



Imaging of osteomyelitis and musculoskeletal soft tissue infections: current concepts

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Osteomyelitis continues to be a common condition in clinical practice, and even though the clinical diagnosis in the late stages is achieved easily, an accurate early diagnosis is more challenging. Prompt and accurate diagnosis can determine morbidity and extent of resolution of the infection. Musculoskeletal inflammation and infection can affect bones, muscles, contiguous soft tissues or joints, and their clinical presentation may not be obvious. Osteomyelitis, which is characterized by progressive inflammatory destruction and new apposition of bone, is still a difficult infection to treat [1,2].

Three different clinical entities may be identified: (1) acute, (2) subacute, and (3) chronic osteomyelitis. Various factors contribute to the development of one entity rather than another. Among those, host resistance (co-morbid conditions, immune status) and early institution of appropriate therapy are important ones. Inadequate or delayed therapy of acute infection may evolve to subacute or chronic infection with associated sequellae.

Acute infection in the bone begins with marrow edema, cellular infiltration, and vascular engorgement and may progress to necrosis and abscess formation [3]. As the infection spreads within the intramedullary cavity, increased pressure causes extension to the cortex by Havers and Volkman's canals with subsequent spread to the subperiosteal space and through the periosteum into the adjacent soft tissues. In osteomyelitis, elevation of the periosteum is prominent in infants and children, whereas in adults, the periosteum is more firmly attached to the bone, producing less elevation [4]. Furthermore, the intimacy of the periosteum and cortex in the

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adult ensures adequate blood supply in most patients and extensive sequestration is not a common finding of adult-onset osteomyelitis.

Purulent material spreads into vascular channels, raising the intraosseous pressure within the medullary cavity, which impairs blood flow. This process may result in ischemic necrosis of bone, which can produce separation of devascularized fragments, (sequestra). Microorganisms, infiltration of neutrophils, and congested or thrombosed blood vessels are principal histologic findings in acute osteomyelitis [5]. If the infection ruptures into the joint space, septic arthritis can occur. This occurs when a metaphyseal abscess ruptures into the joint space in those metaphyses that are intra-articular such as the hip or knee [6,7]. Joint infections increase the intra-articular pressure and may result in subluxation, ischemia, and avascular necrosis.

Cytokines (such as interleukin 1, interleukin-6, interleukin-11, and tumor necrosis factors) generated locally by inflammatory and bone cells are potent osteolytic factors. During infection, phagocytes attempt to contain invading microorganisms and, in the process, generate toxic oxygen radicals and release proteolytic enzymes that lyse surrounding tissues [5]. Proteolytic degradation of the affected cartilage by the exudates can produce chondrolysis and articular deformity [8]. Additional complications of osteomyelitis in pediatric patients include fracture, slipped epiphyses, premature closure of growth plate, and chronic infection [4]. Infection also may spread along the entire length of the tubular bone with involvement of large segments of the diaphysis. The infection eventually can violate and disrupt the cortex itself, producing atrophy and osseous weakening, and predisposes the bone to pathologic fractures.

Subacute osteomyelitis is a localized pyogenic process. Brodie's abscess is a complication that constitutes a well-defined purulent infection of the bone surrounded by granulation tissue and sclerotic bone, essentially an intraosseous bone abscess. Chronic osteomyelitis is a continuing chronic low-grade infection. Biopsy specimens, when obtained, frequently are unable to culture a pathologic organism. This type of infection may be indolent for a long period of time before reactivation of the disease occurs.

One of the distinguishing features of chronic osteomyelitis is necrotic bone, which can be recognized by the absence of living osteocytes. In chronic osteomyelitis, the decreased blood supply to an area of bone may result in the formation of a necrotic devitalized bone fragment (sequestrum) surrounded by granulation tissue. A thick sheath of periosteal new bone (involucrum) can develop around the sequestrum. In addition, an opening (cloaca) may form in the involucrum through which the necrotic bone and debris may drain [4]. Garre's sclerosing osteomyelitis is a form of chronic infection with significant cortical thickening or periosteal reaction.

Osteomyelitis may result from hematogenous dissemination, spread from adjacent soft tissue infection, or direct inoculation. Hematogenous osteomyelitis spread is most common in children, especially in the tubular bones. In contrast, hematogenous osteomyelitis in mature skeleton more commonly affects the spine, pelvis, and small bones [9,10]. In neonates and adults, vascular communications

are present between the epiphysis and metaphysis. Transphyseal vessels allow the spread of infection into the epiphyses and joints in patients younger than 18 month of age. In children, the capillaries in the metaphyses are the terminal ramifications of the nutrient artery. Between the ages of 1 and 16 years, the epiphyseal plate separates the metaphyses from the epiphysis and acts as a barrier to the vascular supply and spread of infection [11]. Epiphyseal osteomyelitis can occur in children, most commonly in the distal femur, because of slow flow in epiphyseal venous sinusoids that drain into radially oriented epiphyseal vessels [12,13]. Multiple foci of disease can be seen in 7% of children and in 22% of neonates [8,14].

The clinical picture of osteomyelitis may be confusing, and laboratory findings, including an elevated erythrocyte sedimentation rate and leukocytosis, are non-specific for bone infection in its early stage or can even be normal. Serial blood cultures are positive in 32% to 60% of cases [1,6,15]. Cultures of blood and material aspirated by needle aspiration of the involved bone yield positive findings in up to 87% of cases [16,17], and the yield from subperiosteal aspiration approaches 90% [18,19]. Clinical presentation of pediatric osteomyelitis may be even more elusive. Infection in the neonate and infant is usually clinically silent. Toddlers may present with limping, pseudoparalysis, or pain on passive movement. The earliest soft tissue changes include swelling, heat, and redness [11].

Because delay in the treatment of osteomyelitis significantly diminishes the cure rate and increases the rate of complications and morbidity, several imaging modalities have been used for early detection of osteomyelitis, including conventional radiography, several nuclear medicine or scintigraphic techniques, computed tomography (CT), magnetic resonance imaging (MRI), and ultrasonography (US). Although these 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. In musculoskeletal infections, the diagnostic imaging evaluation and the resulting information can be extremely helpful to the clinician planning medical or surgical treatment.

In infants and children, acute osteomyelitis is most commonly caused by hematogenous spread. *Staphylococcus aureus* is the most common etiologic agent, followed by B-hemolytic streptococcus, *Streptococcus pneumoniae*, *Escherichia coli*, and *Pseudomonas aeruginosa* [14, 18]. The incidence of infection by *Haemophilus influenzae* has declined dramatically because of widespread Hib vaccination [18,20,21]. Although any bone can be affected, the most commonly involved are the metaphyses of long bones, especially the distal femur and proximal tibia, followed by the distal humerus, distal radius, proximal femur, and proximal humerus [22]. *Staphylococcus aureus* is also the most prevalent infecting organism later in life in osteomyelitis of the mature skeleton, and Gram-negative rods are found in the elderly. Fungal osteomyelitis is a complication of catheter-related fungemia, the use of illicit drugs contaminated by *Candida* sp, and prolonged neutropenia. *Pseudomonas aeruginosa* can be isolated from injectable drug users and from patients with urinary catheters in place for long periods of time (often from vertebral bodies).

The most common form of musculoskeletal tuberculosis is tuberculous spondylitis. Isolated extraspinal bone infection by *Mycobacterium tuberculosis* is less common. The most frequent form of musculoskeletal involvement, excluding the spine, is within muscles and soft tissues [23].

Osteomyelitis is a relatively uncommon complication of HIV-positive patients. Hematogenous dissemination of *S aureus*, however, is the most common source of infection in these individuals, especially in intravenous drug abusers, but *Salmonella* in these patients has also been reported. In a series of 560 HIV-positive patients, 12 cases of osteomyelitis were all caused by either *S aureus* or salmonella infection [24]. Other bacteria such as *Neisseria gonorrhoeae* [25], *Cryptococcus neoformans*, and *Nocardia asteroides* [26] also have been reported. All bones can be affected, as well as the spine and vertebral bodies [26–28]. In these patients, some uncommon forms of bone infections such as bacillary angiomatosis from an unusual bacillus (*Bartonella henselae*) [29] and *M tuberculosis* have been documented [30–32].

Imaging findings

Conventional radiography

Plain radiographs are the first step in the imaging assessment of osteomyelitis because they may suggest the correct diagnosis, exclude other pathology, or provide clues for other pathologic conditions. The earliest sign is the deep soft tissue swelling of muscles and superficial subcutaneous soft tissues. Bone destruction and periosteal reaction are not early findings, but when seen, the infectious process has been present and active for more than 1 or 2 weeks. Comparative views of the contralateral extremity may help to appreciate subtle early findings in pediatric patients [11]. After several days, regional hyperemia and infiltration of affected bone marrow result in bone resorption and osteolysis. Localized osteoporosis and trabecular bone destruction occur.

Later, affection of the cortical bone may be detected because of cortical erosion and lucency with periosteal reaction and elevation with reactive new bone formation (Fig. 1). The fibrous and firm attachment of the periosteum to the cortex in adults resists displacement and subperiosteal abscess formation. Extensive periostitis and involucrum formation are relatively unusual for adults, in contrast to pediatric patients. X-ray changes that depend on decreased bone density require loss of approximately 30% to 50% of bone mineralization for changes to be apparent on plain films [33–35]. The sensitivity for plain film radiography has been reported to range from 43% to 75%, and the specificity from 75% to 83% [3,9,36–38]. X-rays, when positive, are helpful but negative radiographic findings are unreliable to exclude the diagnosis of osteomyelitis in patients with violated bone. In these situations, radiographic findings are nonspecific, being diagnostic in as few as 3% to 5% of culture-positive cases [10,39].



Fig. 1. Plain A. P. radiograph of tibia and fibula of 14-year-old patient demonstrating a pathologic fracture of the proximal fibula with periosteal reaction and erosion of cortical bone secondary to subacute osteomyelitis.

Nuclear medicine

Bone scan

The first examination of choice is a three-phase bone scan. This is readily performed after injection of 25 mCi of methylene diphosphonate (MDP). The patient is imaged with a nuclear medicine gamma camera. The initial or flow phase is acquired at a rate of 2 seconds per frame, followed by blood pool phase images approximately 5 to 10 minutes after injection. Delayed static images of the area of interest are performed 3 hours after injection. Abnormal findings for osteomyelitis typically include increased flow activity, blood pool activity, and positive uptake on 3-hour images. The intensity of uptake becomes more focal and intense at the area of interest and, when positive on all three phases, is highly sensitive for osteomyelitis (sensitivity 73% to 100%) [40–43].

This technique has high sensitivity for osteomyelitis and can reliably differentiate cellulitis from osteomyelitis when no complicating conditions are present. Cellulitis will only be positive on the first two phases and have a normal (not increased) uptake on the 3-hour images. The specificity for osteomyelitis decreases, however, when other conditions are present simultaneously. These

include recent trauma, surgery, placement of orthopedic devices, or diabetes [44–46]. In these conditions the specificity of a three-phase bone scan decreases; most reports are between 73% and 79% but have been reported as low as 38%. These complicating conditions may cause a positive bone scan but the findings are of lower specificity. Further imaging tests will generally be required to assess more accurately possible osteomyelitis in these conditions (Fig. 2).

Gallium scan

Infection has also been identified by injection of 5 mCi of Gallium⁶⁷. This product has improved specificity compared to the three-phase bone scan alone [44,47]. Imaging is typically performed 48 hours after injection but occasionally can be performed at 24 hours. Gallium has occasional false positives from fractures, tumor uptake, and has marked excretion through the gastrointestinal tract. Although more specific than a three-phase bone scan, image quality suffers slightly compared to a three-phase bone scan and takes longer. Alternatively, the

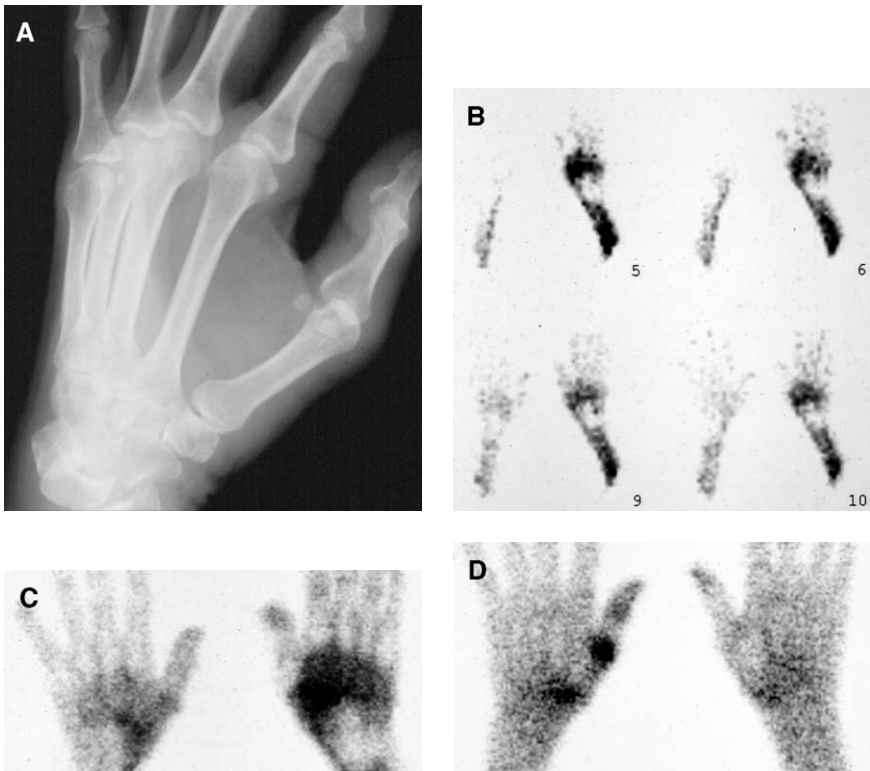


Fig. 2. Patient with a history of puncture wound at the base of the thumb. Plain radiograph (A) of the hand is normal. Three phase bone scan (B–D) demonstrates increased flow of radiotracer to the soft tissues and increased uptake in the bone consistent with osteomyelitis involving the base of the first metacarpal bone.

bone scan has the relative advantage of being very sensitive and, if negative, effectively excludes the diagnosis of osteomyelitis. The reported sensitivity for Gallium scan has ranged from 25% to 80%, with a specificity of 67% [48–50].

White blood cell scan (WBCS)

The WBCS was originally done with Indium¹¹¹-labeled white blood cells and more recently with technetium-99m hexamethylpropyleneamine oxime (HMPAO)-labeled white cells [51]. The indium product has a higher radiation dose to the patient, takes 24 hours to perform, and the images have extensive noise. This product was available in clinical trials earlier than the HMPAO WBCS with a reported sensitivity of more than 90% and a specificity of 78% [47]. This technique was shown to be useful in both complicated and uncomplicated patients. Similar sensitivity and specificity were found with the HMPAO technique. The advantages of the Technetium WBCS that make it preferable for clinical use include same day study and result, lower radiation dose, and better image quality and resolution (Fig. 3).

All these studies require withdrawal of 50 cc of blood and separation of the white cell component from the rest of the blood with radiolabeling of the WBC. After reconstitution of the radiolabeled cells in saline, the cells are reinjected into the patient. This requires more technical preparation and is more expensive than the bone scan. The main advantage of the WBCS, however, is the marked

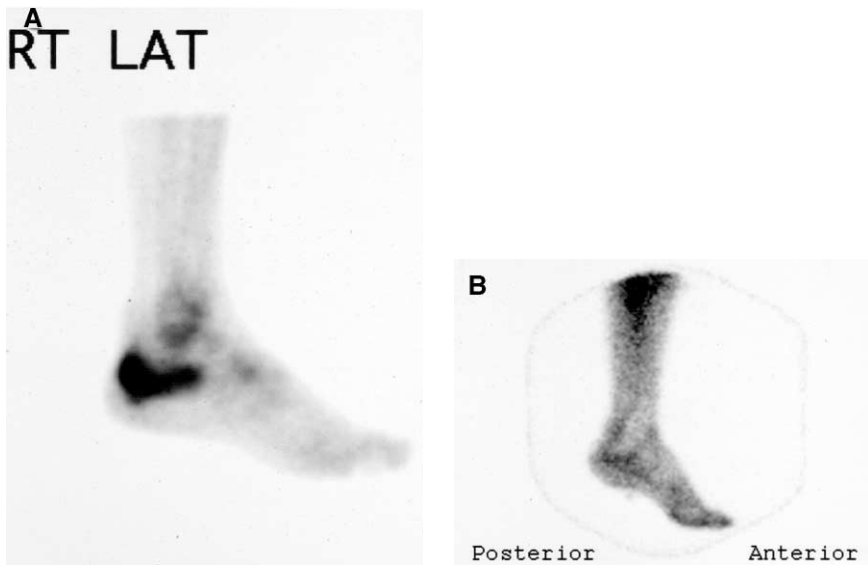


Fig. 3. Patient with a history of trauma and possible osteomyelitis at the level of the right ankle. Bone scan (A) demonstrates increased uptake in the posterior calcaneus. White blood cell scan (B) is normal and excludes the possibility of osteomyelitis. The increased uptake on the bone scan could be explained from prior trauma.

improvement in specificity compared to bone scans, particularly when complicating conditions are superimposed. The specificity increases to 80% to 90% when compared to the bone scan. Limitations include bone marrow uptake in the spine and pelvis, which can interfere with interpretation. These patients can be imaged with either gallium scans or MRI. Other reports have discussed false-negative WBC scans in the evaluation of chronic osteomyelitis or partially treated osteomyelitis [7,46,52].

A drawback of nuclear medicine is its limited spatial resolution with less ability to clearly delineate areas of complex anatomy such as the foot and ankle. Also, the circulatory compromise that predisposes individuals to distal extremity infection may also limit the delivery of isotopes distally. Nuclear medicine can image patients with prostheses without interference from artifact. Another advantage of nuclear medicine over other imaging modalities is that pediatric patients rarely require sedation, children can be scanned more than once after the injection of the radiopharmaceutical, and multiple foci of disease can be demonstrated [34].

New techniques

A technetium-99m-labeled murine immunoglobulin M monoclonal antigranulocyte antibody that binds to human polymorphonuclear leukocyte CD15 antigens has been evaluated. The initial report is promising, with possibly better diagnostic results than other techniques, initial sensitivity of 91%, and specificity of 70% [53]. When combined with bone scanning, the results are improved even more [40,54–56].

Infecton (Ciprofloxacin) labeled with tech-99m has also been studied and recent results are promising. These initial studies also hold some possibility of better clinical results than WBC, gallium, or combined scanning with bone or bone marrow scan [57,58].

Cross-sectional imaging

Computed tomography

CT provides images with high spatial and contrast resolution of bone and surrounding soft tissue, as well as exceptional cortical bony detail. It can provide a good definition of cortical bone destruction, periosteal reaction, and soft tissue changes. Postcontrast images are more useful for soft tissue abnormalities than for bony changes. Increased density of the medullary cavity can be seen, replacing the normal low-density normal fatty marrow, but this finding is nonspecific and may be seen not only in infections but also in neoplasms, hemorrhage, fractures, or irradiation [59]. It is the best method of detection of small foci of intraosseous gas, areas of cortical erosion or destruction, tiny foreign bodies serving as a nidus for infection, and involucrum and sequestration formation [34,60–63].

In chronic osteomyelitis, CT demonstrates abnormal thickening of the affected cortical bone, with sclerotic changes, encroachment of the medullary cavity, and the abnormal chronic draining sinus (Fig. 4). CT is helpful in delineating abnormalities that must be addressed at surgery, such as sequestra, involucra,

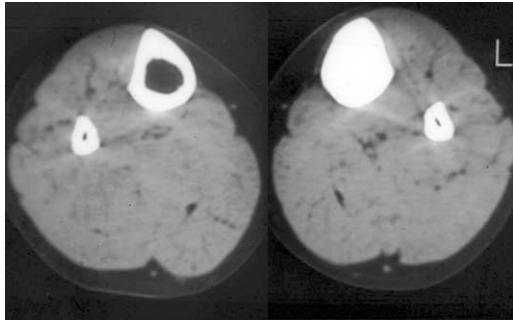


Fig. 4. Forty-year-old female patient with pain secondary to chronic osteomyelitis. Axial noncontrast CT scan of the level of the mid tibia demonstrates extensive sclerosis and obliteration of the medullary cavity of left tibia.

and cloaca. One limitation of CT is in the assessment of body parts with metallic implants because of beam-hardening artifact [3]. The sensitivity and specificity of CT for diagnosis of osteomyelitis has not been established clearly, but it is known to be lower than the sensitivity of MRI [64]. Its use in clinical practice should be limited to specific circumstances and not be used as part of the regular osteomyelitis imaging. One of the indications for CT is for guiding aspirations and biopsies when a bone infection is suspected and a tissue sample is required (Fig. 5).

Ultrasound

The use of ultrasound in the diagnosis of osteomyelitis is limited. Even though sonography can detect deep soft tissue edema and subperiosteal collections, there is no agreement regarding the role of sonography in childhood osteomyelitis. Its role in adult patients is considered even more limited [65–67]. Sonography is most useful in diagnosing the presence of fluid in a joint or extra-articular soft tissue. In the appropriate clinical settings, subperiosteal fluid (pus) collection confirms the clinical diagnosis of osteomyelitis [68].

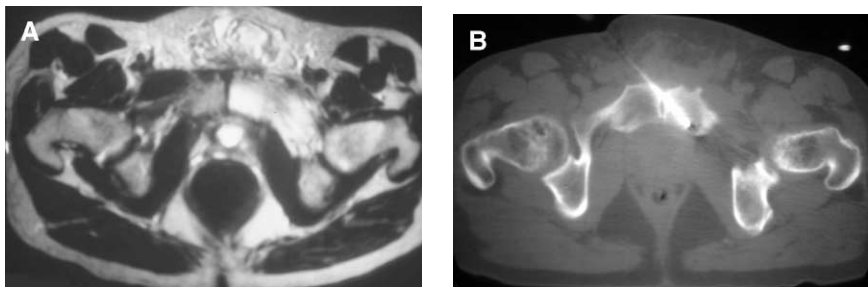


Fig. 5. Fifty-five-year-old male with pain in the pubic region after transabdominal resection of prostate cancer. Axial T2 weighted image at the level of the pubic symphysis (A) demonstrates increased signal in the left pubic ramus suspicious for osteomyelitis. CT guided biopsy (B) of the left pubic ramus demonstrated acute osteomyelitis.

Magnetic resonance imaging

MRI has been widely used for evaluation of osteomyelitis for nearly two decades. Since the introduction of MRI, its high sensitivity for inflammatory processes in either soft tissue or bone has been recognized, and since the initial reports, it has been clear that its sensitivity exceeds that of plain films and CT and similar to that of radionuclide studies [69–73].

Unlike CT images, which depend on tissue and contrast media x-ray attenuation for visualization, MRI relies on the mobile hydrogen concentration of blood and tissues to generate an image. When placed in an external magnetic field, the individual magnetic moments of all hydrogen atoms in the body, including the blood vessels, align themselves with the external magnetic field. The magnetic field strength of most MRI scanners used in clinical practice is between 0.5 and 1.5 Tesla, or approximately 10,000 to 30,000 times the strength of the earth's magnetic field. Energy in the form of a radiofrequency (RF) pulse is used to energize the aligned nuclei to varying degrees. It is the relaxation of these hydrogen atoms that produces a characteristic signal that is used to generate an image. The final MR signal generated by this energy is registered by a receiver coil and transmitted to a computer to create an image. This signal is a very complex function of the concentration of hydrogen atoms (or water content), the relaxation time of these atoms after receiving the additional RF energy, blood flow, scanning parameters, and the imaging protocols. T1 and T2 are commonly used terms that describe an MRI signal. T1 describes the time required for magnetization buildup. T1 reflects the characteristic time constant for spins (which are the intrinsic angular momentum of an elementary particle, in this case water protons) to align themselves with the external magnetic field, or longitudinal relaxation. T2 describes the time for transverse relaxation. It reflects the characteristic time constant for loss of phase coherence among spins caused by interactions between the spins, resulting in loss of transverse magnetization [74]. It is this difference in the concentration of water protons existing between the normal and abnormal bone marrow that determines the ability of MRI to visualize areas of bone infection. Multiple different pulse sequences and different imaging protocols can be used to obtain an image of the musculoskeletal system, and depending on the pulse sequences used, major differences can be noted on the signal intensity and appearance of normal and abnormal tissues.

Suppression of fat signal in MRI has proven to extend the dynamic range of tissue contrast, eliminating the strong interfering signal of fat on T1- and T2-weighted images, and in post-intravenous contrast injection images (gadolinium). These advantages of fat suppression magnetic resonance images have been extensively used in clinical practice [75–87]. These types of sequences are known as chemical-shift imaging (CSI), short T1 inversion recovery (STIR), selective inversion recovery (SPIR), or fat saturation (FATSAT) [88]. By suppressing the signal from fat, the conspicuity of lesions with relatively high water content, such as osteomyelitis, edema, and tumors, increases [56,89,90].

MRI has proven to be extremely sensitive in the early detection of osteomyelitis because of the excellent contrast it provides between the abnormal areas and the

Table 1
Reported sensitivity and specificity of MRI in osteomyelitis

Reference	Sensitivity (%)	Specificity (%)	Anatomic location
Modic et al, 1986 [72]	96	92	Spine
Unger et al, 1988 [73]	92	96	Multiple
Yuh et al, 1989 [38]	100	89	Foot
Wang et al, 1990 [92]	99	81	Foot
Erdman et al, 1991 [89]	98	75	Multiple
Zynamon et al, 1991 [93]	100	78	Foot
Weinstein et al, 1993 [94]	100	89	Multiple
Morrison et al, 1995 [95]	82	80	Foot
Mazur et al, 1995 [96]	97	92	Multiple
Morrison et al, 1998 [116]	84–96	78–88	Foot
Huang et al, 1998 [81]	98	89	Pelvis, hips

normal bone marrow. The sensitivity of MRI for the diagnosis of osteomyelitis generally has been reported between 82% and 100%, and specificity between 75% and 96% (Table 1). There is only one report with lower figures, but without the fat suppression technique, which today is considered mandatory for the evaluation of bone infection [91].

In the acute phase of osteomyelitis, the edema and exudate within the medullary space produce an ill-defined low-signal intensity on the T1-weighted images, and the high signal on T2-weighted and STIR or fat-suppressed sequences (Fig. 6). Usually, the surrounding soft tissues are also abnormal, with ill-defined



Fig. 6. Fifteen-year-old male with knee pain and acute osteomyelitis. Coronal T1 weighted image of the knee demonstrates low signal in the proximal epiphysis extending through the growth plate into the metaphysis of the tibia.

planes. The cortical bone can be disrupted and can have an abnormally increased signal intensity. There is no thickening of the cortex in acute osteomyelitis, which helps to differentiate it from a chronic infection of bone. 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 conventional T1- and T2-weighted images and cannot be used to differentiate fluid collections, such as an abscess, from circumscribed soft tissue edema [3,10]. MRI is also very helpful in differentiating soft tissue edema, inflammation, and cellulitis from osteomyelitis in long bones (Fig. 7). Subperiosteal fluid collections may be seen, with low signal intensity on the T1-weighted sequences and intermediate to high signal intensity on the T2 and fat-suppressed images (Fig. 8).

Bone marrow findings of acute osteomyelitis on MR imaging is nonspecific: other conditions such as trauma with bone bruise, fracture, infarct, ischemia, and neoplastic processes may have the same signal intensity alterations as seen in osteomyelitis. For this reason, clinical correlation and risk factor considerations are very important to assist the MRI findings in achieving the most correct diagnosis.



Fig. 7. Adult patient with soft tissue swelling secondary to acute osteomyelitis. Coronal T2 with fat suppression demonstrates extensive edema of the soft tissues and the bone marrow of the right tibia.



Fig. 8. Axial T1 weighted image of the fibula (A) demonstrates low signal within the medullary cavity at the fibula and erosion of the cortex. Axial T2 weighted image at the same level (B) demonstrates subperiosteal fluid collection around the fibula with extensive soft tissue inflammatory changes which was not as apparent on the T1 weighted image. Coronal T2 weighted image of the fibula (C) demonstrates a pathologic fracture of the proximal fibula with the subperiosteal abscess formation.

Subacute osteomyelitis takes place when the acute infection progresses to intraosseous abscess formation (Brodie's abscess formation). The bone marrow surrounding the Brodie's abscess often demonstrates reactive hyperemia. The internal wall of the abscess is covered by granulation tissue. These changes are well depicted by MRI (Fig. 9). High signal intensity on T2-weighted images around the area of abscess reflects the hyperemic bone marrow. The granulation tissue lining the inner wall of the abscess has low signal intensity on T1. The high signal intensity of the granulation tissue surrounded by the low signal intensity band of bone sclerosis creates a "double-line effect," with peripheral ring enhancement with gadolinium administration and high T2 signal intensity [97].

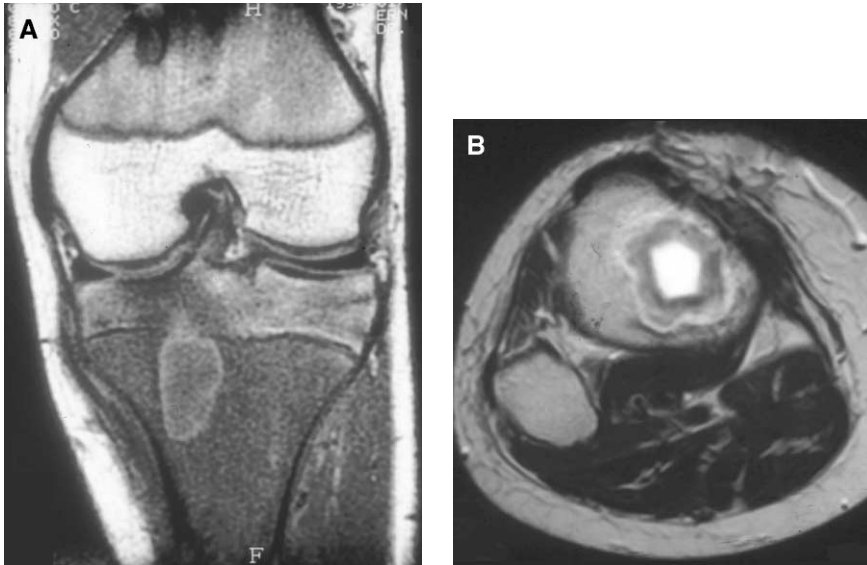


Fig. 9. Sixteen-year-old male patient with history of six weeks of pain in the right knee with fever consistent with Brodie abscess. T1 weighted image of the knee (A) demonstrates the double line effect, a focal area of low signal with alternating bands of high and low signal. Axial T2 weighted image of the proximal tibia at the same level (B) demonstrates a region of high-intensity surrounded by alternating bands of low signal and high signal.

This central abscess with the surrounding granulation tissue, outer ring of fibrotic reaction, and a peripheral rim of endosteal reaction produces a “target” appearance with four distinct layers that are more evident after gadolinium injection [98].

In subacute and chronic osteomyelitis, a peripheral area of low signal intensity (the rim sign) on all pulse sequences is visualized, corresponding to fibrous changes or reactive bone [99]. This sign has been reported in 93% of patients with chronic osteomyelitis, and in less than 1% of patients with acute infection [89]. In chronic osteomyelitis, the usual appearance of high T2 signal in the bone marrow may be absent, and instead, there are areas of devascularized fibrotic scarring in the marrow that are of low signal intensity on both T1- and T2-weighted images [100]. There is a predominant bone sclerosis, with cortical thickening from periosteal apposition and focally reduced bone marrow cavity (Fig. 10). Sinus tracts may be present. In acute osteomyelitis, there is a wide zone of transition and poor definition between the normal and the edematous and infected abnormal marrow. In chronic osteomyelitis, there is often a relatively sharp and better-defined interface between the normal and abnormal marrow [101]. In 50% of cases, subacute osteomyelitis is confused with a tumor, and the bone erosion and periosteal reaction with reactive bone formation can have the same appearance of an osteosarcoma or a Ewing sarcoma [11]. In case of epiphyseal abnormalities, MR can be useful to differentiate epiphyseal osteomyelitis from a neoplasm such as chondroblastoma, osteoid osteoma, enchondroma, or eosinophilic granuloma [22].



Fig. 10. Patient with chronic osteomyelitis after removal of infected hardware for femur fracture. Sagittal T1 weighted image of the femur demonstrates thickening and sclerosis of the cortical bone with obliteration of the medullary cavity. In addition, the proximal third of the femur demonstrates a 1 cm area of low signal with surrounding high signal consistent with formation of a sequestrum.

Gadolinium-enhanced T1-weighted imaging provides additional information in the evaluation of osteomyelitis. Areas of devitalized sequestration do not enhance, further helping in the differentiation of an acute from a chronic process. In the differential diagnosis of a tumor, Gadolinium is also useful because abscess or subperiosteal collections do not enhance, in contrast to tumors, which usually demonstrate important enhancement after contrast injection [102–104].

The diagnostic investigation of patients with history of chronic post-traumatic osteomyelitis and suspected reactivation of bone infection represents a particular challenge for all imaging modalities. In this setting, MRI has been reported to have a sensitivity of 100%, a specificity of 60%, accuracy of 79%, positive predictive value of 69%, and a negative predictive value of 100% [105]. This means that acute activity in chronic osteomyelitis can be excluded with high probability if the MRI findings are negative. In addition, in patients with prostheses, MRI has been reported to be superior to CT for evaluation of bone infection [99]. Furthermore, by providing images in any plane, MRI enables better planning for open or percutaneous drainage of fluid collections and surgical debridement [102,106]. MRI can also contribute to surgical management by assessing the extent of devitalized tissue and by defining the extension to critical adjacent structures like in the spine, physes, or joint spaces, which require modified management to avoid morbidity and complications [104,107,109]. It has been suggested that earlier MRI can replace Tc-99m–labeled scintigraphy and reduce radiographic investigations at the onset of acute osteomyelitis because MR imaging can distinguish isolated soft tissue infection adjacent to bone from true medullary cavity involvement, better identify extent of periosteal and epyphiseal involvement, and obviate the need for conventional radiographs [108,109].

In diabetic patients in whom foot ulcers are common complications, MRI can be very useful to demonstrate the presence of associated osteomyelitis (15%) or septic arthritis. Pedal osteomyelitis results almost exclusively from contiguous infection coming from the soft tissue ulceration and occurs most frequently around the fifth and first metatarsophalangeal joints. One third of patients with advanced infection of the foot show evidence of septic arthritis on MR images [110].

One uncommon but well-known complication of chronic osteomyelitis is the development of a squamous cell carcinoma of the sinus tract, which occurs in 0.23% to 1.6% of patients with a very long-standing infection [111,113]. The chronic discharge of purulent material produces metaplasia of the epithelialized lining of the sinus tract, which subsequently can lead to the formation of a squamous cell carcinoma [112]. Serial radiographs may demonstrate new lytic areas, or in some other cases demonstrate no changes [114]. MRI can demonstrate the presence of an abnormal soft tissue mass, helping in the identification of this complication [113–115].

Summary

The diagnostic imaging of osteomyelitis can require the confluence of multiple imaging technologies. Conventional radiography should always be the first imaging modality. Sonography is most useful in the diagnosis of fluid collections in a joint or in the extra-articular soft tissues but is not useful for evaluating presence of osseous infection. CT scan can be a useful method to detect early osseous erosion and to document the presence of sequestrum, foreign body, or gas formation but generally is less sensitive than other modalities for

the detection of bone infection. Nuclear medicine and MRI are the most sensitive and most specific imaging modalities for the detection of osteomyelitis. Nuclear medicine is particularly useful in identifying multifocal involvement, which is common in children. MRI provides more accurate information of the local extent of the soft tissues and possible soft tissue abscess in patients with musculoskeletal infection.

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