Skeletal Radiol (1987) 16:121–127

Skeletal Radiology

Magnetic resonance imaging in the evaluation of suspected osteonecrosis of the knee

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Abstract. Magnetic resonance imaging (MRI) was performed on 19 patients with suspected or proven osteonecrosis of the knee. The results were compared to radionuclide and plain radiographic studies when possible. The patients were grouped into one of three categories: patients with disease predisposing them to osteonecrosis (e.g., systemic lupus erythematosus (SLE), steroid use, and renal transplants), older patients without risk factors with acute onset of symptoms, and patients with knee pain months or years following trauma.

In six patients with symptoms and predisposing diseases, MRI was abnormal in four cases, all of whom had bilateral abnormalities. In the ten older patients with classical symptoms, MRI was abnormal in seven, and bilateral abnormalities were present in three patients. The three patients with a history of antecedent trauma had normal MRI studies. Two patients with history and scintigraphic evidence of osteonecrosis had negative MRI scans. MRI may be of value in patients with suspected or proven osteonecrosis of the knee by demonstrating bilateral disease in patients with unilateral symptoms, showing the extent of involvement, and establishing the presence or absence of bone marrow changes in patients with positive bone scans and negative plain films.

Key words: Magnetic resonance – Necrosis, bones – Knees

Early experience has demonstrated that magnetic resonance imaging (MRI) is very sensitive in the detection of avascular necrosis (AVN) of the femoral head [15, 17, 18, 24, 25]. To date, little has been written concerning the MRI appearance of osteonecrosis (ON) of the knee. We describe our experience using MRI in the diagnosis of ON of the knee, correlating our findings with plain films and radionuclide images where possible.

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Materials and methods

Clinical records and imaging studies of 19 patients with suspected ON of the knee were obtained for review. These patients fell into one of three groups: (A) a young group ($N=6$) with well-recognized predisposing factors for ischemic necrosis of bone; (B) an elderly group ($N=10$) with acute onset of symptoms and no clear-cut risk factors for AVN; and (C) a group of otherwise healthy patients who experienced pain following trauma to the knee ($N=3$). The imaging studies reviewed included plain radiographs of the knee (PF), radionuclide bone scintigraphy (RN), and MRI. In some cases, RN and/or PF studies were performed elsewhere, and only the interpretations were available.

PF findings were graded according to a modification of the staging system of Koshino et al. [11], whose classification was originally applied only to the femoral condyle. Stage 1 indicates no plain film evidence of ON. In stage 2, there is a discrete area of radiolucency in the subchondral bone. In stage 3, a sclerotic halo surrounds the radiolucency, and there is associated subchondral collapse. In stage 4, knees demonstrate secondary osteoarthritis.

MRI was performed utilizing a General Electric Signa 1.5 Tesla superconducting magnet. All patients were studied with spin-echo pulse sequences. In most cases, both a short pulse sequence, "T1 weighted," (TR ranging from 400 to 800 ms; TE 20 to 40 ms) and a long pulse sequence, "T2 weighted," (TR 2,000–2,500 ms; TE 60–80 ms) were utilized. In seven patients, additional images were obtained using simple proton spectroscopic phase-contrast imaging, also known as "echo-offset," according to the technique described by Dixon [7] (herein "phase-contrast").

Coronal images of the knees were obtained in all but one patient; most patients were also scanned in the sagittal and/or transverse planes. Examinations were performed with a surface

Table 1. Results of imaging studies

Patient	PF (staging)[a]	RN	MRI
Group A			
J.G.	2 R MTP	NA	–
S.S.	3 L MFC	+ L MFC	+ B MFC, R MTP
E.O.	3 L MFC	+ B Knees	+ B Knees, diaphyses
R.A.	1 Infarcts	+ B Knees	+ B Knees, diaphyses
C.O.	2 R MFC, LFC, MTP	+ L LFC, R MFC	+ B MFC, LFC, LTP
C.L.	NA	+ L MTP, R MTP	–
Group B			
G.W.	1	+ L MFC	–
F.R.	1	+ R MTP, LTP	+ R MTP
M.Y.	3 L MFC	+ L MFC, MTP	+ L MFC, MTP
J.S.	3 L MFC	+ L MFC	+ L MFC
L.S.	1	+ L MTP	–
S.L.	NA	+ L LFC	+ L LFC
M.F.	NA	+ L MFC	+ B Knees, diaphyses
R.B.	1	+ L M Knee	+ R MTP, MFC, L MTP
M.M.	2 R MFC	NA	+ R MFC
B.H.	4 R MFC	NA	+ B MTP, R MFC
Group C			
E.M.	NA	–	–
R.O.	1	+ R MTP	–
A.C.	1	+ L MFC	–

L = Left; R = Right; B = Bilateral; PF = Plain radiographs; RN = Radionuclide bone imaging; MFC = Medial femoral condyle; LFC = Lateral femoral condyle; MTP = Medial tibial plateau; LTP = Lateral tibial plateau; – = Normal; NA = Not available

[a] Modified from the rating system by Koshino et al. [11]: 1 = No evidence of ON; 2 = focal subchondral lucency without sclerosis; 3 = subchondral lucency with surrounding zone of sclerosis; 4 = secondary degenerative changes

coil in seven patients, with a body coil in nine patients, and with both coils in three patients.

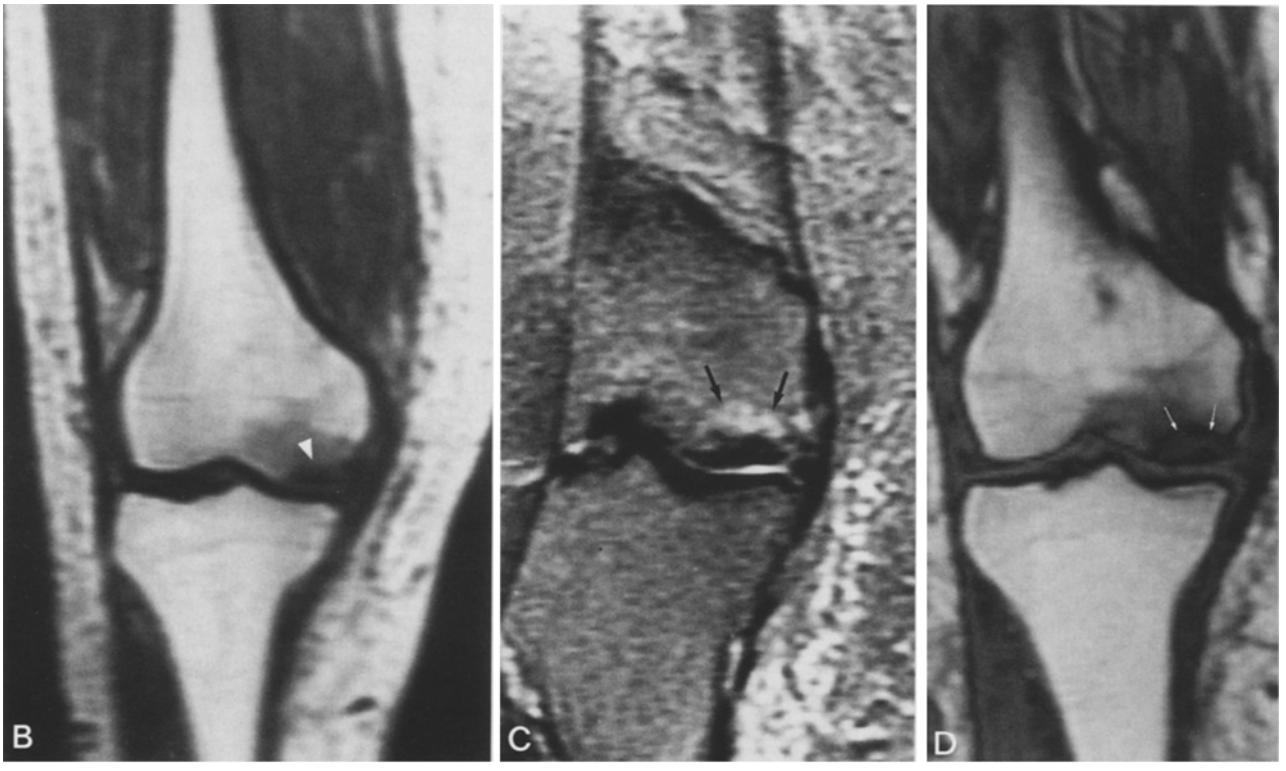
Results

Results are summarized in Table 1. MRI revealed abnormalities in 11 of the 19 patients studied. The typical finding was one or more discrete areas of low signal in the subchondral portion of the femoral condyle and/or tibial plateau on both the short and long pulse sequences (Fig. 1b). The margins of the lesions demonstrated a very low signal on short pulse sequences (Fig. 2b). In 5 of the 11 patients (45%), the margins of the lesions became hyperintense on the long pulse sequences (Figs. 1c, 2b, 3b). In some patients, only the periphery of the lesion was low signal on short pulse sequences, the central portion being isointense with the surrounding normal marrow (Fig. 2). Phase contrast images were obtained in seven patients. In two patients there was no evidence of ON on either imaging sequence. In the other five patients, the use of phase contrast made the areas of osteonecrosis much clearer (Fig. 1d).

In three patients, including two with systemic lupus erythematosus (E.O., R.A.), the areas of abnormality extended into the adjacent diaphyses of the femur and/or tibia (Fig. 3). Nine patients with positive MRI studies also had RN scans performed, all of which were also positive. However, in four of the nine, MRI revealed more extensive involvement than did RN (Fig. 4). Although one patient (F.R.) showed bilateral abnormalities on RN, only the right knee was studied by MRI.

Of the 19 patients studied, MRI demonstrated no evidence of ON in 7 cases. Two patients (G.W., J.G.) had nondiagnostic examinations as a result of suboptimal surface coil placement. Three patients had post-traumatic knee pain and no other evidence of osteonecrosis (group C: E.M., R.B., A.C.). Of the remaining 14 patients, there were two

Fig. 1A–D. An 81-year-old woman (M.M.) with a 1-month history of right-sided knee pain.
A Radiograph of the right knee shows a small subchondral lucency of the medial femoral condyle with a surrounding zone of sclerosis (*arrowhead*).
B Coronal image (TR = 600 ms; TE = 20 ms) of the right knee demonstrates a discrete area of low signal in the medial femoral condyle (*arrowhead*). There is an area of low signal in the periphery of the discrete lesion.
C Coronal image (TR = 2,500 ms; TE = 80 ms) shows a high signal margin (*arrows*) around the lesion probably representing edema.
D With phase contrast technique, the area of abnormality is more clearly defined (*arrows*). Note the torn medical meniscus



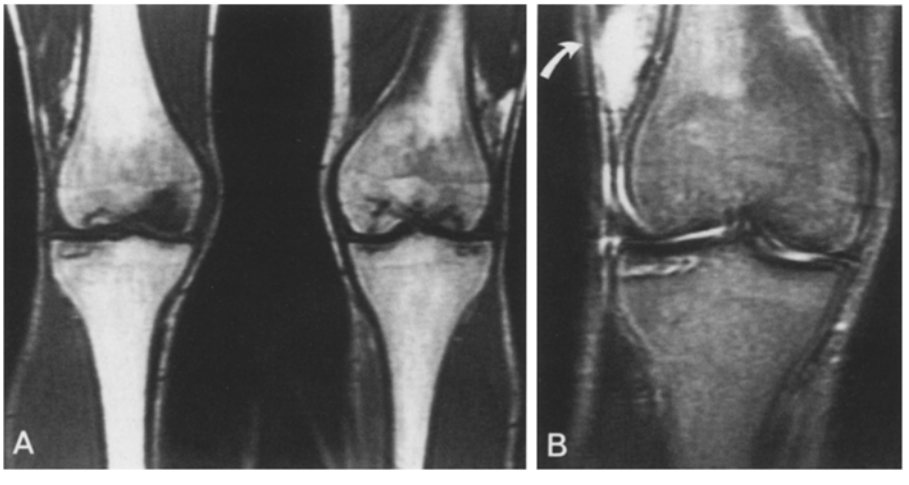


Fig. 2A, B. A 23-year-old man (C.D.) receiving corticosteroids for a renal transplant.
A Coronal image of both knees (TR = 600 ms; TE = 20 ms). There are multiple lesions involving both knees demonstrating low signal margins, with the central portions of the lesions being isointense with the surrounding normal marrow.
B A coronal image of the right knee (TR = 2,500 ms; TE = 80 ms) shows a high signal margin around the lateral tibial plateau lesion. Also shown is a moderate-sized joint effusion (*arrow*)

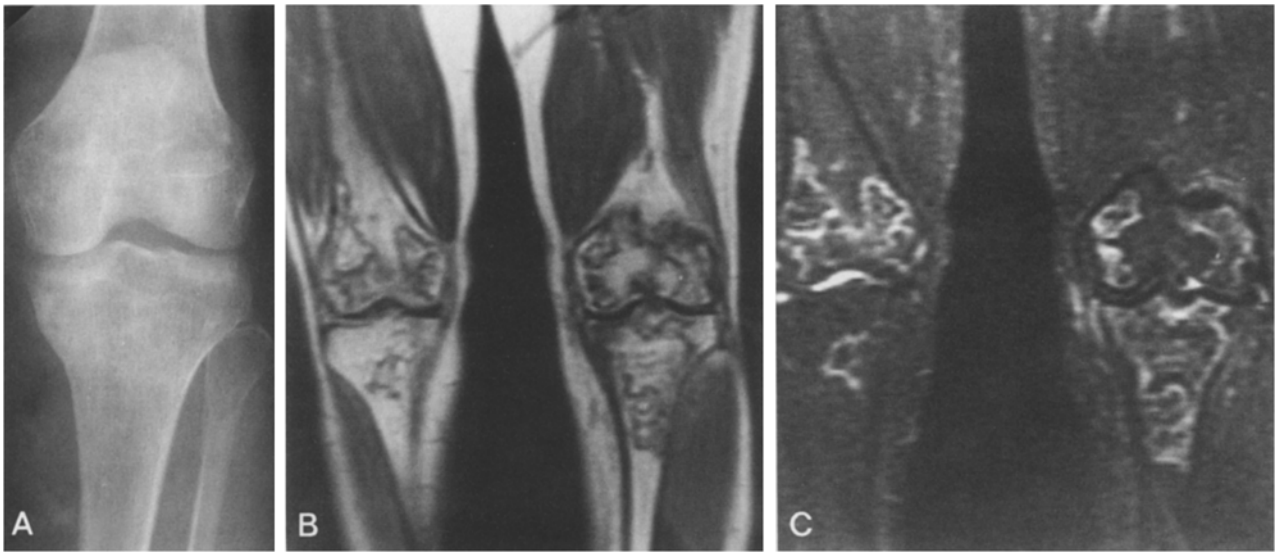


Fig. 3A–C. A 50-year-old woman (E.O.) with systemic lupus erythematosus. **A** A radiograph of the left knee shows patchy sclerosis in the distal femur and proximal tibia compatible with areas of infarction. **B** Coronal image (TR = 600 ms; TE = 20 ms) shows extensive involvement of subchondral bone and adjacent diaphyses. **C** On the long pulse sequence (TR = 2,500 ms; TE = 80 ms), the serpiginous borders of the lesions become hyperintense

whose MRI studies were normal. Nonetheless, they had histories of knee pain and RN images which suggested ON.

Discussion

Spontaneous osteonecrosis of the knee was first described clinically by Ahlbäck et al. in 1968 [2]. In their studies of elderly patients, the syndrome was characterized by acute onset of intense pain in the medial femoral condyle, accompanied by a positive radionuclide bone scan. In addition, all of the patients in their studies developed radiographic findings consisting of one or more of the following: flattening of the articular surface of the medial femoral condyle; subchondral radiolucency, with or without a sclerotic halo; calcified loose bodies; and periosteal reaction. Since then, several other authors have made similar observations [1, 3, 10, 20, 21]. Significantly, while the medial femoral condyle remained the primary site of involvement in these later studies, a minority of patients showed involvement of the medial tibial plateau and the lateral femoral condyle. Recently, several studies have dealt exclusively with these alternate sites of involvement [9, 12, 16].

While spontaneous ON of the knee is a well-accepted entity, it has become clear that a similar condition can develop in patients with well-recognized risk factors for ischemic necrosis of bone ("secondary" ON of the knee), such as those in group A of our study. Thus, ON of the knee has been identified in patients with systemic lupus erythematosus [1, 5], renal transplantation [1, 4, 22], and sickle-cell anemia [3]. Patients who are chronic users of steroids [3] are also at risk.

The group with spontaneous ON consists of elderly, predominantly female patients, similar to those in group B of our study. The age and sex distribution of the latter group is dependent upon the primary disease [1]. Secondary ON of the knee is bilateral in 50% of cases, and involvement of the lateral femoral condyle occurs in up to 60% of cases [1]. This is in contrast to the almost invariable unilateral distribution of spontaneous ON of the knee [1–3, 9, 10, 12, 20, 21] and its predilection for the medial femoral condyle [1–3, 10, 20, 21] and the medial tibial plateau [9, 10, 12]. These differences are reflected in the clinical presentation of the patients in our series. Three of six patients (50%) in group A had bilateral symptoms as opposed to only one of ten (10%) in group B. However, MRI demonstrated bilateral abnormalities in three patients in the latter group.

The etiology of ON of the knee remains unclear. In secondary ON, particularly that due to chronic steroid use, it is probable that the pathophysiology is similar to that which occurs in the hip. This pathophysiology is most commonly believed to be the result of fat emboli of bone [6]. Another explanation invokes alteration of the mi-

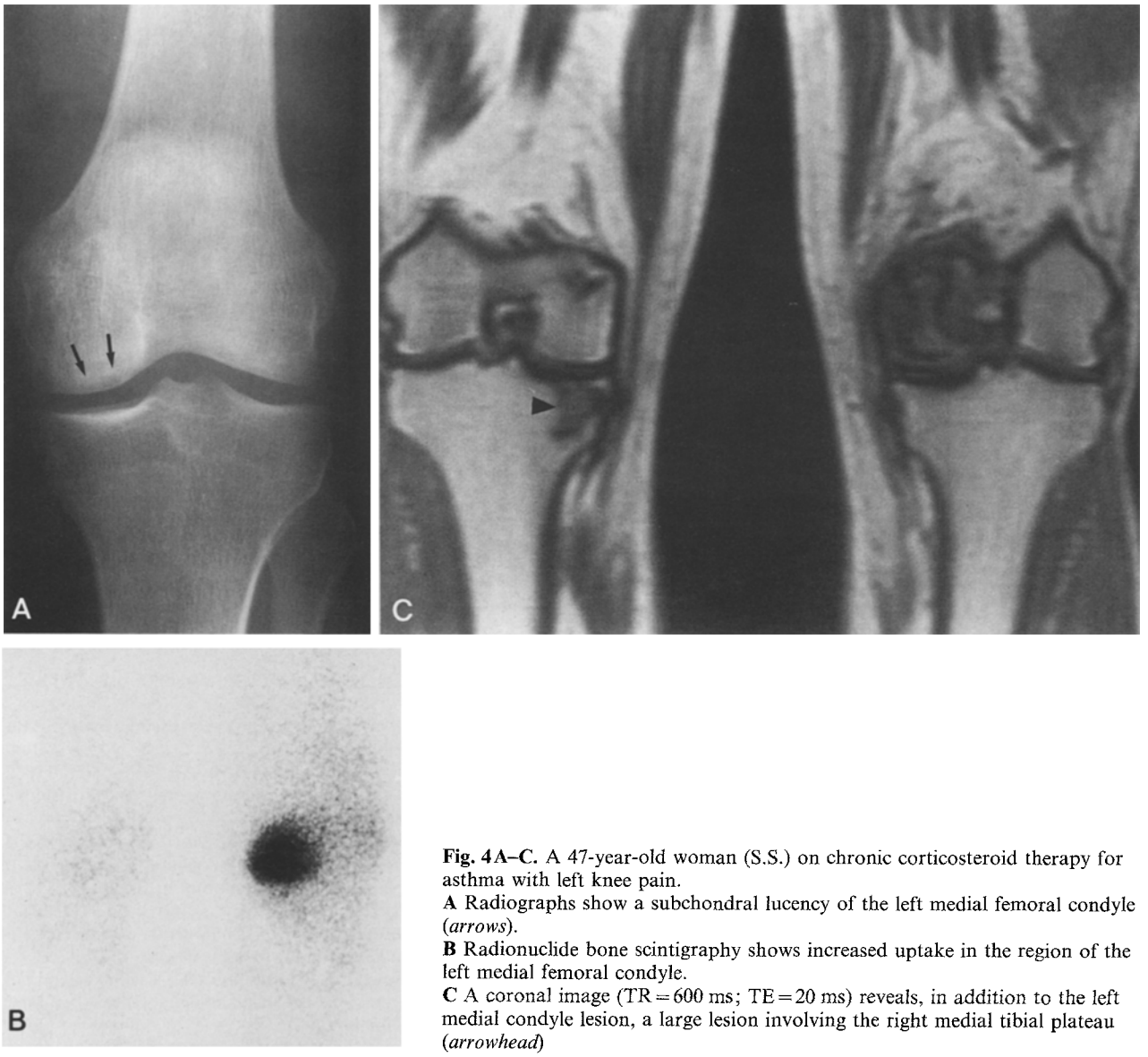


Fig. 4A–C. A 47-year-old woman (S.S.) on chronic corticosteroid therapy for asthma with left knee pain.
A Radiographs show a subchondral lucency of the left medial femoral condyle (*arrows*).
B Radionuclide bone scintigraphy shows increased uptake in the region of the left medial femoral condyle.
C A coronal image (TR = 600 ms; TE = 20 ms) reveals, in addition to the left medial condyle lesion, a large lesion involving the right medial tibial plateau (*arrowhead*)

crocirculation with increased bone marrow pressure and decreased blood flow [1]. In spontaneous ON of the knee, the primary inciting factor may be a microfracture through osteoporotic subchondral bone [8, 10, 13]. Antecedent trauma is uncommon [20]; however, one article has suggested that meniscal tears may be an inciting factor [19].

Traditionally, the diagnosis of ON of the knee is made on the basis of the patient's history and PF and RN findings. Early in the course of the disease, plain radiographs have been reported to be normal from 10 to 43% of the time [1, 3, 8–10, 14, 20, 21]. Bone scintigraphy has proven to be much more sensitive, being positive in virtually all cases [8–10, 12, 13, 21]. Unfortunately, the findings on radionuclide bone imaging are often not specific. Osteoarthritis [8] and stress fracture of the medial tibial plateau [10, 14] may both mimic ON.

We undertook the present study to evaluate the role of MRI in the diagnosis and staging of ON of the knee. The findings consisted primarily of discrete, well-marginated, low signal areas in the subchondral bone, best demonstrated on the short pulse sequences. These are quite similar to results previously described for AVN of the hip [15, 17, 24, 25]. In one study, the findings correlated well with pathologic specimens [24]. The low signal indicated necrosis, in contrast to the high signal from surrounding normal marrow fat. Although pathologic results were available from only one patient

in our series (E.O.), we feel that our findings can be attributed to the similar pathologic changes. Several studies have shown that the pathologic appearance of ON of the knee is similar to that of AVN of the femoral head [1, 3, 9, 10].

At short pulse sequences, a low signal margin was identified in virtually all lesions in our series. This correlates well with the findings by Mitchell et al. [17], who were able to show a similar appearance in 90% of their patients with AVN of the hip. However, in their series, 90% of the lesions demonstrated a high signal about the margins on long pulse sequences. This finding was identified in only 45% of our patients. The cause of this discrepancy is not clear. The margin appears to correspond, at least in the hip, with the histopathological finding of a reactive margin around an area of ischemic necrosis [17], characterized by fibrosis, hyperemia, and inflammation [23]. Similar findings have been demonstrated in ON of the knee [1, 3, 9, 10]. The reactive margin is identifiable in both the spontaneous and secondary forms.

Two of our patients had normal MRI studies despite histories and scintigraphic findings indicative of ON. There are several possible explanations for this inconsistency. In ON of the knee, the necrotic segment is often very tiny and is restricted to the immediate subchondral area [10]. Hypothetically, in some cases, this lesion may be below the resolution of the MRI scan. More likely, in some patients, the RN scans are abnormal for reasons other than ON, such as osteoarthritis or trauma. In fact, with few exceptions, patients underwent MRI only after RN scans demonstrated an abnormality, precluding an assessment of the sensitivity of MRI in patients with normal bone scintigraphy.

In a select group of patients with ON of the knee, treatment is conservative, consisting of analgesics, limiting weight-bearing, and anti-inflammatory medication [1, 12, 14]. Often, in these patients, particularly those with normal radiographs, the scintigraphic changes eventually revert to normal, although abnormalities on PF may eventually appear [12, 14]. The majority of patients in our study have undergone conservative treatment, but to date no follow-up MRI studies have been performed. It remains to be seen if the temporal changes on MRI will mirror those described for plain films and scintigraphy.

In summary, we have described the MRI appearance of proven or suspected osteonecrosis of the knees. Because the majority of patients are treated conservatively, pathologic confirmation is usually not obtainable. In these cases, the diagnosis was based on a combination of patient history and radiographic and/or scintigraphic findings [1, 2, 10, 14]. We feel MRI may be of value in patients with suspected or proven ON of the knee by demonstrating bilateral disease in patients with unilateral symptoms, showing the extent of involvement, and evaluating the presence or absence of bone marrow changes in patients with positive bone scans and negative plain films.

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