
Continuing Education Series

Radionuclide Bone Imaging in the Pediatric Patient

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This is the second of a four-part continuing education series on pediatric nuclear medicine. After reading and studying the article, the nuclear medicine technologist will be able to: (1) discuss the uptake mechanism of Tc-99m-labeled phosphate compounds used for bone imaging; (2) compare normal distribution of bone tracer in children and in adults; (3) discuss important technical considerations for performing bone scintigraphy in children; and (4) identify and discuss clinical applications of bone scintigraphy in children. Information about CEU(VOICE) credit appears immediately following this article.

Radionuclide bone imaging is widely used in nuclear medicine for both pediatric and adult patients. The development of Tc-99m-phosphate compounds coupled with new imaging equipment has made possible improved sensitivity and specificity in the recognition of a number of diseases.

We shall discuss bone-seeking radiopharmaceuticals, imaging techniques, and the spectrum of clinical applications for skeletal imaging in the pediatric population.

Radionuclide Bone Imaging

Technetium-99m-labeled phosphate compounds are the agents of choice for bone scintigraphy. As a result of a variety of clinical studies, the diphosphonates HEDP and MDP are considered the superior radiopharmaceuticals.

The mechanism of osseous localization by these radiopharmaceuticals is not clear; however, it is known that the uptake in bone is dependent upon the extent of bone formation, osseous perfusion, and bone surface area.

Bone metabolism contributes to osseous uptake. Although bones are considered to be relatively static, osteoblastic activity occurs and is increased in children. Epiphyses are most active and, unlike the adult, there is normally increased tracer uptake in these regions in children. Osseous tracer uptake also is dependent on bone blood flow.

One hypothesis for skeletal uptake involves chemisorption of the radiopharmaceutical to the hydration shell around the

hydroxyapatite crystal of bone tissue. The exact mechanism is yet to be fully understood.

Technique

The technical principles used in adult bone imaging may be applied to children with certain modifications and special considerations.

Most patients experience a certain amount of anxiety when undergoing any type of nuclear imaging. Children are no exception and may be apprehensive or even frightened. Therefore, it is imperative that the technologist make the child feel as relaxed as possible. This will make the experience comfortable for the patient and will also facilitate the technologist's work. Table 1 suggests some guidelines for handling pediatric patients in the nuclear medicine department.

Precise patient positioning is extremely important. Imprecise positioning may create artifacts. It has been reported, for example, that there is an increase in tracer uptake at the epi-

TABLE 1. The Care of Pediatric Patients: Suggested Guidelines for Technologists

To do:

- Prepare the scanning area with makeshift toys, e.g., a balloon (from an inflated surgical glove), a puppet (from a bedsheet or a pillow), cartoon drawings, etc.
- Allow the patient's parent, if present, into the scanning area.
- Be friendly and reasonable; ask the child about his or her favorite games, hobbies, etc.
- Once imaging begins, explain to the child how the oscilloscope is taking "pictures."
- Inject with the bevel of the needle face down.
- Use meticulous positioning and exposure techniques.

To avoid:

- Intimidating the child if uncooperative; above all, be patient!
 - Allowing the patient to watch while injection is being administered, unless requested.
 - Keeping the detector over patient longer than necessary.
 - Using physical restraint, unless necessary.
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physeal-metaphyseal region in children under 15 months. This increase in activity is noted when the region is compared to the adjacent diaphysis. If the extremity is inappropriately extended or if the growth plate is not perpendicular to the collimator, these regions may assume a globular shape (1). Immobilization or, if absolutely necessary, sedation may be used.

In pediatric bone imaging, a radiopharmaceutical dose of 150 $\mu\text{Ci}/\text{kg}$ of body weight (2), or 8.3 mCi/m^2 (1), is usually administered intravenously.

After injection, patients should be encouraged to drink fluids to increase tracer blood clearance and to void frequently to decrease bladder irradiation.

Static delayed images are acquired 1.5–3 hr following the injection. Anterior and posterior views are usually obtained and oblique projections are taken when necessary. Imaging routinely includes the entire axial and appendicular skeleton.

The triphasic scintigraphic technique is used when the evaluation of blood flow is desired or when the differential diagnosis of inflammatory disease is sought. Dynamic images are subsequently obtained. Static blood pool images are acquired immediately following the blood flow study. The patient then returns at the appropriate time (1.5–3 hr) for additional static images (1).

Scintillation camera images may be enhanced by use of the appropriate collimator. Since the bones of infants and children are small, routine parallel hole collimators may not be adequate. Additional information is obtained with high resolution, converging, or pinhole collimators. They are often used to magnify regions of interest, for example, hips.

Normal radiopharmaceutical distribution in children is an important consideration. This includes normal variation of increased activity in epiphyseal areas, and preferential uptake in the base of the skull, orbits, temporomandibular joints, sutures of the skull, costochondral junctions, and midshaft of the tibia (1).

Clinical Applications

Neoplasm: The earliest application of pediatric bone imaging was to evaluate bone tumors. Primary bone neoplasms such as osteosarcoma and Ewing's sarcoma cause bone destruction and repair, which affect the localization of bone-seeking agents. A bone image can be used to diagnose such abnormalities and determine their extent.

For the detection of metastatic bone disease, bone imaging has proven to be far superior to conventional x-ray (1). Metastatic bone lesions in children may arise from central nervous system neoplasms such as neuroblastoma, or leukemia, or soft tissue abnormalities such as rhabdomyosarcoma (3).

Benign bone neoplasms do not generally exhibit markedly increased uptake owing to their slow growth but are variable in their appearance. Several benign tumors including osteochondroma, nonossifying fibroma, fibrous dysplasia, and bone cyst have been clearly detected on bone scintigraphy (Fig. 1).

Inflammatory Bone Disease: Bone scans are not only more sensitive than x-ray for detection of metastatic bone disease but may also be superior in indicating injury resulting from

an inflammatory or infectious disorder. This is readily demonstrated in the evaluation of childhood osteomyelitis and in the differentiation of this disease from septic arthritis, cellulitis, bone infarction, and discitis (4,5,6). Early detection of osteomyelitis and septic arthritis is of particular importance because of their potentially crippling effects.

Symptoms of possible inflammatory disease are pain, abnormal gait, local increased heat, erythema, tenderness, and soft tissue swelling. Osteomyelitis induces a proliferation of bacteria; the response mechanism of the host causes occlusion of local blood vessels, resulting in a localized diminution in vascular perfusion (1). The earliest stage of osteomyelitis may show a normal or decreased localization of tracer at the affected site but this occurs rarely and in such unusual sites as

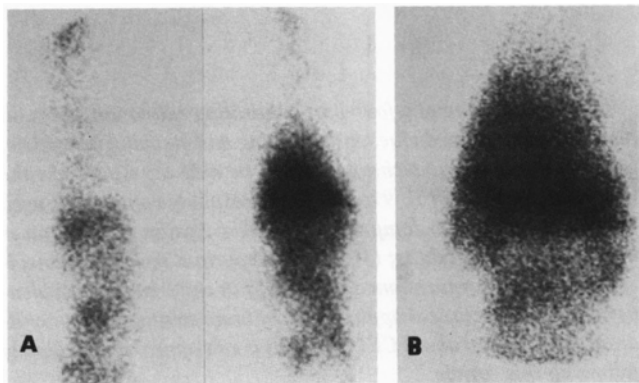


FIG. 1. Increased activity in distal tibial shaft compatible with cystic lesion on x-ray. (A) Conventional image; (B) pinhole image. Pathology: benign.

the femoral head and neck (1). The characteristic scintigraphic appearance of osteomyelitis, however, is rapid and focal radiopharmaceutical accumulation in the affected area. Abnormalities can, therefore, be detected within hours of the onset of infection. By contrast, x-rays may not detect changes for several days or weeks.

Cellulitis is an inflammatory process affecting the soft tissues; it is demonstrated by increased perfusion to the involved soft tissue (1). The differentiation between cellulitis and osteomyelitis may be made via the triphasic technique (7). In a study of 126 patients ranging in age from 8 to 18 (4), early postinfection scintiscans showed diffusely increased activity in soft tissues with no focal osseous accumulation on early or delayed scans for 38 cases of cellulitis. In 44 cases of osteomyelitis, the typical scan pattern consisted of greater focal activity in the soft tissues and bone on the immediate blood pool images, followed by increased focal tracer uptake in the delayed bone study (Fig. 2).

Bone scans are also helpful in locating infectious processes at such unusual sites as the vertebrae or sacroiliac joints (1). Discitis of the spine has also been studied in children (1,3). Involvement of vertebral bodies adjacent to the disc site may become apparent with bone images before x-ray evidence becomes manifest.

It is often clinically difficult to differentiate osteomyelitis from infarction in patients with sickle cell disease. The bone image may be of benefit in these cases. Yet there are limitations.

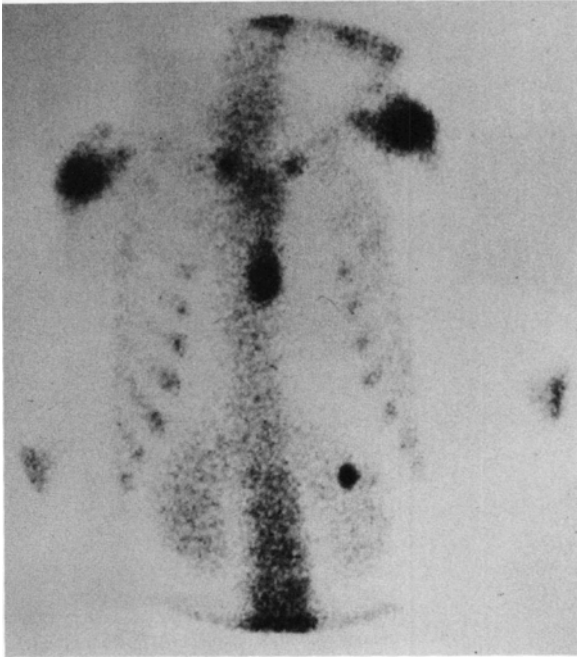


FIG. 2. A 7-year-old boy with focal osteomyelitis of the sternum.

The image should show increased tracer uptake in the case of osteomyelitis, while infarction will demonstrate decreased uptake. In patients with sickle cell disorder, however, an increase in perfusion will occur rapidly following infarction. This hypervascularity has been noted to persist for several days following onset of symptoms. Thus, a careful scrutiny of a patient's clinical history and physical findings is necessary. Majd suggests that the diagnosis of infarction may be differentiated from osteomyelitis on the basis of either or both of the following findings:

- (1) The absence of a typical increase in blood pool activity; or
- (2) A heterogeneous uptake on the delayed scan (4).

The diagnosis of neonatal osteomyelitis is more difficult. To better facilitate the diagnosis, the technologist must give the neonate special attention. Symmetrical positioning is imperative and the use of a pinhole or converging collimator is recommended.

In isolated septic arthritis, the bone image may appear normal since this disorder affects the joint space and does not localize the bone-seeking radiopharmaceutical. However, there is usually increased activity in the periarticular regions on immediate imaging and in the juxta-articular bone on the delayed images (1). There is moderate localization around the affected joints with the accompanying cellulitis and hyperemic response usually associated with a septic process (1,8,9). Gallium-67 citrate may be used in those cases where septic arthritis is suspected and joint images have been negative.

In difficult cases, specifically suspected osteomyelitis, Lisbona and Rosenthal (9) and others (10,11) have suggested use of gallium-67 citrate to give a more confident diagnosis of osteomyelitis when the infection is adjacent to a growth plate (12).

Trauma: Direct trauma to the bone initiates a reparative

response that produces an area of increased tracer accumulation. Depending on the extent of injury and the patient's capability for physiologic bone repair, the bone image will continue to demonstrate increased uptake for months, sometimes years, following the trauma.

The diagnosis of trauma is usually made with traditional x-rays. However, there are instances when bone scintigraphy is preferred. These include sites of occult injury involving the vertebrae and carpal and tarsal bones.

An additional application for bone imaging involves stress fractures. Unlike fractures sustained through direct trauma, stress fractures do not appear on x-rays in the early stages. Stress fractures occur as a result of bone weakening from extensive muscular or mechanical activity. There are also mechanical disturbance in trabeculae that occur in normal bone subjected to repeated episodes of minor stress as noted by Geslien et al. (13).

Stress fractures studied with bone scintigraphy generally involve older children and young adults. The injuries are often associated with increased physical activity (Fig. 3). The areas most commonly affected are knees, tibiae, fibulae, ankles, and feet. Scintigraphic findings demonstrate intense uptake on both immediate and delayed imaging. Traditional x-rays are inconclusive in the early stages. The nuclear medicine findings are valuable for the diagnosis and early treatment of the injury, thereby preventing further damage (14,15).

In cases of child abuse, x-rays may not be as sensitive as bone scans to evaluate the subtle fractures encountered.

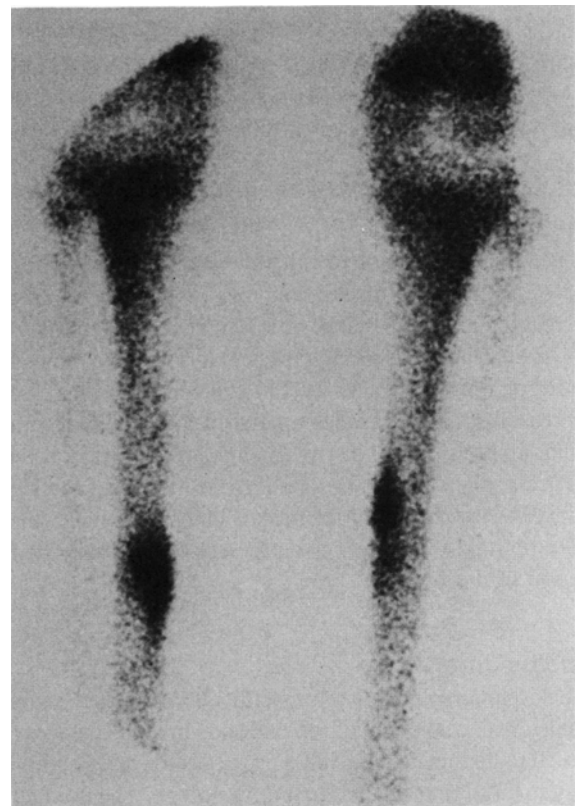


FIG. 3. A young jogger with complaints of bilateral lower extremity pain. Findings consistent with stress fractures of both tibiae of varying ages.

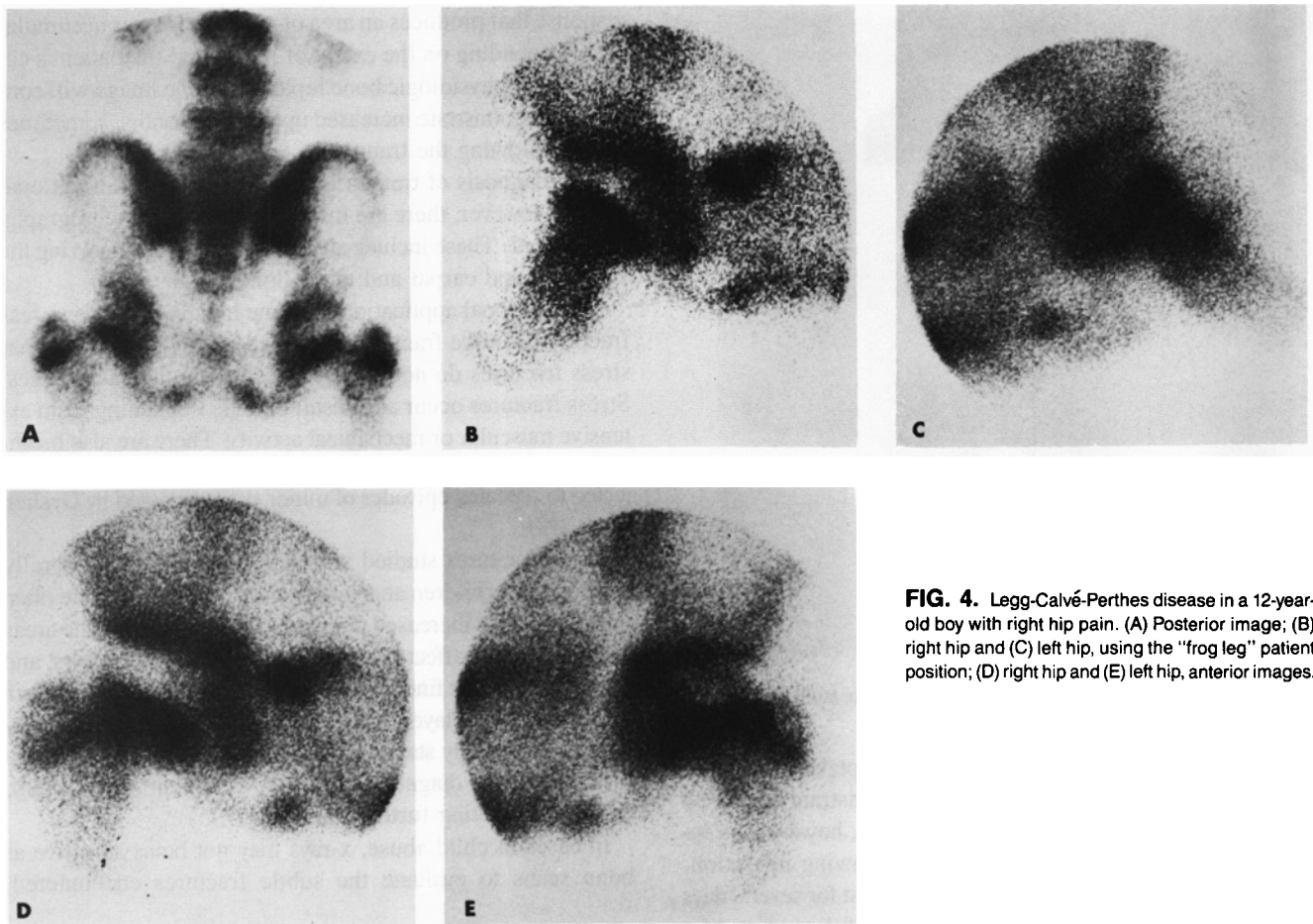


FIG. 4. Legg-Calvé-Perthes disease in a 12-year-old boy with right hip pain. (A) Posterior image; (B) right hip and (C) left hip, using the "frog leg" patient position; (D) right hip and (E) left hip, anterior images.

Sfakianakis et al. studied 44 children to evaluate use of bone imaging in the early recognition of child abuse (16). There were disparities between scans and x-rays in the long bones, ribs, and mandible. It is, therefore, recommended that bone scans be used in conjunction with x-rays for the evaluation of the battered child.

The bone scan is a most valuable study in the diagnosis of Legg-Calvé-Perthes disease and also in the determination of the revascularization status of the involved epiphysis.

Avascular necrosis is a hypovascular lesion that appears as an area of diminished activity. In Legg-Calvé-Perthes disease, an area of decreased tracer uptake in the proximal femoral capital epiphysis (Fig. 4) usually appears on the bone scan. The acetabular region may demonstrate increased uptake secondary to a synovitis. With femoral head involvement, the use of the pinhole collimator is extremely valuable for demonstration of the lesion.

Conclusion

The evolution of bone-seeking radiopharmaceuticals and the concurrent development of sophisticated imaging devices have enabled radionuclide bone imaging to become an effective modality for studying osseous pathophysiology. The use of bone scintigraphy in pediatrics has grown in the past and will undoubtedly continue to do so in the future.

Acknowledgments

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