Interpretation and Classification of Bone Scintigraphic Findings in Stress Fractures

S. Tzila Zwas, Raya Elkanovitch, and George Frank

Departments of Nuclear Medicine and Orthopedic Surgery A, The Chaim Sheba Medical Center, Tel-Hashomer and Sackler School of Medicine, Tel-Aviv University, Israel

A new system for classification of stress fractures identified by bone scintigraphy was developed and divided into four grades according to lesion dimension, bone extension, and tracer accumulation. The scintigraphic findings were evaluated for severity of lesions by extent of the visualized bone response, ranging from ill-defined cortical lesions with slightly increased activity (I) to well-defined intramedullary transcortical lesions with intensely increased activity (IV). Bone scintigraphies using [^{99m}Tc]MDP were obtained in 310 military recruits suspected of having stress fractures. In 235 patients, 391 stress fractures were diagnosed. Forty percent of the lesions were asymptomatic. Most of the lesions were in the tibiae (72%), and 87% of the patients had one or two lesions, while 13% had three to five lesions. Eighty-five percent of the lesions were classified as mild and showed early and more complete resolution on follow-up studies after treatment as compared to the severe grades. Furthermore, specific scintigraphic patterns have been introduced for distinguishing inflammatory shin-splints from stress fractures, allowing for their appropriate early treatment. Thus, early recognition of mild stress fracture scintigraphic patterns representing the beginning of pathologic bone response to stress enabled a prompt and effective treatment to prevent progression of lesions, protracted disability, and complications.

J Nucl Med 28:452–457, 1987

Stress fractures, also known as fatigue or march fractures, commonly involve the bones of the lower extremities and are a well-recognized etiology for skeletal pain in military recruits, athletes, and other young individuals. They occur under conditions of unaccustomed or accelerated physical activity, and develop in seemingly normal diaphyseal bone in those with an apparent susceptibility to this type of pathology (*1,2*).

It is clear that there is no initial bone break in stress fracture as in traumatic fractures. They develop gradually over a period of days and weeks due to repeated excessive stress which causes mechanical disturbance of the cortical osseous trabeculae. When the stress is discontinued, bone replacement occurs with osteoblastic formation. Persistent physical activity results in continued stress tractions and bone resorption, leading to complicated severe stress fractures with microfractures or complete fractures (*3,4*), and ultimately protracted disability.

Received Apr. 7, 1986; revision accepted Sept. 10, 1986.

For reprints contact: S. Tzila Zwas, MD, Dept. of Nuclear Medicine, The Chaim Sheba Medical Center, Tel-Hashomer 52621 Israel.

Bone scintigraphy is known to be much more sensitive than radiography for diagnosing stress fracture (*5–9*). In this long-term study of military recruits begun in 1980 (*10,11*), we attempted to arrive at early scintigraphic diagnosis, to delineate a scintigraphic classification of stress fractures, and to assess the usefulness of the classification for the management and prognosis of stress fractures in conditions of intensive training. In addition, we introduce our observations regarding the distinctive scintigraphic patterns and corresponding disease course of inflammatory shin splints.

MATERIALS AND METHODS

Patients

A total of 310 male military recruits, aged 19–22 yr (mean 20 yr), complaining of gradual onset of localized bone pain and/or swelling and limping, were referred by orthopedists for bone scintigraphy. Stress fracture was suspected after excluding bone trauma. Prior to bone scans, 80 patients had bone radiographs 3 wk or more after onset of symptoms.

Bone Scans

The bone scans were performed using a large field-of-view gamma camera and a parallel hole, high-resolution collimator, 2 to 4 hr following i.v. injection of 20 mCi technetium-99m methylene diphosphonate. The scans routinely included anterior and posterior views of the pelvis and lower extremities, and lateral views or upper skeletal regions in selected cases. For each view 400,000 counts were collected.

The time intervals between the onset of symptoms and the first bone scan was 2–4 wk in 27% of cases, 1–2 mo in 50%, 2–3 mo in 16%, and more than 3 mo in 7% of cases. Most of the bone scans were obtained within 2 wk following referral.

Classifications of Bone Scan Findings

Stress fracture lesions demonstrated on bone scintigraphy were classified quantitatively into five groups according to the number of lesions, ranging from one to five per patient, and qualitatively into clinical and scintigraphic parameters. Comparison was made of the painful bone sites reported by the subject and the scintigraphy picture, and the lesions were classified as symptomatic (painful) or asymptomatic (latent).

Stress fracture scintigraphic patterns were classified into four grades of bone response according to dimension, bone extension, and tracer concentration in the lesions (Fig. 1):

Grade I: Small, ill-defined lesion with mildly increased activity in the cortical region.

Grade II: Larger than grade I, well-defined, elongated lesion with moderately increased activity in the cortical region.

Grade III: Wide fusiform lesion with highly increased activity in the cortico-medullary region.

Grade IV: Wide extensive lesion with intensely increased activity in the transcortico-medullary region.

Treatment Protocol

Treatment determined together with the orthopedists for patients with positive stress fracture findings on bone scintigraphy, whether symptomatic or not, consisted of complete rest and analgesics when needed. The duration of the rest period varied according to the grade of the stress fracture: 3–4 wk for Grades I and II, 4–6 wk for Grade III and IV. Rest period for femoral stress fracture was prolonged by 10 days. Subjects were urged not to resume strenuous physical activity until symptoms disappeared.

Follow-up Studies

Follow-up bone scans up to 2 yr after initial examination were obtained in 66 patients (28%) with a total of 119 lesions. Seventy-nine scans were obtained during this period, many within 2–6 mo following initial examination. Fifty-six patients had one follow-up scan and 11 had two to four additional studies.

RESULTS

Table 1 summarizes the stress fracture data. Among the 310 examined recruits, 235 (76%) had positive bone scan findings with a total of 391 stress fractures. The remainder had soft-tissue lesions (n = 65) or inflammatory shin splints (n = 10). Some 40% of the lesions were asymptomatic. In single-lesion cases the ratio of

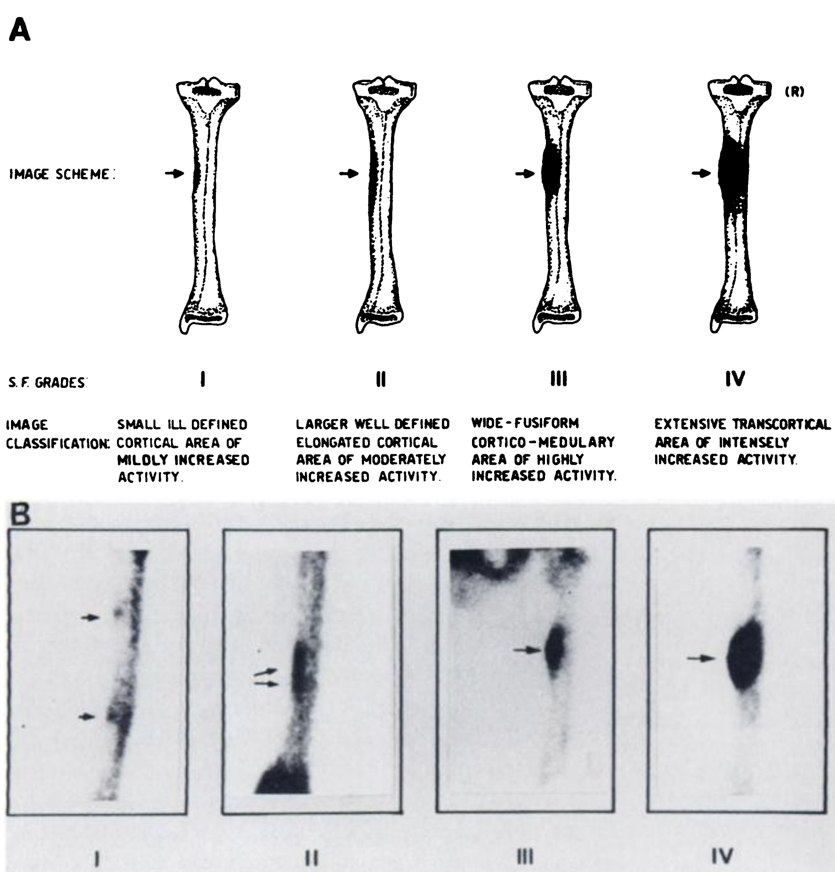

FIGURE 1
Four grades (I–IV) of stress fracture evolution as seen on bone scintigraphy are presented schematically (A) and in actual bone scintigraphies (B).

TABLE 1
Stress Fractures Symptomatology Compared with Scintigraphic Findings

No. of sites/patient	No. of stress fracture sites: Symptomatic	Asymptomatic	Total Sites	Total patients No. %
1	89	35	124	124 (53)
2	99	61	160	80 (34)
3	28	29	57	19 (8)
4	16	24	40	10 (4)
5	1	9	10	2 (1)
Total	233	158	391	235 (100)
%	60	40	100	

asymptomatic to symptomatic stress fractures was roughly 1 to 3; in the 5-lesion group the ratio was 9:1.

The asymptomatic stress fractures were generally located contralaterally or in different bones in the same individual. The majority of stress fractures were in tibiae (72%), predominantly in the mid-third, 15% in femurs, 9% in feet, predominantly in the metatarsal bones, and 3% in fibula. Rare stress fracture sites (1%) included the pubic and sacroiliac regions, and several ribs in one patient. Stress fractures in the tibiae and femurs were located in the medial posterior or anterior cortical regions; those in the pubic region and the feet occupied the full width of these narrow bones. Unilateral stress fractures were more frequent (60%) than bilateral ones.

Table 2 summarizes stress fracture data classified by our four-grade scale: 85% of the lesions were mild (Grades I and II). Most of the asymptomatic lesions were in the mild grades. Different grades of lesions were often found in the same patient (Fig. 2).

Radiographic Findings

The radiographic detectability for stress fractures in this series was only 18% (Table 2). In contrast, scintigraphy disclosed 173 lesions in the 80 patients who had radiographic studies. There were no cases of positive radiographic findings and negative bone scans in clinically suspected stress fracture sites. The percentage of false-negative radiographs was the highest for Grade I lesions, less for Grade II and III, and nonexistent for Grade IV.

TABLE 2
Summary of Positive Stress Fracture Sites and X-Ray Findings in 80 Patients

Scan grades	Total stress fracture sites	Total x-rayed sites	X-ray results: Negative	Positive
I	250	115	110 (96%)	5 (4%)
II	91	34	27 (79%)	7 (21%)
III	34	17	4 (24%)	13 (76%)
IV	16	7	0	7 (100%)
Total	391	173	140 (82%)	32 (18%)

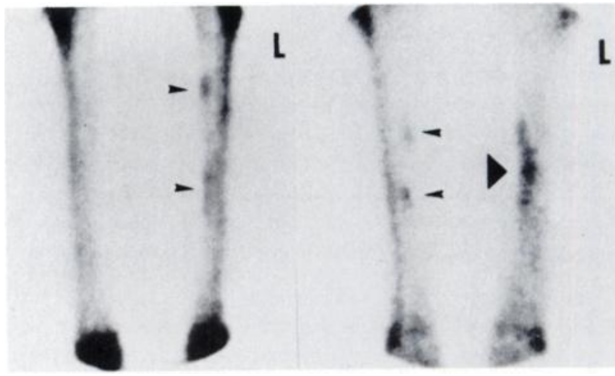

FIGURE 2
Left panel: Bone scan, anterior view, of the tibiae in a 21-yr-old recruit suffering 8 wk from left mid-leg pain, showing 2 Grade I stress fracture lesions in the medial cortex of the left tibia upper third (asymptomatic) and mid-third (symptomatic) (arrows). Right panel: 6 mo later after partial rest and returning to training, with new onset of right leg pain; scintigraphy shows disappearance of the left upper third stress fracture and progression to Grade II of the left mid-third lesion (arrow). Two new Grade I stress fracture lesions are seen in the mid-shaft of the right tibia (symptomatic) (arrow).

Follow-up Findings

The results of clinical-scintigraphic follow-up studies conducted on 66 patients were noteworthy. The 119 stress fracture lesions initially detected in these 66 cases and their scintigraphic follow-up results are summarized in Table 3 and illustrated in Figures 2 and 3. Several patterns of resolution of stress fractures were noted on follow-up bone scintigraphies in this group.

1. Complete resolution of the lesion occurred in 40% of the sites. The severity of the stress fracture was a major factor in the resolution rate, with Grades I and II resolving in the shortest intervals and more completely.

2. Partial or incomplete resolution (regression of lesion from a higher to a lower grade), occurred mostly in Grades III and IV. As shown in Figure 3, the highest partial resolution rate for all stress fracture grades was noted on 2-mo follow-up scintigraphies, while the highest complete resolution rate was noted during 4- to 6-mo follow-ups (Table 3). Thus, 4–6 mo was the optimal time interval for complete stress fracture healing in our group.

3. Persistent unresolved lesions were observed in 13% of the stress fractures, without particular significance to grade. In these cases lack of rest generally accounted for lack of recovery, which was accompanied by persistent pain.

4. Twenty-six new stress fractures were observed in 11 patients. Eight patients had new lesions appearing between 2–6 mo from initial diagnosis, and three be-

TABLE 3
Evolution of 119 Stress Fractures in 66 Patients

Follow-up scan findings	Stress fracture grades I + II (No. = 100) Up to 3 mo	I + II Over 3 mo	III + IV (No. = 19) Up to 3 mo	III + IV Over 3 mo	Total no. of fractures
Disappearance	17 (36%)	28 (55%)	1 (12%)	3 (15%)	49 (40%)
Partial improvement	27 (56%)	16 (30%)	6 (76%)	7 (75%)	56 (47%)
No Change	4 (8%)	8 (15%)	1 (12%)	1 (10%)	14 (13%)
Total	48 (100%)	52 (100%)	8 (100%)	11 (100%)	119 (100%)
New findings	3 (12%)	13 (50%)	—	10 (38%)	26 (100%)

tween 7–12 mo (Table 3). These new lesions occurred upon renewed or continuing intense training, and mainly in patients reporting incomplete rest (Fig. 2). All of them complained of new or recurrent pain when they returned to training.

5. Combined findings (initial stress fractures), complete, partial, or unchanged resolution and new lesions were found in 13 patients with multiple stress fractures (Table 3; Fig. 2). All these cases could be considered complicated, requiring prolonged rest periods.

There was often a discrepancy between persistent or recurrent pain and finding of the stress fracture lesions on scintigraphy. A completely resolved lesion was occasionally accompanied by persistent pain and, as previously mentioned, scintigraphic stress fracture findings were sometimes asymptomatic (painless). Two patients with follow-up studies are detailed in Figures 2 and 3.

DISCUSSION

The pathophysiologic concepts of stress fractures have changed since the last century when "swollen march feet" with metatarsal fractures were described in soldiers (*1*). Since that time, other terminology has appeared in the literature including shin soreness lesions (*12*), shin splint (*13–15*), insufficiency (*12*), fatigue (*1*), and stress (*2–12*) fractures, describing a wide range of bone injuries developing under excessive physical stress applied to bones.

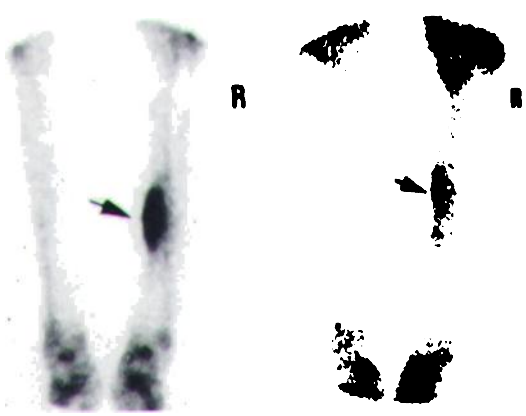

FIGURE 3
Left panel: Bone scan, posterior view, of the tibiae in a 19-yr-old recruit suffering 10 wk from right mid-leg pain, showing right tibial mid-shaft, wide oval-shaped medial corticomedullary lesion consistent with Grade III classification (arrow). Right panel: 6-mo follow-up study after rest treatment showing partial regression of the lesion to Grade II stress fracture lesion (arrow).

Stress or fatigue fractures are often not true fractures, since there is no loss of structural continuity. They begin at sites of accelerated normal remodeling of cortical bone. A true fracture occurs only when the removal of cortex is accelerated beyond the capacity of the periosteal reaction to offer adequate reinforcement. Thus, it seems that the term stress or fatigue "fracture" limits the meaning of the full range of stress bone injuries appearing in the evolution of the dynamic osteogenic bone response. Because of the reactive nature of the lesion and the continuous nature of the bone response to stress in this process, its scintigraphic, as well as radiographic, appearance varies with the time of discovery.

In previously proposed radiographic classifications of stress fractures, the patterns of characteristic bone findings were based mostly on the delayed radiological findings (*2,16*). The scintigraphic patterns of the early metabolic bone changes occurring in the beginning of this process (*3,4*), the early periosteal bone changes described above wherever visualized (*8,17*) were not recognized.

Several authors referred to the periosteal and poorly defined cortical lesions in stress fractures as separate entities, called periosteal reactions (*17*) or shin splints (*15,18*), which were too often left untreated.

Guided by the experience gained in this study, we developed a scintigraphic classification of stress fractures based on a dynamic evolutionary process of bone reaction varying in appearance and progression from early Grade I (mild) to advanced Grade IV (severe). This classification introduced by Zwas et al. in 1980 (*10*) is now fully described. Careful long-term observation of the scintigraphs of our patients revealed a progression in lesions from mild to severe in those cases left untreated, and regression and healing from severe to mild grades in cases properly diagnosed and treated with an appropriate convalescent period.

Comparison of our data with those from other studies reported in the literature raised several problems due to differences in patient populations, diagnostic modalities, and clinical methodology. Patient populations [e.g., military recruits (*1,6,7,9*), athletes and dancers (*8,12,18*)] with significant variation in types of physical strain result in different bone sites being exposed to stress. In our study most of the lesions were in the tibiae, fewer in femurs and feet, and none in the femoral neck. Other above mentioned reports showed different frequencies.

Diagnostic modalities included radiographs (*1–3,12*), scintigraphies (*15,17*), or both (*5,8,14,18*). Our scintigraphic screening routinely included the entire pelvis and lower extremity regardless of the symptomatic bone sites, enabling detection of many asymptomatic lesions (40%). Moreover, we were able to detect many more lesions which we classified as mild stress fractures (85%), which other studies failed to recognize (*15,17,18*). We had a relatively low rate of positive radiographic findings (18%), even though the radiographs were performed 4 wk or more after onset of symptoms. Over 60% remained negative on repeated studies, mainly in the mild grades. There were no false-negative scintigraphies when compared with radiographic findings in our study. These results indicate the high sensitivity and specificity of bone scintigraphy for stress fracture detection.

Clinical methodology varies among studies, including time intervals from onset of symptoms to initial and follow-up examinations. Thus different radiographic and scintigraphic patterns were observed, a factor of importance in such a dynamically evolving process.

These factors can account for most of the lack of concensus in the literature regarding interpretation and classification of stress fracture data. In our study, no clear clinical correlation was found between the time interval from the onset of symptoms and the severity of stress fracture, as seen on scintigraphy (Figs. 2–3). This can be attributed to several factors: differences in type, degree, and severity of stress; the bone region and extent of local osteogenic response; and the length of the rest period prior to scanning. In addition, there was often no clear relationship between the symptomatic site and severity of pain in resolving lesions and the scintigraphic findings on one hand, and high number (40%) of asymptomatic lesions, on the other.

We included in our negative stress fracture group all the normal bone scans (n = 63) and those with nonstress fracture disorders; the latter included shin splints (n = 10) and soft-tissue injuries such as rhabdomyolysis (n = 2).

Stress fractures and shin splint inflammatory lesions (*13*) differed. Shin splints appeared as diffuse nonfocal periosteal uptake, mild in intensity, along the antero-lateral border of the tibiae, extending along the proximal two-thirds of the bone shaft (Fig. 4). Stress fractures, on the other hand, were always located along the medial cortex, focal, single or multiple, elongated, fusiform, or transverse areas of increased uptake. No single stress fracture was seen to extend beyond one-third of the cortical bone length, and was always located and confined to the medial aspect of the cortex (in Grades I and II) or extended intramedullarly to a varying extent (in Grades III and IV).

Shin splints diagnosed clinically and scintigraphically were treated and responded, mainly to anti-inflammatory drugs, while stress fractures of all grades were treated and responded as verified scintigraphically (Figs. 2,3) to rest treatment, with anti-inflammatory drugs having no significant effect. Based on these criteria, we could clearly distinguish between these two different entities in our study. These results differ from some previously suggested "shin splint" scintigraphic patterns (*14,15,18*).

In conclusion, scintigraphy detects stress fracture lesions from the early pathologic metabolic bone response occurring in the periosteal-cortical region. Radiographs detect stress fractures late in the bone reaction process (2–12 wk after positive scintigraphy), are insensitive for diagnosing mild stress fracture lesions, and remain negative throughout their course of resolution. Negative bone scans exclude stress fracture lesions even in clinically suspected cases. Positive bone scans diagnose stress fractures in clinically suspected cases with negative radiographs and enable early and specific treatment. The differential diagnosis of stress fractures from other inflammatory and nonosseous injuries (e.g., shin splints, rhabdomyolysis, hematomas) can easily be

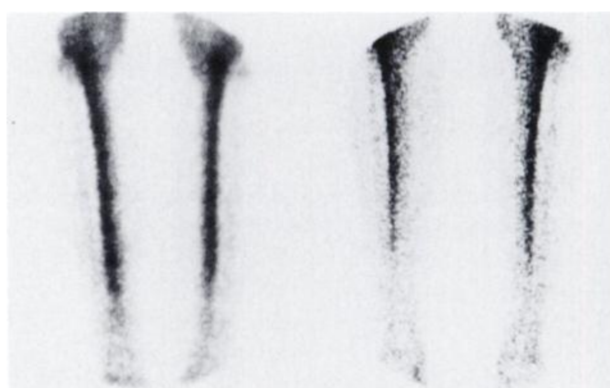

FIGURE 4
Left panel: Bone scan, anterior view, of the tibiae in a 20-yr-old recruit suffering from bilateral leg pain of 8 wk duration, showing diffuse bilateral lateral cortical increase in activity concentration over most of the tibial shafts corresponding to bilateral periosteal response in shin splints. Right panel: 6 mo later after cessation of training with persistent leg pain, mild decrease in the cortical activity is seen, consistent with partially resolved bilateral shin splints.

made by the above outlined clinical-scintigraphic criteria.

ACKNOWLEDGMENTS

The authors thank The Israeli Defence Forces for the cooperation that was obtained during this work, and Lionel M. Liberman, MD, PhD for helpful discussions.

REFERENCES

1. Hallel T, Amit S, Segal D. Fatigue fractures of tibial and femoral shaft in soldiers. *Clin Orthop* 1976; 118:35–43.
2. Wilson ES Jr, Katz FN. Stress fractures: an analysis of 250 consecutive cases. *Radiology* 1969; 92:481–486.
3. Sweet DE, Allman RM. Stress fracture RPC of the month from the AFIP. *Radiology* 1971; 99:687–693.
4. Johnson LC, Stradford HT, Geis RW, et al. Histogenesis of stress fracture. *J Bone Joint Surg* 1963; 45:1542.
5. Geslin GE, Thrall JH, Espinosa JL, et al. Early detection of stress fractures using Tc-99m-polyphosphate. *Radiology* 1976; 121:683–687.
6. Wilcox JR Jr, Moniot AL, Green JP. Bone scanning in the evaluation of exercise related stress injuries. *Radiology* 1977; 123:699–703.
7. Prather JL, Nusynowitz ML, Snowdy HA, et al. Scintigraphic findings in stress fractures. *J Bone Joint Surg* 1977; 59:869–874.
8. Roub LW, Gumerman LW, Hanley EN Jr., et al. Bone stress: a radionuclide imaging prospective. *Radiology* 1979; 132:431–438.
9. Neurman KOA, Elfving S. Stress fractures in soldiers: a multifocal bone disorder. *Radiology* 1980; 134:483–487.
10. Zwas ST, Barski M, Dosoretz C, et al. Early diagnosis of stress fractures in soldiers by Tc-99m-MDP bone scan. Evaluation of efficiency and scintigraphic patterns of appearance and resolution. In: Proceedings of the Fifth Congress of Nuclear Medicine in Israel, 1980: 52–53.
11. Zwas ST, Elkanovitch R, Farin Y, et al. Early detection of stress fractures by bone scintigraphy. *Isr J Med Sci* 1984; 20:290.
12. Devas MB. Stress fractures of the tibia in athletes of "shin soreness." *J Bone Joint Surg* 1958; 40:227–239.
13. Slocum DB. The shin splint syndrome. Medical aspects and differential diagnosis. *Am J Surg* 1967; 114:875–881.
14. Spencer RP, Levinson ED, Baldwin RD, et al. Diverse bone scan abnormalities in "shin splints." *J Nucl Med* 1979; 20:1271–1272.
15. Lieberman CM, Hemingway DL. Scintigraphy of shin splints. *Clin Nucl Med* 1980; 5:31.
16. Provost RA, Morris JM. Fatigue fractures of the femoral shaft. *J Bone Joint Surg* 1969; 51:487–498.
17. Matin P. Bone scintigraphy in the diagnosis and management of traumatic injury. *Semin Nucl Med* 1983; 13:104–122.
18. Holder LE, Michael RH. The specific scintigraphic pattern of "shin splints in the lower leg:" concise communication. *J Nucl Med* 1984; 25:865–869.