A prospective controlled study of diagnostic imaging for acute shin splints

MARK E. BATT, VIVIANE UGALDE, MARK W. ANDERSON, and D. K.SHELTON
University of California, Davis, CA

ABSTRACT

BATT, M. E., V. UGALDE, M. W. ANDERSON, and D. K.SHELTON. A prospective controlled study of diagnostic imaging for acute shin splints. *Med. Sci. Sports Exerc.*, Vol. 30, No. 11, pp. 1564–1571, 1998. **Objective:** The purpose of this prospective, observational study was to examine the relationship of clinical examination, plain radiograph (XR), triple-phase bone scan (TPBS), and magnetic resonance imaging (MRI) in the investigation of patients presenting with acute shin splints. **Methods:** 23 subjects with exercise induced lower leg pain and diffuse tibial tenderness of less than 3 months' duration were recruited. Subjects were excluded if there was clinical evidence of compartment syndrome, muscle hernia, or stress fracture. Each subject underwent XR, TPBS, and MRI within 2 wk of physical examination. Four asymptomatic controls underwent TPBS and MRI. Clinical findings, XR, TPBS, and MRI findings were independently recorded using a consistent template and subsequently analyzed. A single consensus lesion was chosen that provided the greatest overlap and highest grade to allow comparison of clinical and imaging findings. Sensitivity and specificity were calculated from data relating to clinical findings and diagnostic imaging. **Results:** Eighteen subjects had bilateral symptoms and five unilateral with a mean duration of symptom of 5.4 wk (±3.5). Of 41 symptomatic lower legs, there were TPBS abnormalities in 36 and MRI findings in 34. Analysis of clinical findings to TPBS and MRI demonstrated a sensitivity and specificity of 84%, 33% and 79%, 33%, respectively. Assuming TPBS as the "gold-standard," MRI findings demonstrated a sensitivity of 95% and specificity of 67%. There was poor agreement between the grading of TPBS and MRI ($k = 0.3$). In the 5/46 asymptomatic limbs, 3/5 demonstrated uptake on bone scan and 4/5 signal change with MRI. Imaging abnormalities were similarly seen in the four control patients. **Conclusions:** MRI may be used rather than TPBS and radiographs for evaluating acute tibial pain in athletes where avoidance of radiation exposure is desirable. Similar sensitivity and specificity may be expected from both investigations; however, in the light of abnormal TPBS and MRI findings in control and asymptomatic limbs, we recommend further studies be performed to define the extent of nonpathological TPBS and MRI changes. **Key Words:** EXERTIONAL LOWER LEG PAIN, CLINICAL EXAMINATION, RADIOLOGY

Lower leg pain is a common and enigmatic athletic overuse problem of variable reported incidence, in part reflecting imprecise terminology. Typical diagnoses include bone stress injury, nerve compression syndromes, fascial hernia, compartment syndrome, and shin splints. The term shin splints is frequently used synonymously to describe exercise-induced lower leg pain but should be regarded as a descriptive term for exertional lower leg pain not caused by stress fracture, compartment syndrome, or muscle hernia (3). Despite attempts to clarify the definition of shin splints, no discrete diagnostic criteria exist, reflecting the poor understanding of pathophysiology (3,39).

Previous attempts to investigate the pathophysiology of shin splints have included fascial and periosteal biopsy and histology, imaging techniques, compartment pressure measurement, and biomechanical assessment. In a previous study, we used magnetic resonance imaging (MRI) to investigate MR findings in a group of 19 patients presenting with activity-related lower leg pain (1). That study demonstrated a strong correlation between a history of prolonged symptoms and a normal MRI scan. In contrast, patients with relatively short-lived symptoms of shin splints (mean duration of pain: 10 months) demonstrated a spectrum of MRI findings that appeared consistent with a bone stress response. This study attempted to investigate patients with shin splints and thus had specifically excluded those patient who on presentation had clinical findings suggestive of stress fracture. In contrast, Fredericson et al. investigated using MRI a group of collegiate runners who had had a triple-phase bone scan (TPBS) confirming tibial stress reaction or fracture or shin splints (14). In 14 runners with 18 symptomatic legs (the duration of antecedent symptoms is not stated), clinical examination and MRI findings suggests that 11 symptomatic legs had advanced bone stress reaction or fracture. They found that MRI more accurately correlated

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with clinical symptoms than TPBS and suggested that it is a more useful prognostic tool. The initial diagnostic criteria of these two studies were different, and they were not looking at similar groups of patients as localized tibial bone pain was an exclusionary criterion of the former study.

The purpose of this prospective, observational study was to compare clinical examination, plain radiographs, TPBS, and MRI findings of patients presenting with acute shin splints. TPBS has previously been regarded as the gold-standard investigation for shin splints, and it was our hypothesis that MRI might provide similar sensitivity but improved specificity. For the purpose of this study, acute shin splints is defined as less than 3 months of exertional lower leg pain, with diffuse tenderness of the posteromedial tibia. Patients with clinical findings suggestive of stress fracture or compartment syndrome were excluded from this study.

MATERIALS AND METHODS

Subjects. Twenty-three experimental subjects with exertional lower limb pain and four controls were recruited from local high schools, colleges, universities, running clubs, and professional dance companies. Eleven female and 12 male subjects with exertional lower leg pain ranging in age from 14 to 58 yr (mean 22, SD 10.5) were entered into the study. Four asymptomatic age- (range: 19–33 yr (mean 26.6, SD 5.1) and activity-matched subjects (2 female and 2 male subjects) acted as controls. Informed consent was obtained from all participants. The study was approved by the Human Subjects Review Committee and Radiation Review Board at our institution. All subjects underwent a history and physical examination. All subjects were examined for posteromedial tibial tenderness, pain with tibial percussion, and pain with hopping. Specific entry criteria for experimental subjects included: 1) a history of exercise induced lower leg pain of less than 3 months' duration, initially relieved by rest and exacerbated with exercise; 2) diffuse linear tenderness to palpation along the posteromedial tibia extending along a distance of at least 5 cm (with or without other foci of tenderness); and 3) no clinical evidence of compartment syndrome or muscle herniation. Subjects with localized tibial bone pain, exacerbated by percussion, suggestive of tibial stress fracture were excluded. Inclusionary criteria for control subjects were: 1) no prior history of shin splints or stress fractures and 2) no palpable tenderness of the posteromedial tibia when compared with a control site over the lateral epicondyle of the elbow.

Experimental protocol. Experimental subjects had plain film radiographs, MRI, and TPBS performed within 2 wk of the physical examination. Control subjects had MRI and TPBS performed within 2 wk of the physical examination.

Radiographs. In experimental subjects, plain radiographs of both tibiae were taken in the anteroposterior, lateral, and oblique projections.

Grade	Bone scan[a]	MRI[b]
0	No abnormal uptake	Normal
1	Focal (1a) or elongated (1b) superficial uptake	Mild-moderate periosteal edema : FSE-IR weighted images
2	Focal uptake <30% of tibial width	Moderate-severe periosteal oedema. Marrow edema : FSE-IR images
3	Focal uptake encompassing 30-60% tibial width	Moderate-severe edema of periosteum and marrow : T1 and FSE-IR images
4	Uptake with >60% tibial all width	Low-signal fracture line on sequences, with severe marrow edema : both T1 and FSE-IR images

Figure 1—Bone scan and MRI grading schemes for acute shin splint lesions. [a]Adapted from Zwas, S. T., R. Elkanovitch, and G. Frank. Interpretation and classification of bone scintigraphic findings in stress fractures. *J. Nucl. Med.* 28:452–457, 1987; [b]Adapted from Fredericson, M., A. G. Bergman, K. L. Hoffman, and M. S. Dillingham. Tibial stress reaction in runners: correlation of clinical symptoms and scintography with a new magnetic resonance imaging grading system. *Am. J. Sports Med.* 23:472–281, 1995.

MRI. MRI was performed on a 1.5 T system (Signa, General Electric, Milwaukee, WI). Using the body coil, fast spin echo inversion recovery images (FSE-IR: TR/TE/TI = 3000–5000/51–76/140–160 ms) were obtained of both lower legs in the sagittal and axial planes. Axial T1 weighted images (TR/TE = 500–800/10–20 ms) were also acquired in most patients. Slice thickness and gap were 4 mm and 1 mm, respectively, and FOV of 30–48 cm were used for sagittal imaging. Axial slice thickness ranged from 5–10 mm with a FOV of 22–48 cm (typically 25–30 cm). Other parameters included a matrix of 256 × 160–256 and 1–4 signal acquisitions on all sequences (256 × 192, 2 NEX, in most cases). If abnormal signal intensity was identified in the tibial marrow, additional axial FSE - IR and T1 weighted images were acquired through the area of interest using either the head coil (FOV = 20–30 cm), if bilateral, or a dedicated extremity coil (FOV = 10–21 cm), if unilateral, for improved resolution. A grading system adapted from Fredericson et al. (14) was applied to all MR images. Grade 0 was added to represent a normal examination. A grade 1 scan demonstrated mild-moderate periosteal edema on FSE-IR images only with no focal bone marrow abnormality. Grade 2 scan indicated more severe periosteal edema with bone marrow edema on FSE-IR images only. Grade 3 demonstrated moderate to severe edema of both the periosteum and marrow on both T1 and FSE-IR weighted images. Grade 4 demonstrated a low-signal fracture line on all sequences, with changes of severe marrow edema on both T1 and FSE-IR weighted images (Fig. 1).

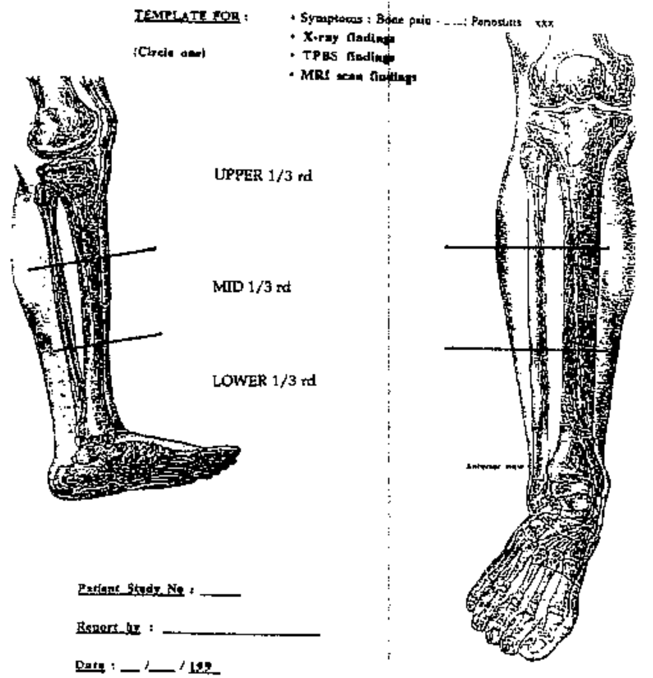

Figure 2—Tibial template used for recording clinical and radiological findings.

Bone scan. Triple phase bone scans were performed on all subjects (Picker, Cleveland, OH); 25 mCi of Technetium 99m was utilized for dynamic, blood pool, and delayed images in four planar views of the tibiae. A grading system modified from Zwas et al. was devised to correspond with MR grading (43). Grade 0 was a normal scan. Grade 1 demonstrated focal (1a) or elongated superficial cortical uptake (1b). Grade 2 indicated a focal area of uptake <30% of tibial width. Grade 3 showed focal uptake encompassing 30–60% of tibial width. Grade 4 uptake encompassed >60% of tibial width (Fig. 1). For all TPBS analysis, delayed phase scan results were used rather than flow or blood pool images. Positive flow and blood pool images were interpreted as more in keeping with a stress fracture, rather than periosteal changes (16,23).

Image analysis. MRI and plain radiographs were analyzed by a single experienced musculoskeletal radiologist. Bone scans were analyzed by a different radiologist specializing in nuclear medicine. The location of lesions found by clinical examination and the different imaging techniques were drawn independently on templates of tibiae (Fig. 2). Clinical findings, TPBS and MRI abnormalities were ascribed to upper, mid, or lower tibiae. Once template analysis was complete, clinicians and radiologists met to provide a consensus reading of the radiology that was then matched with patient demographics and clinical findings. Control subjects' images were analyzed in a similar manner.

Statistical analysis. Means and standard deviations were computed for age and symptom duration. Sensitivity and specificity values were calculated from positive findings on clinical examination and TPBS and MR imaging. To assess the measure of agreement between the comparative grading of the TPBS and MRI findings, the weighted kappa statistic (k) was used. Strength of agreement of observed k values was interpreted as follows: 0.00–0.20 slight, 0.41–0.60 moderate, and 0.81–1.00 almost perfect (12).

RESULTS

History and examination. Of 23 patients meeting the entry criteria of shin splints, 5 demonstrated unilateral symptoms and 18 bilateral. The range of symptom duration was 1–12 wk with a mean of 5.4 wk (SD ± 3.5) for the right shin and 5.1 wk (SD ± 3.2) for the left shin. All experimental subjects were competitive high school, collegiate, club, or professional athletes: 11 long/middle distance runners, 3 track and field jumpers, 3 sprinters, 2 ballet dancers, 2 ultimate Frisbee players, 1 gymnast, 1 basketball player; 17/23 subjects performed activities 5–7 $d \cdot wk^{-1}$ and 4/23 subjects 2–4 $d \cdot wk^{-1}$.

Physical examination. Physical examination revealed hyperpronation as the most frequent biomechanical abnormality (6/23), followed by 4/23 genu varus, 2/23 cavoid feet, 2/23 femoral anteversion, 1/23 leg length discrepancy, and one subject with decreased hip range of motion ipsilateral to shin pain.

Eighteen subjects had bilateral symptoms and 5 unilateral providing 41 symptomatic limbs in 23 patients. The tibial distribution of posteromedial pain was: proximal 2, proximal → mid 3, mid 15, mid → distal 14, distal 5 and diffuse proximal → distal 2 (Table 1). Pain with tibial percussion was found in 11/41 limbs. Increased tibial pain with hopping occurred in 21 of 46 limbs. Provocative muscle testing was unrewarding being positive for only 9 subjects with no consistent muscle group involvement.

Diagnostic Imaging

On 4 of the 46 sets of tibial radiographs, there was periosteal elevation. The remaining 42 demonstrated no abnormal findings. Of the 41 lower legs with clinical findings, delayed phase TPBS abnormalities were seen in 36 and abnormal MRI findings in 34 legs. The following analyses were performed:

Sensitivity and specificity analysis. Comparison of clinical findings to TPBS findings revealed a TPBS sensitivity of 84% and specificity of 33%. The correlation of clinical findings to MRI revealed a MRI sensitivity of 79% and specificity of 33% (Table 2). Assuming TPBS as the "gold-standard" investigation, correlation of imaging findings of MRI with those of TPBS demonstrated MRI had a sensitivity of 95% and specificity of 67%.

TABLE 1. The tibial distribution of periosteal findings on physical examination with associated TPBS grade 1B lesions.

Location (Tibial 1/3rd)	Periosteal Pain (%)	1B TPBS Lesions (%)
Proximal	5	41
Prox → mid	7	14
Mid	37	18
Mid → distal	34	22
Distal	12	4
Prox → distal	5	0

TABLE 2. Correlation of positive clinical, TPBS and MRI findings for consensus lesions with clinical findings assumed to be the gold standard.

	Clinical +ve	Clinical −ve
TPBS +ve	36	2
TPBS −ve	7	1
MRI +ve	34	2
MRI −ve	9	1

Analysis of the comparative grading of the TPBS and MRI findings:. There was a poor agreement between the grading schemes used for analysis of TPBS and MRI abnormalities with a weighted kappa statistic $k = 0.3$. Grade 1 TPBS findings were the most frequent, found in 30 of 46 tibiae (65%) followed by normal findings in 7 of 46 tibiae (15%). In contrast grade 2 and 3 findings were the most frequent MRI abnormalities occurring in 23 of 46 (50%) and 12 of 46 (26%), respectively (Table 3). In the two cases, where stress fracture was diagnosed, the abnormal findings (grade 4) of both imaging techniques were consistent (Table 4).

Grade 1 TPBS changes are typically regarded as being consistent with "shin splints" (26,35,43). Of 36 abnormal TPBS findings, grade 1 TPBS changes were most commonly reported in 30 of 46 tibiae (65%), with corresponding MRI grades of: 3/30, grade 0; 18/30, grade 2; and 9/30, grade 3.

Analysis of the location of clinical, TPBS, and MRI findings. This analysis was complex, resulting from the numerous different lesions identified in the tibiae. Clinical and imaging findings were identified and classified according to their sagittal location within the tibia (proximal, mid, distal thirds; Fig. 2, Table 5). For the purposes of comparing clinical findings, TPBS, and MRI, a single consensus lesion was chosen from each symptomatic limb. The distribution of consensus lesions was predominately mid to mid-distal third of the tibia (Table 6). When all lesions were considered, the distribution of findings was more even between the tibial thirds with a significant involvement of the proximal tibia, particularly on TPBS. Bone scan findings tended to be more widespread than either clinical examination or MRI. Locational analysis of posteromedial pain, and TPBS grade 1 findings demonstrated a preponderance of clinical lesions in the mid and mid-distal thirds of the tibia contrasting with 74% of grade 1 TPBS lesions occurring in the upper two thirds of the tibia (Table 1). Delayed phase TPBS findings were more diffusely located than either clinical or MRI findings.

The location of MRI findings appeared to correspond more consistently with clinical findings (Table 6). Based on the classification of Fredericson et al., 8 normal scan were reported in 46 limbs (14). Forty-six abnormal MRI foci were seen in 35 limbs, with a distribution given in Table 3. Periosteal fluid and endosteal changes were localized on axial cuts (Fig. 3) and observed to be predominately anteromedial (Table 7). Endosteal changes had the following sagittal tibial locations: 16 mid, 17 mid-distal, 2 mid-proximal, 3 proximal, and 2 distal tibia.

Asymptomatic limbs and controls. Of the five asymptomatic limbs, four had abnormal findings on both TPBS (grades 1a × 2, 1b and 2) and MRI (grade 2 × 5) with one demonstrating no abnormal findings on either TPBS or MRI. Imaging of the four control patients demonstrated normal radiographs but positive TPBS in the two women and MRI findings in all four controls. The abnormal uptake on TPBS was consistent with grade 2 superimposed on Grade 1b, which corresponded with MRI grade 3 findings. The two male controls demonstrated normal TPBS but bilateral grade 2 MRI findings.

DISCUSSION

This is the first reported prospective, observational study of acute shin splints. The use of the term shin splints is recognized as being imprecise, and thus for the purposes of this study, a set of specific diagnostic criteria were used to produce a homogeneous study population that excluded patients with clinical evidence of stress fracture, muscle hernia, compartment syndrome, and those with chronic symptoms. In a previous study, Fredericson et al. studied a group of 14 intercollegiate runners (18 symptomatic legs) presenting with medial tibial pain, which included medial tibial stress syndrome, tibial stress reaction or stress fracture confirmed on TPBS. The duration of symptoms was not stated; however, 11 of their 14 runners had pain with ambulation, 56% had focal TPBS findings, and 81% had high grade stress injury on MRI indicating that this population was biased toward athletes with tibial bone stress injury or fracture (14).

Clinical findings. Posteromedial tenderness was most commonly found in the mid or distal thirds of the tibia, which is consistent with previous reports of medial tibial syndrome (7,28,31) but not consistent with tibial stress fracture, which more typically occur in the proximal or mid-third (6,10,11,15,24,43). Similarly, unlike studies of tibial stress injury or fracture a female preponderance was not observed (14,24). The clinical findings, specifically the location of periosteal tenderness is of particular interest in this group of patients, all of whom presented with acute shin splints. Periosteal traction at the site of lower leg muscle origins is a cited cause of periostalgia and yet anatomically only flexor digitorum longus, soleus muscles, and the crural fascia have significant longitudinal origins below the mid-tibia where the majority of periosteal symptoms and signs occur (4,9,28,36). This study suggests that the etiology of acute shin splints may be related to bone stress injury rather than a primary periosteal injury. We found low grade diffuse uptake (Grade 1B,2) on TPBS corresponding with endosteal MRI findings, which lends support to this concept. These findings are consistent with our previous study in which

TABLE 3. TPBS and MRI observed in symptomatic tibiae expressed as percentages.

Grade	TPBS (%)	MRI (%)
0	15	17
1	65	0
2	9	50
3	7	26
4	4	7

TABLE 4. Comparative TPBS and MRI grades for consensus tibial lesions.

	0	1	2	3	4	MRI
0	5	0	2	0	0	7
1	3	0	18	9	0	30
2	0	0	2	2	0	4
3	0	0	1	1	1	3
4	0	0	0	0	2	2
TPBS	8	0	23	12	3	46

patients with short-lived symptoms were demonstrated to have MRI findings interpreted as a continuum of bone stress injury (1). The concept of stress microfracture as a cause of shin splints is not new but was previously reported based on histological studies in a group of patients with persistent pain recalcitrant to conservative treatment (18).

Abnormal biomechanics were found in eight subjects (35%) with frequently more than a single abnormality being present in a given athlete. Hyperpronation of the foot was the most frequent biomechanical abnormality, which is consistent with previous studies of patients with shin splints (8,17,22,38,42). Unlike DeLacerda's study, isolated lower leg muscle group testing was not positive in either significant numbers (17%) or with a consistent muscle group involvement (8). In this group of patients, we did not find this to be a useful component of physical examination, and this mitigates against traction periostalgia as a significant cause of pain in these patients.

Imaging Analysis

Clinical findings and radiology. Periosteal abnormalities were seen on plain radiographs in only four patients (5 limbs), which is consistent with the short symptom duration (average 5–6 wk) of this patient group (18,33,40). In two of the four patients, there was good locational agreement of periosteal elevation, TPBS, and MRI. In these two patients, the TPBS and MRI gradings were consistently high, compatible with bone stress reaction despite the short duration of symptoms (2 and 4 wk).

Compared with clinical examination, TPBS and MRI demonstrated sensitivity and specificity, respectively, of 84% and 33% and 79% and 33%. These figures are remarkably similar demonstrating good agreement in the ability to detect lesions present. However, the poor specificity reflected in part the more diffuse imaging findings. Previous reports of the use of scintigraphy in evaluating patients presenting with exertional lower leg pain have not addressed the sensitivity and specificity of TPBS (2,6,17,23,26,27,29,34,43). The ability of this technique to detect small alterations in bone turnover leads to high sensitivity. However, low specificity reflects the inability of this technique to exclude patients without disease as is manifest by positive scans in asymptomatic athletes and controls (6). The MRI figures are comparable, providing similar test information but with no radiation exposure, which is particularly advantageous for young patients. Assuming TPBS as the gold standard, MRI had high sensitivity (95%) with a specificity of 67%. For a single patient, this reflects differences in the site of TPBS and MRI abnormalities within the tibia and suggests that these techniques may be imaging different processes: MRI displaying site of damage and subsequent local bone response, whereas TPBS demonstrates the more diffuse osteoblastic response to lower leg overuse injury.

Comparative grading of the TPBS and MRI findings. The current study demonstrates a poor agreement between the grading schemes used for TPBS and MRI analysis. The four lesion grades used by Zwas et al. were taken as stress fractures in different stages of evolution and clinically their group of patients presented with localized bone pain compatible with stress fracture (43). The utility of this scheme for analysis of patients with shin splints may be questioned and further compromised as they did not utilize angiographic or blood pool phases which may be of use for delineating inflammatory lesions, specifically periostitis (16). No systematic study of the utility of all three phases of the bone scan in this population has been reported to date. Zwas et al. separately described shin splints as diffuse nonfocal anterolateral tibial uptake, extending along the proximal two-thirds of the tibia in contrast to Matin and Holder, who included posteromedial uptake (17,26,27). The findings of the current study are at variance with both.

The MR images were analyzed according to a scheme recently devised by Fredericson et al. who reported good correlation between the grades obtained on TPBS (Zwas grading) and MRI (in 14 of 18 (77.8%) legs examined) (14,43). This is in contrast to the results reported here, which demonstrate a poor agreement with MRI grades that are typically higher than the corresponding TPBS grades. Grade 3 TPBS (50%) and MRI (55%) changes were those most frequently reported by Fredericson et al., whereas we reported TPBS grade 1 (65%), and MRI grade 2 (50%), grade 3 (26%) abnormalities most frequently. Differences in patient populations may partially explain this discrepancy. We have reported lower grades consistent with our population of patients with nonlocalized short-lived tibial bone pain (with clinical stress fracture excluded) compared with Fredericson et al.'s group of patients with localized tibial pain and positive TPBS consistent with stress reaction or fracture (14).

This study supports the concept of acute shin splints representing a bone stress injury despite low grade diffuse uptake seen on TPBS. We suggest the higher grade MRI lesions are characteristic of bone stress injury and may provide more prognostic information for the clinician in this group of patients. This is of great significance as previously these lesions were regarded as relatively benign, self-limiting inflammatory injuries of the periosteum or crural fascia

TABLE 5. All identified clinical or radiographic (TPBS/MRI) lesions with associated tibial location (as per Fig. 2).

Location (Tibial 1/3rd)	Clinical	TPBS	MRI
	% (*N*)	% (*N*)	% (*N*)
Prox	22 (13)	35 (28)	12 (6)
Prox → mid	3 (2)	11 (9)	4 (2)
Mid	25 (15)	22 (17)	35 (18)
Mid → distal	32 (19)	23 (18)	35 (18)
Distal	14 (8)	8 (6)	12 (6)
Prox → distal	3 (2)	1 (1)	2 (1)
Total (*N*)	59	79	51

TABLE 6. Consensus lesions with associated tibial location (as per Fig. 2).

Location (Tibial 1/3rd)	Clinical %	TPBS %	MRI %
Prox	5	3	5
Prox → mid	7	10	11
Mid	37	36	39
Mid → distal	34	38	36
Distal	12	10	11
Prox → distal	5	3	3

for which reducing inflammation was the key to treatment. With this better pathophysiological understanding, rest followed by a gradual return to sport with activity modification would be a more appropriate management for this injury as bone remodeling is the essence of resolution of the problem.

Analysis of the location of the MRI findings. Axial cuts of the tibia demonstrated periosteal fluid and endosteal changes to be predominately postermedial/anteromedial (Fig. 3). This is the tensile surface of the tibia and corresponds to the typical location of diaphyseal tibial stress fracture. Bone stress injury results from cumulative microtrauma; the relative contributions of repetitive axial loading over tibial bending is conjectural (30). However, unlike Fredericson et al., who demonstrated periosteal edema along the contiguous origins of the posterior compartment muscles, the anteromedial periosteal edema and endosteal changes seen in our patients further argues against the notion of a muscle traction induced periosteal injury in these patients.

From animal studies, it is known that long bones placed under increased strain respond by producing subperiosteal woven bone and that this response may exhibit a dose-response relationship with mechanical loading (5,13,19,21,41). Unlike previous clinical studies, we have demonstrated MRI findings of endosteal changes. Endosteal buttressing has also been observed in animal studies as a response to elevated strain (5,13). Its demonstration in this study lends weight to the notion that in patients presenting with acute shin pain (even when clinically diffuse), the pathophysiology is likely to include bone fatigue. Clinical presentation of posteromedial tibial pain partially corresponds with MRI periosteal or endosteal findings. This, however, appears more consistent with the diffuse uptake patterns seen on TPBS. Locational analysis of TPBS is less precise than MRI as it does not provide cross-sectional imaging. The discrepancy may be interpretational or alternatively represent a temporal phenomenon with MRI demonstrating greater site specificity early in bone remodeling. Widespread late phase TPBS uptake (grade 1b) is probably indicative of diffuse periosteal reaction which as time progresses become more localized with greater cortical involvement. Like Chisin, we suggest that low grade TPBS findings in patients presenting with tibial pain be considered as stress fractures in evolution and accordingly be managed with a period of relative rest (6).

Asymptomatic limbs and controls. Of five clinically asymptomatic limbs, one was truly negative with no findings on either TPBS or MRI. The remaining four had abnormal findings on both MRI (grade 2) and TPBS (grades 1 × 4). This is not an unexpected finding as both TPBS (2,25,43), and MRI (20) have been previously reported to demonstrate asymptomatic foci. On bone scan these foci are typically regarded as grade 1 or 2 and probably representing "bone strain" or physiological bone remodeling (25,35). Only a small comparative control cohort was used in this study. These subjects were age- and activity-matched yet asymptomatic.

Asymptomatic bone scan foci have been previously reported, and although MRI may offer improved site specificity, caution is required as increasingly it is recognized that marrow edema may result from exercise alone and represent asymptomatic foci (20,25,32,34,37). The implication of these "false-positive" scans in the clinical setting is profound. These imaging techniques may be overly sensitive in the clinical setting highlighting the need for further study of asymptomatic controls.

The absence of symptoms in these patients is consistent with the findings in the four control subjects, and it is now an accepted finding, although previously considered to be incompatible with bone stress injury (34). These findings do, however, present a potential confounder when relating imaging to clinical findings. Likewise, MRI findings of marrow edema in foot and ankle of asymptomatic runners and nonrunners has been recently reported (20). These MRI findings, like those of bone scans, may represent physiological bone remodeling or the early uncoupling of bone resorption and accretion (bone stress reaction) and be compounded by adverse biomechanics (37).

Study Weaknesses

For correlation of clinical, TPBS, and MRI findings, a single consensus lesion providing greatest overlap was chosen. Several patients demonstrated more than a single site of

Figure 3—Axial (fast SE IR) MR image of the mid-tibia of a 16-yr-old female cross-country and track runner presenting with shin splints. Demonstrates high signal intensity periosteal fluid, periosteal reaction, and increased endosteal marrow signal.

TABLE 7. MRI findings and locational analysis.

	Subperiosteal Fluid	Endosteal Change
Anteromedial	17	17
Posteromedial	1	11
Anterolateral	1	0
Medial	0	2
Anterior	0	2
Posterior	2	2
Diffuse	0	6

abnormality in a given leg, and thus when selecting a single lesion, we made an assumption that abnormal findings demonstrated by each of the techniques arose from a consistent pathophysiological entity. To ensure that a consistent lesion was examined by each of the techniques, consensus reading was employed which introduces the possibility of interpretation bias; however, before consensus analysis, all images had been evaluated and graded independently.

For analysis of the different techniques, either clinical examination or TPBS were taken as providing a gold-standard for comparison. This was a necessary methodological assumption based on current practice. However, we know that neither are wholly reliable as evidenced by the requirement for other diagnostic tests. Furthermore, neither the TPBS nor MRI classifications reliably accounted for the longitudinal extent of identified lesions, which in our group of patients with diffuse clinical symptoms would have been appropriate.

Finally, longitudinal follow-up of this cohort would have provided clinical outcomes that may have enhanced the interpretation of our imaging findings.

CONCLUSIONS

1. This study lends support to the belief that acute shin splints represents a bone stress injury. The relationship between shin splints and stress fracture remains controversial, but this study suggests that that acute shin splints and stress fracture are related along a continuum of bone microdamage and associated reparative responses. Diffuse linear TPBS uptake has previously been interpreted as the discrete pathological entity of periostitis, typical of shin splints. We have corresponding MRI changes of bone stress injury and believe these injuries should no longer be regarded as benign, self-limiting inflammatory lesions.

2. MRI may be used rather than TPBS and radiographs for evaluating acute tibial pain in athletes where avoidance of radiation exposure is desirable. Similar sensitivity and specificity may be expected but as we have previously shown would temper this recommendation in patients with more chronic symptoms. Previous studies have demonstrated absent MRI changes in patients with chronic shin splints the pathophysiology of which remains unclear (1). Further studies investigating the etiology of pain in patients with chronic shin splints is warranted.

3. The demonstration of abnormalities in asymptomatic limbs and controls emphasized the requirement for further research to define the extent of TPBS and MRI nonpathological changes.

4. A revised TPBS/MRI grading scheme is required for these injuries and should include the distribution, extent, and severity of these lesions.

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Address for correspondence: Dr. Mark E. Batt, Centre for Sports Medicine, Queen's Medical Centre, Nottingham NG7 2UH, United Kingdom. E-mail: Mark.Batt@nottingham.ac.uk.

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