producing periostitis without invasion of the cortex. *B,* The infection subsequently breaches the periosteum and invades the cortex, spreading via haversian and Volkmann's canals. *C,* Lastly, the medullary bone and marrow spaces may become infected. *D,* Vertebral osteomyelitis and discitis in the cervical spine of an orthopaedics patient. A sagittal T1-weighted (700/11) MR image using fat-saturation was performed after intravenous administration of gadolinium-containing contrast material. It reveals extensive contrast-enhancement the prevertebral soft-tissues (*white arrows*), discs, vertebrae (*black arrows*), and interspinous ligaments. Although there is mass effect on the spinal cord (*curved arrow*), the cord otherwise is not involved. (*A* to *C Adapted from* Resnick D: Diagnosis of Bone and Joint Disorders, 3rd ed. Philadelphia, WB Saunders, p 2345; with permission.)

occur merely in the presence of an adjacent soft tissue infection. Periosteal new bone also commonly occurs after traumatic initiation of a soft tissue infection. Even when intracortical tunneling and intramedullary radiolucency are observed, one must keep in mind that a similar aggressive appearance may be created by disuse osteoporosis, transient regional osteoporosis, or reflex sympathetic dystrophy.

Direct Implantation of Infection

Most infections caused by direct implantation of bacteria into bones are caused by deep puncture wounds and tend to occur in the hands and feet (Fig. 4). Animal bites are another cause of infections affecting the musculoskeletal system. Although cats account for approximately 10% of animal bites and dogs for about 90%, significant infections result from

Figure 4. Direct implantation of infection. Following a puncture wound from a needle, osteomyelitis and septic arthritis occurred. Radiograph demonstrates joint space narrowing (*arrows*) and osseous destruction involving the metatarsal head and proximal phalynx (*open arrows*).

20% to 50% of cat bites versus only 5% of dog bites. It is interesting that dog bites are less likely to result in infection despite the fact that sentry dogs bite with a pressure of 450 psi, which is enough to perforate sheet metal.[79] Most human bite injuries are related to fist fights, with the metacarpophalangeal joints representing the most common region of osteomyelitis and secondary joint infection.

Osteomyelitis occurring as a result of direct implantation of pathogens during open fractures and instrumentation is not uncommon, with approximately 2% of all orthopedic procedures complicated by infection.[52] Perhaps most troublesome of all infections, both in terms of radiologic diagnosis and orthopedic treatment, are infections that occur in the presence of orthopedic hardware placed for fracture fixation, arthroplasty, or spine stabilization. Regardless of the exact etiology, radiographs can document that violation of the periosteum and cortex occurs prior to or contemporaneous with medullary infection.

SUBACUTE AND CHRONIC OSTEOMYELITIS

Brodie's Abscess

Bone abscesses that occur during the subacute or chronic stage of hematogenous osteomyelitis commonly are known as *Brodie's abscesses.* These pyogenic lesions classically appear in the metaphyses of long bones in children, with the tibia being the single most common site. Patients may present in the subacute or chronic stage of infection because the particular strain of microorganism (usually *Staphylococcus*) exhibits diminished virulence.

Radiography. Radiography characteristically displays a Brodie's abscess as an elongated lucent lesion of 1 to 4 cm surrounded by eburnation (Fig. 5). The radiolucent cavity is lined by granulation tissue, and sometimes contains a nidus or a small volume of purulent fluid.

Micro-organisms may or may not be cultured successfully. Although Brodie's abscesses usually insult the metaphyses of long bones, they also may offend the carpus, tarsus, and diaphyses of long bones. Such abscesses may be central, subcortical, or cortical. When intracortical, a Brodie's abscess (a lucent lesion with surrounding sclerosis and periostitis) occasionally may appear similar to an osteoid osteoma or even a stress fracture.

Chronic Osteomyelitis: Active versus Inactive

Chronic osteomyelitis may be defined by the presence of a bone infection lasting for more than 6 weeks. It is most often a complication of open fracture, but also may be associated with vascular insufficiency; inadequate or inappropriate treatment; or compromised immunity (e.g., AIDS, chemotherapy).

Chronic osteomyelitis may be classified as either active or inactive. Both phases of infection may show bone destruction and sclerosis by radiography. The most specific sign of active infection with radiographic or tomographic techniques is the presence of a sequestrum because sequestra commonly harbor viable pathogens (Fig. 6). Other signs of active chronic osteomyelitis include soft tissue swelling, periostitis that is fluffy or fine, and osteolysis that is progressive or poorly defined.[116]

Healing of osteomyelitis is characterized by thickening of the cortex and resolving osteolysis. The marrow cavity is replaced progressively by granulation tissue, fibrous tissue, and cellular or fatty marrow. The deposition of fat into the bone marrow, displayed as high T1-signal intensity on MR images, is a useful sign of bone healing.[46]

Recognition and treatment of chronic musculoskeletal is important because squamous

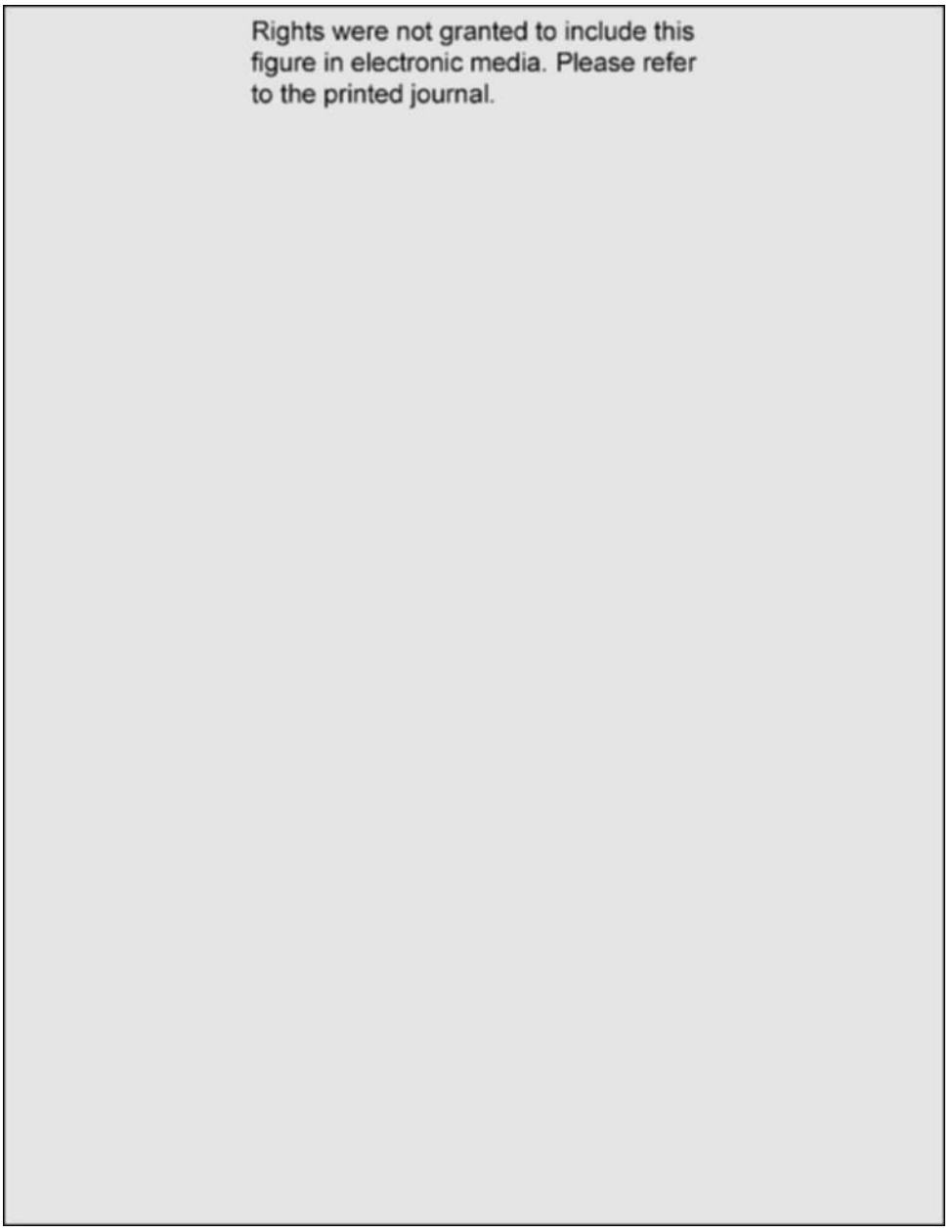

Figure 5. Brodie's abscess. (*A, C, D, Courtesy of* S. Harms, MD, and G. Greenway, MD, Dallas, Texas; *B, From* Harms SE, et al, Radiology 173:743, 1989, with permission.)

cell carcinomas may develop in 0.5% of patients with longstanding, draining infection.[74] In a recent investigation[85] of 39 patients with chronic osteomyelitis complicated by squamous cell carinoma, the malignancy affected the sinus tract, without bone involvement, in 12 patients. After surgical treatment with amputation in 35 patients and limb salvage in 4 patients, the 5-year survival rate was 69%.

ADVANCED IMAGING OF SUSPECTED OSTEOMYELITIS

Conventional radiography remains the initial imaging test of choice for suspected osteomyelitis. Radiography is readily available, relatively inexpensive in screening and follow-up of patients, and often helpful in correctly interpreting advanced imaging studies. Unfor-

Figure 6. Sequestrum. Conventional tomography demonstrates focal area of sclerosis in the tibia (*arrow*) which represented a necrotic, infected fragment (surgically confirmed).

tunately, as a projectional (rather than a cross-sectional) imaging technique, radiography is insensitive to the detection of early osteomyelitis. Bone destruction and periostitis may not be detected for approximately 2 weeks after the initiation of a pyogenic infection. Furthermore, differentiation among edema, cellulitis, and abscess formation is not possible with radiography. These shortcomings have driven the application of other, advanced imaging techniques.

In addition to radiography, imaging methods available for the detection of infectious diseases in the musculoskeletal system include sonography, computed tomography (CT) scan, radionuclide techniques, and MR imaging. Each of these techniques has pros and cons, and can be considered complementary in many situations.

Sonography

Sonography is most useful in diagnosing the presence of fluid collections in a joint (e.g., pyarthrosis) or the extra-articular soft tissues (e.g., abscess). Sonography also facilitates precise localization for diagnostic aspiration and therapeutic drainage of fluid collections. Although abnormalities, such as periostitis, that occur at the surface of an infected bone may be visualized by sonography, this technique is not useful for evaluating intraosseous abnormalities.

Computed Tomography

CT is an imaging method with relatively high spatial resolution that provides exceptional detail of cortical bone in a cross-sectional display. CT may be helpful in the evaluation of musculoskeletal infections, and generally is the best method for the detection of small areas of osteolysis in cortical bone, small foci of gas, and minute foreign bodies that may be associated with infections (Fig. 7).[4, 49, 78, 82, 108, 126]

CT also may help to delineate abnormalities that may be specific for osteomyelitis or must be addressed at surgery. These characteristic findings include sequestra (a segment of necrotic bone that is separated from living bone by granulation tissue); involucra (a layer of living bone that has formed about the sequestrum); and cloacae (an opening in the involucrum through which the sequestrum and granulation tissue may be discharged). Sequestra can be delineated exquisitely by CT, appearing as fragments of dense bone often surrounded by soft tissue or fluid density. Unlike radiography, CT can detect increased intraosseous density that is a sign of infection, reflecting the accumulation of pus replacing fat in the marrow space. Abnormally increased density within medullary bone is a nonspecific finding, but may be quantified quickly and reproducibly by CT in Hounsfield units. In this measurement system, water density is assigned a value of zero. Gas and fat have known Hounsfield unit numbers less than zero, whereas progressively higher (positive) Hounsfield unit numbers are assigned to fluid, soft tissue, cortical bone, and metal.

Iodinated contrast material usually is administered intravenously to help delineate abnormalities, such as cloacae, abscesses, and necrotic tissue (which do not show enhancement) from the surrounding, often hyperemic soft tissues. Contrast material used during CT, however, is not completely without risk. These risks include the potential for nephrotoxicity and anaphylactoid reaction; the latter complication is a fatal one for approximately 1 in every 40,000 patients receiving iodinated contrast material intravenously.[93] Other, modest disadvantages of CT include the exposure to ionizing radiation and the examination's cost. CT also is limited in assessment of body parts with metallic implants because of beam-hardening artifact.

Scintigraphy

An extensive overview of scintigraphic techniques relevant to orthopedics is provided by

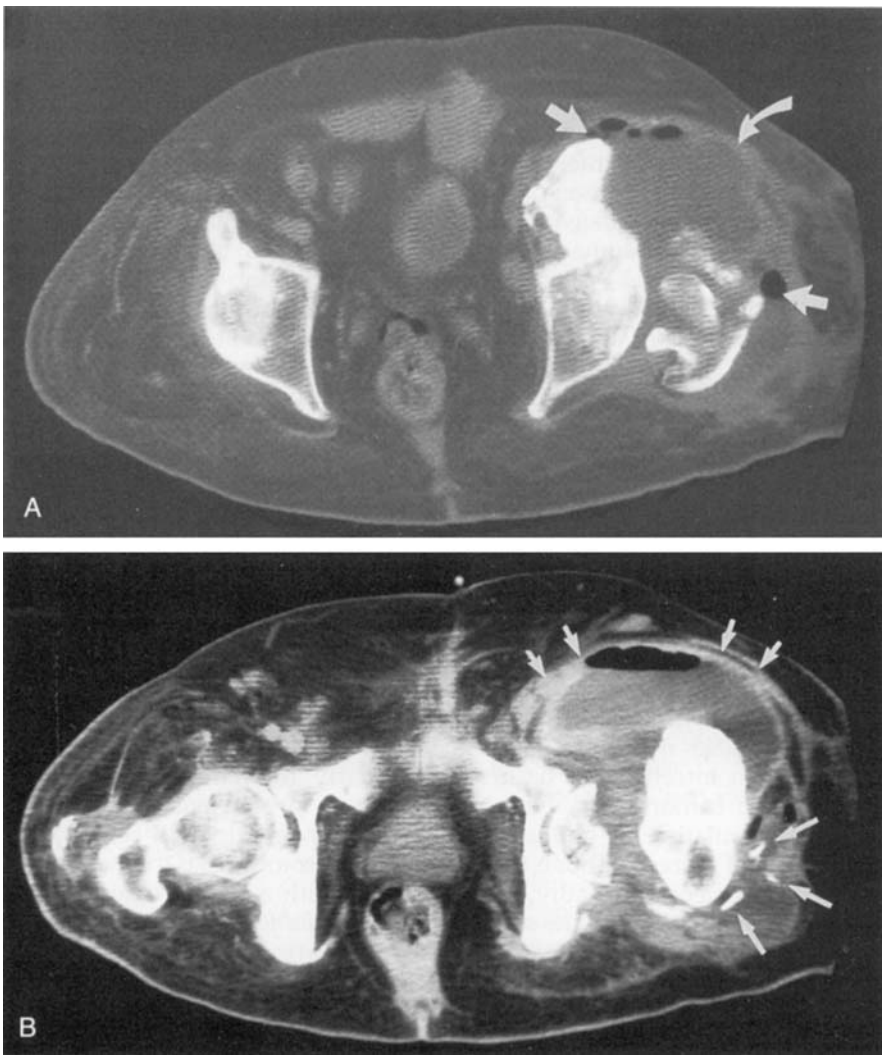

Figure 7. Femoral head osteomyelitis with abscess adjacent to the hip in a paraplegic man with a decubitus ulceration. *A*, Axial CT filmed with "bone windows" shows large fluid collection adjacent the hip (*curved arrow*) with multiple air-fluid levels (*arrows*). There is abundant heterotopic ossification anteriorly and ossific fragmentation laterally. *B*, Axial CT filmed with soft-tissue windows shows rim enhancement at the periphery of the abscess (*short arrows*). The small, dense fragments in the lateral soft tissues represent sequestra (*longer arrows*).

Donohoe elsewhere in this issue. The three most commonly used nuclear medicine tests on orthopedic patients use the radioactive forms of technetium, gallium, and indium. All of these well-established techniques are considered highly sensitive to the presence of an acute osseous infection, but can be relatively nonspecific for evaluating the precise nature or extent of an infection.

With technetium-99m methylene diphosphonate (MDP) scintigraphy, signs of osteomyelitis can be detected approximately 24 to 48 hours after the clinical onset of the infection.[49] When cellulitis is present without osteomyelitis, increased activity is found in the inflamed area during the early (angiographic and blood pool) phases of a three-phase bone scan, but there is relatively normal bone activity on the delayed images. Osteomyelitis is characterized by focal accumulation of the radioactive tracer during all three portions of a three-phase bone scan.

The sensitivity and specificity of technetium-99m MDP bone scans vary in different

study groups, ranging from 69% to 100% and 38% to 82%, respectively. If radiographs are normal and osteomyelitis is the only diagnosis being considered seriously, then the three-phase bone scan often is an excellent diagnostic test. Increased accumulation of tracer, however, can be seen with other conditions, such as bone tumors and neuropathic osteoarthropathy, as well as following trauma or surgery.

Furthermore, although bone scanning provides physiologic information about blood perfusion and osteoblastic activity, the spatial resolution is relatively poor. Surgical lesions, such as abscesses and sequestra, are not visualized by technetium-99m MDP bone scan.

Additional testing with other radiopharmaceuticals (gallium-67 or indium-111–labeled leukocytes) is often used to compensate for the limited specificity of three-phase technetium-99m bone scans. Gallium-67 scans often are combined with technetium-99m scans and are considered positive for infection if the gallium uptake is greater than the technetium uptake in the suspected region.[1, 109] Gallium-67, however, not only accumulates in infected bone, but also may collect in infected soft tissues, hematomas, and some tumors (e.g., lymphoma). Increased accumulation of gallium-67 also is found in areas of increased bone turnover (e.g., neuropathic osteoarthropathy, fracture, postsurgical change), reducing the specificity of this study for infection. Furthermore, this test must be used with caution in patients treated with antibiotics, because a false-negative result may occur in this setting.[86] Overall, the combination of gallium-67 and technetium-99m MDP has been reported to have a sensitivity and specificity of 69% to 70% and 83% to 93%, respectively, for the detection of osteomyelitis.[109, 122]

Scintigraphy performed using leukocytes labeled with radioactive indium-111 (or technetium-99m hexamethyl propyleneamine oxime) is positive at an earlier stage of acute osteomyelitis than technetium-99m MDP scintigraphy. In the postoperative patient, indium-111–labeled leukocyte scans generally are more helpful than MR imaging in the diagnosis of acute musculoskeletal infections.[12, 87] Several caveats, however, must be mentioned. First, indium-111 leukocyte scans may be unreliable in differentiating between septic and aseptic loosening of a painful arthroplasty.[105] Although controversial,[7] many investigators believe that routine aspiration of joint arthroplasties before revision is most valuable in the diagnosis of infection.[23, 70] Second, because the indium-111 scan uses polymorphonuclear leukocytes (not lymphocytes), it has a reduced sensitivity in detecting chronic osteomyelitis.[103, 104] Third, given the poor spatial resolution of indium-111 scintigraphy, differentiation among soft tissue infections, septic arthritis, synovial inflammatory disorders, and bone infection may be difficult.[61, 84] Finally, to achieve a confident diagnosis, technetium-99m bone scanning often must be combined with either gallium-67 or indium-111 scanning. The completion of two scintigraphic tests takes a minimum of approximately 3 days and commonly is more expensive than MR imaging.

MR Imaging

Fundamentals of Image Acquisition. The process of forming MR images is complex, but can be simplified as follows. From our knowledge of basic physics, we recall that movement of electrical charges (e.g., current flowing in a wire) generates a surrounding magnetic field. Similarly, the natural spin of each (positively charged) proton within our bodies creates a minute magnetic field (Fig. 8). The magnetic axis of protons, like the needle of a compass, aligns with a strong external magnetic field. The magnetic field strength of most MR scanners is between 0.5 to 1.5 T, or approximately 10,000 to 30,000 times the strength of the Earth's magnetic field.

In order for images to be produced, a radio-antenna coil is placed next to the part of the body being examined and a pulse of radiowaves is transmitted to the patient. The patient's protons absorb energy from the radiofrequency pulse, which changes the protons' alignment in the magnetic field. As the charged protons wobble back into alignment with the main magnetic field, they generate an electrical voltage (termed *MR imaging signal*) that is detected by the radio-antenna coil.

The MR imaging signal intensity (or brightness) for each tissue on an MR image depends on the intrinsic characteristics of that tissue (e.g., water content) and on the sequence of the radiofrequency pulses applied to tissue. The two most important parameters in determining the character of the MR images are (1) the repetition time (TR), the time that elapses between applying sequential radiofrequency pulses to the patient, and (2) the echo time (TE), the time that elapses between apply-

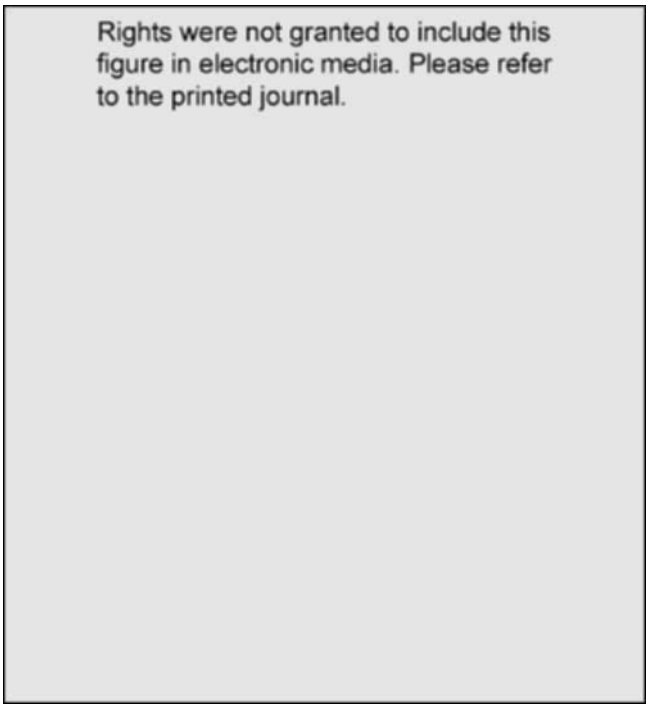

Figure 8. Summary of steps involved in the formation of an MR image, starting with the patient entering the magnetic field. (*Adapted from* Edelman's Clinical MRI, 2nd ed, p. 4, with permission.)

ing a radiofrequency pulse and measuring the MR signal that returns to the radio-antenna coil. These values typically are recorded on each MR image (and are shown parenthetically in the figure legends throughout this article).

When TR and TE are relatively short, T1-weighted images are produced. T1-weighted images exhibit fat as high-signal intensity, whereas muscle and water are of intermediate-signal intensity. T1-weighted images provide the best ratio of signal intensity to noise, and thus the best anatomic display.

When TR and TE are relatively long, T2-weighted images result. T2-weighted images display tissues with a high water content as high-signal intensity, relative to fat and muscle. A third commonly used pulse sequence, short tau inversion recovery (STIR), suppresses the bright signal from fat (e.g., in subcutaneous tissues and bone marrow). By suppressing the signal from fat, the conspicuity of lesions with relatively high water content (e.g., edema, tumor) increases.[38, 63, 117] The STIR pulse sequence is considered highly sensitive for abnormalities, with a negative predictive value for acute osteomyelitis approaching 100%. STIR images, however, generally have a lower spatial resolution than the conventional T1- and T2-weighted images[102] may overestimate the extent of infection,[63] and cannot be used to differentiate fluid collections (e.g., abscesses) from circumscribed soft tissue edema.[38]

Indications and Contraindications. In infants and children, MR imaging may be used in an effort to achieve a diagnosis before destructive changes are identified by radiography. Because the epiphyses remain incompletely ossified, evaluation of early physeal and epiphyseal infection is impossible with routine radiography, and MR imaging is the most appropriate tool to exclude involvement of the cartilaginous epiphyses. In a prospective study of 43 children with clinically suspected osteomyelitis, MR imaging was superior both in sensitivity (97%) and in specificity (92%) to technetium-99m MDP bone scintigraphy for the detection of osteomyelitis.[83] As with scintigraphy, however, the MR imaging appearance of hematogenous osteomyelitis may be nonspecific because other lesions (e.g., infiltrating neoplasms, stress fractures) may have a

similar appearance.[5,59] Placing the MR imaging findings in clinical context clearly is helpful for establishing the correct diagnosis.

Of course, MR imaging is not necessary in all cases. MR imaging generally should be limited to patients with inconclusive findings, patients with infections of the pelvis and spine, or those who may undergo surgical debridement and drainage.[50,83]

In adult patients, MR imaging also may aid in the preoperative evaluation to determine the presence and extent of active disease, even when radiographs remain negative (Fig. 9). In particular, this technique indicates whether inflammation is limited to bones, or joints, or to soft tissues, or whether several of these structures are affected. The full extent of infection and surrounding edema is displayed, facilitating preoperative planning of the maximal degree of debridement or the level of amputation. In the setting of spinal infections, the use of MR imaging in diagnosis and preoperative planning is well established (Fig. 10).[20]

Despite all of the attributes of MR imaging, however, it has several limitations. The use of MR imaging for following the infection's therapeutic response to treatment is limited and remains to be defined. In addition, several contraindications to high-field MR imaging continue to preclude its use in many patients including those who have cardiac pacemakers; intraocular metallic foreign bodies; and ferromagnetic implants, such as aneurysm clips. A small but significant number of patients also are unable to undergo MR imaging because of claustrophobia, obesity, or bulky traction devices. Recent placement of orthopedic instrumentation is a relative contraindication as well. Although instrumentation causes local artifacts by producing inhomogeneity in the magnetic field, these problems are minimized by the use of new orthopedic hardware (e.g., titanium spinal instrumentation) and new MR imaging techniques (e.g., fast spin echo imaging).

Sensitivity and Specificity. The sensitivity of MR imaging for the diagnosis of osteomyelitis generally has been reported between 82% and 100%. MR imaging is sensitive for the early detection of osteomyelitis, owing to the contrast it typically provides between the abnormal and normal bone marrow.[11,12,38,64,80,89,114,117]

Normal adult (fatty-replaced or yellow) bone marrow has high-signal intensity on T1-weighted images and intermediate-signal intensity on T2-weighted sequences (Table 1). Red (hematopoietic) marrow has low signal intensity on T1-weighted images and intermediate-signal intensity on T2-weighted images. With osteomyelitis, bone marrow is replaced

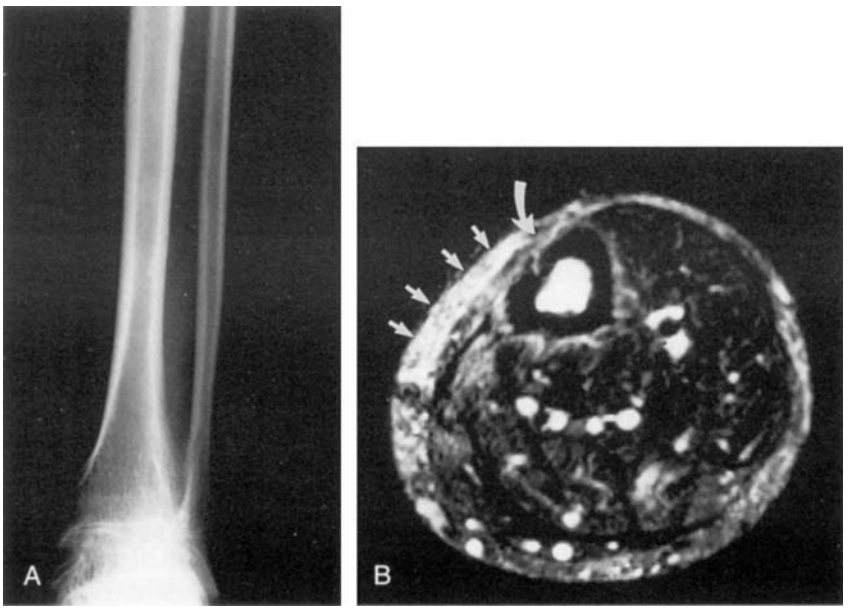

Figure 9. MR imaging diagnosis of osteomyelitis in the setting of negative radiographs. *A*, Frontal view of the tibia and fibula is negative for osteomyelitis. *B*, Axial STIR MR image reveals high (fluid) signal intensity in the bone marrow of the tibia, in a cloaca penetrating the cortex (*curved arrow*), and in the subcutaneous fat (*arrows*).

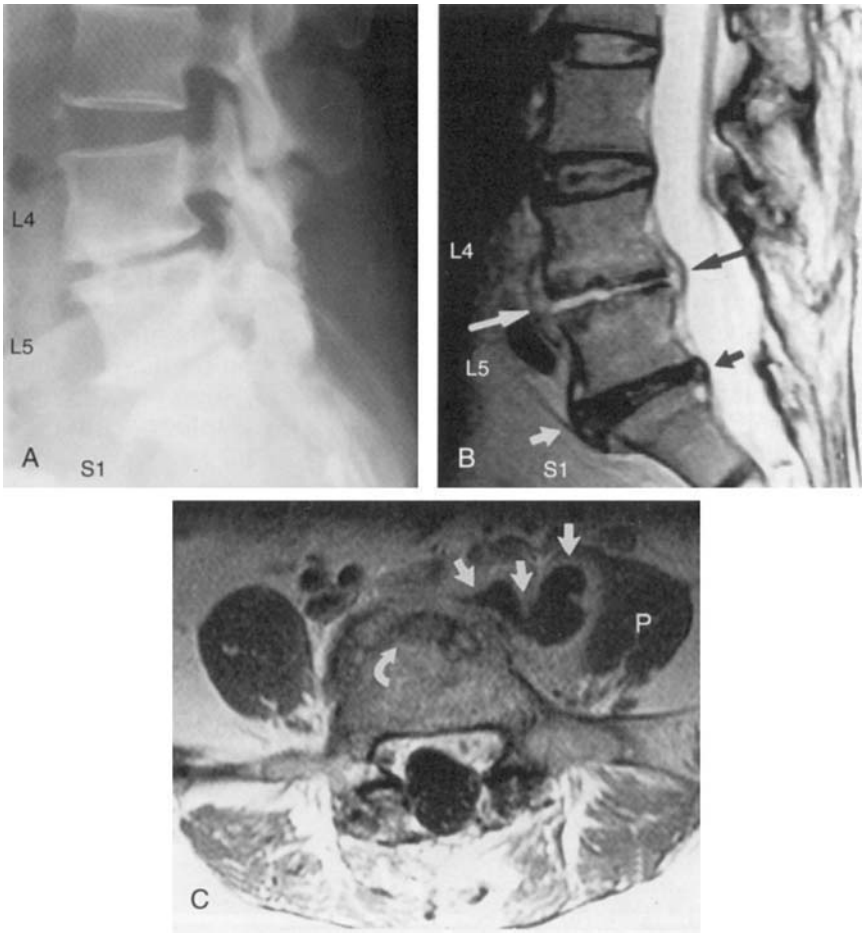

Figure 10. MR imaging diagnosis of discitis and abscess in a post-operative patient. *A,* Lateral radiograph shows disc space narrowing at L4-5 and L5-S1, as well as laminectomy changes at L4 and L5. *B,* Sagittal T2-weighted (3500/90) MR image shows a narrowed hyperintense L4-5 disc space, with displacement of the anterior and posterior longitudinal ligaments (*large arrows*) owing to discitis. By comparison, the hypointense L5-S1 disc is dessicated, with bulging both anteriorly and posteriorly (*small arrows*). *C,* After the administration of gadolinium, and axial T1-weighted (735/14) MR image was performed; it demonstrates erosion of the anterior vertebral body (*curved arrow*), a paravertebral fluid collection with an enhancing rim (*arrows*), and lateral displacement of the psoas muscle (P).

Table 1. RELATIVE MR SIGNAL INTENSITY OF TISSUES

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Adapted from Resnick's Bone and Joint Imaging, 2nd ed, 1996, p 84, with permission.

by fluid and inflammatory cells. Consequently, infected areas are displayed as regions of reduced signal intensity on T1-weighted sequences and as increased signal intensity on T2-weighted and STIR sequences (Fig. 11).[11, 32, 38, 64, 80, 114, 117, 129] Anatomic abnormalities occurring in the setting of acute and chronic osteomyelitis include erosions and perforations of the cortex, periosteal bone formation, and soft tissue edema.

Despite high sensitivity, MR imaging lacks specificity in the diagnosis of osteomyelitis. Specificity of MR imaging for osteomyelitis has been reported to range between 53% and 94%.[21, 88, 89] Many disorders of the musculoskeletal system can produce similar abnormalities in signal intensity. These conditions include tumors, fractures, surgical alterations, bone infarction, metabolic disorders, and sterile intraosseous fluid collections.[27, 33, 38, 53, 91, 114] To further complicate matters, sympathetic edema may be seen in bone marrow adjacent to areas of active soft tissue inflammation. Because both edema and purulent material are displayed as regions of high T2-signal intensity, sympathetic edema in the bone marrow may be indistinguishable from osteomyelitis. The more profound the T2-signal intensity in the bone marrow, however, the more likely the abnormality is osteomyelitis.[26]

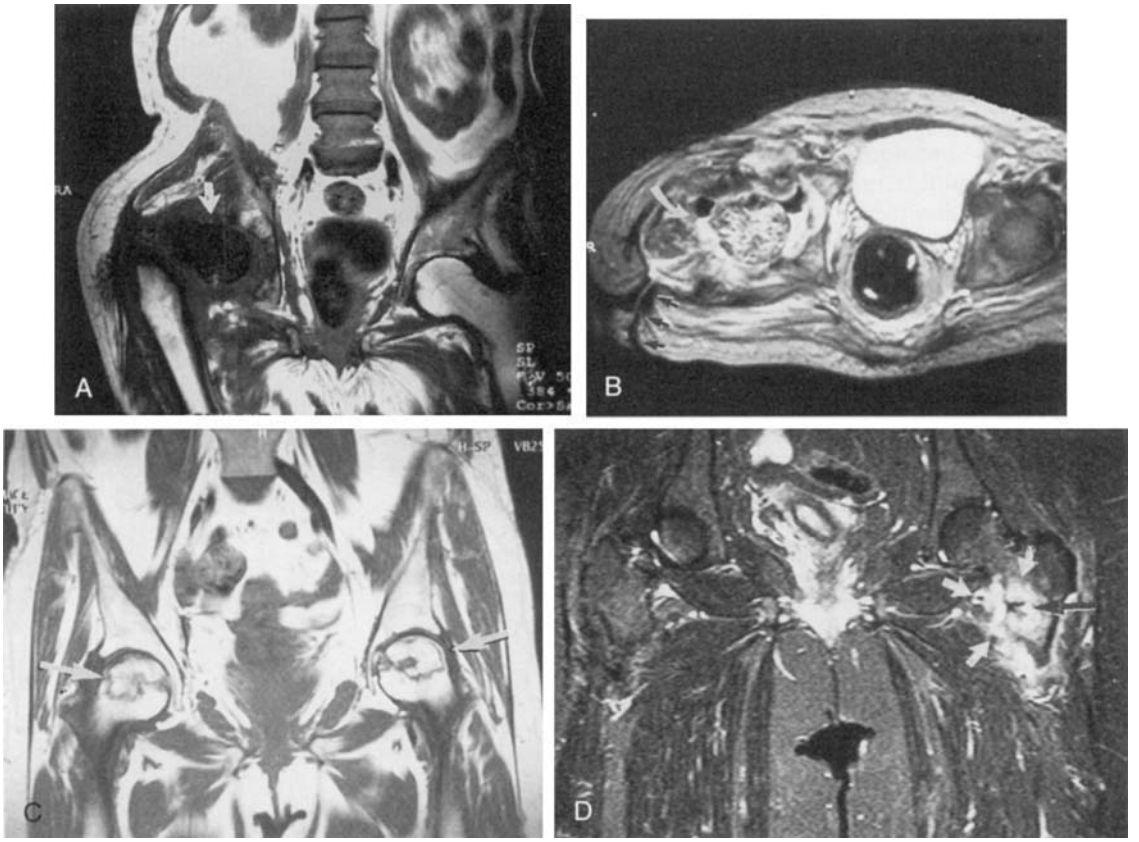

Figure 11. Femoral head osteomyelitis with septic hip in paraplegic man with a decubitus ulceration. *A*, Coronal T1-weighted (680/20) MR image demonstrates a pathologic fracture through the femoral neck with varus angulation. The necrotic femoral head is edematous, displaying low T1-weighted signal intensity (*arrow*). *B*, Axial T2-weighted (3500/80) fat-saturated MR image shows high T2–weighted signal intensity in the femoral head, air-fluid levels in the hip joint (*curved arrow*), and a cloaca extending to the skin ulceration (*arrows*). For comparison, two other common causes of signal intensity abnormalities in the bone marrow of the proximal femur are shown. *C*, Osteonecrosis in a patient with a history of hip pain and corticosteroid use. Coronal T1-weighted (680/20) MR image demonstrates a geographic area in the femoral heads that is marginated by a serpentine line of low signal intensity (*arrows*). *D*, Fatigue fracture in a young athlete with hip pain. Coronal STIR MR image shows a linear area of low signal intensity fracture (*long arrow*), surrounded by high signal intensity edema in the bone marrow and soft tissues (*short arrows*). Note that the signal intensity of the marrow and subcutaneous fat is dark or "suppressed" with the STIR sequence, so areas with fluid are quite conspicuous.

Thus, it is the size, shape, and location of the signal intensity abnormalities (as well as the clinical context) that allow the presumptive diagnosis of osteomyelitis to be proffered (see Fig. 11). Unless typical features are present, such as the characteristic morphology of a fracture and infarct, differentiation among these processes with MR imaging alone may be difficult or impossible.[38] Secondary signs that support the diagnosis of osteomyelitis include cellulitis, a sinus tract, and cortical disruption. Cellulitis is considered the most sensitive, but most nonspecific, sign of osteomyelitis in the extremities of adults. Conversely, the presence of a sinus tract is an insensitive, but relatively specific, finding in favor of the diagnosis of osteomyelitis.

Gadolinium-containing Contrast Material. Gadolinium-containing contrast material commonly is injected intravenously during the course of an MR imaging examination. As with iodinated contrast material used for CT scanning, gadolinium-containing contrast agents distribute preferentially to areas of (infectious and noninfectious) inflammation. The dominant effect of the MR imaging contrast agent in these inflamed areas is to cause increased-signal intensity on T1-weighted images. Because fat also appears bright on T1-weighted sequences, images usually are acquired with a fat-saturation technique: this technique makes fat look relatively dark and allows inflamed, enhancing areas to be displayed conspicuously.

Gadolinium-enhanced MR imaging may be valuable in evaluating musculoskeletal infections in at least three ways.[32, 88, 89, 110] First, contrast material has been reported to be helpful in distinguishing abscesses from surrounding cellulitis.[58] Granulation tissue in the wall of an abscess often enhances avidly following the administration of a gadolinium contrast agent, whereas fluid in the abscess does not enhance.[32] Second, granulation tissue lining sinus tracts enhances, potentially making their presence more conspicuous. Finally, whereas vascularized granulation tissue surrounding a sequestrum enhances, sequestered bone does not. However, gadolinium contrast agents do not necessarily contribute to the distinction between osteomyelitis and bone marrow edema. Another primary drawback of gadolinium-containing contrast materials is that they increase the cost of the examination by approximately $100. The side-effect profile of these drugs is quite favorable, with severe reactions reported only rarely.

Subacute and Chronic Osteomyelitis. With MR imaging, Brodies' abscesses appear as rounded, well-circumscribed areas of low T1-signal intensity and high T2-signal intensity.[114] In subacute[114] and chronic[12] osteomyelitis, a peripheral area of fibrous tissue or reactive bone may be seen as a rim of low-signal intensity on all pulse sequences. The usual appearance of acute osteomyelitis (high T2-signal intensity in the bone marrow), however, may be absent in some cases of chronic osteomyelitis.

Differentiation between active and inactive chronic osteomyelitis may be problematic in individual cases.[28] The MR imaging features that suggest the presence of *active* chronic osteomyelitis include sequestra, cloacae, abscesses, and subperiosteal fluid collections. Sequestra characteristically appear as areas of low-signal intensity on all pulse sequences, and do not enhance following gadolinium-contrast administration.[32, 80, 82, 96, 110] Sinus tracts appear as linear or curvilinear areas of high-signal intensity on T2-weighted images, which involved both bone and soft tissue[80] and may exhibit contrast enhancement.[32]

Diagnostic difficulties also may arise in cases following surgical intervention, because both postoperative and postinfectious granulation tissue may show increased-signal intensity on T2-weighted images. Infection is suggested by high T2-signal intensity that becomes more extensive on serial MR imaging examinations or persists more than 9 months following surgical intervention.[80] Healed osteomyelitis is characterized by the return of fat to the marrow cavity, which is seen as increased marrow signal intensity on T1-weighted images.[46, 117] In the postoperative setting, leukocyte-labeled scintigraphic scans may be particularly beneficial.

INFECTION OF SOFT TISSUES

Cellulitis

Cellulitis is defined as diffuse inflammation of the connective tissues owing to infection. Streptococci, and less frequently staphylococci and other bacteria, are the offending pathogens.[100] Complications may occur by contiguous spread of infection to the adjacent bones and joints, leading to superimposed osteomyelitis, septic arthritis, and lymphadenitis (Fig. 12).[31, 35, 57] The clinical presentation of cellulitis can range from erysipelas to more serious necrotizing cellulitis or fasciitis with high fatality rates.[98, 131]

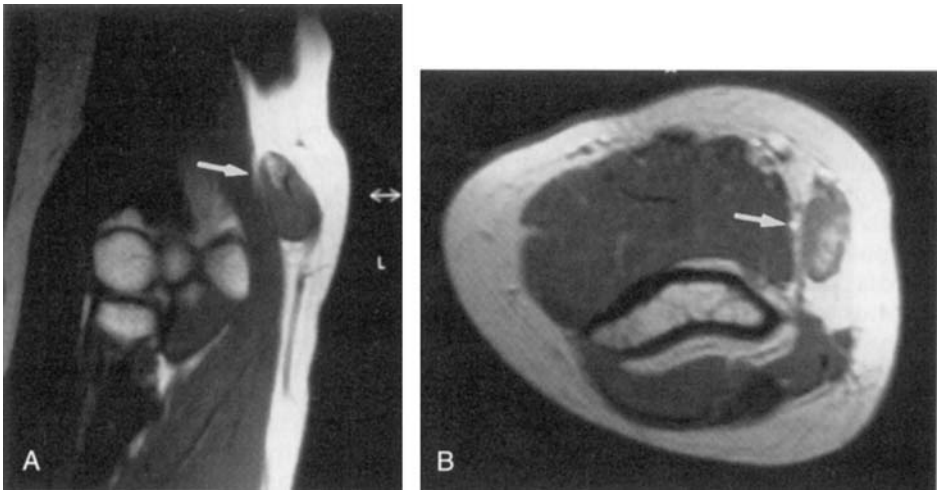

Figure 12. Cat scratch disease in a 24-year-old woman with cat exposure. *A*, Coronal T1-weighted (556/15) MR image shows a mass of predominantly intermediate signal intensity in the epitrochlear region of the elbow (*arrow*). *B*, Following administration of gadolinium-containing contrast material, an axial T1-weighted (420/15) MR image demonstrates heterogeneous contrast enhancement. Although generally not required for diagnosis, cross-sectional imaging typically reveals epitrochlear, axillary, or groin adenopathy in otherwise healthy patients with pet cats. The causative agent is the bacterium Rochalimaea henselae.

Soft tissue infections generally are apparent clinically, and a substantial imaging work-up usually is not necessary. Radiographs often are ordered to rule out osteomyelitis, but reveal only nonspecific findings of soft tissue edema. CT and MR imaging have proved helpful in the early detection of various soft tissue infections.[9, 10, 40, 43, 78, 98, 100, 111, 131] Major indications for CT or MR imaging involve the detection of soft tissue abscesses and early recognition of necrotizing fasciitis, indicating the need for surgical intervention.[98, 131] With MR imaging, abscesses appear as focal collections of fluid, whereas cellulitis is seen as diffuse areas of low-signal intensity on T1-weighted images and high-signal intensity on T2-weighted images in the soft tissues.[114, 117]

Septic Tenosynovitis

The synovial lining of tendon sheaths commonly become inflamed owing to rheumatologic diseases (especially rheumatoid arthritis) and infectious processes. Septic tenosynovitis usually is associated with an adjacent cellulitis or an episode of penetrating trauma.

Radiographic signs consist of soft tissue swelling and, occasionally, subjacent osteomyelitis. Although fluid collection in tendon sheaths, especially in diabetic feet, may be physiologic and, therefore, have no clinical relevance, contrast enhancement of the tendon sheath is indicative of inflammation. MR imaging can be helpful in revealing the extent of the soft tissue abnormality for therapeutic planning and prognostic purposes (Fig. 13).[62]

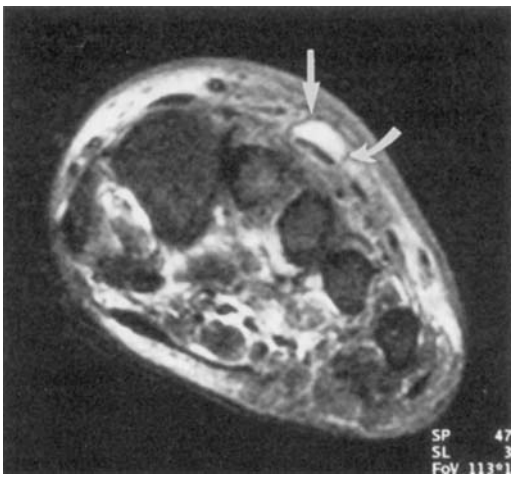

Figure 13. Septic tenosynovitis in a middle-aged woman with a painful, erythematous foot. Coronal STIR MR image demonstrates high signal intensity fluid (*arrow*) within the tendon sheath surrounding the low signal intensity extensor digitorum longus tendon (*curved arrow*). Although MR imaging cannot differentiate between sterile and infected fluid at this time, aspiration of this collection yielded 6 mL of purulent material containing Group B Streptococcus.

Septic Bursitis

Bursae are sacs of synovial tissue that mitigate friction between bones and tendons or between bones and skin. Although bursae normally facilitate the gliding of one musculoskeletal structure on another, they can become dysfunctional and painful when inflamed secondary to infection, trauma, rheumatoid arthritis, or other processes.[16]

Septic bursitis is responsible for up to one third of all bursitis cases seen by physicians. Approximately 90% of all septic bursitis affects the olecranon (70%) or prepatellar (20%) bursae.

In most cases, the infections occur by direct inoculation of pathogens into the superficially situated subcutaneous bursae through a break in the skin. Predisposing factors may include immunosuppression; substance abuse; diabetes; rheumatoid arthritis; and skin disorders, such as psoriasis. A variety of pathogens can cause septic bursitis, but *Staphylococcus aureus* is isolated in approximately 80% of all cases.[16]

Radiographically, soft tissue swelling and subcutaneous edema are observed around the infected bursae. Usually, septic arthritis is not a feature of infective bursitis involving subcutaneous bursae, but it may be present in infections of deep bursae that communicate with joints (e.g., the popliteal bursa). Reactive joint effusions may be found, however, in sterile joints adjacent to infected bursae. With MR imaging, bursitis appears as a fluid collection in the anatomic location of the involved bursa, with typical low T1-signal intensity and high T2-signal intensity. Unfortunately, differentiating septic from aseptic bursitis by means of imaging is not possible at this time.

Infectious Myositis

Pyogenic myositis affects mainly children and young adults following penetrating trauma, but also is found in intravenous drug abusers and immunocompromised hosts.[40] In drug abusers, capricious injection techniques can cause varying degrees of local muscle trauma, inflammation, infection, and even myonecrosis.[78] In AIDS patients, nonclostridial myonecrosis predominates over clostridial infections.

Inflammatory myopathies may be caused by common viruses (e.g., influenza, Coxsackie, herpes, and hepatitis) or parasites (Fig. 14). *S. aureus* is the most frequent organism responsible for pyogenic myositis.[100] In a large study of patients with pyomyositis, multiple lesions were found in 43% of patients.[24] Multifocality, however, is not a specific feature of pyomyositis, and also can be seen in polymyositis, lymphoma, Kaposi's sarcoma, and metastases.[125]

Figure 14. Cysticercosis in an 88-year-old man from Mexico with a recent history of seizures. Oblique radiograph of the hip reveals multiple calcified cysticerci in the adductor muscles of the thigh (*arrows*). The long axis of the calcified cysts lies in the plane of the surrounding muscle bundles. Although the tapeworm Taenia solium may be asymptomatic in the peripheral musculature, it is an important public health concern in many persons from developing countries because it often infects the brain.

Sonography and CT are used most often for the imaging evaluation of patients with myositis, but MR imaging also is useful.[34, 40] Characteristic MR imaging findings include muscle swelling and enlargement, sometimes with single or multiple intramuscular abscesses. Abnormalities usually are limited to the affected muscle, and surrounding soft tissue edema generally is less pronounced than in cellulitis, dermal infections, and Kaposi's sarcoma.[40, 111]

In the absence of abscess formation, diabetic muscle infarction and myopathies must be considered in the differential diagnosis.[118] Other differential diagnostic considerations include lymphoma, Kaposi's sarcoma, and polymyositis, especially in patients who are HIV positive.[40]

Necrotizing Fasciitis

Necrotizing fasciitis is a rare, fulminating gangrene involving the fascia. Risk factors in-

clude debilitating systemic conditions, such as diabetics, chronic renal failure, cancer, alcohol or drug abuse, and poor nutrition.[99] Fournier, [41] who originally described this condition in 1883, also reported other predisposing conditions: syphilis, priapism, and even excessive coitus!

Clinical diagnosis is made difficult by the nonspecific nature of symptoms until late in the disease process. Patients may present with an area of gangrenous skin that is far smaller than the widespread infection in the underlying fascial planes. Crepitus, secondary to subcutaneous gas, is observed in 50% of patients at presentation.[8] Although the gas-forming organism *Clostridium perfringens* is isolated in 10% of cases, other organisms, such as *Escherichia coli, Streptococcus,* and *Staphylococcus* usually are responsible. Multiple organisms are isolated in approximately 75% of cases.[47]

Because early diagnosis and extensive debridement are associated with improved prognosis, radiologic evaluation commonly is used. Radiography may show deep fascial gas on rare occasions.[51] CT is likely the single best imaging examination because it displays gas, asymmetric fascial thickening, and abscesses that commonly are present in critically ill patients.[128] MR imaging also has been used in the imaging evaluation[98, 131] but may be less useful than CT.[77]

SPECIFIC SITUATIONS

Musculoskeletal infections have been studied sedulously for centuries. Still, several specific situations deserve special attention here because they are especially topical or common: CRMO, musculoskeletal infections in HIV positive patients, and pedal infections in diabetic patients.

CRMO

CRMO is a chronic osteomyelitis of unknown cause that occurs often in multiple and symmetric locations.[13, 14, 45] CRMO typically affects children and young adults. Clinically, patients complain of local pain and swelling, and they occasionally experience a fever and weight loss. In as many as 40% of patients with CRMO, palmoplantar pustulosis is present. Given the association between osseous and certain dermatologic abnormalities, the acronym SAPHO (synovitis, acne, pustulosis, hyperostosis, and osteitis) has gained increasing acceptance in the literature.[17]

Histologic findings are those of inflammation, with specific features that vary depending on the acuity of the process. Laboratory analysis generally is unsuccessful in isolating a specific organism. Indeed, this disease may not be primarily an infectious process at all, but rather may represent an atypical seronegative osteoarthropathy.[17]

Although virtually any bone may be affected, this variety of osteomyelitis tends to have a predilection for the metaphyses of long bones in the lower extremity and the medial aspects of bones in the anterior chest wall.[30, 65] In particular, the most frequently affected bones are the tibia, femur, fibula, clavicle, and sternum. The clinical course of CRMO can be a protracted one, with the duration of symptomatic exacerbations and remissions often ranging from 2 to 7 years.[113]

With radiography and CT, the dominant feature is sclerosis, which commonly is seen in combination with osteolysis, periostitis, and expansion (Fig. 15). Occasionally, skeletal deformity may be seen as a sequelae of CRMO. Bone scintigraphy helps in staging CRMO by defining the distribution of the process. MR imaging has detected the presence of a dominant soft tissue mass preceding radiographically detectable bone lesions in a patient with CRMO.[113] In some cases, biopsy may become necessary to differentiate among osteomyelitis, sarcoma, lymphoma, and fibrous dysplasia.

Musculoskeletal Infections in HIV Positive Patients

In patients with HIV, a variety of common and opportunistic organisms may cause infections of bones, joints, muscles, subcutaneous tissues, and skin.[48, 75, 78, 97, 100, 101, 111, 127, 130]

One unusual, but particularly characteristic, form of osteomyelitis in HIV positive patients is bacillary angiomatosis. Bacillary angiomatosis is an infectious disease caused by a gram-negative rickettsia-like organism that frequently leads to osteolytic bone lesions (Fig. 16).[6, 54, 111, 127] With MR imaging, lobulated masses may be observed adjacent to bone; these masses are slightly hyperintense to muscle on T1-weighted images and exhibit high-signal intensity on T2-weighted images.[6]

Pyomyositis (bacterial myositis) frequently may be associated with HIV and can be unifo-

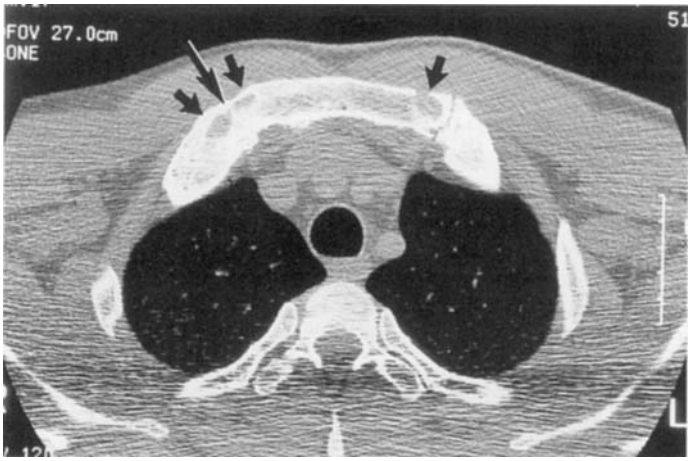

Figure 15. Chronic recurrent multifocal osteomyelitis in a young man with years of pain in the upper-anterior chest wall. CT scan of the chest shows ankylosis of the first rib and the sterum (*long arrow*), with multiple foci of osteolysis (*short arrows*). There also is increased sclerosis and expansion affecting the sterum and first ribs.

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Figure 16. Human immunodeficiency virus infection: Bacillary angiomatosis. This 34-year-old homosexual man had pain and swelling in the calf of 6 weeks duration. A poorly, defined osteolytic lesion of the fibula is evident. Cultures of the lesion revealed organisms similar to those causing cat-scratch disease. (*From* Conrad SE, et al: J Bone Joint Surg [AM] *73*:774, 1991.)

cal or multifocal.[40, 111, 127] When abscess formation is not present, diabetic muscle infarction and myopathies must be considered in the differential diagnosis.[118] Other differential considerations may include lymphoma, Kaposi's sarcoma, and polymyositis.[40]

Diabetic Foot Infections

Foot diseases take a huge toll on diabetic patients,[28] accounting for more hospital days than any other aspect of their disease.[36, 44] Fully 6% of the US diabetic population of 14 million undergoes amputation of a portion of their lower extremities.[66] Diabetic foot disease generally can be divided into four categories according to pathogenesis: (1) infectious; (2) neuropathic; (3) vascular; and (4) other miscellaneous maladies (e.g., spontaneous tendon ruptures[56]). The focus of this section is on pedal osteomyelitis in diabetic patients.[16a]

Owing to the presence of ischemia and diminished sensation in the feet of many diabetic patients, soft tissue ulcerations commonly form beneath weightbearing bony prominences.[28] Highly characteristic locations for ulcerations are in the plantar soft tissues beneath the metatarsal heads, the phalanges, and the calcaneus. These ulcers are the conduit by which infection is permitted to spread to adjacent soft tissues, joints, and bones. Not surprisingly, approximately 95% of diabetic patients with osteomyelitis in the foot have associated

ulcers.[5] Conversely, if an ulcer is not present, osteomyelitis is considered unlikely.

Nonhealing ulcers affect approximately 1.5 million diabetic patients in the United States.[69] Osteomyelitis develops in one third to two thirds[92, 112, 123] of patients with deep ulcers that do not respond to local care. Organisms responsible for osteomyelitis may be either aerobic (e.g., *E. coli*) or anaerobic (e.g., *Bacteroides*), and more than one species often are present.[3, 121]

Clinical diagnosis of osteomyelitis is notoriously difficult. On physical examination, fever is uncommon, and a foot ulceration need not expose the bone for osteomyelitis to be present.[5] Cellulitis is pervasive, but nonspecific, for osteomyelitis. On laboratory analysis, the erythrocyte sedimentation rate may be normal[112] and bacteremia is uncommon.[5] To confuse the diagnosis, further neuropathic joint disease may mimic, or be superimposed upon, osteomyelitis.

The radiologic evaluation of musculoskeletal infection is the subject of substantial controversy, but certain principles can be agreed upon. In all cases of suspected osteomyelitis, radiography should be the initial screening imaging examination of choice. When radiographs are positive for osteomyelitis, as manifest by cortical erosion and periosteal new bone adjacent to an ulceration and cellulitis, further imaging studies often are not needed. Radiographs, however, generally do not become positive in this setting for 10 to 20 days after the onset of symptoms.[18, 119] The evaluation of diabetic pedal osteomyelitis generally has a disappointing sensitivity of 43% to 75% and specificity of 69% to 83%.[67, 71, 94, 129] Furthermore, radiography is notoriously poor at detection and evaluation of septic arthritis[28] and abscess formation,[89] which may be associated with osteomyelitis.

CT can be a useful method to detect early osseous erosion, as well as to document the presence of a sequestrum, foreign body, subcutaneous gas, or occult fracture. CT, however, does not allow distinction between edema, suppuration, granulation tissue, and postoperative fibrosis. Although no large study has compared the accuracy of CT with MR imaging in the evaluation of pedal infection, one study subjectively found that MR imaging showed infection more clearly than CT in many patients.[12]

The three-phase bone scan is an excellent way to exclude osteomyelitis in uncomplicated situations because of its low false-negative rate. Unfortunately, it has a low specificity when applied to diabetic feet because of radiopharmaceutic accumulation in neuropathic bones. In an effort to increase the specificity of conventional bone scintigraphy, white blood cells (WBC) may be labeled with radioactive tracers, such as indium-111. Indium-111–WBC scans, however, are time consuming, have poor spatial resolution for distinguishing bone from soft tissue infection, and may be falsely positive in cases of fracture[68] or neuropathic osteoarthropathy. In one series, 31% of neuropathic feet were falsely positive for infection.[106]

A wide variety of satisfaction with nuclear medicine techniques has been reported. In a recent study comparing MR imaging versus indium-111–WBC scintigraphy, the authors concluded that MR imaging is superior to scintigraphy for the evaluation of infection in the foot, with a sensitivity and specificity of 89% and 86%, respectively, for MR imaging (versus 78% and 86%, respectively, for scintigraphy).[25] Using a combination of three-phase bone scanning and indium-11–WBC scintigraphy for the diagnosis of diabetic pedal osteomyelitis, the published sensitivities have ranged from 73% to 100% and the specificities have ranged from 55% to 91%.[61, 67, 71, 106] The accuracy of either scintigraphic technique, when used without the other is substantially lower. When both scintigraphic examinations are used in combination, however, the cost is higher than that of an MR imaging examination with intravenous contrast material.[89] Because contrast material is not necessary routinely,[60, 76] the cost of MR imaging often can be further reduced in price.

MR imaging is highly sensitive in determining the presence and extent of inflammation, two cardinal objectives in any preoperative evaluation. In particular, MR imaging can help delineate whether an infection is limited to bones, to joints, or to soft tissues, or whether several of these structures are affected. Such an evaluation allows planning of the degree of debridement or the level of amputation, so that the viability of adjacent tissues may be preserved. Based on MR imaging, one recent study demonstrated that there was no recurrent infection at the surgical margin in 100% of feet treated with limited resection.[89]

The diagnosis of osteomyelitis by MR imaging is made by detecting low T1 and high T2 (or STIR) signal intensity in the bone marrow, with enhancement after intravenous injection of contrast material (Fig. 17). Given that these signal intensity abnormalities are commonly seen in diabetic patients with neuropathic os-

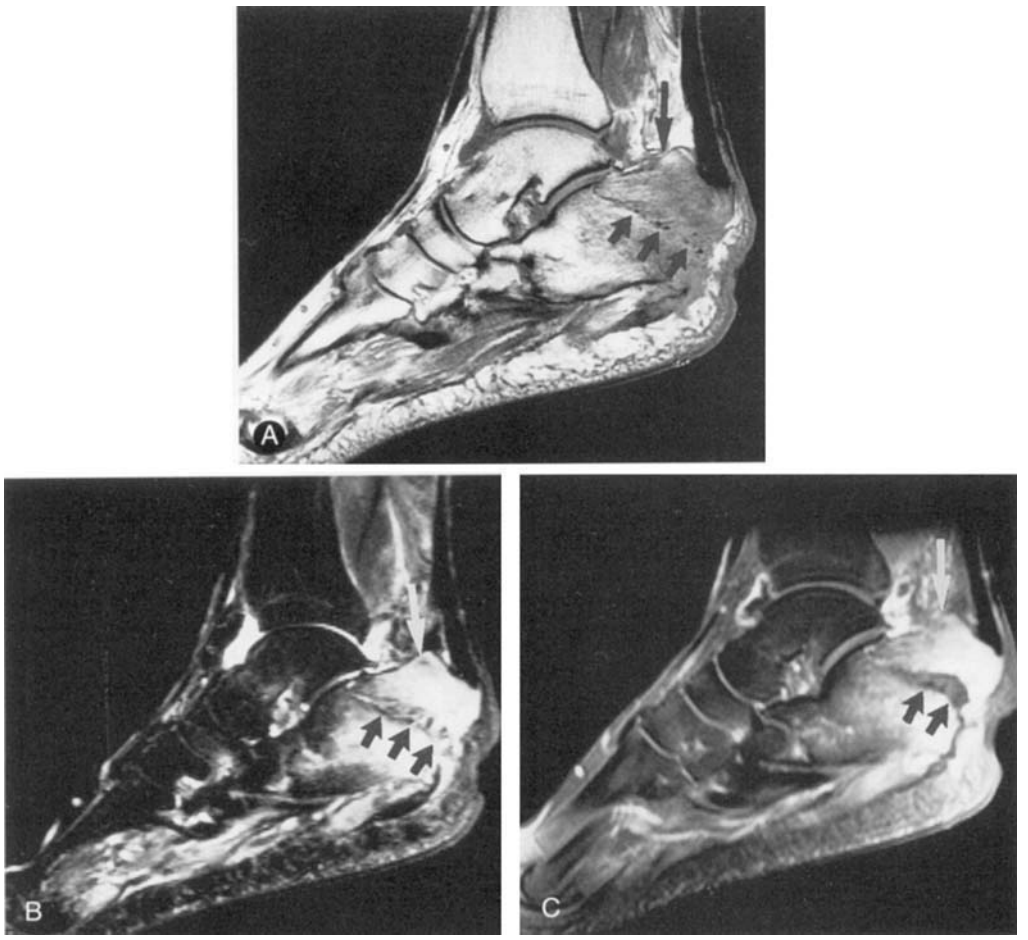

Figure 17. Osteomyelitis and pathologic fracture in the calcaneus of a diabetic patient. *A*, Sagittal T1-weighted (840/14), *B*, STIR, and *C*, fat-saturated contrast-enhanced T1-weighted (850/15) MR images of foot. These images reveal how T1 and high STIR signal intensity in the bone marrow, with enhancement after intravenous injection of contrast material (*long arrows*). The foci of very low signal intensity within the pathologic fracture plan represents gas (*short arrows*). An adjacent skin ulcer is present (*curved arrow*).

teoarthropathy, additional imaging findings must be looked for in this population that include extension of a sinus tract from the skin to bone, cortical interruption, rim-enhancing abscess within the marrow, and sequestrum formation. Although these latter criteria are indispensable, the diagnosis of osteomyelitis in the feet of diabetics has a reported sensitivity and specificity of 82% and 80%, respectively, compared with 89% and 94%, respectively, in nondiabetics.[20] Other authors have reported MR imaging sensitivities of 99% to 100% and specificities of 81% to 95% in the diagnosis of diabetic pedal osteomyelitis.[120, 122]

The total cost of diagnosis, surgical treatment, and hospitalization for amputation procedures performed on the feet of diabetics with osteomyelitis is slightly lower when contrast-enhanced MR imaging is the chosen preoperative imaging modality.[89] MR imaging provides accurate anatomic delineation of the extent of abnormalities within bones and soft tissues, thus helping the surgeon to plan the level of amputation (Fig. 18). Although MR imaging is commonly considered an expensive technique,[37] it may be the best and most cost-effective method of diagnosis for many patients.[72, 89]

CONCLUSION

Although radiography remains the mainstay of the imaging evaluation, other imaging

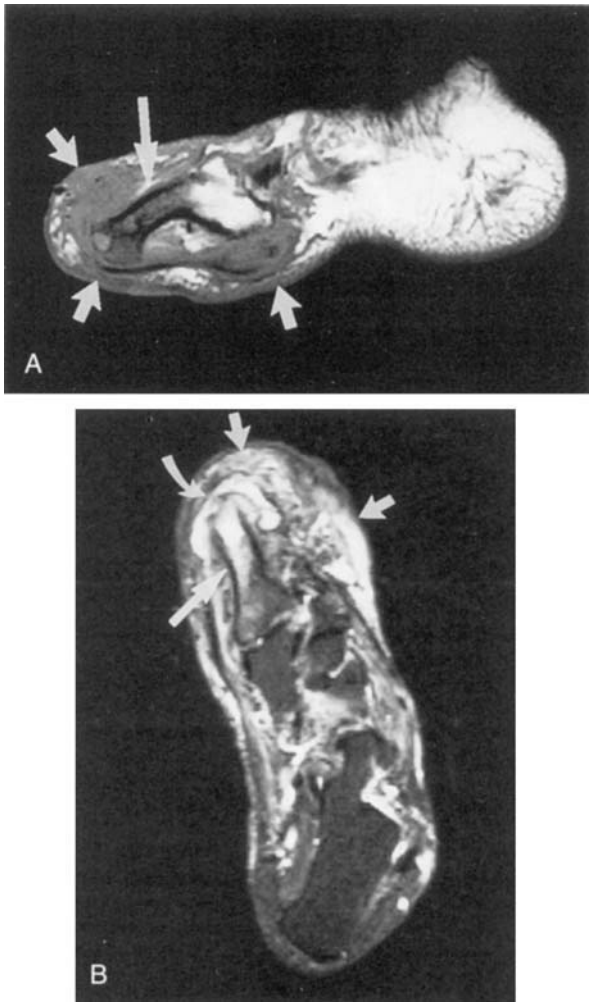

Figure 18. Osteomyelitis and abscess centered at the distal first metatarsal of a diabetic patient with a history of previous foot surgery. *A*, Sagittal T1-weighted (770/14) MR image shows low signal intensity inflammatory changes in the metatarsal (*long arrow*) and surrounding soft tissues (*short arrows*). *B*, Axial STIR MR image reveals a crescentic, high signal intensity fluid collection (*curved arrow*) with inflammatory changes in the metatarsal (*long arrow*) and surrounding soft tissues (*short arrows*).

techniques often provide important supplemental information that can help guide patient management. Sonography is most useful in diagnosing the presence of fluid collections in a joint or in the extra-articular soft tissues. CT scan can be a useful method to detect early osseous erosion, as well as to document the presence of a sequestrum, foreign body, subcutaneous gas, or occult fracture. Nuclear medicine techniques and MR imaging are highly sensitive, but not highly specific, for the diagnosis of acute osteomyelitis. MR imaging generally is superior to nuclear medicine in providing information regarding the regional extent of an infection and the presence or absence of surgical lesions, such as abscesses and sequestra.

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Address reprint requests to

Robert D. Boutin, MD
Department of Radiology
Beth Israel Deaconess Medical Center
330 Brookline Avenue
Boston, MA 02215