In children, hematogenous osteomyelitis is an infection that primarily affects the most vascularized regions of the growing skeleton. The disease has increased in frequency, virulence, and degree of soft-tissue involvement. The change in clinical manifestations and management over the past 2 decades should be reflected in the current imaging approach to the disease. Imaging of infection must depict the location of a single focus or of multiple foci of involvement and the presence of drainable collections. This review provides an overview of the imaging implications directed by the changing epidemiology, the newer insights of anatomy and pathophysiology, the imaging characteristics with emphasis on specific locations and disease complications, and the differential diagnosis considerations. In addition, basic imaging guidelines for appropriate extent of area to image based on patient age are provided.
The metaphysis is the primary site of infection in children owing to its abundant vascularity; a metaphyseal equivalent, at the junction of bone and cartilage in a skeletally immature flat or round bone, has similar vascularity to the metaphysis of a long bone, and therefore, is also particularly susceptible to osteomyelitis.

Imaging of pediatric osteomyelitis should answer: whether there is infection, what is its location, whether it is multifocal, whether there are drainable collections, and whether there are poor prognostic signs such as an extensive subperiosteal abscess or bone marrow ischemia.

Changes in clinical presentation over the past few years mandate the need to image the tissues that surround the bone, and the adjacent joint and veins, by the use of either sonography or MR imaging.

to be associated with complications. An important aspect of the disease involves the tissues outside the bone (Fig 1). As it has become clear that more prompt and better-targeted therapy leads to better outcomes, pharmacological and surgical therapies also have been modified (1,2). Given the changes in clinical manifestations and management, we must adjust the imaging approach to the disease. In this review, we will emphasize the changing epidemiology and clinical manifestations of osteomyelitis and discuss the implications for imaging.

Definition and Epidemiology

Acute hematogenous osteomyelitis is an infection that usually affects the growing skeleton, involving primarily the most vascularized regions of the bone. It is considered an acute process if the symptoms have lasted less than 2 weeks (2,3). Acute osteomyelitis has an incidence of 8–10 per 100,000 in developed countries and an even higher incidence, up to 80 per 100,000, in developing countries (1,4,5). The incidence of septic arthritis is about half that of osteomyelitis. In the United States, there has been a 2.8-fold increase in the incidence of osteomyelitis in the past 2 decades (6). By contrast, over this same period, the incidence of septic arthritis has remained unchanged (7).

The most common organism that infects the bones is *Staphylococcus aureus*, followed by the respiratory pathogens *Kingella kingae*, *Streptococcus pyogenes*, and *Streptococcus pneumoniae* (1,6,8). Both methicillin-sensitive and methicillin-resistant isolates of *S aureus* are associated with osteomyelitis. Methicillin-resistant *S aureus* (MRSA) accounts for 30%–40% of osteoarticular infections in the United States and a lower percentage of cases in northern Europe and the Middle East (2). The course of community-acquired *S aureus* osteomyelitis appears to be more severe in recent years, primarily in cases caused by MRSA and potentially related to the presence of the Panton-Valentine leucocidin, or PVL, gene. This gene encodes for a toxin that produces tissue necrosis and destruction of neutrophils (9), and is associated with a higher rate of septic shock and greater need for surgical interventions and prolonged hospitalization (10). Children with PVL-positive staphylococcal infections are more likely to have multifocal osteomyelitis, large subperiosteal abscesses, multiple bony abscesses, deep venous thrombosis, and associated myositis and psoasitis (11).

In the past 10–15 years, there has been a remarkable increase in the recognition of *K kingae* as an infecting organism. In Europe and the Middle East, *K kingae* now is the most common pathogen in young children with osteomyelitis or septic arthritis (1). This bacterium is a facultative anaerobic, β-hemolytic, gram-negative bacillus that colonizes the posterior pharynx of approximately 10% of healthy children between 12 and 24 months of age. Disease due to *K kingae* affects mostly children between 6 months and 4 years of age and involves primarily the musculoskeletal system in the form of septic arthritis, spondylodiscitis, and osteomyelitis. *K kingae* is difficult to recover from cultures, even when samples are inoculated into blood culture vials. It was largely unrecognized in the past, but polymerase chain reaction–based assays have been increasingly used for diagnosis, as this technique greatly enhances the detection of the organism.

Osteomyelitis affects primarily young children, with half of all pediatric cases in children younger than 5 years of age (3). Children affected by *K kingae* are even younger, as the disease is almost always seen before the age of 4 years. Boys are affected twice as often as girls, and this difference has been ascribed to a greater exposure to microtrauma (1). The role of trauma
is important, as highlighted by the fact that one-third of children with osteomyelitis have a history of a recent injury (12). Other organisms play a role in infections within specific populations. Gram-negative organisms such as Escherichia coli and group B streptococci are more common in neonates and young infants (13), and in one series accounted for 60% of musculoskeletal infections seen before 4 months of age (14). Pseudomonas aeruginosa infection occurs in association with puncture wounds through sports shoes, and Salmonella infection is prominent in patients with sickle cell disease (4). Fungal osteomyelitis is most often due to Candida species and generally occurs in immunocompromised hosts. Similarly, mycobacterial osteomyelitis occurs in immunocompromised patients and among children living in regions where mycobacteria are endemic (14).

**Pertinent Anatomic Concepts**

The current paradigm describing the anatomic basis of osteomyelitis in children comes from the seminal work of Trueta (15), who established that the metaphysis is the primary site of infection (Fig 2) because of its vascular characteristics. He found that the metaphyseal spongiosa contains abundant blood vessels with leaky endothelium and sluggish flow that end in capillary loops (13). More recent research has found that these vessels actually are terminal and that bacteria lodge at the junction between the physis and the metaphysis (16). The periosteum also is highly vascular in the child, but it is unclear whether it can be the site of origin of infection (17).

In the first 18 months of life there is a communication between the epiphyseal and metaphyseal vessels (18). This communication results in direct extension of metaphyseal infections into the epiphysis (Fig 3). Epiphyseal extension can cause destruction of the epiphyseal cartilage and secondary ossification center and also can affect the cells of the germinal zone of the physis, which ultimately result in permanent growth disturbance. Easy extension into the epiphysis also contributes to the higher incidence of septic arthritis in this age group (14). Transphyseal extension of pyogenic osteomyelitis is considerably more common than is classically taught (19).

The junctions of bone and cartilage in skeletally immature flat bones, round bones, and epiphyseal ossification centers have a structure similar to that of the metaphyses of long bones. They are highly vascularized, have sluggish flow, and contain more hematopoietic marrow than the remainder of the adjacent bone. These so-called metaphyseal equivalents (20) exist in the vicinity of the triradiate cartilage (Fig 4), the ischiopubic synchondrosis, the sacroiliac joint, the periphery of round bones such as the talus, and the periphery of the secondary centers of ossification. In these bones, osteomyelitis begins in the metaphyseal equivalent locations. A targeted search for a focus of infection in the metaphyseal equivalents is particularly important in the pelvis, where the infection of bone may be subtle relative to the more pronounced surrounding soft tissue changes (Fig 4b).

The periosteum of the growing skeleton has two layers: a superficial, strong layer called the fibrous peristeum and an inner, very vascular layer called the cambium of the periosteum, which plays a role in membranous bone growth (21). An infection can reach the subperiosteal space, probably from the metaphyseal focus but possibly also by means of direct seeding (22), and subsequently disseminate through the vascularized cambium (23). The fibrous layer of the periosteum can be separated easily from the underlying parent bone by pus, and a subperiosteal abscess can develop. The spread of a subperiosteal
Subperiosteal collection can lead to ischemia of the bone (24,25).

Some metaphyses such as the proximal femur and the proximal radius are intracapsular. This anatomy allows an infection to spread directly from the affected metaphysis into the adjacent joint space. In other joints, such as the knee, the infection invades the joint only after it affects the epiphysis.

**Diagnosis and Key Imaging Questions**

Imaging must be tailored to answer those questions that will alter management. Osteomyelitis can be difficult to detect clinically as symptoms, physical examination, and laboratory findings can be deceptive at presentation, variable, and nonspecific (26). The main questions to be addressed by imaging are as follows:

(a) Is there an infection?

(b) Where is the infection?

(c) Are there drainable collections?

**Is There an Infection?**

We need to confirm or exclude acute osteomyelitis. Prompt diagnosis is crucial for a successful outcome, since complications of osteomyelitis increase markedly when treatment is delayed. A delay in treatment can lead to septic arthritis, subperiosteal abscess, pyomyositis, deep vein thrombosis, physeal damage with subsequent permanent impairment or deformity, chronic infection, septicemia, failure of multiple organ systems, and death (27). Therefore, initial evaluation of osteomyelitis should be performed as soon as possible.

Children with bone infection usually complain of pain with ambulation, fever, and focal tenderness, and sometimes redness that worsens over the course of several days. Only 36% of children have an elevated white blood cell count, but if both the erythrocyte sedimentation rate and the C reactive protein values are abnormally increased, the sensitivity for infection is 98% (2).

Conventional radiographs should be the first step in the imaging evaluation. Although radiographs are diagnostic in less than 20% of cases of acute staphylococcal osteomyelitis of childhood (23,28), they may be helpful...
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in directing the subsequent imaging evaluation and, more importantly, show whether symptoms are the result of a different condition such as trauma or tumor. MR imaging has become the recommended modality for evaluation of a child with suspected osteomyelitis (29). If the child can be evaluated with MR imaging within hours of the suspected diagnosis of osteomyelitis, it is reasonable to proceed first with this modality. As more centers have MR schedules that approach 24-hour availability, emergency MR imaging has become a reality.

The evaluation of a suspected site of infection should include a combination of T1-weighted images and STIR images in the coronal or sagittal plane, axial fat-suppressed T2-weighted images, and postgadolinium fat-suppressed T1-weighted images in axial and longitudinal planes (Fig 6). If MR imaging is unavailable, the evaluation can include a combination of scintigraphy to detect osseous involvement (30) and sonography to depict extraosseous findings such as subperiosteal or soft-tissue abscess, joint effusion, and deep venous thrombosis (31,32). Sonography may show deep soft-tissue swelling as an early sign of osteomyelitis (33). It is crucial to recognize that the current high incidence of extraosseous abnormalities makes scintigraphy alone insufficient to evaluate osteomyelitis (34). A triple-phase bone scan and magnification images when necessary, can increase sensitivity (34). At one large pediatric hospital in the United States, the cost of scintigraphy is approximately 55% of the cost of an MR imaging examination. Scintigraphy usually does not require sedation; however, its role is limited and the radiation exposure (organ-specific absorbed dose) is substantial, specifically higher than 10 mGy for the bone marrow and 50 mGy for the urinary bladder (35).

An area of bone infection shows bone marrow with low signal intensity on T1-weighted images (compared with the adjacent muscle) and high signal intensity on STIR or T2-weighted images (Fig 6). On fat-suppressed gadolinium-enhanced T1-weighted images, bone infection usually is seen as an area of increased enhancement relative to the adjacent normal marrow (Fig 6c). However, marrow enhancement at times can be heterogeneous or diminished compared with normal marrow. Ischemia within the areas of infected marrow, seen as areas that enhance less than normal or not at all on contrast-enhanced MR images (36), is analogous to the “cold bone scan” seen scintigraphically (34). Diminished enhancement of the marrow probably is multifactorial, related to elevated intramedullary pressure, vascular thrombosis, and destruction of the periosteal blood supply. Detection of reduced marrow enhancement is important, as it indicates increased disease severity and higher risk for subsequent complications such as pathologic fracture.
Infection of the Epiphyseal Cartilage and Bone in Infants

Imaging of osteomyelitis in a neonate or young infant is particularly difficult, as the bone marrow is highly hematopoietic and thus relatively rich in water and poor in fat content during the first months of life (38). As we rely on a decrease in marrow fat signal intensity on T1-weighted images to detect infection, these images are ineffective for detection of infection in this young age group. STIR or T2-weighted images are also less reliable, although detection of edema signal intensity in the deep soft tissues suggests bone infection. In these children who have very little marrow fat, there is no advantage in using fat suppression, particularly for gadolinium-enhanced images (Fig 7).

In infants, the epiphyseal cartilage can be infected with or without involvement of the adjacent bone. Infection isolated to the epiphyseal cartilage may be undetectable without the use of gadolinium enhancement (Fig 8) as even STIR and T2-weighted images have a low sensitivity for the detection of chondritis (36). Most cases of epiphyseal osteomyelitis or chondritis occur in children younger than 4 years of age, are sometimes subacute, have few symptoms and laboratory findings, and are often caused by K kingae (Fig 9) (39). Infants infected by K kingae have milder clinical symptoms, only slightly more than one-third have an elevated white count at presentation, and 80%-90% have a modestly increased erythrocyte sedimentation rate and C reactive protein value (40). Epiphyseal osteomyelitis caused by S aureus or by Mycobacteria has more symptoms and a poorer prognosis (39).

Where Is the Infection?

Establishing the location of the lesion and determining whether there is multifocality is paramount for appropriate treatment (Fig 10). Blood cultures are positive in less than or equal to 40% of infected children (41), whereas bone, joint, or soft-tissue cultures have a higher yield, in the range of 70% (2). Therefore, it is important to localize the site of infection accurately to guide the diagnostic evaluation and the best site to obtain a tissue sample for culture. The site of an infection usually is easy to determine in adolescents, but younger patients have fewer localizing signs and a higher risk of multifocality. A recent report questioned whether finding a second focus or any contralateral disease makes a difference in management (42). Although the series represents a large experience with 54 patients with proven skeletal infection, only one of these children had multifocal disease.

In neonates, older infants, and young children, it is reasonable to perform whole-body MR imaging with coronal STIR sequences to locate the focus or foci of infection. Due to the small body size in the youngest patients, this imaging approach can be accomplished in less than 10 minutes, as only one or two imaging stations are necessary. Once the location is established or confirmed, we perform focused high-spatial-resolution imaging of the affected area. In older children who are larger and longer, because of growth, imaging of the entire body becomes less practical and less important. A child older than 5 years usually can describe symptoms reliably and thus identify other sites of possible infection. Additionally, the risks of multifocality and of upper extremity involvement are less. In the group between 5 and 10 years of age, we have opted for a compromise solution, namely: In children with lower extremity signs and symptoms, we perform coronal STIR imaging from the pelvis to the feet, since this strategy is likely to demonstrate more than two-thirds of cases with unsuspected multifocal disease (Fig 10). According to Peltola et al (1), the lower extremities account for 75% of the infections in children, with the femur (27%), tibia (26%), pelvis (9%) and feet being the most common locations (Fig 11). Again, this imaging approach can be accomplished in less than 10 minutes. In comparison, routine MR imaging of the entire body would take nearly twice as long and would thus be less feasible. In the group of children older than 10 years of age, it is adequate and most practical to examine only the symptomatic area.

A triple-phase bone scan using technetium 99m (99mTc)-labeled methylene diphosphonate continues to be a reasonable alternative to answer the question of multifocal disease (29). However, it does require an additional examination, it may be less readily available in an emergency situation, and it entails radiation exposure, delivering an effective dose of approximately 2.8 mSv for a 1-year-old (43). Other scintigraphic approaches such as imaging with the child’s white blood cells labeled with a radiotracer, either indium 111 or 99mTc–HMPAO, are infrequently used in children (29). In the future, radiolabeled anti-granulocyte antibodies and antibody fragments, and radiolabeled peptides that target bacteria may provide new avenues for imaging bone infection (44).
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**Are There Drainable Collections?**

Surgical drainage is performed for microbiologic diagnosis, control of the infection, and preservation of function (5). MR imaging is the most reliable modality for the evaluation of intraosseous collections. An intraosseous abscess is seen as an area of high signal intensity in the bone on STIR or T2-weighted images. On gadolinium-enhanced images, the typical appearance is a nonenhanced center surrounded by a peripheral rim. MR imaging can also help to delineate the extent of bone involvement and the presence of sequestrum, which is a devitalized bone fragment that separates the infective process from the remainder of the bone.

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**Figure 8:** MR images in a 4-week-old infant, born at 36 weeks’ gestation, who presented with right knee redness and swelling. (a) Axial fat-suppressed T2-weighted image of the right knee shows abundant hyperintense signal intensity within the soft tissues around the anterior portion of the knee and thickened synovium of the suprapatellar bursa (white arrow). There is discontinuity of the anterolateral epiphyseal border (black arrow) with a subtle focal area of abnormal signal intensity within the epiphyseal cartilage (+). (b) Axial fat-suppressed T1-weighted image obtained after intravenous contrast agent administration shows an avascular area within the anterolateral epiphyseal cartilage (arrow) that is contiguous with the joint effusion. There is diffuse enhancement of the surrounding soft tissues. (c) Sagittal fat-suppressed T1-weighted image obtained after intravenous contrast agent administration shows the focal area of epiphyseal cartilage infection (arrow) and associated septic arthritis. *Citrobacter braakii* was eventually isolated from a cartilage biopsy.

**Figure 9:** Coronal fat-suppressed gadolinium-enhanced T1-weighted MR image in a 10-month-old girl with distal humeral osteomyelitis due to *K. kingae*. There is abnormal enhancement in the cartilage of the capitellar epiphysis (arrow) and in the articular and periarticular soft tissues. (Image courtesy of Jie Nguyen, MD.)

**Figure 10:** MR images in a 7-year-old boy with fever, limping, and right leg pain. (a) Coronal T1-weighted image shows marked irregularity of the signal intensity in the marrow of the distal tibial metaphysis, consistent with osteomyelitis. (b) Coronal STIR image of the pelvis in the same patient shows increased signal intensity (arrow) in the right ischiopubic region consistent with a second focus of infection. There is an abscess within the obturator externus muscle lateral to the focus of infection.
by a rim of enhanced tissue (45). Since enhancement is a reflection of vascular supply, it is likely that antibiotics will not penetrate sites where the intravenous contrast material does not. Although abscesses can be seen consistently on STIR or T2-weighted images, the confidence for detection of purulent collections increases with the use of intravenous contrast material (46).

Subperiosteal collections are depicted well with sonography and MR imaging (22). The key structures to identify are an elevated fibrous layer of the periosteum, which is separated from the underlying bone cortex by pus. The fibrous layer of the periosteum appears as an echogenic line at sonography and as a hypointense linear structure at MR imaging. The subperiosteal fluid lies between the periosteum and the bone and is of low or mixed echogenicity (Fig 12) and of high signal intensity on T2-weighted or STIR images. The identification of the “V” configuration, where the elevated periosteum and underlying bony cortex meet at the perichondrium (Fig 5), defines the location of an abscess as being in the subperiosteal space rather than in the adjacent soft tissues. On T1-weighted images of subperiosteal collections, high-signal-intensity globular structures within the abscess correspond to fat globules (Fig 13) (47). These are mainly seen in older children and are formed by the lytic effect of the bacterial enzymes or ischemic insult on the bone marrow fat, with subsequent adipocyte lysis and release of intracellular fat. Detection of fatty globules, or in some cases a fat-pus layer, is important.

Figure 11: Relative frequency of osteomyelitis in the different bones including all pediatric age groups. Osteomyelitis affects more commonly the fast growing areas and involves the lower extremities more than the upper ones. (Modified from references 1,2.)

Figure 12: Subperiosteal collection in an 8-year-old boy with proximal fibular osteomyelitis. Sonogram demonstrates the elevated echogenic periosteum (black arrow) and the sonoluent subperiosteal collection between the periosteum and the cortex (white arrow).

Figure 13: Subperiosteal abscess with fat globules in a 7-year-old boy with a left distal fibular osteomyelitis. Coronal T1-weighted MR image shows the low signal intensity periosteum (black arrow) converging with the bone at the perichondrium. More cephalad, a subperiosteal collection is seen to contain high signal intensity (fat) globules (white arrows).
because it defines the subperiosteal abnormality as an abscess and can help differentiate it from other subperiosteal process such as tumor.

In bones with subperiosteal collections, T1-weighted images often show diffuse heterogeneity of the bone marrow signal intensity, with relatively diminished enhancement following intravenous contrast agent administration compared with unaffected bone (Fig 14). This same phenomenon has been described on bone scans, in which a subperiosteal abscess is suspected when there is decreased tracer uptake in bone. Both modalities presumably reflect ischemia of bone, which has resulted from the stripping of periosteal blood vessels by the purulent collection (48). Sonography allows serial measurements of the subperiosteal abscess, which may guide management, particularly in children who fail to respond adequately to therapy.

How large must an abscess be before it needs drainage? The literature regarding guidelines for drainage of abscesses is both limited and conflicting. In one study that utilized sonography in 38 subjects with osteomyelitis, subperiosteal abscesses up to 3 mm in diameter resolved successfully without surgery. This study suggests that whether or not an abscess requires drainage can be decided based on the clinical scenario, particularly the response to antibiotics (33). A more recent study suggested that soft-tissue collections larger than 2 cm in diameter usually do not resolve with antibiotics alone and require percutaneous drainage or surgery (49).

Specific Locations

Spinal Osteomyelitis

Vertebral osteomyelitis has a bimodal incidence: There is one peak in early childhood and another one in the 6th decade (50). The incidence appears to be increasing, and this is believed to be related to the increased utilization of intravascular devices and intravenous drug abuse (51). The disease begins in the vicinity of the vertebral body endplate, where there is a metaphyseal equivalent. Bacterial infections involving the spine almost always affect the disk space. The most severe cases can extend into the epidural space and result in rapid neurologic deterioration and permanent sequelae if not treated immediately. Although most (86%) epidural abscesses occur in association with osteomyelitis (51), epidural abscess may be the only abnormality. Paraspinal abscess formation may also occur, with or without threat to the central nervous system. Infections can be low grade and produce only chronic back pain and disk destruction. These infections typically are caused by \textit{S. aureus} and are unlikely to result in epidural involvement (52). There is increasing evidence that \textit{K. kingae} may be responsible for spondylodiscitis in infants (53).

Radiographs, obtained in part to exclude other pathologic conditions, may show disk space narrowing, effacing or sclerosis of the endplates, and alignment abnormalities. Multiple levels are involved in 6% of the cases, and skip lesions are seen in 3% (50). Contrast-enhanced MR imaging should be obtained in all patients suspected of having a spinal infection. In osteomyelitis there is abnormality in the signal intensity of the disk and the adjacent endplates, with paraspinal edema signal intensity or frank abscess. If there are neurologic findings, it is paramount to search for evidence of a spinal epidural abscess (54). An epidural abscess occurs in slightly more than one-third of cases of spondylodiscitis and is seen as a ring-enhancing lesion within the epidural space, with or without cord compression (50). Because of the frequency of noncontiguous skip lesions, it is advisable to image the entire spine. Surgery is indicated if there are neurologic deficits, spinal instability, or inadequate response to antibiotics (51).

Pelvic Osteomyelitis

Pelvic osteomyelitis occurs more frequently in older children (mean age, 10 years) (55), but the clinical evaluation is difficult because the presenting symptoms can mimic other pathologic conditions. The clinical presentations vary: Infection near the sacral roots can produce nerve irritation and therefore present with a lumbar disk syndrome. Infection in the gluteal region can manifest as a subgluteal abscess, and infection in the ilium that extends into the iliac fossa can present with abdominal pain. In our experience some patients
have undergone sonography or computed tomography (CT) first for evaluation of suspected right lower quadrant disease. Radiographs are almost always unrevealing. Radiographs are associated with substantial soft-tissue inflammation in 85% of cases and abscesses in 55% of cases (49) (Fig 10b). For this reason, it is important to image the soft tissues adequately. Since the bone abnormality often is relatively small compared with the extent of soft-tissue involvement, the focus of osteomyelitis can remain undetected, which results in a misleading diagnosis of myositis or a soft-tissue abscess. It is important to search for small areas of abnormal marrow signal intensity in metaphyseal equivalent locations (Fig 15). Another clue to the existence of the soft tissues or muscles (Figs 7, 10b), particularly in the pelvis. In recent years there has been an important increase in the incidence of thrombophlebitis, which now occurs in 10%–30% of cases, typically in association with MRSA infection (56,57). At times the infection can result in septic emboli to the lungs and the brain (Fig 16).

Infections of the intracapsular portion of the proximal femoral metaphysis or of the periarticular pelvis can extend into the hip joint. Recent studies have shown that up to 60% of patients with a clinical picture suggestive of septic arthritis of the hip have pelvic osteomyelitis (58,59). In patients with suspected septic arthritis and more than three predictive factors of bone infection (age > 3.6 years, symptoms such as fever, or non-weight-bearing for more than 3 days, high C-reactive protein level, low platelet count, and elevated absolute neutrophil count) (39,58–60), it is justified to obtain MR images of the pelvis to exclude osteomyelitis. It is not possible by using imaging to reliably differentiate a reactive effusion from septic arthritis, and when there is a sizable effusion in the vicinity of a focus of bone infection, the joint fluid should be aspirated. It also is essential to recognize that septic arthritis of the hip, regardless of the presence of coexisting osteomyelitis, is associated with decreased epiphyseal perfusion in more than 80% of cases (61).

It is imperative to identify deep venous thrombosis, as pulmonary emboli occur in almost half of children who have osteomyelitis and deep venous thrombosis (62,63) (Fig 16). Deep venous thrombosis occurs almost exclusively in the vicinity of the infected bone or in association with central venous catheters. Thus, when evaluating cross-sectional images of the bone infection, it is imperative to look for thrombi in the adjacent veins. In children with osteomyelitis who (a) are critically ill at presentation, (b) have important pulmonary findings, or (c) are persistently bacteremic with MRSA, sonographic evaluation for deep venous thrombosis should be performed of and adjacent to the site or sites of infection.

Delayed complications from acute osteomyelitis include growth arrest, fracture, and chronic osteomyelitis. In slightly more than one-fourth of cases of osteomyelitis, there is focal destruction of the physis, which allows formation of a bridge of bone. This bony bridge tethers the epiphysis to the metaphysis and disrupts normal growth. MR imaging can depict the bony bridge as early as 6 months after the infection. Fortunately, many children with physical involvement show resolution of the physeal insult with adequate antibiotic therapy (64,65). A recently observed phenomenon is the development of pathologic fractures. In a series composed primarily of children with MRSA infections, patients with initial MR images showing a sharp zone of decreased bone marrow enhancement, or subperiosteal abscess more than half of the bone circumference, had increased incidence of fracture 2 months later (10,37).

If on unenhanced T1-weighted images an abscess reveals a discrete peripheral zone of relatively higher signal intensity compared with the central cavity or the surrounding reactive marrow, subacute osteomyelitis should be suspected. This halo of relatively higher

**Additional Imaging Findings**

It is important to identify complications of osteomyelitis that occur during the acute infection and those that develop later in the course of the disease. The initial focus of osteomyelitis can extend into the adjacent medullary cavity, invade the subperiosteal space and surrounding soft tissues, as well as cross the adjacent physis into the epiphysis and possibly the joint (Fig 1). Extension of the infection into the soft tissues can result in cellulitis or myositis, both of which may develop into an abscess of the soft tissues or muscles (Figs 7, 10b), particularly in the pelvis. In recent years there has been an important increase in the incidence of thrombophlebitis, which now occurs in 10%–30% of cases, typically in association with MRSA infection (56,57). At times the infection can result in septic emboli to the lungs and the brain (Fig 16).

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no fluorodeoxyglucose uptake despite showing persistent changes on MR images (69). Since fluorodeoxyglucose uptake becomes normal 3–4 months after surgery or trauma, it also helps to differentiate residual postsurgical changes from persistent infection (69,70). It is likely that PET/MR imaging will have an important role in the imaging of complex cases of osteomyelitis, but its role is not yet established (71).

Is It Something Different than Osteomyelitis?

Several conditions that can present with fever, extremity pain, and radiographs showing aggressive bone destruction can mimic acute osteomyelitis. Tumors include metastatic neuroblastoma and Langerhans cell histiocytosis (LCH) in children less than 5 years of age, and leukemia, Ewing sarcoma, and osteosarcoma in older children. Most of these lesions present with bone destruction, often accompanied by a development of a cloaca, from the Latin word sewer, which is a linear defect in the bone that penetrates the cortex and allows for spontaneous drainage of purulent material. A sinus tract is a channel lined with granulation tissue that allows pus to drain from the infected bone to the skin surface (29).

If symptoms persist after therapy, it becomes difficult to determine whether an infection is active or not. Increased signal intensity on STIR or T2-weighted images, increased enhancement following intravenous contrast agent administration, and increased scintigraphic uptake can persist for months following the resolution of the infection. Positron emission tomography (PET) imaging seems to be the most reliable technique for evaluation of chronic bone infection. In a recent series, PET imaging was shown to be superior to MR imaging for distinguishing between active infection and healing in these children, as successfully treated osteomyelitis had only minimal or no fluorodeoxyglucose uptake despite showing persistent changes on MR images (69). Since fluorodeoxyglucose uptake becomes normal 3–4 months after surgery or trauma, it also helps to differentiate residual postsurgical changes from persistent infection (69,70). It is likely that PET/MR imaging will have an important role in the imaging of complex cases of osteomyelitis, but its role is not yet established (71).
soft-tissue mass. The clinical presentation can overlap, as children with infections and tumors can have fever and localized bone findings. However, a tumor often is associated with longer symptom duration. Although the plain radiographic findings can sometimes overlap, it is important to underscore that radiographically detectable bone destruction is a late finding in osteomyelitis and that patients typically have experienced symptoms for more than a week before findings become apparent. On MR images, osteomyelitis is not associated with a discrete mass. In younger children, LCH can result in dramatic bone destruction and perilous edema. However, unlike osteomyelitis, LCH is primarily diaphyseal (72). On MR images of osteomyelitis, there is an abundant perilous edema that extends along the marrow and into the soft tissues. This extension results in an ill-defined margin between normal and abnormal marrow, which fades away from the center of the infection. Ewing sarcoma and other malignancies such as osteosarcoma usually have a sharper margin between the affected and the unaffected marrow on T1-weighted images (73).

Any disease that causes marrow infiltration, inflammation, or edema can be confused with osteomyelitis. The most difficult differentiation is between infectious osteomyelitis and chronic nonbacterial osteomyelitis (CNO), particularly its most severe form, termed chronic recurrent multifocal osteomyelitis (CRMO). The differentiation between an infectious process and CRMO is particularly difficult in the extremities (74). Both of these conditions produce bone destruction, primarily affect the metaphyses and metaphyseal equivalents, and can extend into the physis. With CNO/CRMO, symptoms typically are less acute and involvement is frequently multifocal (more than 80% of cases) (75) and often symmetric (76). The most common sites of involvement in CNO/CRMO are the pelvis, lower extremities, shoulders, and spine (77). In the tubular bones, nearly 90% affect the physis (77). Unlike hematogenous osteomyelitis, CNO/CRMO often involves the clavicle. Lesions of CNO/CRMO in the axial skeleton usually show only mild marrow edema without soft-tissue edema, which is unlike bacterial osteomyelitis. Inflammatory markers such as C-reactive protein and erythrocyte sedimentation rate are only mildly elevated in CNO/CRMO (78). In recent years there has been great interest in using a clinical score that can help differentiate between osteomyelitis and CNO/CRMO, thus avoiding biopsies (79). The parameters that predict CNO/CRMO are as follows: normal blood cell count (odds ratio [OR], 81.5); symmetric bone lesions (OR, 30.0); lesions with marginal sclerosis (OR, 26.8); normal body temperature (OR, 20.3); lesions in the vertebra, clavicle, or sternum (OR, 13.9); more than one radiologically proven lesion (OR, 10.9); and C-reactive protein level greater than 1 mg/dL (OR, 6.9). This score has shown to have a positive predictive value of 97% and a sensitivity of 68% (79).

In sickle cell disease, it is very difficult to differentiate between infection and infarction (vaso-occlusive crisis). Children with osteomyelitis present with a longer duration of pain, fever, and swelling than patients with sickle cell disease and vaso-occlusive crises. If more than one site is affected, vaso-occlusive crisis is more likely (80). The major problem from the standpoint of imaging is that infarction and infection can coexist and their imaging findings overlap. A recent study (81) attempted to differentiate infection from infarction by using MR imaging with fat-suppressed T1-weighted images. With this sequence, stagnant blood in an infarction has high signal intensity, whereas infected, edematous marrow has low signal intensity. Differentiation was not possible, because in the few cases in which infection was demonstrated, infection developed in areas of infarction. On the other hand, it is well known that infection can produce bone ischemia even in individuals without sickle cell disease (14). Another major challenge is that infarction is nearly 50 times more common than infection in patients with sickle cell disease (80). Evaluation of the performance of any modality is hindered by the fact that the pretest probability is much greater for infection than with infection. Scintigraphic evaluation is based on a combination of bone marrow imaging using 99mTc sulfur colloid and bone scanning using 99mTc methylene diphosphonate (82). In the series by Skagg et al, infarcts showed no uptake on the marrow scans whereas infections showed increased uptake on bone scans but normal activity on marrow scans. Although the authors were successful in diagnosing four cases of osteomyelitis, the technique assumes that infarction and infection do not coexist (which they can), and the combination of both bone and marrow studies delivers a considerable amount of radiation (83). Similar to infection, infarction can produce edema of the bone and adjacent soft tissues, subperiosteal fluid collection, and bone destruction (84). Therefore, differentiation between infection and infarction on the basis of detecting fluid in osteomyelitis at either MR imaging or
ultrasonography (85) also is susceptible to error (Fig 18).

Other lesions that can resemble osteomyelitis include osteoid osteoma, repetitive or chronic trauma, and septic embolic lesions. On MR images, stress reactions are primarily diaphyseal and the edema is predominantly intramedullary, whereas osteomyelitis usually causes circumferential edema and affects the bones and soft tissues almost equally.

The Role of Imaging in Modern Therapy

Imaging, particularly MR imaging, can have a substantial impact on outcome. First, it is important to identify the causative organism and begin antibiotics as soon as possible. Therefore, it is crucial to perform the MR imaging shortly after the suspicion of osteomyelitis is raised. Prompt initiation of appropriate antibiotic therapy is an important predictor of outcome, since a delay in initiation of therapy greater than 3 days results in significant worsening in prognosis (86). Second, it is crucial to guide surgical interventions. Early cultures from the site of infection and thorough surgical decompression of all foci of infection help target the therapy and decrease complications (87). Hence the need for the radiologist to communicate that there is one or more areas of infection, the location of the infection, and, in some cases, whether there are collections of pus large enough to require drainage (87).

Conclusion

The imaging approach to acute hematogenous osteomyelitis in children has to be directed not just to the detection of the primary focus of infection but also to the evaluation for collections of pus in the subperiosteal space, soft tissues, and joints. Bone infection, particularly by *S. aureus*, is associated with disease in those areas and with adjacent thrombophlebitis. It also is important to detect concomitant foci that also may require drainage. Infection caused by *K. kingae* is recognized more often and typically involves the epiphyses of infants and young children (88).

Disclosures of Conflicts of Interest: D.J. disclosed no relevant relationships. J.P.D. disclosed no relevant relationships. J.D. disclosed no relevant relationships. T.L. disclosed no relevant relationships. J.W.S.G. disclosed no relevant relationships.

References


