Assessing the Limping Child with Skeletal Scintigraphy

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Skeletal scintigraphy is frequently used in the clinical investigation of young children who present with limping as their only or predominant symptom. This article reviews techniques used for pediatric skeletal scintigraphy, skeletal tracer distribution in the immature skeleton and scintigraphic manifestations of relatively common conditions that can produce limping in children 1–6 yr old. Acute osteomyelitis, vertebral infections, transient synovitis, septic arthritis, Legg-Calvé-Perthes disease, lower extremity injuries in toddlers and osteoid osteoma are emphasized.

Key Words: skeletal scintigraphy; osteomyelitis; avascular necrosis; osteoid osteoma

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The differential diagnosis for young children who present with limping as their only or predominant symptom is extensive. Imaging studies, including skeletal scintigraphy, are needed to determine the correct diagnosis for many of these children. Imaging is especially valuable for toddlers, who are unable to verbalize their complaints, provide a clear history or cooperate with physical examination. Imaging is also useful in older children, as the pain they may report associated with limping is often referred pain and does not reliably localize the underlying problem. This article describes techniques used at Children's Hospital, Boston, MA, for pediatric skeletal scintigraphy, discusses the normal age-related distribution of bone-seeking agents in the skeleton and reviews scintigraphic manifestations of relatively common conditions that can produce limping in children 1–6 yr old.

PEDIATRIC SKELETAL SCINTIGRAPHY: GENERAL CONSIDERATIONS

General considerations for preparing and handling children in nuclear medicine, which were reviewed in a previous issue of this journal (*1*), will not be repeated here except to emphasize that relatively simple immobilization techniques are sufficient and sedation rarely is required. This is true even in young children, so long as the imaging team invests time and effort in gaining the trust and allaying the anxieties of the child and the parents.

Because acute osteomyelitis is a major concern in children with limping who are referred for skeletal scintigraphy, a three-phase study is generally indicated. For three-phase skeletal scintigraphy, we administer 7.4 MBq/kg ^{99m}Tc-methylene diphosphonate (minimum: 74 MBq; maximum: 740 MBq). A radionuclide angiogram is recorded at one frame per second for 60 sec on a 128 × 128 matrix. Immediately after the radionuclide angiogram, tissue-phase images of 300,000–500,000 counts are acquired. As symptoms often are poorly localized, the entire lower extremities and the pelvis must be evaluated frequently during this phase. We obtain multiple-spot skeletal-phase images of the entire body 4 hr after radiopharmaceutical administration. We use a high- or ultrahigh-resolution collimator. Lower-resolution collimators are avoided because of the small size of the structures being studied. Images of each region of the skeleton are acquired for the same amount of time required for a 500,000-count anterior image of the thorax. If the extremities are not well visualized with this approach, 300,000-count images of the extremities are acquired. Great care must be taken in positioning the extremities symmetrically and the physes perpendicular to the detector (*2,3*). The urinary bladder should be emptied, either by voiding or catheterization, before obtaining images of the pelvis.

Resolution better than that provided by high- or ultrahigh-resolution collimation is sometimes required. This is optimally achieved with pinhole collimation (*4–6*). For pinhole imaging, we acquire images of 100,000–300,000 counts on a 256 × 256 matrix. Pinholes of 2 mm–3 mm diameter provide excellent anatomic detail without prohibitive decline in system sensitivity.

SPECT is performed in cases where its greater three-dimensional lesion localization and greater contrast relative to planar imaging are potentially beneficial. Skeletal SPECT is particularly useful in detecting focal abnormalities of the spine and pelvis. Triple-detector systems are preferred for SPECT of young children because of these systems' capacity to provide high-quality examinations in relatively short periods of time. Typically, 120 images are obtained on a 128 × 128 matrix using an ultrahigh-resolution collimator. We use a noncircular 360° orbit. Acquisition times of 20 min–30 min are practical and enable recording of total counts of 3.6 million–10 million (*2*).

We note that the above technical preferences have proven valuable over the years, but they are not offered under the pretense that they are the only appropriate methods.

BONE-SEEKING TRACERS IN THE GROWING SKELETON

Imaging specialists must be familiar with the normal distribution of tracers within the skeleton at different ages to avoid mistaking normal variations for pathologic conditions or vice versa. Minimal experience will prevent most individuals from mistaking physiologically high tracer avidity of the long bone physes for pathology. A more detailed knowledge of the scintigraphic appearance of the growing skeleton, which has been extensively reviewed and described elsewhere (*3,6,7*), is essential, however, for imaging specialists who are involved (even occasionally) in the care of children. Without such knowledge, increased tracer localization at growth centers of the small, flat and irregular bones or absent tracer localization in structures that have not begun ossification can be mistaken for abnormalities. Comparison of side-to-side symmetry of radionuclide localization is valuable in all patients, but will not prevent mistaking the normal for the abnormal in all instances. This is especially true regarding the ischiopubic synchondrosis,

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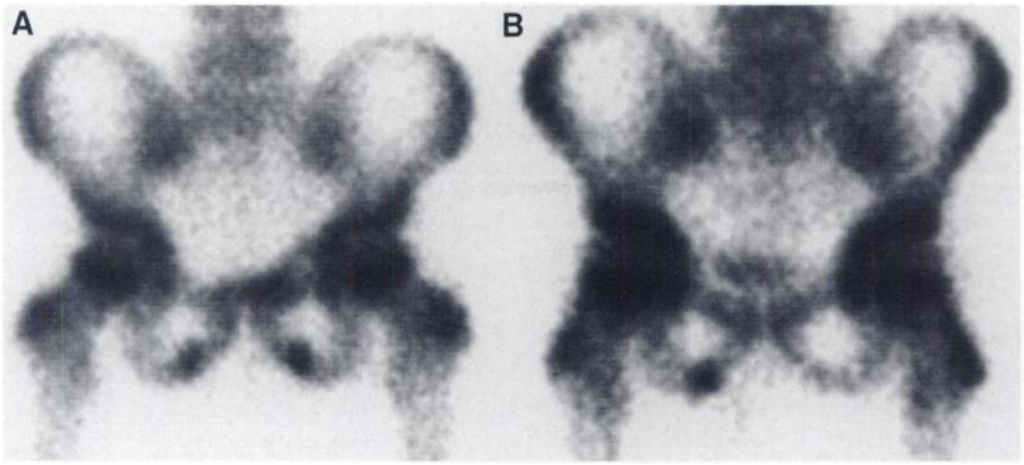

FIGURE 1. Normal ischiopubic synchondroses. The ischiopubic synchondroses of the 6-yr-old boy whose scintigraphic image is depicted in (A) appear as symmetric, well-defined foci of high tracer localization. The synchondroses of the 5-yr-old boy depicted scintigraphically in (B) have an asymmetric appearance.

the cartilaginous junction between the ischium and the inferior pubic ramus, which typically ossifies between the ages of 4 yr and 12 yr. Although they are often symmetric in appearance (Fig. 1A), the ischiopubic synchondroses commonly appear asymmetric (Fig. 1B) (*8,9*).

PATHOLOGIC CONDITIONS

A discussion of all conditions that lead to limping in childhood is well beyond the scope of this article. Instead, we review the conditions that we have most commonly encountered in children 1–6 yr old.

Acute Osteomyelitis

Acute osteomyelitis is a common pediatric problem that occurs at any age, but it most frequently affects children through 5 yr of age. Acute osteomyelitis in children is typically hematogenous in etiology. It most frequently affects the highly vascular metaphyses of the long bones and metaphyseal equivalents of the flat and irregular bones. Metaphyseal-equivalent osteomyelitis is particularly common in the pelvis, where bone adjacent to the sacroiliac joints, symphysis pubis, ischiopubic synchondroses or triradiate cartilages are most commonly affected (*10–12*).

Clinical diagnosis of acute osteomyelitis can be quite difficult. Limping or refusal to bear weight is often the only symptom. Pain, when present, is often poorly localized or referred. Swelling and tenderness often are absent. Fever may accompany other signs, may be the only sign or may be absent. Only about one-third of affected children have leukocytosis. The erythrocyte sedimentation rate (ESR) is elevated in 90% of cases but is nonspecific. Bacteriologic cultures often provide important information but are frequently negative. The infective organism, most often *staphylococcus aureus*, is identified by blood and/or bone culture in 50% to 70% of cases (*13–15*).

Radiographically, focal or confluent radiolucencies and periosteal new bone are not visualized for 7–10 days after the onset of infection (*13,16*). Earlier radiographic manifestations, such as deep soft-tissue swelling and subcutaneous edema, are neither consistently observed nor specific. In cases in which symptom duration is less than 7 days, radiographs are most useful in helping to exclude other pathologic conditions that clinically may resemble acute osteomyelitis. An important consideration regarding radiographic diagnosis is that poor symptom localization often results in the requested radiographic evaluation not including the infected bone.

Since early reports (*17–19*), skeletal scintigraphy has shown sensitivity and specificity of approximately 95% for the diagnosis of acute osteomyelitis (*20*). Typically, radionuclide angiographic and tissue-phase images of acute osteomyelitis reveal regionally increased tracer delivery and localization and skeletal-phase images demonstrate focally increased tracer localization in an infected bone (Fig. 2). An infrequently encountered pattern of decreased tracer localization, sometimes referred to as cold osteomyelitis, has also been observed (*21–23*). This may occur early in an infection when there is impaired tracer delivery due to occlusion of the regional microcirculation and relatively little osteoblastic repair. Decreased tracer localization also may be encountered later secondary to regional tamponade resulting from a subperiosteal collection or a joint effusion. Acute osteomyelitis occasionally involves multiple skeletal sites in children 1–6 yr old (*15,24*).

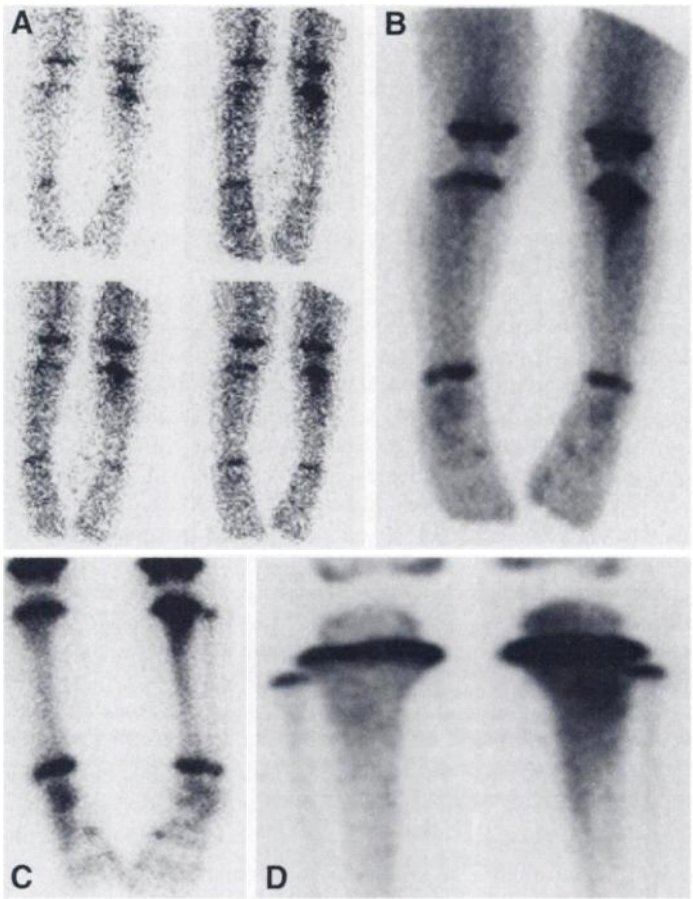

FIGURE 2. Acute osteomyelitis in a 2-yr-old girl. (A) Radionuclide angiography, (B) tissue-phase imaging and skeletal-phase imaging with a (C) high-resolution and (D) pinhole collimator show increased tracer localization in the left proximal tibial metaphysis. Also noteworthy is the absence of tracer localization in the tarsal naviculars, which have not begun ossification.

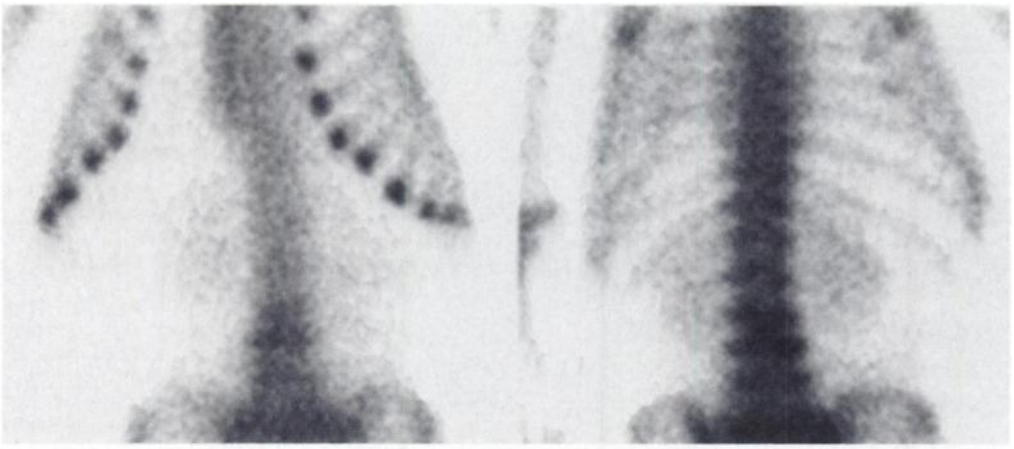

FIGURE 3. Diskitis. Anterior and posterior images depict increased tracer localization affecting the L3 and L4 vertebrae of an 18-mo-old girl. Reprinted with permission from Connolly LP, Treves ST. *Pediatric skeletal scintigraphy with multimodality imaging correlations*. New York: Springer-Verlag;1998.

This, along with poor symptom localization and differential diagnostic considerations (discussed below), requires that skeletal scintigraphy include the whole body and not be confined to a single anatomic area. False-negative scintigrams are unusual, but they may occur in the transitional period from decreased to increased localization (*25*).

Because of the successes achieved with MRI in many skeletal diseases, including acute osteomyelitis (*26,27*), comparisons frequently are drawn between scintigraphy and MRI. The relative merits of these two modalities have not been established (*28*). Published reports (*26,27*) and our experience suggest that both scintigraphy and MRI are highly sensitive and specific for detecting acute osteomyelitis in children. Important considerations, apart from relative sensitivities and specificities, include the value of the whole-body evaluation readily provided by scintigraphy but not yet practical with MRI, the need to use sedation routinely in performing MRI in children under 5–6 yr old and the benefit of the excellent anatomic detail provided by MRI. The latter is most relevant when evaluating the spine or pelvis where extension to the epidural space or pelvic soft tissues, respectively, may be the main cause of morbidity and in cases in which soft-tissue, subperiosteal or intraosseous abscess is suspected because of poor clinical response to antibiotic therapy. Additional considerations include the availability and quality of imaging equipment, radiation exposure issues and cost.

At our institution, we prefer skeletal scintigraphy for the initial evaluation of infants and children whose radiographs are normal or equivocal. In the unusual case in which a clinical question has been confidently limited to the spine or pelvis, MRI is substituted for skeletal scintigraphy. Antibiotic therapy, which may be initiated based on clinical suspicion before scintigraphy, is either continued or begun if scintigraphy is abnormal. In the occasional case of acute osteomyelitis that does not respond to antibiotic therapy within 48 hr, gadolinium-enhanced MRI is performed to determine if a localized abscess has developed (*2,6,29*). In cases in which scintigraphy is normal but clinical suspicion is high, alternatives include repeat skeletal scintigraphy after 2–3 days, ^{67}Ga-citrate scintigraphy, labeled leukocyte imaging and, if symptoms are sufficiently localized, MRI.

Vertebral Infections

The spectrum of disorders of the pediatric spine includes diskitis, vertebral osteomyelitis and epidural abscess. Diskitis most commonly affects children between the ages of 6 mo and 4 yr. It usually involves the lumbar region, with L3–L4 and L2–L3 the most common sites. Symptoms are notoriously nonspecific, and limping is a frequent presenting complaint. Hematologic evaluation often reveals only an elevated ESR and mild leukocytosis. Disk-space narrowing with or without erosion of adjacent endplates may not be apparent radiographically for 2–7 wk after symptom onset. Skeletal scintigraphy provides an earlier diagnosis, as it generally is abnormal after symptoms have been present for more than 7 days (*30,31*). Skeletal scintigraphy is particularly valuable in suggesting the diagnosis in the many cases in which symptoms are nonspecific or referred. Increased radionuclide localization involving the vertebral endplates and bodies adjacent to the inflamed disk is the typical scintigraphic manifestation (Fig. 3). With vertebral osteomyelitis, there is involvement and eventual loss of height of a vertebral body. Clinical presentation is identical to that described for diskitis. Skeletal scintigraphy typically reveals increased radionuclide localization in a single vertebra, although the scintigraphic appearance may resemble that of diskitis. SPECT increases the sensitivity of scintigraphy for the diagnosis of diskitis and vertebral osteomyelitis (*32*). Because no scintigraphic finding suggests or excludes an epidural abscess, which may complicate diskitis and vertebral osteomyelitis, MRI is recommended in all cases of pediatric vertebral infection (*29*).

Septic Arthritis and Transient Synovitis

Septic arthritis and transient synovitis are the most frequently encountered joint-related conditions in the differential diagnosis of a limping child for whom scintigraphy is requested. Beyond the neonatal period, septic arthritis most commonly affects children younger than 3 yr old and results from organisms entering a joint by either hematogenous seeding of the synovium, spread from acute osteomyelitis involving intra-articular bone or direct puncture wounds. Children affected by transient synovitis, an idiopathic condition also commonly referred to as toxic synovitis, are typically 5–10 yr old. There is overlap in the age distribution of children with these conditions, and both most commonly involve the hip or knee (*33*).

As with suspected acute osteomyelitis, imaging evaluation generally begins with radiographs. These may, however, appear normal despite the presence of a joint effusion (*34*). This is especially true of the hip, where ultrasonography has proven invaluable for identifving effusions and guiding diagnostic aspiration (*35*).

Skeletal scintigraphy of joints affected by either septic arthritis or transient synovitis may show increased periarticular localization on any or all phases of a three-phase study. In cases of hip involvement, diminished or absent tracer localization may be noted in the femoral capital epiphysis because of tamponade of intracapsular vessels by an effusion (Fig. 4). This generally normalizes after arthrocentesis. Demonstration of a

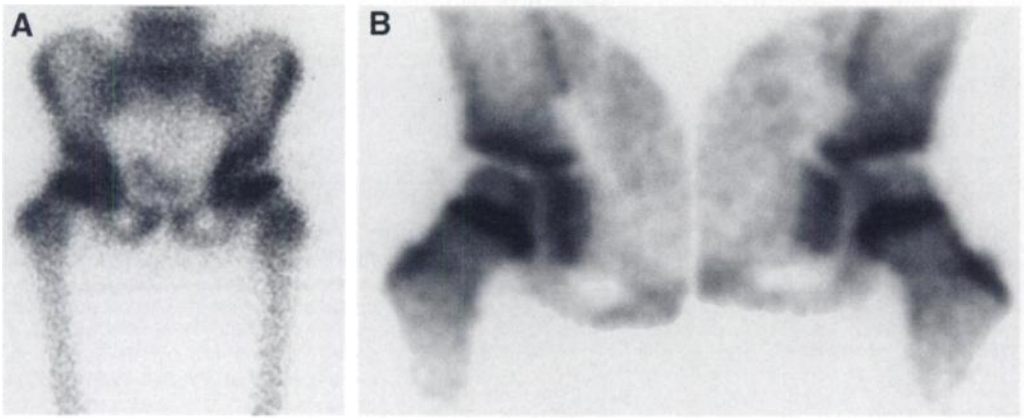

FIGURE 4. Transient synovitis with tamponade. (A) Anterior high-resolution planar imaging of a 4-yr-old girl with a left hip effusion shows asymmetrically decreased to absent tracer localization in the left femoral capital epiphysis. (B) Pinhole imaging reveals that tracer localization in the left femoral capital epiphysis is decreased relative to the normal degree of uptake demonstrated contralaterally. Reprinted with permission from Connolly LP, Treves ST, Connolly SA, et al. Pediatric skeletal scintigraphy: applications of pinhole magnification. *Radiographics* 1998;18:341–351.

focal area of increased tracer localization indicates osseous pathology, most commonly osteomyelitis and occasionally fracture, and essentially excludes a diagnosis of transient synovitis. In some cases, especially of transient synovitis, skeletal scintigraphy is normal (*36–39*). It is important to note that scintigraphic findings do not distinguish septic arthritis from transient synovitis or other conditions that affect the joints of children. Examination of joint fluid for white blood cells and organisms is required to distinguish between infectious and noninfectious etiologies.

Legg-Calvé-Perthes Disease

Legg-Calvé-Perthes disease, idiopathic avascular necrosis of the immature femoral capital epiphysis, occurs most often between the ages of 5 yr and 8 yr. Legg-Calvé-Perthes disease typically is unilateral, but it is bilateral in just over 10% of cases. It most commonly affects white male children. Limping is the most common symptom. Pain may be present and localize to the affected hip or be referred to the thigh or knee. In the majority of cases, the clinical presentation is insidious, and radiographs reveal findings such as small size, sclerosis or fragmentation of the affected epiphysis (*33,40*). Frequently, however, radiographs are obtained before these manifestations are present. In this setting and in cases in which symptoms are poorly localized and hip radiographs are not obtained, skeletal scintigraphy is highly valuable. Absence of radionuclide localization in the femoral capital epiphysis, which is best depicted with pinhole magnification (Fig. 5), is the earliest scintigraphic finding and predates radiographic manifestations by as much as 4–6 wk (*41*).

Traumatic Injuries

Lower extremity fractures are commonly associated with children beginning to walk upright. The most characteristic injury is a spiral or oblique tibial fracture (toddler's fracture). Fractures of the calcaneus and cuboid also are relatively common (Fig. 6) (*42–47*). A child with one of these injuries usually refuses or is reluctant to bear weight on the affected extremity. In many cases, symptoms may be so poorly localized that radiographs of the affected bone are not obtained. Even when the appropriate radiographic evaluation is requested, diagnostic findings may be absent or subtle. Skeletal scintigraphy, which is more sensitive than radiography for early fracture diagnosis (*48,49*), is highly valuable for diagnosis of these injuries. Tibial fractures are usually manifested as diffusely increased diaphyseal tracer localization. A spiral orientation is delineated infrequently. Focal, linear or diffuse radionuclide localization is seen with calcaneal and cuboidal fractures. Because more than one of these injuries or associated upper-extremity injuries are detected in some cases, whole-body evaluation is indicated.

Some abused children present with limping as their only or predominant reported symptom. Imaging specialists must be vigilant to this possibility and assess the specificity of any injury or injuries for this diagnosis (*50,51*). This can be problematic in children 1 yr–6 yr old, as accidental injuries are common. Whenever a question arises, close review of the injured child's history and family situation is necessary.

Osteoid Osteoma

Osteoid osteoma is a benign lesion consisting of a small round or ovoid mass, referred to as a nidus, that contains vascular channels, osteoid and osteoblasts. The majority of osteoid osteomas are located in the appendicular skeleton. Osteoid osteomas are typically manifested by pain, which is often dramatically relieved with salicylates, and are detected most often in adolescents and young adults. The occurrence of osteoid osteomas in children younger than 6 yr is well described, however (*52*). Diagnosis is particularly challenging in these young children, who may present only with limping or referred pain. Osteoid osteomas usually are detected radiographically. They may, however, escape detection when symp-

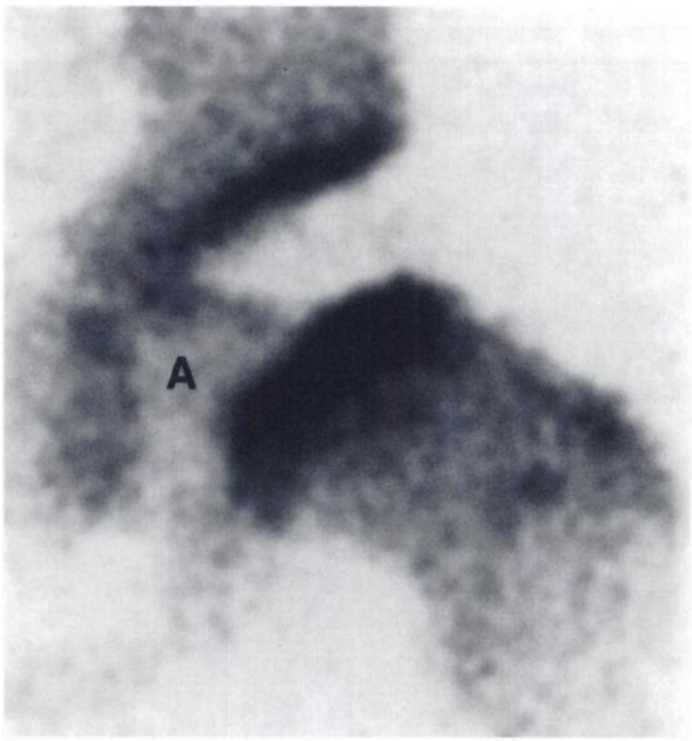

FIGURE 5. Legg-Calvé-Perthes disease. Pinhole imaging shows absence of tracer localization in the left femoral capital epiphysis of a 4-yr-old boy. Tracer localization in the acetabulum (A) should not be mistaken for preserved localization in the medial portion of the epiphysis.

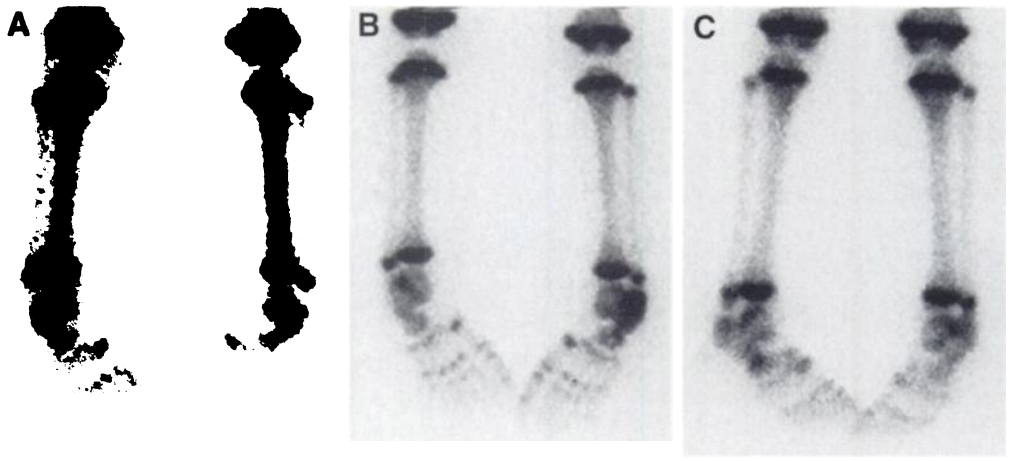

FIGURE 6. Injuries in toddlers. Skeletal scintigraphy shows increased tracer localization involving the left tibia (A), the left calcaneus (B) and the right cuboid (C) in three children 20–26 mo of age. Of note are the absence of tracer localization in the unossified tarsal naviculars and the prominent tracer localization in metatarsal and phalangeal ossification centers.

toms are poorly localized or radiographically occult, particularly when located in the femoral neck.

Skeletal scintigraphy is essentially 100% sensitive for the detection of osteoid osteomas (*53*). Prominent tracer delivery and early localization are often, but not invariably, noted on radionuclide angiography and tissue-phase imaging. Skeletal-phase images typically show well-localized, focal, marked tracer localization in osteoid osteomas. An adjacent zone of less prominently increased localization in reactive bone is often observed (Fig. 7) (*54–56*).

Systemic and Nonskeletal Diseases

Skeletal scintigraphy may be the first test to detect an abnormality and suggest a correct diagnosis in diseases such as sickle cell anemia, leukemia, neuroblastoma and Langerhans' cell histiocytosis, particularly when their initial presentation relates to skeletal symptoms, including limping (*57,58*). Even when dealing with what seems to be a relatively straightforward case, imaging specialists must carefully search for findings such as abnormal uptake at multiple sites or tracer localizing to a soft-tissue mass that would indicate the need for further evaluation. Skeletal scintigraphy reveals unsuspected urinary tract pathology in some children with nonspecific clinical presentations.

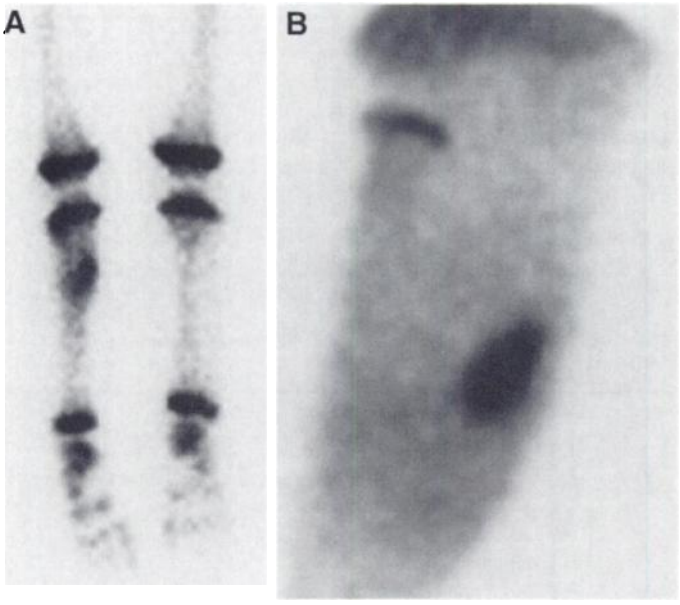

FIGURE 7. Osteoid osteoma. (A) Skeletal scintigraphy of a 4-yr-old boy shows intense tracer localization in the right tibial diaphysis medially. (B) Pinhole imaging (lateral projection) shows a well-defined focus of intense tracer localization in the tibia anteriorly with an adjacent zone of slightly increased localization.

CONCLUSION

Among imaging studies, skeletal scintigraphy is unique in its ability to simultaneously detect skeletal pathology with high sensitivity and provide a whole-body evaluation with relative ease. These characteristics make skeletal scintigraphy an essential method for evaluating young children with limping.

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