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Stress Injuries of Bone: Analysis of MR Imaging Staging Criteria

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Rationale and Objectives. The authors examined the prognostic value of magnetic resonance (MR) imaging in stress injuries of bone.

Materials and Methods. Clinical follow-up data were collected in 35 patients who underwent MR imaging because of suspected stress fractures. MR findings were correlated with total duration of symptoms, the time to return to sports activity, and findings at follow-up radiography.

Results. The MR imaging finding of a "fracture" or "fatigue" line or a cortical signal intensity abnormality was predictive of a longer symptomatic period, whereas muscle edema was predictive of a shorter symptomatic period. A published grading system could be used in only 24 patients; the MR imaging grade of injury did not show correlation with clinical outcome.

Conclusion. The MR imaging finding of either a medullary line or a cortical abnormality appears to indicate a more severe stress injury of bone. A previously published MR imaging grading system for stress injuries of the tibia was not prognostic in this more heterogeneous patient group.

Key Words. Bones, injuries; bones, MR; fractures; fractures, stress.

Stress-related injuries of bone are common ailments in athletically active individuals and account for at least 10% of the cases encountered in a typical sports medicine practice (1). The response of bone to physical stress is a dynamic continuum ranging from accelerated remodeling, to fatigue, and eventually to bone failure (1,2). Radiographs are insensitive to the early phase of bone remodeling associated with stress injuries but are believed to confirm stress fracture when they demonstrate a fracture lucency or callus formation. Radionuclide bone scanning depicts the early changes in bone metabolism caused by physical stress as ill-defined areas of mildly increased tracer uptake (2,3). This scintigraphic pattern may herald a symptomatic, radiographically occult "stress reaction." A stress fracture, on the other hand, typically exhibits more intense and focal tracer localization on the bone scan (4). Unfortunately, the scintigraphic features of a stress reaction are nonspecific and may commonly be encountered in asymptomatic athletes (3). Hence, the accuracy and reliability of scintigraphic staging of stress injuries is questionable.

With its superior spatial resolution and sensitive depiction of inflammation, magnetic resonance (MR) imaging likely depicts so-called stress reactions (5), as well as stress fractures of bone. Fredericson et al (6) suggest that the severity of stress-related tibial injuries can be gauged with a combination of MR imaging findings in the periosteum and marrow and with differential findings on T1- versus T2-weighted MR images.

A test that could improve prognostication of stress injuries would be of major practical value, particularly for managing injuries in high-level athletes. The differentiation of a stress reaction from stress fracture affects treatment and the prescribed period of rest away from sport. We performed this study to examine the potential utility of MR imaging for gauging the severity of stress injuries of bone, as elucidated by clinical outcomes. In particular,

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Figure 1. MR image in a 32-year-old female runner shows findings of a fracture line. Axial SE MR image (1,800/70) through the calcaneus reveals an irregular low-signal-intensity line (arrows) in the marrow space of the tuberosity. Radiographs obtained 4 weeks later (not shown) revealed medullary callus formation in the same region.

we sought to define the prognostic importance of periosteal as opposed to marrow findings at MR imaging.

MATERIALS AND METHODS

Patients were included in this study if they had a positive MR imaging examination for a clinically suspected stress-related bone injury of the fatigue type. Patients with a history of specific, antecedent trauma were excluded, as were those with chronic renal disease and those receiving steroid therapy. Thirty-five patients were identified for whom adequate clinical follow-up information was available. There were 18 female and 17 male patients ranging in age from 13 to 78 years (mean, 32 years). Thirteen patients were elite athletes and 16 were involved in a regular sport activity. Six patients, all of whom were younger than 55 years, were not involved in a regular sports activity. Stress injuries were located in the tibia ($n = 13$), femoral neck ($n = 10$), metatarsal ($n = 6$),

calcaneus ($n = 2$), distal femur ($n = 1$), patella ($n = 1$), or fibula ($n = 2$). All patients received specific treatment for their stress injuries, including a prescribed period away from physical activity.

MR imaging was performed with either a 1.5-T (Signa, GE Medical Systems, Milwaukee, Wis; or Magnetom Vision, Siemens, Iselin, NJ) or 1.0-T (Magnetom Impact, Siemens) system. Femur and pelvic studies were performed with a body coil, and extremity examinations were performed with a transmit-receive extremity coil. All studies included T1-weighted spin-echo (SE) imaging (repetition time, 400–650 msec; echo time, 15–25 msec [400–650/15–25]). In addition to T1-weighted SE imaging, one of the following sequences was performed: conventional T2-weighted SE (1,800–2,200/70–80), fast SE short-tau inversion recovery (STIR) (3,000–5,000/25–35 [effective]/120–150 [inversion time, msec]), or T2-weighted fast SE (2,000–5,000/70–100 [effective]). Spectral fat saturation was used with fast SE sequences. STIR or spectrally fat-saturated images were obtained in all but five patients. Images were acquired in at least two orthogonal imaging planes for all studies except examinations of the hips, for which images were acquired in only the coronal plane. Section thickness varied from 3 to 5 mm, the image matrix was 192–256 × 256, two signals were acquired, and the echo train length for fast SE images was 8.

MR images were jointly reviewed by two radiologists (C.J., A.G.) who retrospectively scored each case with respect to standardized criteria. In cases in which criteria were equivocal, the opinion of a third radiologist (L.Y.) was used to reach consensus. MR imaging criteria included (a) MR imaging “fracture” line (Fig 1) or an intracortical signal intensity abnormality (Fig 2), (b) muscle edema (Fig 3), (c) periosteal or juxtacortical edema (Fig 2), and (d) marrow changes on T1-weighted SE images that were equal to or greater in extent than corresponding findings on T2-weighted or STIR images. These findings were scored on a binary scale. Muscle edema was scored as positive when juxtacortical edema extended into adjacent muscle bellies, and, hence, this criterion is a subset of criterion c. The fourth criterion was adapted from the classification of Fredericson et al (6), who attributed a higher grade to lesions present on both T1- and T2-weighted images.

Radiographs were available for 31 of the 35 patients. Radiographic follow-up was considered to be adequate if radiographs were obtained more than 28 days after the onset of symptoms, unless they were already positive at

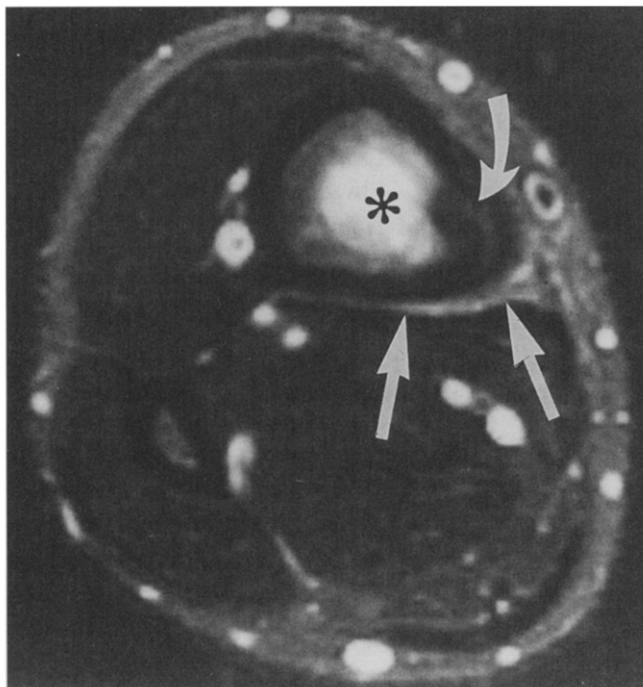


Figure 2. MR image in a 21-year-old male elite track and field athlete illustrates cortical and periosteal signal intensity abnormalities. Axial fast SE MR image (4,000/90, echo train length, 8) obtained with spectral fat saturation reveals prominent marrow space edema (*), as well as a linear area of increased cortical signal intensity medially (curved arrow). Increased signal intensity is also noted in the periosteum posteriorly (straight arrows). Radiographs (not shown) revealed a solid periosteal reaction in this area, but no fracture lucency.

earlier follow-up. Twenty-five patients met this criterion. Because of the small number of patients, radiographs were simply classified as positive or negative for purposes of analysis. The presence of periosteal reaction, callus formation, or a fracture line was considered a sufficient "positive" criterion. Radiography was performed an average of 15 (standard deviation, 30) days after MR imaging.

Clinical records were reviewed for all patients, and 27 patients were also interviewed by telephone. The information collected included (a) symptom duration until MR imaging, (b) total duration of symptoms, and (c) the time before the patient returned to sport. A return to a regular sports activity predicated on recovery from stress injury existed for only 21 of the 35 patients; the other 14 patients either did not participate in regular sport activity or did not return to it for other reasons.

The same readers retrospectively classified the MR findings into the stages proposed by Fredericson et al (6), as follows: grade 1 = periosteal edema without marrow

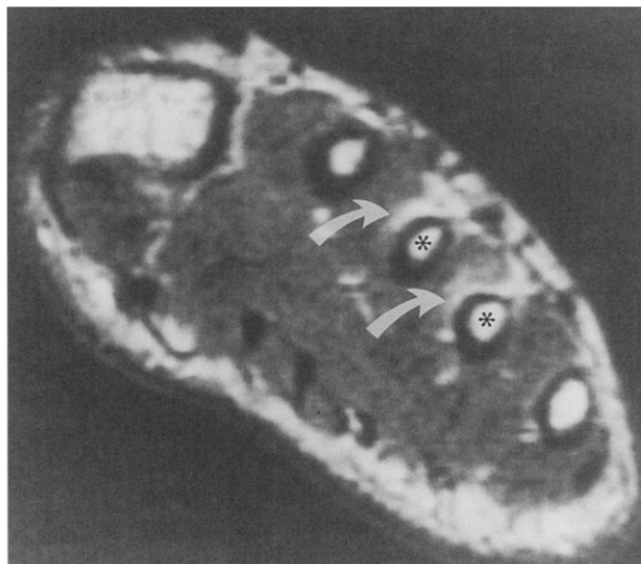


Figure 3. MR image in a 20-year-old female elite track athlete shows muscle edema. Coronal oblique SE MR image (1,867/70) reveals juxtacortical high signal intensity (arrows) around the 3rd and 4th metatarsals (*) that extends into the dorsal interosseus muscles. Radiographs obtained 6 weeks later (not shown) revealed solid periosteal reaction about the 3rd and 4th metatarsal shafts but no fracture lucencies.

findings, grade 2 = periosteal edema plus marrow findings on T2-weighted images only, grade 3 = periosteal edema plus marrow findings on T1- and T2-weighted images, grade 4 = periosteal edema and marrow findings on T1- and T2-weighted images plus the presence of a fracture line.

Nonparametric tests were used to analyze the clinical outcome measures because these variables were not normally distributed. The MR imaging grade was compared with the duration of symptoms and the time to return to sport with a Spearman rank correlation. Mann-Whitney rank-sum tests were used to compare MR imaging signs with the duration of symptoms before MR imaging and MR imaging signs and radiographic findings to the duration of symptoms and the time to return to sport. The value of various MR imaging criteria for predicting the severity of injury as gauged by means of clinical outcome was assessed by using logistic regression (version 6.1; SPSS, Chicago, Ill). For this analysis, patients were placed into two injury groups on the basis of outcome. Patients were classified into group 1 (less severe) if the time to return to sport was less than or equal to 12 weeks or, in those patients who did not return to sport, if the duration of symptoms was less than or equal to 16 weeks; otherwise, patients were classified into group 2 (more severe).

Table 1
MR Imaging Findings and Clinical Outcome

MR Imaging Finding	All Patients		Group 2 (n = 19) [†]
	Median Duration of Symptoms (wk)*	Median Time to Return to Sport (wk) [†]	
Fracture line			
Positive	14 (19)	14 (12)	12 (63)
Negative	10.5 (16)	6 (9)	7 (44)
Muscle edema			
Positive	9 (15)	12 (9)	6 (40)
Negative	19 (20)	14 (12)	13 (65)
Periosteal edema			
Positive	14 (24)	14 (13)	13 (54)
Negative	14 (11)	12 (8)	6 (55)
Marrow changes [§]			
Positive	14 (21)	12 (13)	11 (52)
Negative	15 (14)	14 (8)	8 (57)

*Numbers in parentheses are numbers of patients.

[†]Applies to only 21 of the 35 patients. Numbers in the parentheses are the numbers of patients.

[‡]Numbers in parentheses are percentages.

[§]The extent of marrow changes on T1-weighted SE images was equal to or greater than that on T2-weighted or STIR images.

Table 2
MR Imaging Signs and Prediction of Clinical Outcome (Group 1 vs Group 2)

MR Imaging Finding	Odds Ratio*	95% Confidence Interval	P Value
Fracture line	9.7	1.1, 83	.04
Muscle edema	0.03	0.001, 0.5	.02
Periosteal edema	16.0	0.8, 317	.07
Marrow changes [†]	0.37	0.05, 3.0	.34

*Odds of group 2 membership associated with a positive MR imaging sign/odds of group 2 membership associated with a negative MR imaging sign.

[†]The extent of marrow changes on T1-weighted SE images was equal to or greater than that on T2-weighted or STIR images.

RESULTS

MR Imaging Signs and Clinical Outcome

The relationship between clinical outcome and the various MR imaging findings is summarized in Table 1. The global median duration of symptoms was 14 weeks (range, 2–68 weeks). Patients with muscle edema at MR imaging had a shorter duration of symptoms than did patients without muscle edema ($U = 79$, $P < .02$). Results of univariate analyses did not reveal statistically significant differences in duration of symptoms for patients who

were positive for any of the other three MR imaging criteria.

The global median time to return to sport was also 14 weeks (range, 3–68 weeks). Results of univariate analyses did not reveal any statistically significant differences in the time to return to sport for patients who were positive for any of the four MR imaging criteria.

Results of logistic regression indicated that the MR findings of muscle edema and fracture line were significantly predictive of the injury group (16 patients in group 1, 19 patients in group 2) (Table 2). Muscle edema was

Table 3
MR Imaging Grade versus Clinical Outcome

Grade	Patients (n = 24)		Patients with Tibial Injury (n = 13)	
	Median Duration of Symptoms (wk)	Median Time to Return to Sport (wk)	Median Duration of Symptoms (wk)	Median Time to Return to Sport (wk)
1	20.5 (4)	4 (3)	44 (2)	36 (1)
2	20.5 (2)	... (0)	... (0)	... (0)
3	14 (9)	13 (6)	23 (4)	14 (3)
4	16 (9)	19 (4)	12 (5)	10 (2)

Note.—Numbers in parentheses are numbers of patients. Data are for the patients who met the criteria for the grading system of Fredericson et al (6).

predictive of group 1 membership, whereas a fracture line was predictive of group 2 membership. Muscle edema was present in 15 patients and occurred in the absence of bone findings in only one case. Muscle edema was accompanied by a fracture line in 11 of 15 cases and by a marrow signal intensity change of some type in 14 of 15 cases.

Duration of Symptoms before MR Imaging

The median duration of symptoms before MR imaging was 8 weeks (range, 1–52 weeks). The duration of symptoms before MR imaging was highly correlated with both the total duration of symptoms (Spearman $r = .86$, $P < .001$) and the time to return to sport ($r = .87$, $P < .0001$).

The median duration of symptoms before MR imaging was 3 weeks for subjects with muscle edema and 8 weeks for subjects without muscle edema (Mann Whitney $U = 81.5$, $P < .03$). The duration of symptoms before MR imaging was very similar for groups defined by the presence and absence of each of the other three MR imaging signs.

MR Imaging Grading System

Only 24 of the 35 patients met the criteria for grades of injury as defined by Fredericson et al (6) (grade 1, $n = 4$; grade 2, $n = 2$; grade 3, $n = 9$, grade 4, $n = 9$). A lower frequency of periosteal signal intensity changes in our patients largely explains this discrepancy. Four patients who would otherwise have met grade 4 criteria and five who would otherwise have met grade 2 criteria did not have periosteal signal intensity abnormalities.

In the 24 patients who met the criteria for the grading system of Fredericson et al, there was no statistically significant correlation between the MR imaging grade and either the duration of symptoms (Spearman $r = -.03$, $P = .44$) or the time to return to sport ($r = .31$, $P = .30$, $n = 13$) (Table 3).

Of the 13 patients with tibial injuries, only 11 met the criteria for the grading system of Fredericson et al. Only six of the 13 patients with tibial injuries returned to a regular sports activity. For the patients with tibial injuries, the MR imaging grade of injury did not show correlation with either the duration of symptoms ($n = 11$, $r = -.58$, $P = .06$) or the time to return to sport ($n = 6$, $r = -.51$, $P = .30$).

Radiographic Findings

Twenty-five patients had adequate radiographic follow-up. The median duration of symptoms was 15 weeks for patients with positive radiographs ($n = 18$) and 20 weeks for patients with negative radiographs ($n = 7$). This difference was not statistically significant ($U = 61$, $P < .93$).

Seventeen of the 25 patients with adequate radiographic follow-up returned to a regular sports activity. The median time to return to sport was 14 weeks for patients with positive radiographs ($n = 13$) and 15 weeks for subjects with negative radiographs ($n = 4$) ($U = 26$, $P = .999$).

Of the four MR imaging signs, only one (marrow changes on T1-weighted images equal to or greater than those on T2-weighted or STIR images) was significantly associated with positive radiographic findings ($\chi^2 = 5.30$, $P = .02$).

DISCUSSION

Results of previous studies with bone scintigraphy have suggested that the pattern of tracer localization may help differentiate a stress reaction from a stress fracture (4). This distinction influences treatment and prognosis. A stress fracture is treated more aggressively, entails a

longer convalescence, and is likely symptomatic for longer. MR imaging is highly sensitive for a spectrum of osseous injuries (7–9). The MR imaging finding of a low-signal-intensity line in the marrow space, extending to the cortex, has been described as a hallmark of stress fracture, distinguishing it from an occult trabecular injury or “bone bruise” (10). Because this MR imaging finding often occurs in the absence of corresponding abnormalities on concurrent and follow-up radiographs, it might be better described as a “fatigue” line than an MR imaging fracture line, as suggested by Slocum et al (11).

Results of our study suggest that the MR imaging finding of a cortical signal intensity abnormality or a fracture or fatigue line in the medulla has prognostic value. These findings are associated with a longer time to clinical recovery, which supports the interpretation of these MR signs as markers of frank stress fractures. We could not identify a reliable marker for minor stress injuries or stress reactions. The finding of periosteal edema alone (grade 1) was uncommon (four of 35 patients), and it was not associated with either a shorter duration of symptoms or a quicker return to sport. Interestingly, the MR imaging finding of muscle edema was predictive of a shorter clinical course, which seems paradoxical if muscle edema is a more severe manifestation of periosteal or juxta-cortical edema. Patients with muscle edema tended to have undergone MR imaging closer to the onset of their symptoms. The confounding correlation between the duration of symptoms before MR imaging and total symptom duration could partially explain the prognostic value of muscle edema. Accordingly, this result requires further examination in a more powerful study.

The MR imaging findings of periosteal edema and cortical signal intensity abnormalities or medullary lines did not show statistically significant correlation with radiographic findings, despite adequate radiographic follow-up evaluation in 25 patients. This result again emphasizes the higher sensitivity of MR imaging for stress injuries of bone compared with radiography but probably says little about the prognostic value of MR imaging. Interestingly, radiographic abnormalities were not associated with a longer duration of symptoms or a slower return to sports.

The proposed MR imaging classification by Fredericson et al also ascribes prognostic value to the presence of an MR imaging fracture line (6). This classification, which was based on tibial injuries, further suggests that lower-grade stress injuries are manifested as periosteal edema alone. Only 24 of our 35 more heterogeneous cases met the classification criteria of Fredericson et al,

largely because there was a lower frequency of periosteal abnormalities in our patients. This discrepancy may be partly explained by the uniform use of fat-suppressed T2-weighted imaging in the study by Fredericson et al, which would be more sensitive for minor periosteal findings. The grading system of Fredericson et al was not predictive of the time to clinical recovery in the 24 patients in our study who fit the grading system.

Variability in the aggressiveness of treatment, patient compliance, and tolerance to pain could all compromise the validity of reported symptom duration as a proxy of injury severity. The premise that stress fracture has a longer symptom duration than other causes of bone pain can certainly be debated. Patients with “shin splints” may have more refractory symptoms than patients with stress fractures (12). However, although shin splints may bear some relation to a stress reaction of bone, they remain a poorly defined and likely heterogeneous clinical entity and a large percentage of cases will have normal MR images (13).

Our study has several weaknesses, including the small number of patients and the non-Gaussian distribution of our subjective outcome measures—duration of symptoms and time to return to sport. These factors limit the power of our study. MR imaging findings expectedly evolve over time; marrow edema typically resolves within 6 months in cases of femoral neck fatigue fractures (11). The variable interval between symptom onset and MR imaging may confound an analysis of MR imaging signs, as discussed with respect to muscle edema. Finally, the detection of subtle MR imaging fracture lines and cortical abnormalities will depend on image orientation and resolution, which vary for the different anatomic sites included in our study.

Perhaps in part because of these limitations, a robust MR imaging grading system for stress injuries of bone does not emerge from our study. A published MR imaging grading system for the tibia was not prognostic in our more heterogeneous patient group, at least as reflected by clinical follow-up data. The appearance, evolution, and clinical implication of a stress injury may in fact vary depending on its anatomic site, which determines the persistent mechanical stresses that are applied to the injury. Despite limited power, our study does suggest that the MR imaging finding of a fracture or fatigue line or an intra-cortical signal intensity abnormality indicates a more debilitating stress injury of bone. The MR imaging finding of periosteal edema rarely occurred alone and was not independently associated with a more favorable prognosis.

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