Subchrondral Bone Infractions in Acute Ligamentous Knee Injuries Demonstrated on Bone Scintigraphy and Magnetic Resonance Imaging

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Bone scintigraphy is used to detect radiographically silent fractures. Magnetic resonance imaging (MRI) is currently used to screen knee injuries for cartilage and ligament damage. MRI also delineates bone marrow and fractures. We investigated the bone scintigraphic findings in patients who had subchondral bone injuries demonstrated on MRI. Thirteen patients underwent MRI, three-phase bone scintigraphy with SPECT, and arthroscopic surgery after sustaining acute traumatic hemarthrosis of a knee. They all had clinically unsuspected subchondral bone injuries demonstrated on MRI with normal radiographs and normal overlying articular cartilage at arthroscopy, consistent with occult fractures. All showed focal bone repair on scintigraphy. Two of the 13 patients showed additional bone injuries only on bone scan. Two other patients scintigraphically showed focal bone repair at the medial femoral condyle due to avulsion of the medial collateral ligament. SPECT was easier to interpret than multi-view planar imaging. Bone scintigraphy confirms subchondral fractures demonstrated on MRI but also demonstrates ligament avulsion injuries and additional more subtle bone injuries.

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Bone scintigraphy is commonly used to detect fractures in patients with negative radiographs and clinical signs and symptoms consistent with a fracture. Bone scintigraphy is generally regarded as sensitive but nonspecific.

Magnetic resonance imaging (MRI) is currently being used to screen patients with acute knee injuries for ligamentous disruption and cartilage damage. In contrast to arthroscopy, MRI is noninvasive. MRI is a relatively new modality, however, because of its ability to delineate bone marrow, it may accurately detect bone fractures. At least six centers, in eight publications to date, have serendipitously demonstrated bone injuries on MRI in a subset of patients with acute knee injuries (*1–8*). These bone abnormalities were seen in addition to ligamentous and cartilaginous injuries of which anterior cruciate ligament tears were the most frequent (approximately 85%).

Demonstration of subchondral bone injuries may be important clinically. It is well recognized that a minority of patients with normal cartilage undergo menisectomy and later develop debilitating cartilage destruction. This may be due to altered weight-bearing mechanics in the knee or to disruption of the subchondral elements under the cartilage. Extended prohibition of weight-bearing may prevent collapse of the subchondral cancellous bone buttress in this subset of patients with knee injuries.

We conducted a blinded prospective study to determine the bone scintigraphic findings in patients who sustained an acute internal derangement of the knee and subchondral fracture on MRI. Thus, MRI was the "gold standard" for a bone injury. All patients underwent surgery which served as our "gold standard" for soft-tissue injury or injury to cartilage. Soft-tissue injuries included avulsion of ligament insertions or ligament disruptions.

METHODS

Patients

Thirteen athletic patients, 11 males, 2 females, aged 16–53 yr, 26 ± 10 yr (mean ± s.d.) sustained acute traumatic hemarthroses of the knee. They underwent immediate anterior-posterior, lateral and oblique radiographs which were negative for fractures. Within days of the injury, they underwent MRI, bone scintigraphy and arthroscopic confirmation and repair or reconstruction of ligamentous disruption.

MRI

MRI imaging was performed with a GE Signa imager at 1.5 T (GE Medical Systems, Milwaukee, WI). Coronal and sagittal imaging of contiguous sections 5 mm thick was performed with a repetition time of 500 msec, an echo time of 20 msec, a 16-cm field of view, a 256 × 128 matrix, and one excitation. In addition, the anterior cruciate ligament (ACL) was evaluated with oblique

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sagittal T2-weighted images (2,000/30, 60 [repetition time msec/echo time msec]) as described previously (9).

Bone Scintigraphy

Imaging was performed on a GE 400A digital tomographic camera-computer system (GE Medical Systems, Milwaukee, WI). Following injection of 15 mCi (555 MBq) of ^{99m}Tc-MDP, a three-phase bone scan was performed with a dynamic flow study, blood-pool images, and 2-hr delayed static images in the anterior, posterior, medial and lateral projections. SPECT was also performed using a circular orbit and 64 20-sec radial images with reconstructed images in the axial, coronal and sagittal planes. Scintigraphy was interpreted without knowledge of the MRI results and vice-versa.

SPECT images of the knee were obtained from an additional seventeen subjects of similar age, mean age 27 yr (range 18–44 yr), without any knee complaints. They were referred for bone scintigraphy to rule out shin splits or stress fractures of the lower legs or feet. These subjects served as controls.

Surgical Confirmation

All patients underwent clinical examination under general anesthesia and arthroscopic surgery by one surgeon (PJF). Preoperatively, the surgeon had access to the MRI and bone scintigraphy results. Surgery verified ligamentous injury, e.g., complete or partial tears of the anterior or posterior cruciate ligaments or avulsion of the medial collateral ligament. The cartilage was examined visually in the medial, lateral and patellofemoral compartments.

RESULTS

Bone scintigraphy confirmed the MRI finding of a subchondral fracture in all 13 patients (Table 1) (Figs. 1 and 2). However in two patients, bone scintigraphy demonstrated additional bone lesions not seen on MRI (Patients 2 and 12 in Table 1). These extra bone lesions on bone scintigraphy were less intense than the MRI-documented bone lesions. In addition, two patients showed focal increased uptake peripherally at the medial femoral condyle which was shown at MRI and surgery to be the site of avulsion of the insertion of the medial collateral ligament (Patients 6 and 12 in Table 1). Patient 12 is illustrated in Figure 3 and shows this focal increased activity at the medial femoral condyle at the confirmed site of avulsion of the medial collateral ligament. These avulsions tended to be more focal, more peripheral and less intense on bone scintigraphy than the MRI-documented subchondral bone injuries but were otherwise identical. Both patients with avulsion of the insertion of the medial collateral ligament showed a triad of bone scintigraphic findings: faint uptake in the medial femoral condyle and "kissing" adjacent lesions in the lateral femoral condyle and lateral tibial plateau (Fig. 3).

Moderate to severe hyperemia was seen in the majority of the patients (11/13). Pure *anterior* cruciate ligament tears without an associated posterior cruciate tear demonstrated *posteriorly* located tibial bone injuries in nine patients. Both patients with pure *posterior* cruciate tears demonstrated *anterior* tibial bone lesions. When there were multiple bone lesions, they could be easily seen on the coronal slices of the SPECT images as illustrated in Figure 2. In 10 patients, all scintigraphic findings were seen on the planar images. In two patients, the planar images

TABLE 1
MRI Findings in Subchrondral Fractures

Patient no.	Mechanism	Bone scan abnormalities	MRI bone abnormalities	Surgical diagnosis
1	All-terrain vehicle	LAT TIB	same	ACL
2	Baseball	LAT FEM LAT TIB	LAT FEM†	ACL/MCL
3	Skiing	LAT FEM/TIB	same	ACL/LM
4	Hockey	LAT FEM/TIB	same	pACL
5	Skiing	LAT FEM/TIB & MED TIB	same	ACL/LM
6	Squash	LAT FEM/TIB MED FEM*	same	ACL/MCL
7	Snowmobile	LAT FEM/TIB	same	ACL/LM
8	Skiing	LAT TIB	same	ACL
9	Baseball	MED and LAT TIB	same	PCL/LM
10	Soccer	MED and LAT TIB	same	PCL/pACL/MCL
11	Hockey	LAT FEM and MED TIB	same	ACL
12	Football	LAT TIB LAT FEM MED FEM*	LAT TIB†	ACL/MCL
13	Fall	LAT TIB	same	ACL/PCL/LM

LAT = lateral, MED = medial, FEM = femur, TIB = tibia, ACL = anterior cruciate ligament tear, pACL = partial ACL tear, MCL = medial collateral ligament tear, PCL = posterior cruciate ligament tear, and LM = lateral meniscal tear.

Figures 1, 2, and 3 illustrate Patients 10, 11, and 12, respectively.

* Avulsion of femoral insertion of medial collateral ligament evident on bone scan.

† Bone infraction on MRI demonstrated only at this location not at other abnormal scintigraphic sites.

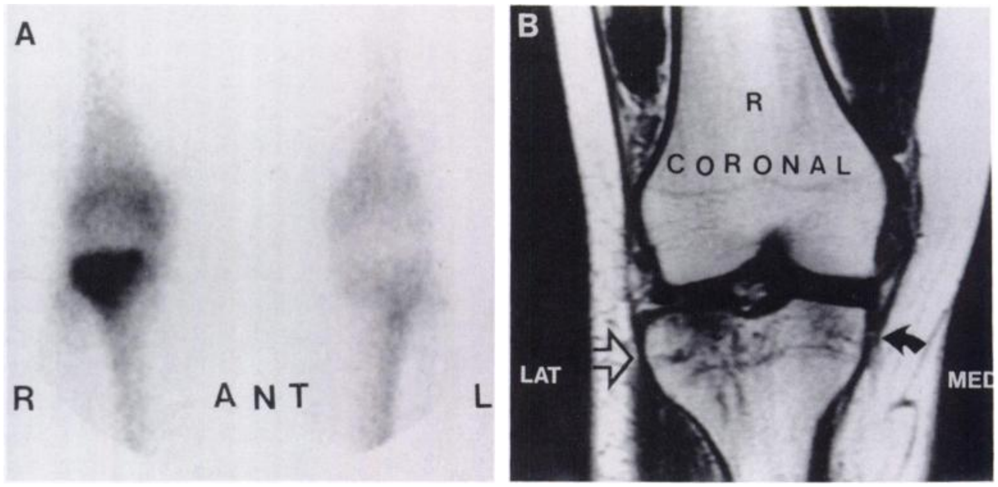

FIGURE 1. Patient 10. (A) Anterior bone scintigraphy demonstrates intense periarticular uptake throughout the proximal tibia, involving the lateral tibial plateau more than the medial. (B) MRI confirms an extensive subchondral bone injury identical to the bone scintigraphy. The lateral tibial plateau lesion (hollow arrow) is more extensive than the medial tibial plateau lesion (curved arrow).

showed diffuse uptake about the knee joint due to profound hyperemia, whereas the SPECT image showed a focal bone lesion (Patients 2 and 8). SPECT demonstrated an additional lesion in another patient (Patient 3). Planar image interpretation required careful inspection of all four planar views (anterior, posterior, medial and lateral), particularly when multiple lesions were present (Fig. 2). If SPECT images were not available, the lateral projection

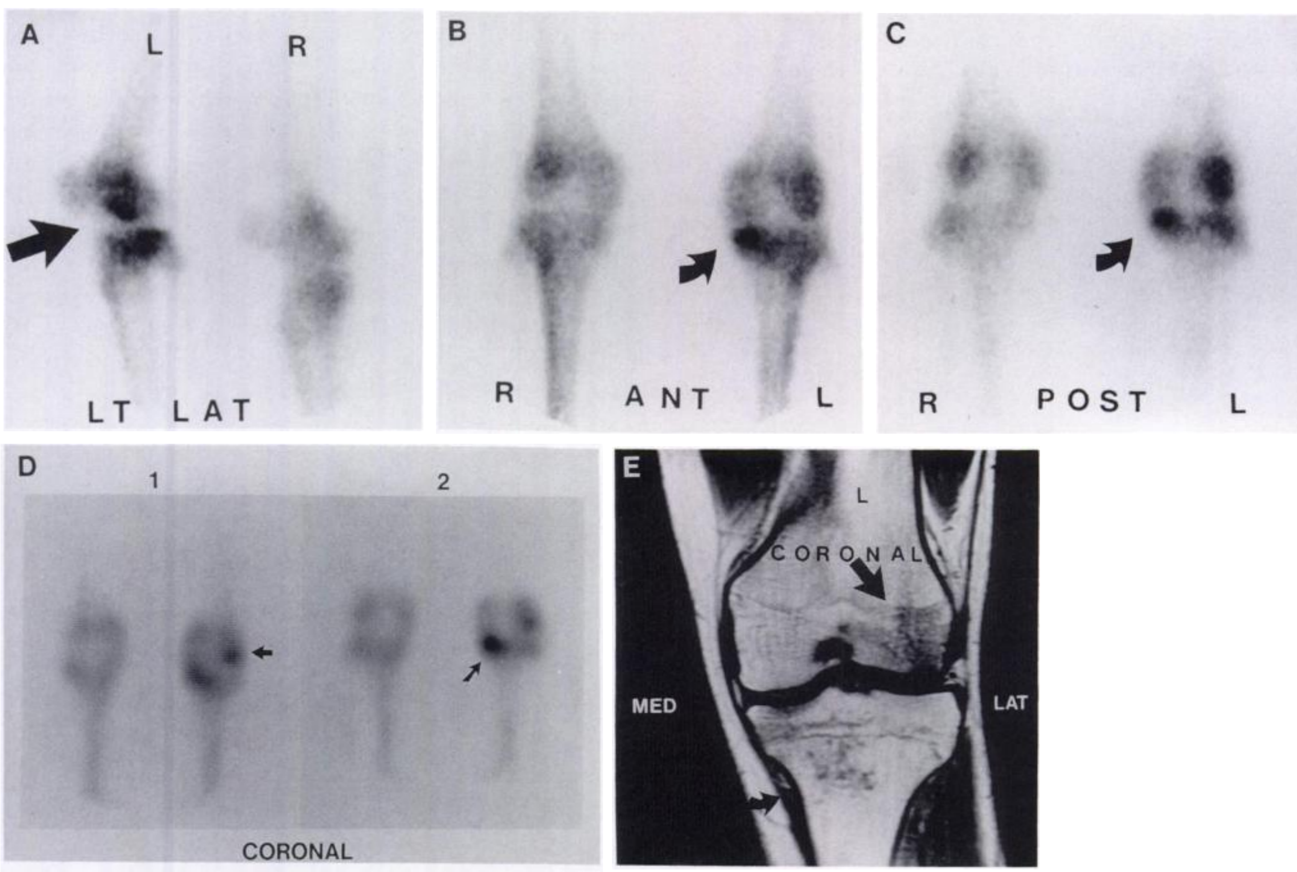

FIGURE 2. Patient 11. (A) Lateral bone scintigraphy demonstrates an obvious focal lesion in the subchondral bone in the weight-bearing region of the lateral femoral condyle (arrow). This is the only planar image that demonstrates the focal femoral lesion. (B) Anterior bone scintigraphy demonstrates an additional lesion in the left medial tibial plateau (curved arrow). There is diffuse periarticular increased uptake about the knee but no definite lateral femoral condyle lesion is identified in the anterior projection. (C) Posterior bone scintigraphy has been mirror-imaged to facilitate comparison. The medial tibial plateau lesion (curved arrow) has been again demonstrated along with diffuse increased periarticular uptake. The focal lateral femoral condyle lesion is not appreciated. (D) Coronal SPECT demonstrates the left lateral femoral condyle lesion on cut #1 (arrow) and the medial tibial plateau lesion on cut #2 (curved arrow). The SPECT image is probably easier to interpret. (E) Coronal MRI confirms the lateral femoral lesion (arrow) and the medial tibial plateau lesion (curved arrow).

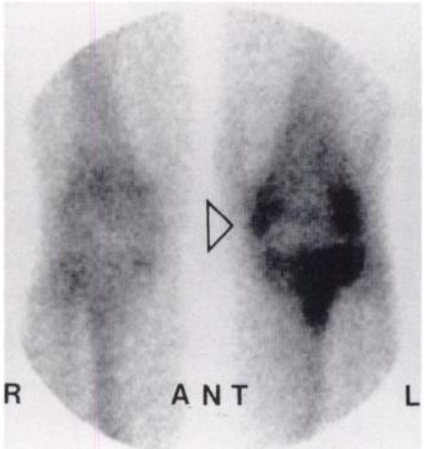

FIGURE 3. Patient 12. Anterior bone scintigraphy demonstrates a large intense lesion in the left lateral tibial plateau which was confirmed on MRI. The less intense lesion in the lateral femoral condyle was not seen on MRI. The faint but definite focal uptake peripherally in the medial femoral condyle (arrow head) was an avulsion of the insertion of the medial collateral ligament on MRI and confirmed at surgery. The classic triad of avulsion of the medial collateral ligament with opposite "kissing" lesions laterally is obvious on scintigraphy. Knowledge of this type of injury facilitates scintigraphic interpretation, however, avulsion injuries could be misinterpreted as fractures.

would be mandatory to demonstrate lateral femoral articular lesions that occur with anterior cruciate ligament tears (Fig. 2). Posterior planar views were required in one (Patient 2) and helpful in another (Patient 5) to demonstrate posterior tibial plateau lesions.

The seventeen control subjects with asymptomatic knees who underwent SPECT imaging of the knees did not show any abnormality in the femur or tibia in the knee region.

DISCUSSION

Osteoarthritis (idiopathic osteoarthrosis or primary hypertrophic osteoarthritis) is a debilitating disease due to degeneration of articular cartilage. Predisposing conditions include: obesity, occupations associated with chronic repetitive trauma (e.g., pneumatic drill workers and veteran military parachutists) and sports associated with impaction injuries (e.g., football, soccer, sport parachutists, and weight-lifting). It is distressing to demonstrate normal articular cartilage on arthroscopy immediately after a knee injury and to later demonstrate cartilage destruction. Knee injuries with negative radiographs frequently demonstrate subchondral infractions on MRI. At arthroscopy, the majority of these patients reveal normal overlying cartilage. Systematic probing of the articular cartilage may show easy depression of the cartilage due to insufficient osseous infrastructure in some of these patients. If subchondral fractures could be accurately detected, an altered postoperative rehabilitation program could be prescribed to the patient in an attempt to prevent collapse of the subchondral bone. This might include a partial or non-weight-bearing regimen. Thus, the ability to reliably detect subchondral bone injuries could affect clinical management.

There is experimental evidence that osteoarthritis can be produced from repetitive impact loading at physiological levels (*10,11*). Antecedent to the development of experimental osteoarthritis is the occurrence of subchondral fractures in the cancellous bone resulting in reduced bone compliance. Cartilage, muscles and cancellous bone absorb the compression forces during impaction (*11*). After repair of cancellous bone fractures, the rigid callous (*10*) causes the cartilage to absorb more of the force. Loss of the bony foundation beneath the cartilage would also cause abnormal stress on the cartilage.

MRI is currently used at some centers to screen acute knee injuries for ligamentous tears and avulsions as well as meniscal tears. At least six centers have demonstrated, in a subset of acute knee injured patients, incidental subchondral bone injuries (*1–8*). To date, none have correlated these MRI bone injuries to bone scintigraphy.

Bone scintigraphy is widely available and is extensively being used to screen for radiographically silent fractures. It is generally regarded as sensitive but nonspecific. Focal bone repair can occur in a variety of conditions that can be seen in association with knee trauma. Bone scintigraphy has been used extensively to assess chronic knee pathology (*12,13*). It is well known that degenerative joint disease is demonstrated scintigraphically before radiographic changes are evident (*12*). Focal increased bone repair has been demonstrated at chronic torn menisci presumably from local synovitis (*12–17*). Osteochondritis dissecans occurs in patients who frequently have a history of trauma (*18,19*); the characteristic location of these lesions should assist differentiation from subchondral fractures. Osteochondritis dissecans frequently occurs at the lateral aspect of the medial femoral condyle in a non-weight-bearing region. In contrast, the subchondral infractions occur in weight-bearing regions usually at the lateral compartment. One transient knee lesion that is scintigraphically indistinguishable from subchondral fractures is spontaneous osteonecrosis of the knee (*20*). However, these lesions occur in older females and usually are not associated with significant trauma.

We investigated the scintigraphic appearance of MRI-documented subchondral fractures in patients with acute knee injuries. One interpretive problem with bone scintigraphy that we encountered was the presence of gross hyperemia. Identification of an island of increased bone repair in a sea of generalized increased bone activity was particularly difficult in a few cases on planar imaging. This problem was not encountered on SPECT imaging. All the MRI-documented bone infractions demonstrated intense focal increased bone repair on SPECT and almost all on multi-view planar imaging. Some centers only obtain anterior planar views of the knees. We found that four views of the knees, i.e., anterior, posterior, medial and lateral views, were required to see the MRI-demonstrated lesions. The lesions were more easily interpreted with SPECT. Avulsions of ligamentous insertions (medial collateral ligament) also demonstrated focal increased bone repair on scintigraphy. This could be confused with a subchondral fracture. Indeed, prospectively, we misinterpreted these avulsion injuries as minor bone fractures. Appreciation of its peripheral location at the medial aspect of the knee and its association with opposite "kissing" lesions laterally in the femoral condyle and tibial plateau may assist in interpretation. This triad of injuries is exemplified by the classic football knee injury where the player is tackled from the lateral aspect of the knee. The player's foot is implanted on the ground. The impact causes a forced valgus angulation at the knee with avulsion of the medial collateral ligament and an impaction injury laterally on both sides of the knee. Bone scintigraphy detected all of the MRI lesions, however, some additional subtle bone lesions were detected only on scintigraphy. These additional subtle bone lesions could not be confirmed with another independent modality, but their location was appropriate for the type of sustained trauma.

Bone scintigraphy can detect radiographically-silent, MRI-demonstrated, subchondral bone infractions as well as avulsions of ligaments and more subtle MRI-silent bone injuries.

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