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Diagnostic Utility of T1-Weighted MRI Characteristics in Evaluation of Osteomyelitis of the Foot

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OBJECTIVE. The purpose of this study was to evaluate the diagnostic utility of specific characteristics on T1-weighted MR images in the diagnosis of pedal osteomyelitis.

MATERIALS AND METHODS. The study included all adult patients who underwent MRI of the foot for evaluation of suspected osteomyelitis over an 11-month period. Images were retrospectively reviewed for specific criteria on T1-weighted images, including signal intensity of affected bone marrow (normal or decreased), distribution of abnormal signal intensity (subcortical or medullary), and pattern of involvement (hazy reticulated or confluent). The presence of osteomyelitis was presumed if the surgical pathologic result was positive or if there was lack of clinical improvement despite conservative management. Rapid clinical improvement with conservative management was considered an indication that osteomyelitis was not present.

RESULTS. Images from 74 examinations were evaluated. In 20 cases, osteomyelitis was considered present, and in 54 it was presumed absent. In 19 of the 20 cases (95%) in which osteomyelitis was considered present, marrow T1 signal intensity was decreased, in a medullary distribution, and in a confluent pattern in all cases. In 30 of the 54 cases (56%) in which osteomyelitis was presumed absent, T1 signal intensity was decreased, but only five cases (9%) had a medullary distribution and confluent pattern. Twenty-three cases (43%) had a hazy reticulated pattern, and two cases (4%) had only subcortical distribution. None of the cases with a subcortical distribution or hazy reticulated pattern of abnormal signal intensity had positive results for osteomyelitis. Confluent decreased T1 marrow signal intensity in a medullary distribution was 95% sensitive in the prediction of osteomyelitis with a specificity of 91%, negative predictive value of 98%, and positive predictive value of 79%.

CONCLUSION. Findings on T1-weighted MR images, specifically a confluent pattern of decreased T1 marrow signal intensity in a medullary distribution, correlate highly with the presence of pedal osteomyelitis.

Foot ulcers are a common complication of diabetes mellitus, occurring in as many as 15% of patients with diabetes [1]. Pedal osteomyelitis is a major source of morbidity among these patients, and timely clinical recognition and diagnosis are important for initiation of appropriate medical and surgical therapy. Radiography, nuclear medicine studies, and MRI have all historically played prominent roles in the evaluation and diagnosis of pedal osteomyelitis. Radiography is readily accessible and often serves as a primary screening study, but it has low sensitivity in the absence of cortical bone destruction, which is often a late finding. Nuclear medicine studies have high sensitivity but low specificity and are less helpful than MRI in characterizing associated soft-tissue pathologic changes such as abscess and phlegmon. MRI has come to play an increasingly important diagnostic role. Not only can the findings be used to characterize the primary bone marrow lesion, but also MR images exquisitely show associated secondary soft-tissue abnormalities that can aid in the diagnosis of osteomyelitis and other suspected or unsuspected pathologic conditions. MRI has been found to have superior diagnostic performance in comparison with radiography, ^{99m}Tc bone scanning, and WBC studies [2].

Previous studies [3–13] have identified findings on MRI that are helpful in suggesting the diagnosis of osteomyelitis, including decreased T1 marrow signal intensity, increased T2 marrow signal intensity, and associated gadolinium enhancement. Supportive secondary

Keywords: infection, MRI, osteomyelitis

DOI:10.2214/AJR.08.1376

Received June 10, 2008; accepted after revision July 08, 2008.

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AJR 2009; 192:96–100

0361–803X/09/1921–96

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findings include adjacent soft-tissue ulcers with sinus tracts, phlegmon, abscess formation, and overlying cellulitis. Our clinical experience, however, has shown that T2-weighted MRI may be overly sensitive in the diagnosis of osteomyelitis and that high-quality, triplanar T1-weighted imaging should play a dominant role in evaluation of suspected osteomyelitis. Increased T2 signal intensity can be seen in other noninfectious causes of marrow edema, including avascular necrosis, primary and metastatic tumors, fractures, stress reaction, and altered biomechanics [14, 15].

Collins et al. [16] have identified specific T1-weighted MRI characteristics that suggest the presence of osteomyelitis, specifically a confluent pattern and medullary distribution of decreased marrow T1 signal intensity. In that study, no patient with decreased T1 marrow signal intensity limited to a subcortical distribution or with a hazy reticulated pattern had surgically confirmed osteomyelitis. The purpose of this study was to further delineate the performance characteristics of these criteria in a general population of patients undergoing MRI of the foot for evaluation of possible osteomyelitis.

Materials and Methods

All adult patients at our institution undergoing MRI of the foot for evaluation of suspected osteomyelitis over an 11-month period (August 2005–June 2006) were identified through a computer search of the radiology information system. Repeated examinations of the same patient were excluded from the study, as were examinations of patients who had insufficient clinical follow-up to establish the presence or absence of osteomyelitis. Included were a total of 74 examinations of 73 patients (including one patient with bilateral examinations). Demographic information collected from the electronic medical record included age, sex, presence of diabetes, specific area of clinical concern about the imaged foot (if one was indicated), presence of documented skin ulcer, and clinical or radiographic evidence of neuropathic arthropathy (Table 1). The study protocol was approved by the institutional review board, which approved a retrospective review of medical records and imaging of all study patients.

MRI was performed with a dedicated foot and ankle extremity coil on a 1.5-T superconducting system (Signa, GE Healthcare). Imaging parameters included field of view of 12–18 cm and slice thickness of 3 mm. T1-weighted imaging was performed in three planes with conventional spin-echo technique (TR/TE, 500/10–20; number of signals acquired, 1 or 2; matrix size, 256 × 256). Imaging also included either fat-suppressed T2-weighted fast spin-echo or fast spin-echo inversion recovery sequences. Fat-suppressed T2-weighted fast spin-echo images (3,500–400/70–90) were obtained with 2 signals; echo-train length, 8; matrix size, 256 × 256; fat saturation was performed with selective presaturation of lipid resonance peaks. In some cases, inversion recovery sequences (3,000–5,000/50; inversion time, 150 milliseconds; number of signals acquired, 2; echo-train length, 8; and matrix size, 256 × 192 matrix) were performed in place of fast spin-echo T2-weighted imaging. Only the T1-weighted sequences, however, were reviewed as part of this study.

TABLE 1: Demographic Characteristics of Study Population

Characteristic	No.	%
Total no. of studies	74	100
Sex		
Men	49	66.2
Women	25	33.8
Age (y)		
Mean	65.1	
Range	26–92	
Associated conditions		
Diabetes	40	54.1
Neuropathic arthropathy	9	12.2
Method of diagnosis		
Pathologic confirmation	26	35.1
Clinical	48	64.9

Images were reviewed retrospectively and jointly by two experienced board-certified musculoskeletal radiologists who formed a consensus opinion regarding the presence or absence of specific T1-weighted imaging findings. Specifically evaluated were T1 signal intensity of the affected bone marrow in comparison with adjacent normal fatty marrow (isointense or decreased), distribution of the abnormal signal intensity (subcortical or medullary), and pattern of abnormal signal intensity (hazy reticulated or confluent).

T1 marrow distribution was considered to be medullary if it involved a geographic area of the medullary canal and to be subcortical if it was limited to a linear area of abnormal signal intensity immediately adjacent to the cortical bone that was less than 3 mm thick. T1 marrow pattern was considered confluent if there was contiguous and complete replacement of marrow fat with decreased T1 signal intensity. It was defined as hazy reticulated if the marrow fat was not completely replaced, hazy areas of fatty signal intensity being scattered within the incompletely replaced marrow fat. These criteria were used in an earlier study by Collins et al. [16].

MR images were reviewed in a manner simulating clinical practice. Reviewers were blinded to the final diagnosis of presence or absence of osteomyelitis. They did, however, know the specific clinical area of concern (if one had been specified) and whether a documented foot ulcer was present. The reviewers also had access to any available radiographs for correlation if desired.

Medical records of the patients were reviewed to discern clinical outcome and an ultimate diagnosis of presence or absence of osteomyelitis. Histopathologic results were used for patients who underwent surgical intervention within 60 days after MRI. For patients who did not undergo surgery, secondary clinical end points were used to establish a presumed diagnosis of presence or absence of osteomyelitis. If pathologic results were not available, a positive blood culture result and radiographic progression or lack of clinical improvement despite conservative management were considered to indicate the presence of osteomyelitis. Rapid improvement after conservative management, including nonsurgical treatment or localized soft-tissue débridement and oral or IV administration of antibiotics, was considered to indicate the absence of osteomyelitis. These criteria were based on the presumption that osteomyelitis does not heal without surgical débridement and are a standard used in similar studies when tissue diagnosis was unavailable [3– 5, 8, 10, 11, 13].

Results

Of the 74 cases included in the study, 20 were subsequently established as osteomyelitis on the basis of histopathologic results or secondary clinical end points; in 54 cases, the absence of osteomyelitis was established (Table 2). Eighteen of the 20 cases of osteomyelitis were confirmed pathologically; in the other two, osteomyelitis was presumed present on the basis of secondary clinical end points. In 46 of the 54 cases in which osteomyelitis was absent, the absence was established clinically; in eight cases, pathologic findings confirmed the absence of disease.

In 19 of the 20 cases in which osteomyelitis was present, decreased marrow T1 signal intensity was found with a geographic medullary distribution and confluent pattern of abnormal signal intensity in all cases (Figs. 1 and 2). None of the cases of osteomyelitis had decreased T1 signal intensity limited to a subcortical distribution or with a hazy reticulated pattern. There was a single case of false-negative findings interpreted as normal at MRI but subsequently confirmed as positive for osteomyelitis at pathologic examination after below-knee amputation 10 days after MRI.

TABLE 2: Comparison of MRI Findings in Presence and Absence of Osteomyelitis

Finding	Osteomyelitis Present (*n* = 20)	Osteomyelitis Absent (*n* = 54)
Marrow T1 signal intensity		
Normal	5 (1)	44 (24)
Decreased	95 (19)	56 (30)
Distribution of abnormal signal intensity		
Subcortical	0 (0)	4 (2)
Medullary	95 (19)	52 (28)
Pattern of abnormal signal intensity		
Hazy reticulated	0 (0)	43 (23)
Confluent	95 (19)	9 (5)

Note—Values are percentages with numbers of cases in parentheses.

Twenty-four of the 54 cases (44%) in which osteomyelitis was absent had normal marrow T1 signal intensity. In comparison, 30 of the 54 cases (56%) had decreased marrow T1 signal intensity. However, 23 of the 30 cases (77%) had a hazy reticulated pattern of abnormal T1 signal intensity (Figs. 3 and 4), and two cases were limited to only a subcortical distribution (Fig. 5). Five of the 54 cases (9%) in which osteomyelitis was absent had decreased marrow T1 signal intensity with a confluent pattern and geographic medullary distribution. Using decreased marrow T1 signal intensity with a geographic medullary pattern and confluent distribution as an indicator of osteomyelitis in this population, the calculated sensitivity was 95%; specificity, 91%; and overall accuracy, 92%. The calculated positive predictive value was 79% and the negative predictive value, 98%.

The presence or absence of neuropathic arthropathy was documented in each case on the basis of historical or radiographic findings with the anticipation that this condition can be a confounding factor in these cases. Nine of the 74 cases (12%) had evidence of neuropathic arthropathy. In three of these cases, osteomyelitis was present, and in six it was absent. All nine cases were correctly identified. All three cases of osteomyelitis had confluent medullary decreased T1 marrow signal intensity in the suspected area. Two of the six cases in which osteomyelitis was absent had hazy reticulated abnormal marrow signal intensity. The other four cases had normal marrow signal intensity. In these limited nine cases, there were no false-positive or false-negative results.

Discussion

Prompt clinical recognition of osteomyelitis is essential for proper medical and surgical treatment. Radiography and nuclear medicine studies have historically played a prominent role in the evaluation of osteomyelitis and continue to serve a role. MRI, however, is currently considered the advanced imaging technique of choice because of its increased sensitivity and specificity in the diagnosis of bone infection and in characterization of additional associated soft-tissue abnormalities.

Previously described primary findings at MRI include decreased marrow signal intensity on T1-weighted images, increased marrow signal intensity on T2-weighted images, and enhancement after IV administration of gadolinium. In a previous study by Collins et al. [16], specific T1-weighted MRI findings were statistically significant in differentiation of pathologically proven cases of osteomyelitis from cases in which pathologic results were negative for osteomyelitis. These findings included decreased marrow T1 signal intensity that was medullary in distribution and confluent in pattern. In that study, no case of pathologically proven osteomyelitis had decreased marrow T1 signal intensity that was limited to a subcortical distribution or had a hazy reticulated pattern. Because of the design of the previous study [16], however, no cases of true-negative or false-negative results were included for review. Thus the sensitivity and specificity of the findings were not calculated. The study described herein included a general population of patients undergoing MRI evaluation of the foot to rule out pedal osteomyelitis to capture a population truly representing a standard clinical practice, including the previously lacking true- and false-negative results, allowing calculation of sensitivity and specificity of the findings.

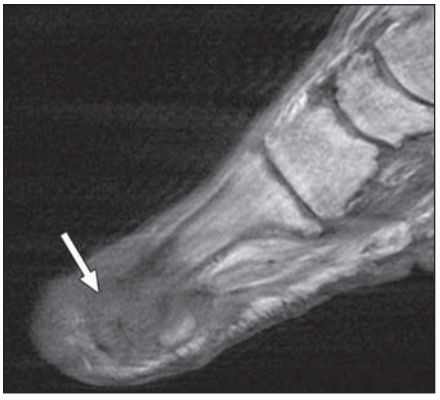
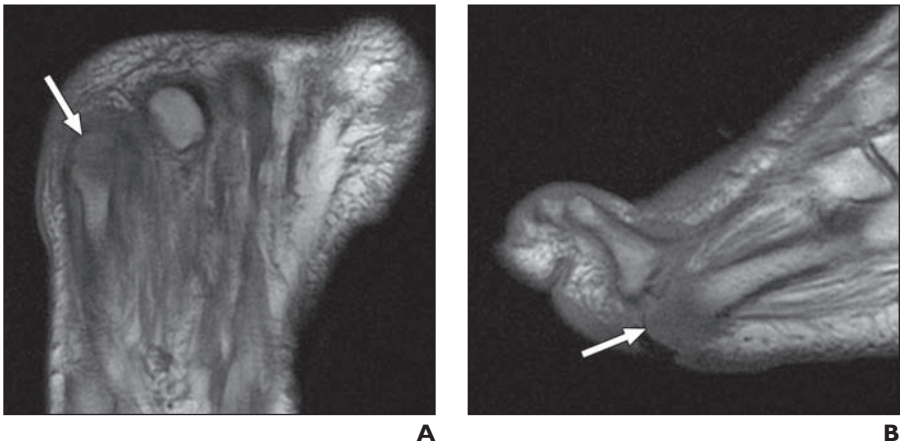


Fig. 1—82-year-old diabetic woman with ulceration over dorsal aspect of first metatarsophalangeal joint. Sagittal T1-weighted MR image shows confluent decreased T1 marrow signal intensity (*arrow*) in medullary distribution involving metatarsal head and neck. Patient underwent below-knee amputation 5 days after MRI. Changes of acute and chronic osteomyelitis were confirmed at histopathologic examination.



A **B**

Fig. 2—80-year-old nondiabetic man with ulceration along lateral fifth metatarsal head. **A** and **B,** Coronal (**A**) and sagittal (**B**) T1-weighted MR images show focal geographic area of confluent decreased T1 signal intensity (*arrow*) in medullary distribution in fifth metatarsal head. Histopathologic examination 13 days after MRI confirmed presence of osteomyelitis.

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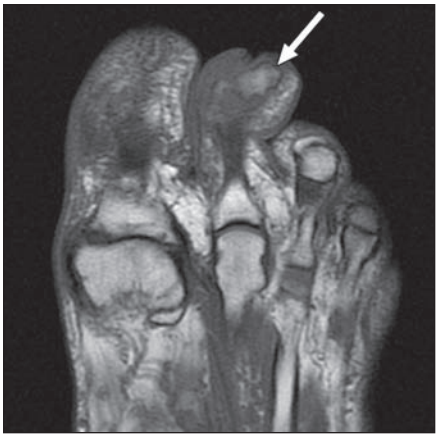
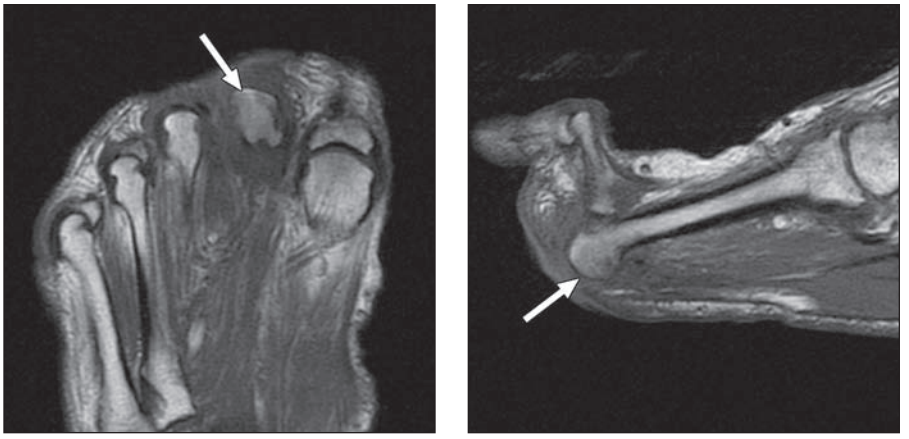


Fig. 3—81-year-old man with painful, swollen second toe without ulceration. Coronal T1-weighted MR image shows hazy reticulated decreased marrow signal intensity (*arrow*) in distal phalanx of second toe, consistent with reactive edema. Clinical diagnosis was gout, and patient responded well to medical treatment.



A **B**

Fig. 4—54-year-old diabetic woman with skin ulcer along plantar second metatarsal head. **A** and **B,** Coronal (**A**) and sagittal (**B**) T1-weighted MR images show hazy reticulated decreased marrow T1 signal intensity (*arrow*) in second metatarsal head, consistent with reactive edema. Also present is hammertoe deformity of second toe with dorsal dislocation at metatarsophalangeal joint. Patient was treated with conservative management and local wound care, and ulcer healed satisfactorily without recurrence.

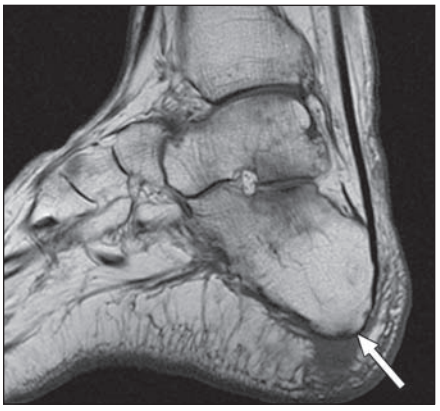


Fig. 5—26-year-old man with spina bifida and chronic neurotrophic ulcer over plantar aspect of left calcaneus. Sagittal T1-weighted MR image shows mild cortical irregularity of plantar aspect of calcaneus with only minimal subcortical abnormal low T1 signal intensity (*arrow*). Patient received local wound care only, and wound healed.

In many regards, MRI has become the accepted standard of care in establishing the diagnosis of osteomyelitis. This standard presented unique challenges to this project in that most patients deemed not to have osteomyelitis at MRI did not proceed to surgery. One of the strengths of the previous project [16] was that all included cases had pathologic findings available for review. However, to evaluate a true and representative population of patients undergoing MRI for this indication and to calculate sensitivity and specificity of the findings, additional secondary clinical end points had to be defined for patients who did not undergo surgery.

Morrison et al. [5] considered a positive blood culture result with radiographic progression or lack of clinical improvement despite conservative management a positive indicator of osteomyelitis in cases in which histopathologic results were lacking. Rapid improvement after conservative management, consisting of nonsurgical management or localized soft-tissue débridement and oral or IV antibiotics, was considered an indication of the absence of osteomyelitis. Our secondary clinical end points were modeled on this prior standard. This policy was based partially on the presumption that true osteomyelitis does not heal without surgical intervention. As expected, most of the cases of osteomyelitis in our population (18 of 20, 90%) had pathologic confirmation. In most of the cases in which osteomyelitis was absent (46 of 54, 85%), the determination was based on the secondary clinical end points. This limitation is recognized but was unavoidable.

Studies have shown the sensitivity and specificity of MRI with the primary end points of decreased marrow T1 signal intensity, increased marrow T2 signal intensity, and IV gadolinium enhancement. Before the 2005 study by Collins et al. [16], however, no study to our knowledge had shown the diagnostic utility of specific patterns of abnormal T1 marrow signal intensity. We found that a confluent pattern and medullary distribution of decreased marrow T1 signal intensity correlates highly with the presence of osteomyelitis, with a sensitivity of 95%, specificity of 91%, and negative predictive value of nearly 100%. This finding is based solely on findings on T1-weighted images without consideration of T2-weighted and gadolinium-enhanced images.

Other investigators have emphasized findings on T2-weighted and gadolinium-enhanced images. Morrison et al. [4] reported a sensitivity and specificity of 79% and 53% for unenhanced MRI and 88% and 93% for fat-suppressed contrast-enhanced images. In light of concerns regarding nephrogenic systemic fibrosis and its possible link to gadolinium administration in patients with reduced renal function, gadolinium may now be contraindicated in the imaging of many patients with diabetes, placing more importance on establishing an accurate imaging diagnosis with unenhanced images. In the past, we have noted that findings on gadolinium-enhanced images strongly parallel findings on T2-weighted images and generally do not provide additional information regarding primary marrow abnormalities.

Morrison et al. [5] also emphasized the importance of associated secondary MRI findings in increasing sensitivity and specificity in the diagnosis of osteomyelitis, including cutaneous ulceration, cellulitis, soft-tissue mass, abscess, sinus tract, and cortical interruption. Those findings were not specifically assessed in this study but presumably could augment the confidence of the diagnosis.

Radiographs were made available for review as part of this study, if desired, for clarification of the findings on T1-weighted images in select cases but were not primarily evaluated. Radiographs were only referenced in several cases and served primarily to confirm the presence of neuropathic or postsurgical

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changes in the examined foot. In most cases, findings on radiographs remain normal in early cases of osteomyelitis. In our clinical experience, however, even when the findings are positive, the surgeon often still wants to know the extent of marrow involvement on MRI for surgical planning and to document the presence and extent of associated soft-tissue abnormalities.

In previous studies [14, 15], some documented causes of false-positive findings at MRI have included reactive marrow edema, neuropathic arthropathy, stress reaction, and altered weight mechanics. Noninfectious reactive marrow edema is a somewhat controversial entity but may represent hyperemia in the bone marrow related to inflammation or infection in the adjacent soft tissues. This entity likely correlates with many of the cases of the hazy reticulated pattern of abnormal signal intensity on T1-weighted images of our study population.

In our results, there was one case with a false-negative finding. The images were interpreted as normal with no associated abnormal signal intensity on T1-weighted images. The patient underwent below-knee amputation 10 days after the original examination for advanced peripheral vascular disease and nonhealing foot ulcers. The surgical pathologic findings surprisingly confirmed the presence of osteomyelitis underlying a focal area of skin ulceration. Despite repeated review of this case and the available clinical records, no good explanation can be provided for this one anomalous result. This case, however, was the only one in which the findings were false-negative.

Neuropathic arthropathy can complicate the MRI diagnosis of osteomyelitis, producing profound changes on MR images, even in the absence of superimposed infection. Although all nine cases of neuropathic arthropathy in our study were characterized correctly on the basis of the findings on T1-weighted images, we recognize that this group was a small subsample and that the results would not withstand statistical validation. In our daily practice, we do recognize the challenge imposed in many of these cases. Ahmadi et al. [17] reported findings that may help identify superimposed infection in these cases, including periarticular soft-tissue fluid collections, sinus tracts, and soft-tissue fat replacement. Also in our experience, we have found that distribution can be helpful in that the changes of neuropathic arthropathy often involve the midfoot, whereas areas of skin ulceration and suspected osteomyelitis are more commonly located at pressure points of the forefoot or calcaneus. In difficult cases, we have found that further imaging with nuclear medicine ^{111}In-labeled WBC scanning sometimes can be helpful. Results of a study by Lipman et al. [18] suggested that ^{111}In WBC scanning may have better specificity than MRI in the diagnosis of osteomyelitis in the setting of neuropathic arthropathy.

It has been our clinical experience that T2-weighed MRI is overly sensitive in the diagnosis of osteomyelitis and that high-quality T1-weighted imaging in all three anatomic planes should be the foundation of an osteomyelitis examination. Additional fat-saturated T2-weighted and gadolinium-enhanced images should be read in conjunction with these T1-weighted images. Knowledge of the exact site of clinical concern is important to tailor the examination appropriately and perform a targeted high-resolution study.

Our findings show that on T1-weighted MR images, the presence of decreased marrow signal intensity with a medullary distribution and confluent pattern of involvement correlates highly with the presence of osteomyelitis. The sensitivity is 95%; specificity, 91%; and negative predictive value, 98%. None of the cases of osteomyelitis in our series had a limited subcortical distribution or hazy reticulated pattern of abnormal marrow signal intensity on T1-weighted images. At MRI of the foot for clinically suspected pedal osteomyelitis, emphasis should be placed on acquisition of high-quality T1-weighted images in three planes. Specifically, evaluation should be performed for evidence of a confluent pattern and medullary distribution of decreased marrow signal intensity on T1-weighted images. Images obtained with fat-suppressed T2-weighted and gadolinium-enhanced sequences should be interpreted in conjunction with findings on the T1-weighted images.

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