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Stress fractures in athletes

A study of 320 cases

G. O. MATHESON,* MD, D. B. CLEMENT, MD, D. C. MCKENZIE, MD, PhD, J. E. TAUNTON, MD, D. R. LLOYD-SMITH, MD, AND J. G. MACINTYRE, MD

From the Division of Sports Medicine, Department of Family Practice, and the British Columbia Sports Medicine Clinic, University of British Columbia, Vancouver, British Columbia, Canada

ABSTRACT

We analyzed cases of 320 athletes with bone scan-positive stress fractures (M = 145, F = 175) seen over 3.5 years and assessed the results of conservative management. The most common bone injured was the tibia (49.1%), followed by the tarsals (25.3%), metatarsals (8.8%), femur (7.2%), fibula (6.6%), pelvis (1.6%), sesamoids (0.9%), and spine (0.6%). Stress fractures were bilateral in 16.6% of cases. A significant age difference among the sites was found, with femoral and tarsal stress fractures occurring in the oldest, and fibular and tibial stress fractures in the youngest. Running was the most common sport at the time of injury but there was no significant difference in weekly running mileage and affected sites. A history of trauma was significantly more common in the tarsal bones. The average time to diagnosis was 13.4 weeks (range, 1 to 78) and the average time to recovery was 12.8 weeks (range, 2 to 96). Tarsal stress fractures took the longest time to diagnose and recover. Varus alignment was found frequently, but there was no significant difference among the fracture sites, and varus alignment did not affect time to diagnosis or recovery. Radiographs were taken in 43.4% of cases at the time of presentation but were abnormal in only 9.8%. A group of bone scan-positive stress fractures of the tibia, fibula, and metatarsals (*N* = 206) was compared to a group of clinically diagnosed stress fractures of the same bone groups (*N* = 180), and no significant differences were found.

Patterns of stress fractures in athletes are different from those found in military recruits. Using bone scan for diagnosis indicates that tarsal stress fractures are much more common than previously realized. Time to diagnosis and recovery is site-dependent. Technetium[99] bone scan is the single most useful diagnostic aid. Conservative treatment of stress fractures in athletes is satisfactory in the majority of cases.

Stress fractures are a common injury presenting to sports medicine clinics. Stress fractures may comprise as much as 10% of all sports injuries[47] and between 4.7% and 15.6% of injuries to runners.[8,15,39,48] With the current interest in fitness, particularly attained through running, stress fractures have become a significant diagnostic and therapeutic challenge for medical practitioners providing care to athletes.

Since the first description of fatigue fracture in a soldier,[6] many extensive clinical surveys of stress fractures in military recruits have been reported.[20,32,56,86] Although these studies have contributed considerably to our understanding of stress fractures, the military population differs from the athletic population.[47] Military recruits often have a lower degree of musculoskeletal fitness at the time of injury, and are required to march in stiff footwear on nonyielding surfaces.[32] The rate of loading of the musculoskeletal system in military recruits is rapid, and the pattern of loading associated with marching is distinct. It is likely that military recruits have specific patterns of injury which reflect these factors.

Clinical surveys of stress fractures in athletes are less common, with the largest study to date being reported by Devas.[24] As in military studies, Devas used radiographs for diagnosis. The inherent limitations in using radiographs to diagnose stress fractures are well known. Devas suggested that in the absence of abnormal radiographs, clinical diagnosis should be made. Since the publication of his monograph, the technetium[99] bone scan, developed in 1971, has been used increasingly in diagnosing stress fractures in athletes. Bone scan diagnosis has changed the clinical picture and definition of stress fracture in athletes.

The largest study using bone scan is Orava's report of 200 cases in which only 18% were women and 15% were run-

* Address correspondence and reprint requests to: Gordon O. Matheson, MD, British Columbia Sports Medicine Clinic, 3055 Westbrook Mall, University of British Columbia, Canada V6T 1W5.

ners.[63] Many case reports and smaller series have appeared[35,70,71,73,79–81] but have not lent themselves to meaningful analysis because of their sample size. Another problem with the clinical surveys to date is their lack of uniformity in defining stress fracture; they often use radiographic and bone scan imaging interchangeably in diagnosis. This lack of homogeneity in the study design and type of diagnostic aid used may account for differences in site distribution, demographics, time to diagnosis and recovery, specific sports involved, and results of treatment reported in surveys of stress fractures in atheletes.

The difficulties in comparing studies of separate populations and in using different diagnostic criteria have limited our understanding of the true clinical picture of stress fractures in atheletes. The purpose of this study is to provide descriptive data from the 320 cases of bone scan-positive stress fractures in athletes and to document the results of conservative treatment. We also have compared a group of athletes with stress fractures diagnosed by bone scan to a group diagnosed clinically, in order to assess the accuracy of our clinical diagnosis.

MATERIALS AND METHODS

A mainframe computer registry was used to provide the names of all patients diagnosed with stress fracture at the British Columbia Sports Medicine Clinic from December 1981 to July 1985. Cases studied were restricted to athletes in whom diagnosis was confirmed by the presence of focal uptake of technetium[99] polyphosphonate on triple phase bone scan at the site of pain. Athletes with diffuse uptake of technetium[99] and those with focal uptake superimposed on diffuse uptake at the site of pain were excluded from the study. This restriction allowed the study 320 cases.

All athletes underwent physical examination and history, including demographic data, by one of the authors. In runners, mileage at the time of injury was recorded. Any history of trauma was recorded, with trauma defined as an impact-producing event, either a direct blow or a "sprain," from which point the onset of pain could be traced. Any training errors were recorded, including inappropriate increases in the volume and pace of activity, as well as improper footwear and training surfaces. Times to diagnosis and healing were recorded. Time to diagnosis was defined as the time from onset of pain to the confirmation of stress fracture on bone scan. In the case of bilateral complaints, time to diagnosis was the time from onset of the first complaint. Time to healing was defined as the time from diagnosis to return to preinjury activity level.

Focal tenderness and swelling at the site of pain were noted at examination. Particular attention was given to recording the biomechanical alignment of the lower extremity. Indicative factors included excessive genu varum (greater than 4 cm between the medial femoral condyles), tibial varum (of greater than 10°), subtalar varus (of greater than 3°), and forefoot varus (of greater than 2°). Foot type was assessed as normal, pes cavus, or pes planus.

Radiographs taken at the time of presentation were recorded and results were noted. Bilateral stress fractures were considered as one case and were diagnosed on the basis of bilateral pain and uptake of radionuclide on bone scan. The location of technetium[99] uptake within bone at the site of pain was recorded, and the frequency of uptake at nonpainful sites was recorded and classified as either focal or diffuse.

In addition to those subjects who were diagnosed as having stress fracture on the basis of bone scan, a group of clinically diagnosed stress fractures of the metatarsal ($N = 41$), fibula ($N = 20$), and tibia ($N = 119$) were studied using the same data collection techniques. Clinical diagnosis was based on a pattern of increasing pain, a positive "hop-test" (pain at the site of stress fracture reproduced by one-legged hopping), painless passive or resisted range of motion in adjacent joints, and swelling and localized tenderness or callus. The clinically diagnosed group ($N = 180$) was compared to the bone scanned group of metatarsal, fibular, and tibial stress fractures ($N = 206$) to determine if any differences existed between the two populations.

Data was coded and entered into the university's mainframe computer. Data analysis was carried out using BMD statistical software. Stress fractures of the spine ($N = 2$), sesamoids ($N = 3$), and pelvis ($N = 5$) were excluded from the analysis because of their low numbers. Data analysis was done after grouping the stress fractures by site. Chi-square testing for independence of means was used for ordinal data, and analysis of variance (ANOVAs) and Hotelling's T^2 test were used for interval data. The level of significance was set at 0.01 to avoid the risk of inflating the Type I error rate associated with multiple comparisons.

RESULTS

Three hundred twenty cases (M = 145, F = 175) were studied, with the distribution according to sex and injury location shown in Figure 1. The tibia was the most frequent site of injury (49.1%), with the tarsals being the second most common (25.3%). The remaining stress fractures were to the metatarsals (8.8%), femur (7.2%), fibula (6.6%), pelvis (1.6%), sesamoids (0.9%) and back (0.6%).

The right side was involved 38.1% of the time ($N = 122$), and the left side 45.3% ($N = 145$). Bilateral stress fractures occurred in 16.6% of the cases ($N = 53$).

The mean age was 26.7 years (range, 13 to 61), with the mean age for males being 29.2 years and for females 25.1 years. The results of a 5 × 2 factorial analysis of variance with age as the dependent variable are presented in Figure 2. A significant age difference ($P = 0.0060$) was found, with femoral and tarsal stress fractures more common in older athletes and fibular and tibial stress fractures more common in younger athletes. Males were found to be significantly older ($P = 0.0005$) than the females.

Table 1 shows the sports involved at the time of injury. Running was by far the most common sport. Information on weekly mileage in runners was available in 187 of the 221 runners and is listed in Table 2. A 5 × 2 ANOVA revealed

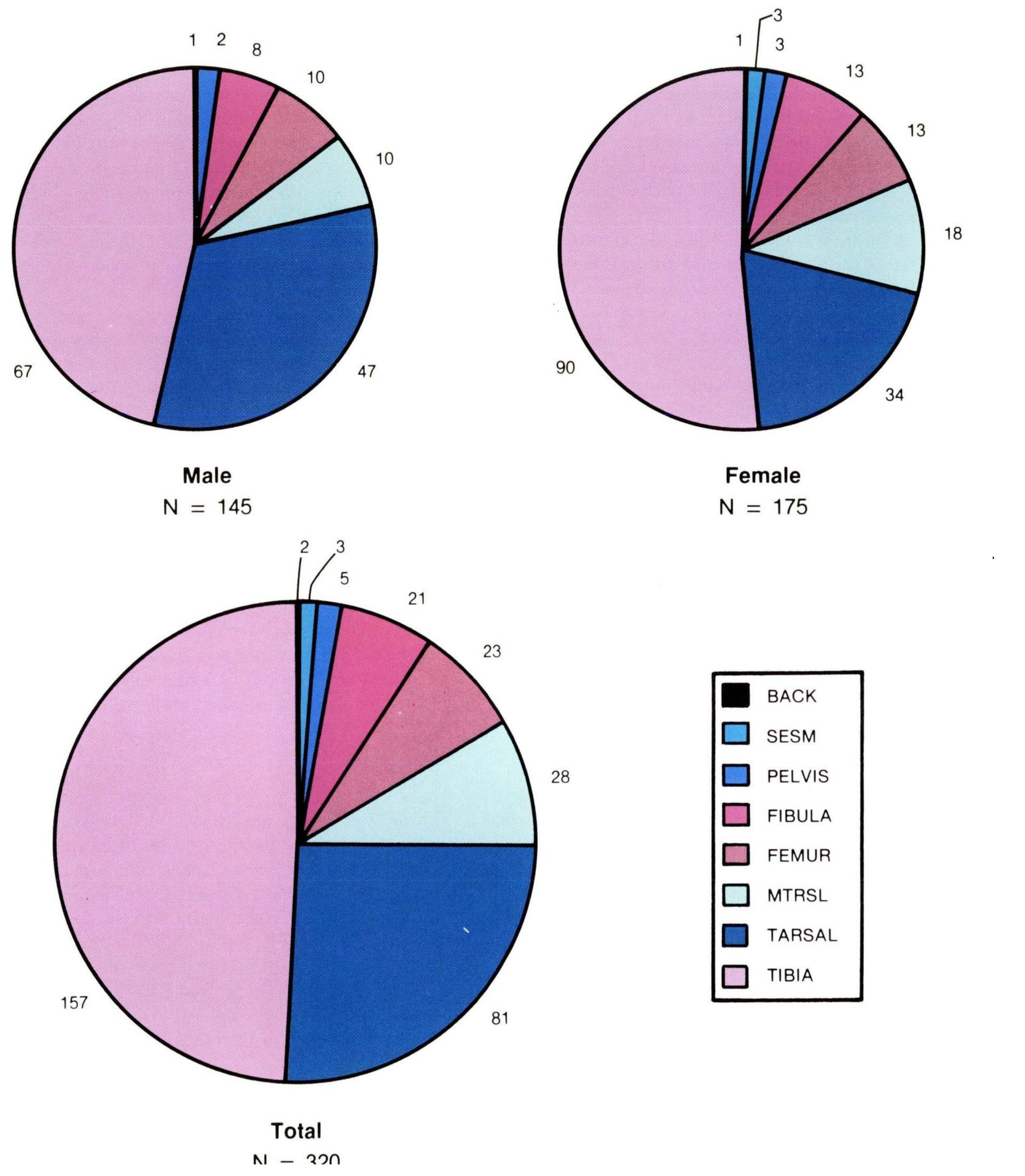

Figure 1. Distribution of stress fractures.

no significant difference between the means for the weekly running mileage of males and females ($P = 0.1744$) and no significant difference in weekly mileage between the five sites of stress fracture ($P = 0.3108$).

A history of trauma was found in 9.9% of cases, and its frequency was compared across all sites using chi-square (Fig. 3). A significant finding ($P = 0.0000$) was the frequent history of trauma in tarsal bone stress fractures when compared with other bones. A history of trauma was significantly more common in sports other than running ($P = 0.007$),

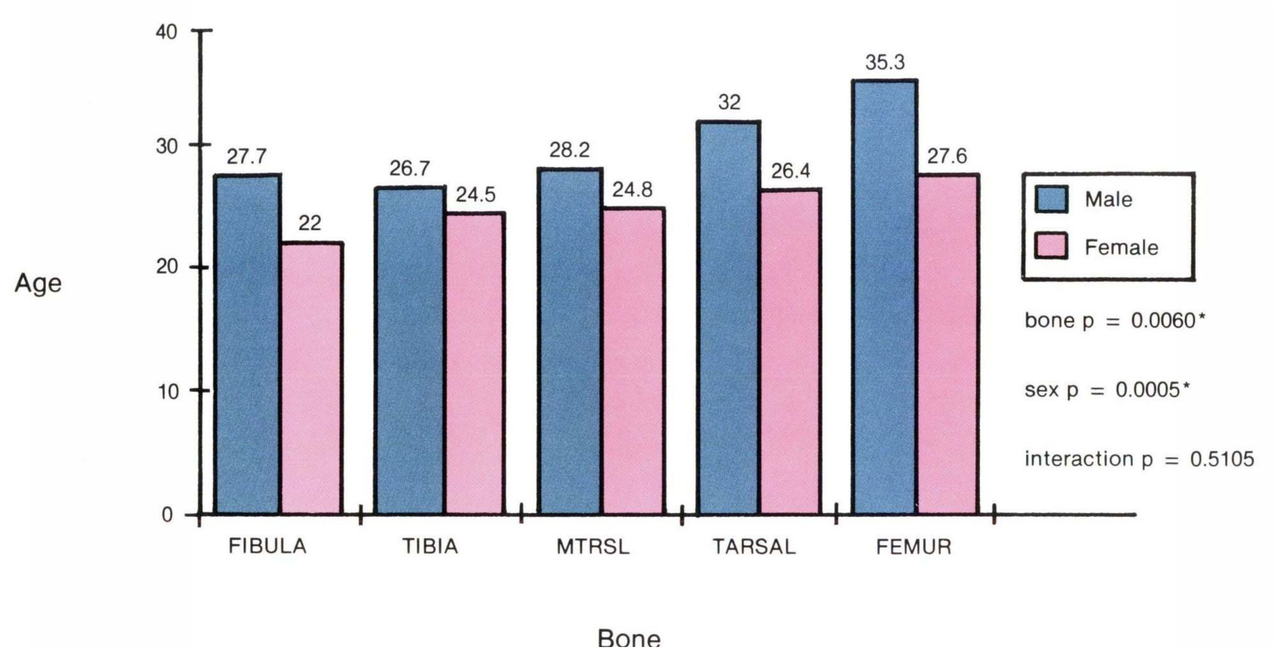

Figure 2. Age: Bone × Sex; 5 × 2 ANOVA.

TABLE 1
Sports involved at time of stress fracture

Running	221
Fitness class	25
Racquet sports	15
Basketball	12
Soccer	6
Baseball	6
Figure skating	5
Volleyball	5
Football/rugby	5
Dancing	3
Hockey	2
Gymnastics	2
Not recorded	13
Total	320

TABLE 2
Weekly running mileage[a]

$N = 187$	Tibia	Tarsal	Metatarsal	Fibula	Femur
Male	37.6	32.8	38.6	25.0	43.6
Female	27.2	34.8	26.0	28.7	36.9

[a] Bone $P = 0.3108$, sex $P = 0.1794$, interaction $P = 0.3444$.

occurring only 5.6% of the time in runners but 20% of the time in other sports. The time to diagnosis was significantly longer in the group with a history of trauma (Fig. 4).

Training errors were found in 22.4% of all stress fractures and were equally common in all bone groups when tested with chi-square.

Average time to diagnosis was 13.4 weeks (range, 1 to 78) and average time to recovery was 12.8 weeks (range, 2 to 96). A significant difference between the means for time to recovery ($P = 0.0092$) was found, with tarsal stress fractures taking the longest time and femoral stress fractures taking the least (Fig. 5). A similar trend was found in time to diagnosis but was not significant ($P = 0.0492$). No correlation was found between time to diagnosis and time to recovery ($P = 0.7310$).

Localized tenderness was found in 65.9% of cases and swelling in 24.6% of cases. The fibula and tarsal bones had the highest frequency of focal tenderness, and the metatarsals and tarsal bones had the highest frequency of swelling (Fig. 6). The femur had the least detectable tenderness and swelling. The presence or absence of tenderness ($P = 0.7393$) or swelling ($P = 0.3996$) did not influence the time to diagnosis or recovery when compared using Hotelling's T^2.

The frequency of varus alignment is presented in Table 3. Genu varum was found in 29%, tibial varum in 18.9%, subtalar varus in 71.9%, and forefoot varus in 72.6%. An index for varus alignment was calculated by assigning equal weight to the presence of genu varum, tibial varum, forefoot varus, subtalar varus, and pronation. Subjects were grouped as having mild (0 to 1), moderate (2 to 3), or severe (4 to 5) varus alignment. Chi-square testing was used to compare the frequency of stress fracture in the three groups, and the severity of varus alignment was found to be independent of the site of stress fracture ($P = 0.03$). A two-way multiple analysis of variance revealed no significant difference in time to diagnosis and recovery across the three groups of varus alignment.

The frequencies of foot types are shown in Figure 7. Pronated feet were most commonly found in tibial stress fractures and tarsal bone fractures and were least common in metatarsal fractures. Cavus feet were found most commonly in metatarsal and femoral stress fractures.

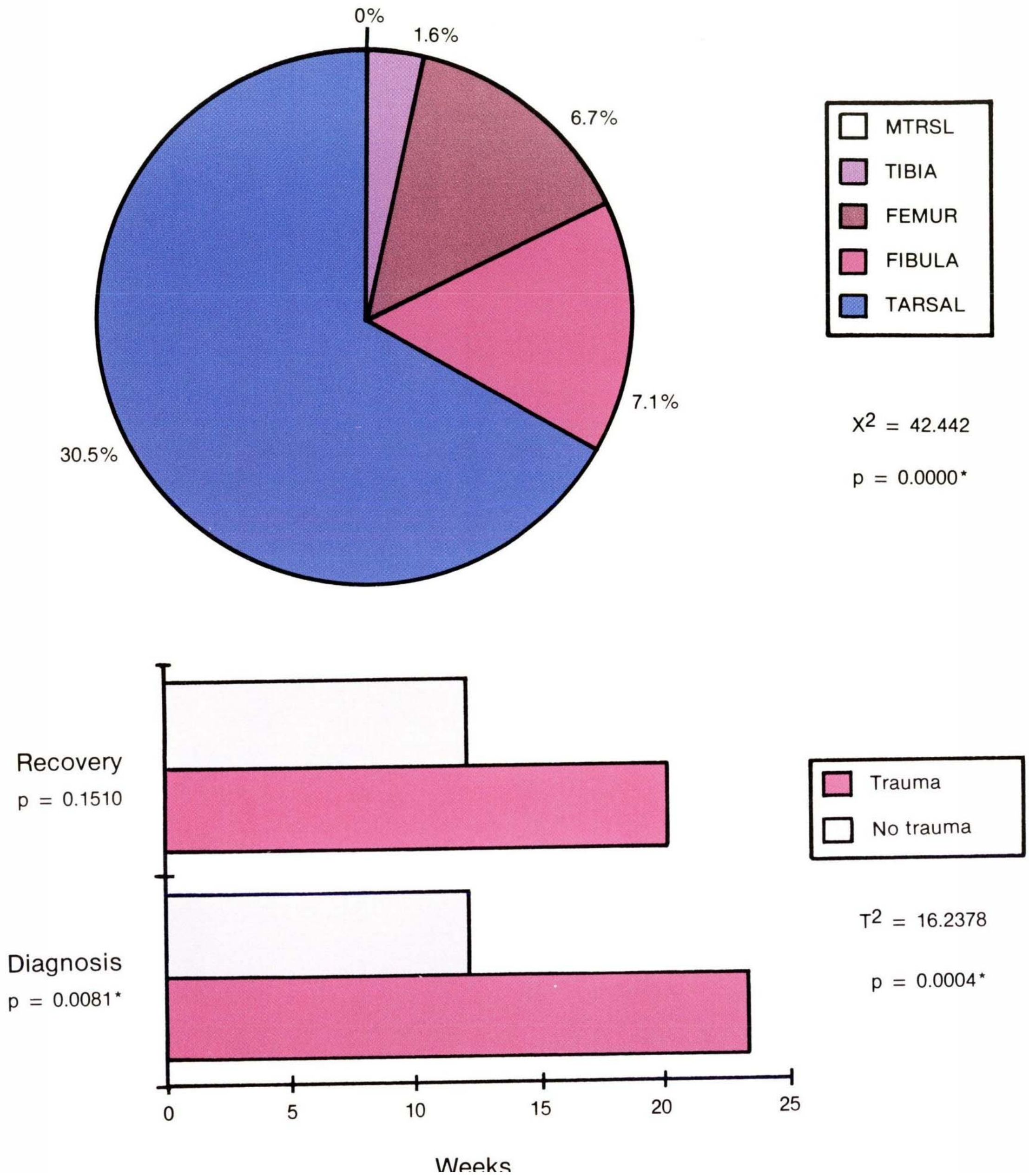

Figure 4. Trauma history: Time to diagnosis and recovery; Hotelling's T^2 test.

Radiographs were taken in 43.3% of cases at presentation, but were abnormal in only 9.8%. An abnormal radiograph was defined as showing evidence of a stress fracture, including a lucent line in cortical bone or periosteal new bone. Chi-square was used to compare the frequency of abnormal radiographs across all bones, and no significant difference was found ($P = 0.9443$). Abnormal radiographs were reported in 21.1% of cases with a history of trauma and in only 8.4% of those without a history of trauma.

The groups of clinically diagnosed stress fractures of the tibia, fibula, and metatarsals ($N = 180$) and the group diagnosed using bone scan ($N = 206$) were compared using chi-square and Hotelling's T^2. Results are shown in Figure 8 and Table 4. Although the means for body weight and time to recovery were different, no significant differences were found between the two populations.

DISCUSSION

The present study shows the tibia to be the most common site of stress fracture. This is in agreement with most other surveys of stress fractures in athletes[48,63,80,81] with the ex-

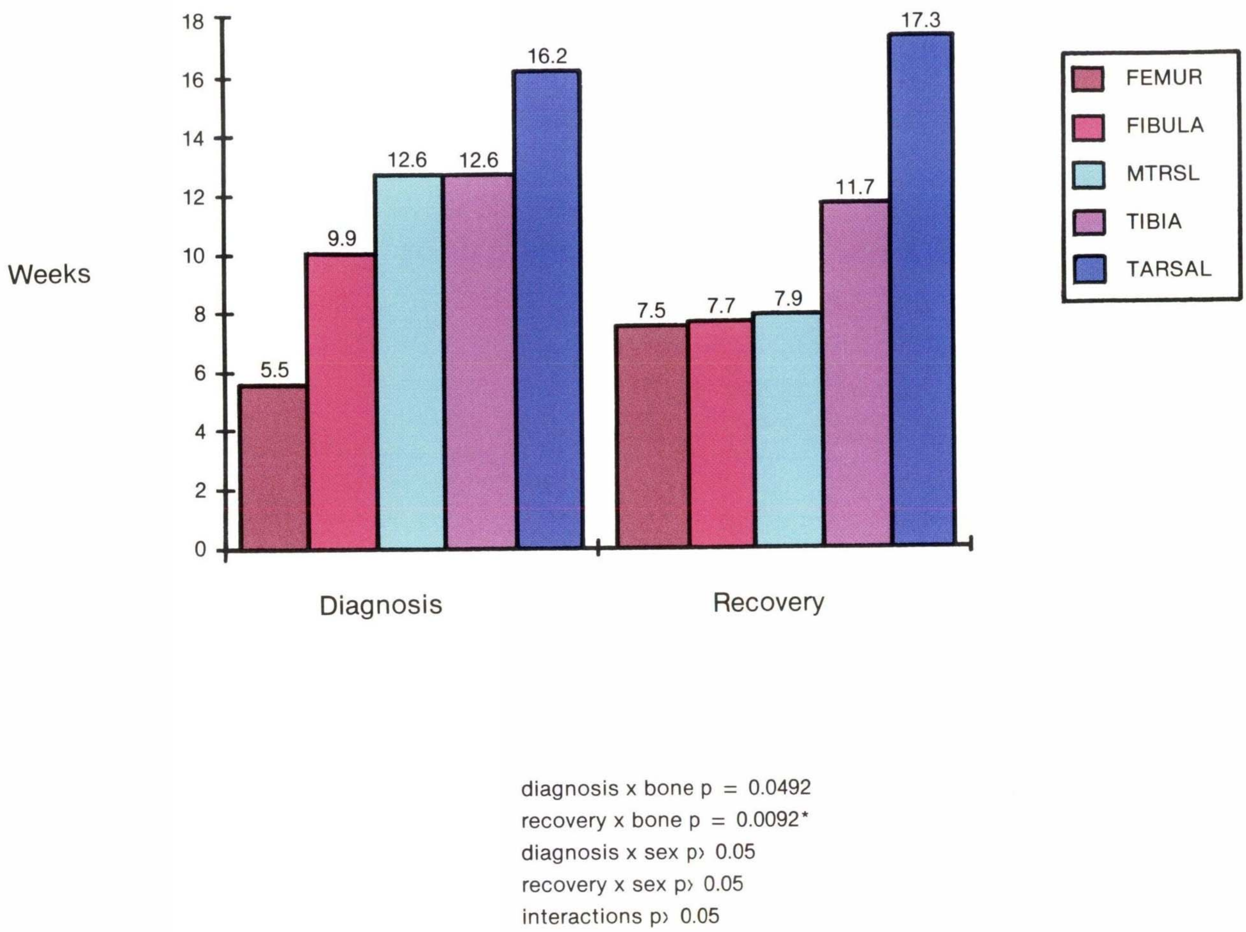

Figure 5. Time to diagnosis and recovery; 5 × 2 ANOVA.

ception of Devas,[22,24] who found the most common site to be the metatarsal, followed by the fibula. Military studies in the United States invariably report the most common sites to be the calcaneus or metatarsal,[20,32,56,85,86] although other countries with different recruit training regimes have found different patterns.[30] In surveys of military recruits, calcaneal stress fractures are almost closely correlated to the style of marching.[32] However, in studies of either military recruits or athletes, tarsal stress fractures other than the calcaneus, are reported infrequently. Orava[63] found only two tarsal stress fractures in his series of 200 cases, and military studies report the frequency to be less than 1%.[32,56,85,86]

There are several possible reasons for the differences between our results and those of other studies of athletes. Using bone scan for diagnosis creates a relatively homogeneous population independent of clinical suspicion or radiographic changes that are known to vary significantly with time and with the specific bone involved. Tarsal stress fractures are a significant diagnostic challenge.[38] The large number in this series reflects an increased index of suspicion regarding the diagnosis of foot and ankle pain in the athlete. The present survey may also have a higher frequency of tarsal stress fractures because athletes with a history of trauma in which the radiograph was normal were included.

The major differences between the site distribution of stress fractures in the present study and site distribution in military studies are related to the fitness of the injured individual and the type of exercise involved. Military reports have studied the stress fracture frequency in untrained recuits undergoing a vigorous training program over a short period in which the osseous system often has insufficient time to allow for bone remodeling. Lombardo and Benson[44] have found that the osseous system loading rate is more important than the absolute load in etiology of stress fractures of the femoral neck. In addition, recruits use hard footwear, train on cement or asphalt surfaces, and have a markedly emphasized heel strike. Greaney et al.[36] reported that when tennis shoes were substituted for combat boots and the training surface was changed to grass, the rate of calcaneal stress fractures decreased from 20.5% to 7%. In a prospective study of 312 military recruits in Israel, the group given a shock absorbing orthotic device had a 29.2% incidence of stress fractures, whereas the control group had an incidence of 46.1%.[54] In contrast to the military population,

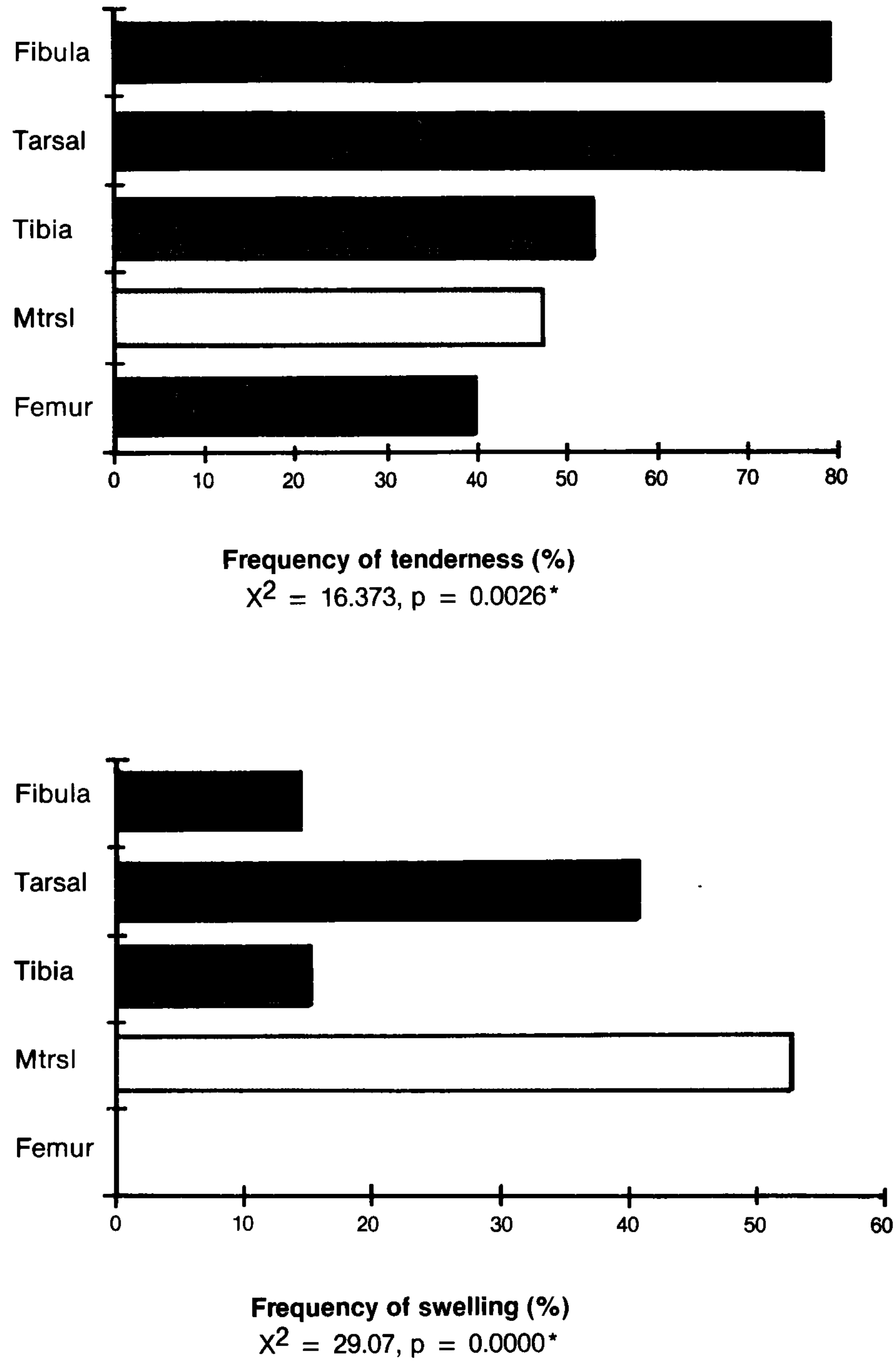

Figure 6. Frequency of tenderness and swelling; chi-square.

the athlete is fit and has osseous system adaptations that have occurred over a longer period of time. This is reflected by the lower frequency of training errors found in the present study. Athletes usually train on a variety of surfaces and use footwear specifically designed or adapted for their particular sport.

The differences in our study reflect the use of the bone scan to detect x-ray negative stress fractures in high risk bones or at sites where physical findings are of limited value. These sites include the femur, tarsals, tibial plateau, spine, sesamoids, and pelvis. The diagnosis is difficult to confirm at these sites without the use of bone scan. The literature contains many reports of stress fractures of the navicular[33,82] tibia,[5,62] and femur[1,10,44,69,76] that have gone on to completion with disabling results.

Those athletes with a history of trauma took considerably

TABLE 3
Percent varus alignment for all bones[a]

	Male	Female	P value
Genu varum	40.1	19.8	0.0803
Tibial varum	20.4	18.2	0.5329
Subtalar varus	74.2	72.1	0.0230
Forefoot varus	77.0	71.1	0.0634

[a] Sex $P > 0.01$, interaction $P > 0.01$.

longer to diagnose. This may be because the bony injury at the time appeared minor in comparison with the soft tissue component and the radiographs taken at the time of injury were normal, or it may reflect the higher incidence of trauma in tarsal stress fractures and their longer time to diagnosis.

A history of trauma to the tarsal bones was commonly found in the present study, a finding previously reported.[12] Although the frequency of trauma was lower in running than in other sports, running still accounted for the greatest number of tarsal stress fractures. A Berndt and Hardy Type I osteochondral injury to the dome of the talus[3] may produce a positive scan, but this lesion would be expected to show a lucent defect radiographically.[82] It is conceivable that the same type of injury could result in bony damage sufficient to initiate remodeling without necrosis and cartilaginous degeneration and in which x-ray investigation would remain normal. Nine of the traumatic talar stress fractures in this series had normal CT arthrotomograms of the ankle joint.

The time to diagnosis and recovery varied according to the site of the stress fracture. In our study, a trend toward a longer time to diagnosis in tarsal stress fractures existed, although these findings were not significant. This is in agreement with other studies.[12,83] Whether this represents a unique difference in tarsal stress fractures rather than a low index of suspicion when diagnosing foot pain remains to be determined. Since the correlation between time to diagnosis and time to recovery was not significant, we cannot conclude that the prolonged recovery time in tarsal bones is related to the longer time to diagnosis. Of interest is the relatively short time to diagnosis and recovery in femoral stress fractures, a finding previously reported.[81] Again, this may reflect the high index of suspicion with these injuries and the tendency toward early scanning and treatment. Our policy has been to scan all cases of suspicious hip or groin pain in which no obvious source for the pain could be found. We have found the "hop-test," in which the patient attempts to hop on the injured leg, to be of great assistance in reproducing deep hip pain. A positive hop-test indicates a high likelihood of stress fracture and the need for a bone scan.

Localized tenderness and swelling are significant findings in stress fractures but cannot be relied on as the sole criteria for the diagnosis. Periostitis of the tibia and fibula can produce similar findings, although usually in a more diffuse pattern. Callus on palpation can be an important diagnostic finding. The frequency of clinically significant tenderness and swelling is lower in stress fractures of the back, femur, and pelvis because of the overlying soft tissues.

Biomechanics and alignment are important factors in the etiology of stress fracture.[39,40,67] Varus alignment was a frequent finding in our study. The rigid pes cavus foot was found to be more common in stress fractures of the metatarsal and femur, possibly as a result of the reduced shock absorption associated with this foot type.[17] Excessive pronation is known to increase tibial torsion during the support phase of running.[50] As in other studies,[80] pronated feet were found more commonly in stress fractures of the tibia and fibula. Tarsal bone stress fractures were also common in individuals with pronated feet. This may be a result of

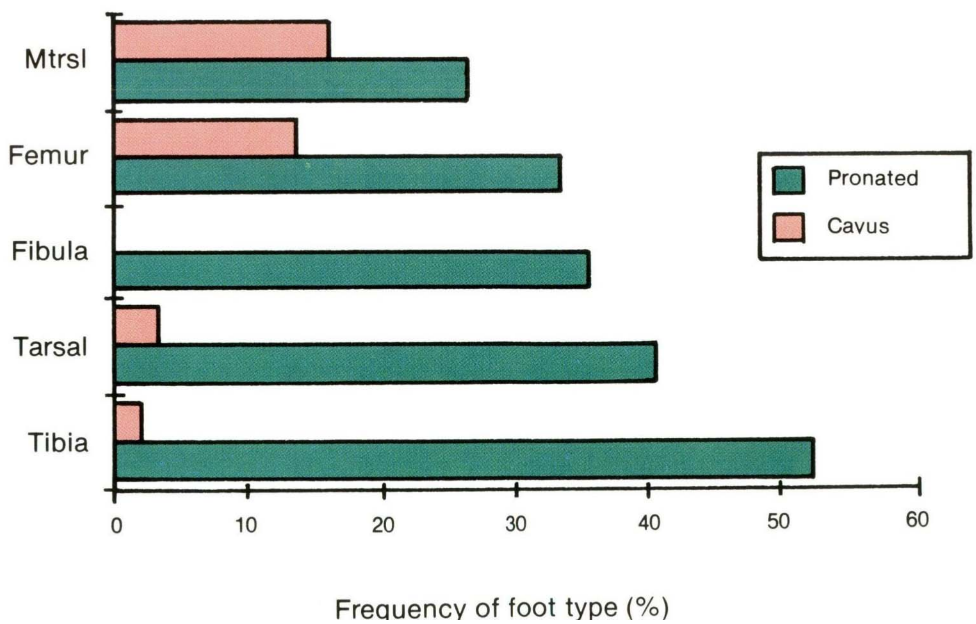

Figure 7. Foot type × bone injured; chi-square.

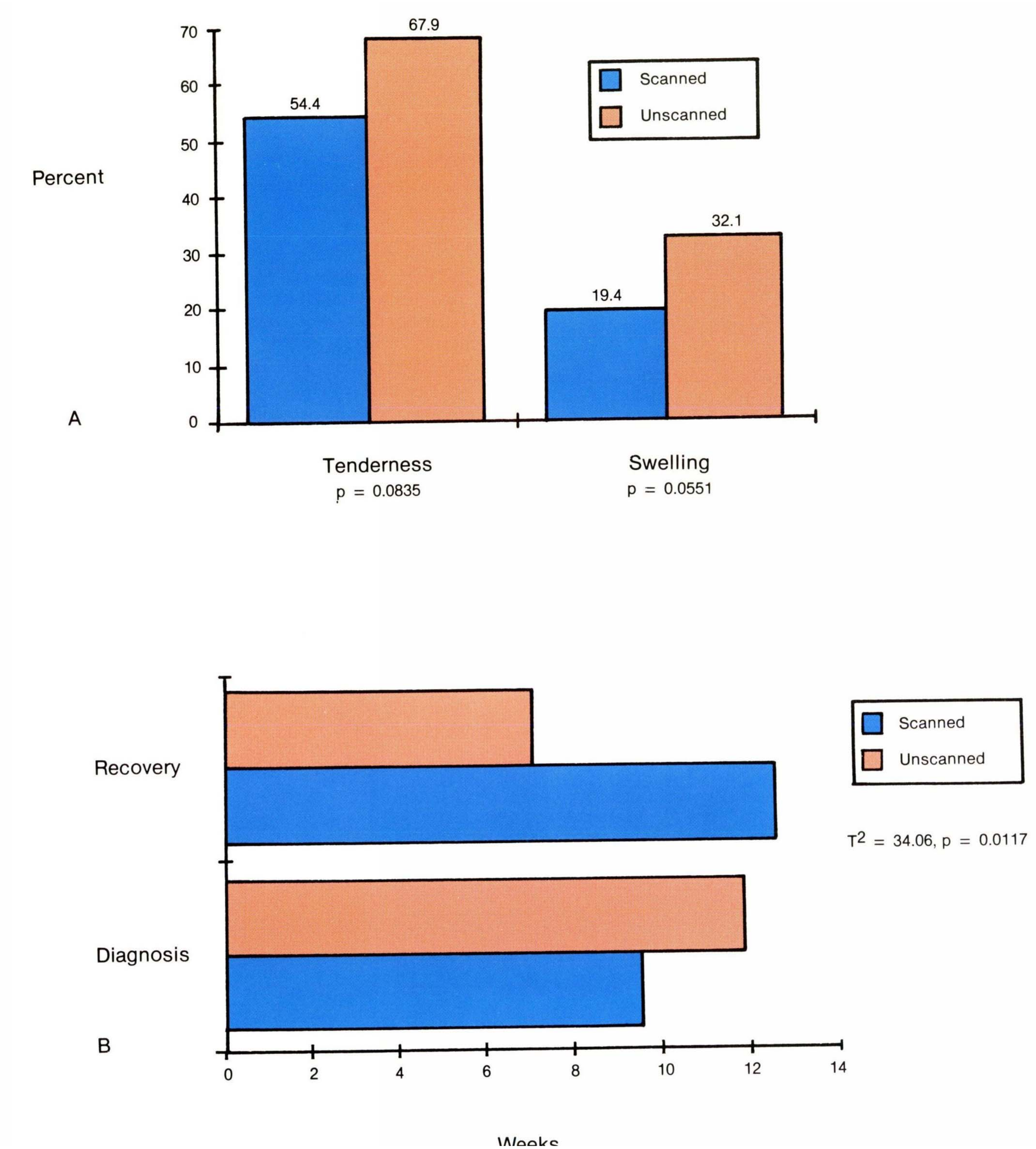

Figure 8. Scanned versus unscanned: Frequency of tenderness and swelling; chi-square.

TABLE 4
Hotelling's T^2 comparing scanned and unscanned stress fractures (tibia, fibula, and metatarsals)

	Scanned (N = 206)	Unscanned (N = 180)	P value
Age (yrs)	27.2	29.2	0.4145
Height (cm)	169.4	165.5	0.1673
Weight (kg)	61.7	58.1	0.2625
Mileage	35.3	23.4	0.0027[a]
Diagnosis (wk)	9.6	11.9	0.4597
Recovery (wk)	12.6	7.1	0.0016[a]

[a] $T^2 = 34.06$, $F = 2.57$, df = 11, 49, $P = 0.0017$.

increased stress on the talar neck associated with this foot type.[12]

The low frequency of radiographs taken at the time of presentation (43.3%), reflects our growing loss of faith in the diagnosis of stress fracture using plain radiographs. Other authors have indicated similar reservations,[10,12,14,29,44,51] perhaps due to the knowledge that bony changes are radiographically evident in only 30% to 70% of cases.[16,36,70,73,74,81] In addition, the period of time from the onset of pain to positive radiographic evidence of a stress fracture can vary from 2 weeks to 3 months depending on the specific bone injured.[27,68,80] Tarsal stress fractures are notorious for producing negative radiographic findings.[33,66,83] This may be reflected in the low number reported in other series. A significant number of stress fractures fail to show any radiographic abnormality even when followed for long periods of time.[22,29,31,36,68,84] The clinician is faced with uncertainty when considering the differential diagnosis of stress fracture and is reluctant to increase his uncertainty by relying on an insensitive diagnostic aid in cases of suspected stress fracture. This is especially true for such sites as the spine, femur, or tarsals.

Bone scan is an extremely sensitive tool for diagnosing stress fractures. Various reports in the literature have reviewed the pattern of uptake of technetium[99] in athletic injuries.[16,84] The scintigram can be used to differentiate soft tissue injury from osseous injury with considerable accuracy[71,73] and may be positive within 6 to 72 hours of onset of pain.[12,36,45] The use of the triple phase bone scan (TPB) provides quantification of an angiogram, blood pool, and delayed static image,[65] and allows the differentiation of old stress fractures from acute ones and partial from complete ones. Bone scans also allow the interpretation of abnormalities that may occur at locations distant from the site of pain in those atheletes presenting with referred pain. Although Milgrom[53] reported three cases of negative bone scan with impending stress fracture of the tibia, the scintigrams in his report were limited to anterior and posterior views. This finding had not been reported previously and has not been encountered in our experience, possibly because our nuclear medicine department routinely obtains oblique views.

Ultrasound, thermography, computerized axial tomography, and magnetic resonance imaging have all been used in the diagnosis of stress fracture, with variable results. Although ultrasound and thermography have held promise in diagnosing stress fractures at selected sites with less cost and radiation than scintigraphy,[34,61] their overall accuracy has proven to be too low to allow their use independently.[25,31,49,57,59,77] Thermography is limited by its inability to distinguish conclusively soft tissue from osseous injuries. The usefulness of ultrasound is limited to superficial bones where there is little overlying soft tissue. Ultrasound is also a subjective test, relying on the patient's perception of pain for an adequate diagnosis. Computerized tomography is even less sensitive than radiography in the diagnosis of stress fracture.[19] While some authors have suggested using a combination of ultrasound, radiography, and thermography to diagnose stress fractures, the inconvenience and added uncertainty associated with this approach limits its practicality. Studies of otherwise healthy athletes have shown the bone scan to be virtually 100% sensitive in diagnosing stress fractures, although its specificity is slightly lower than the radiograph.[40] Radiographic evaluation, on the other hand, is quite insensitive but very specific. There are numerous reports of athletic individuals of all ages having bone biopsies and occasionally surgery for stress fractures mistaken for tumors even when bone scan and tomography have been used.[9,11,18,60] Currently, the diagnostic accuracy of radiography and bone scan used in combination is not improved with the use of additional diagnostic aids. If any tests are to be used in combination, it should be these two. Continued refinement of other techniques may allow quicker, less expensive testing in those bones in which the diagnosis is less critical.

The linear uptake of technetium[99], particularly in the tibia, has received various interpretations.[37] Some authors consider it to be periostitis,[73] others call it stress fracture,[55,70,78] while others feel it is a precursor to stress fracture.[48] It is our impression that periostitis or tibial stress syndrome, as reported by Clement,[14] may be a separate clinical syndrome which can be bone scan negative. This impression is supported by two studies in which diffuse linear uptake of radionuclide on bone scan was found to be associated with biopsy evidence of inflammation, vasculitis, and periosteal new bone without evidence of stress fracture.[52,58] The pattern of radiographic changes with periostitis is reported to be different from stress fracture.[42] Rupani et al.[73] failed to find focal uptake superimposed upon diffuse uptake in 238 consecutive bone scan-positive stress fractures. While the mechanisms producing stress fracture and tibial stress syndrome may be similar and the possibility remains that the two conditions may coexist, it has yet to be shown that tibial stress syndrome or periostitis is part of the continuum of stress fracture.

The group of stress fractures that were diagnosed clinically in the present study did not differ from the bone scanned group in terms of demographic features, weekly mileage, biomechanical abnormalities, tenderness and swelling, and time to diagnosis and recovery. It would thus appear that the diagnosis of stress fracture of the tibia, metatarsal, and fibula can be made clinically with reasonable certainty. The unscanned group, however, did have a shorter time to recovery than the scanned group and may have had stress fractures which were less severe. Clinical diagnosis of stress fractures of the femur, tarsal bones, back, pelvis, or sesamoids was not attempted without the use of the bone scan, and our present series therefore contains a higher proportion of these stress fractures in the scanned group.

After the diagnosis of stress fracture was made, treatment was instituted following the plan outlined by Clement.[14] Phase I included pain control through local physiotherapy, nonsteroidal antiinflammatory medication, and ice massage. Modified rest was recommended, which included normal weightbearing in day to day activities but elimination of offending activity. Cycling, swimming, and running in water were offered as alternative nonweightbearing activities to maintain fitness. During this phase, stretching and flexibility were emphasized, as was local muscle strengthening and retraining.

Phase II began when the athlete had been pain free for 10 to 14 days and included continuation of the modalities of Phase I plus a gradual reintroduction of sport. Pain was found to be the most satisfactory guide in assessing progress and increasing the workload in the recovery phase. The single most important factor in Phase II rehabilitation was the graded reintroduction of activity on an alternate day basis. Scully and Besterman[75] showed that a rest period during training cut the stress fracture rate in military recruits from 4.8% to 1.6%. Phase II also included the modification of other risk factors, including running surfaces, footware, and the control of excessive pronation through the use of corrective orthotic devices.

All cases in this series were treated conservatively in the above manner. Certain stress fractures, such as the proximal diaphysis of the fifth metatarsal[21] or the navicular,[83] have been reported to require early immobilization or surgical treatment. In the present series, two cases of navicular stress fracture were immobilized (one basketball player and one football player). Although reports of recalcitrant stress fractures of the tibia have advised surgical drilling,[64] all tibial stress fractures in the present study were managed conservatively with excellent results. Three cases of tibial stress fracture with delayed healing were treated with electromagnetic radiation. None of the cases in this series went on to complete fracture. It is our impression that early diagnosis and treatment will allow successful conservative management in the vast majority of cases.

Two main theories are currently used to explain the etiology of stress fractures in athletes. The first is that muscle weakness reduces the shock absorption of the lower extremity and allows the redistribution of forces to bone, increasing the stress at focal points in the bone.[14,28] This is supported by Skinner's calculations on femoral neck stress fractures in runners.[76] He found that the stress applied to the femoral neck in running was well below the single cycle failure load, and that stress fracture therefore must have been the result of muscle fatigue during long runs. The second theory is that muscle pull across a bone produces enough repetitive force to create stress fracture.[23,79] This is supported by the occurrence of stress fractures in nonweightbearing upper extremity bones such as the humerus in a baseball pitcher. While the relative contribution of each mechanism to the etiology of stress fracture is unknown, it is likely that both play a part. Periostitis, however, probably results solely from the pull of muscles at their insertion in bone.

Several authors have put forward the concept of stress fracture as representing one point on a continuum of bone remodeling from early osteoclastic resorption to frank fracture.[2,26,46,48,71,72] The earlier histologic studies of Johnson et al.[41] and the recent animal model of stress fracture by Li et al.[43] have shown that early osteoclastic resorption of bone followed by osteoblastic new bone formation is part of the remodeling process in response to physical stress. It is assumed that the existing microstructure is temporarily weakened during the initial period in which the rate of osteoclastic resorption is greater than the rate of new bone formation. At this point, continued physical loading can produce a plastic deformation in the overload zone of weakened bone and a resultant stress fracture.[13] Stress fractures, then, are focal structural weaknesses occurring during bone remodeling in response to the repeated application of subthreshold stresses.

The term "stress fracture" dates back to early military reports where the radiograph was interpreted as either normal or abnormal, implying an "all or none" phenomenon. Uncertainty regarding the interpretation of the uptake of technetium[99] at asymptomatic sites has raised the question of the definition of stress fracture diagnosed by bone scan.[4,7,29,51,70,73] Our impression is that asymptomatic uptake of radionuclide in athletes represents active, painless remodeling of bone in response to stress. We feel the term "bone strain" more appropriately reflects the true dynamic response of bone to stress and allows the interpretation of bony stress to be considered along a continuum of remodeling.[46] The term "bone strain" implies an osseous response to physical stress which is not unlike that of the response of other musculoskeletal tissues such as muscle, ligament, and cartilage. The usefulness of the concept of bone strain as representing a continuum of response to physical stress is apparent in the clinical situation. The physician may be presented with patients in whom the clinical picture can be anywhere along the continuum.

CONCLUSIONS

Stress fractures should always be considered in the differential diagnosis of lower extremity pain in the athlete. The use of the technetium[99] bone scan allows early detection and treatment, particularly in bones at risk of progressing to complete fracture. The concept of bone strain allows a wide spectrum of clinical presentations of stress fractures to be considered and avoids grouping patients based on specific physical or radiographic findings. Conservative management is effective in treating the vast majority of these injuries, although a few will require immobilization or surgical intervention. The goal in rehabilitation of stress fracture patients should be to return the athlete to full activity by reintroducing sport at a rate which allows remodeling adequate for the osseous system to meet the required physical stresses.

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REFERENCES

1. Bargren JH, Tilson DH: Prevention of displaced fatigue fractures of the femur. *J Bone Joint Surg 53A:* 1115–1117, 1971
2. Belkin SC: Stress fractures in athletes. *Orthop Clin North Am 11:* 735–742, 1980
3. Berndt AL, Hardy M: Transchondral fractures (osteochondritis dissecans) of the talus. *J Bone Joint Surg 41A:* 988–1020, 1959
4. Blatz D: Bilateral femoral and tibial shaft stress fractures in a runner. *Am J Sports Med 9:* 322–325, 1981
5. Brahms MA, Fumich RM, Ippolito VD: Atypical stress fracture of the tibia in a professional athlete. *Am J Sports Med 8:* 131–132, 1980
6. Breithaupt MD: Zur pathologie des mensch lichen fussess. *Medizin Zeitung 24:* 169–177, 1855
7. Brill DR: Sports nuclear medicine: Bone imaging for lower extremity pain in athletes. *Clin Nucl Med 8:* 101–106, 1983
8. Brubaker CE, James SL: Injuries to runners. *J Sports Med 2:* 189–198, 1974
9. Burks RT, Sutherland DH: Stress fracture of the femoral shaft in children: Report of two cases and discussion. *J Pediatr Orthop 4:* 614–616, 1984
10. Butler JE, Brown SL, McConnell BG: Subtrochanteric stress fractures in runners. *Am J Sports Med 10:* 228–232, 1982
11. Cahill BR: Stress fracture of the proximal tibial epiphysis: A case report. *Am J Sports Med 5:* 186–187, 1977
12. Campbell G, Warnekros W: A tarsal stress fracture in a long-distance runner. *J Am Podiatr Assoc 73:* 532–535, 1983
13. Chamay A, Tschantz P: Mechanical influences in bone remodeling; experimental research on Wolff's law. *J Biomech 5:* 173–180, 1972
14. Clement DB: Tibial stress syndrome in athletes. *J Sports Med 2:* 81–85, 1974
15. Clement DB, Taunton JE, Smart GW, et al: A survey of overuse running injuries. *Physician Sportsmed 9:* 47–58, 1981
16. Collier BD, Johnson RP, Carrera GF, et al: Scintigraphic diagnosis of stress-induced incomplete fractures of the proximal tibia. *J Trauma 24:* 156–160, 1984
17. Cornwell G: Sports medicine and the pes cavus foot. *Br Columbia Med J 26:* 573–574, 1984
18. Crass JR, L'Heureux P: Bone scan appearance of stress fractures: Differentiation from osteosarcoma. *Minn Med 9:* 535–539, 1981
19. Daffner RH, Martinez S, Gehweiler JA: Stress fractures in runners. *JAMA 247:* 1039–1041, 1982
20. Darby RE: Stress fractures of the os calcis. *JAMA 200:* 131–132, 1967
21. Delee JC, Evans JP, Julian J: Stress fracture of the fifth metatarsal. *Am J Sports Med 11:* 349–353, 1983
22. Devas MB: Stress fractures in athletes. *Proc R Soc Med 62*: 933–937, 1969
23. Devas MB: Stress fractures in athletes. *J Roy Coll Gen Pract 19:* 34–38, 1970
24. Devas MB: *Stress fractures*. Edinburgh, Churchill Livingstone, 1975
25. Devereaux MD, Parr GR, Lachman SM, et al: The diagnosis of stress fractures in athletes. *JAMA 252:* 531–533, 1984
26. Dugan RC, D'Ambrosia R: Fibular stress fractures in runners. *J Fam Pract 17:* 415–418, 1983
27. Engher W: Stress fractures of the medial tibial plateau. *J Bone Joint Surg 59A:* 767–769, 1977
28. Frankel VH: Editorial comment. *Am J Sports Med 6:* 396, 1978
29. Geslien GE, Thrall JH, Espinosa JL, et al: Early detection of stress fractures using ^{99m}Tc-polyphosphate. *Radiology 121:* 683–687, 1976
30. Giladi M, Alcalay J: Stress fracture of the calcaneus—still an enigma in the Israeli army. *JAMA 252:* 3128–3129, 1984
31. Giladi M, Ziv Y, Aharonson Z, et al: Comparison between radiography, bone scan, and ultrasound in the diagnosis of stress fractures. *Milit Med 149:* 459–461, 1984
32. Gilbert RS, Johnson HA: Stress fractures in military recruits—A review of twelve years experience. *Milit Med 131:* 716–721, 1966
33. Goergen TG, Venn-Watson EA, Rossman DJ, et al: Tarsal navicular stress fractures in runners. *AJR 136:* 201–203, 1981
34. Goodman PH, Heaslet MW, Pagliano JW, et al: Stress fracture diagnosis by computer-assisted thermography. *Physician Sportsmed 13:* 114–132, 1985
35. Graham CE: Stress fractures in joggers. *Tex Med 66:* 68–73, 1970
36. Greaney RB, Gerber FH, Laughlin RL, et al: Distribution and natural history of stress fractures in U.S. Marine recruits. *Radiology 146:* 339–346, 1983
37. Holder L, Michael RH: The specific scintigraphic pattern of "shin splints" in the lower leg. *J Nucl Med 25:* 865–869, 1984
38. Hunter LY: Stress fracture of the tarsal navicular. *Am J Sports Med 9:* 217–219, 1981
39. James SL, Bates BT, Osternig LR: Injuries to runners. *Am J Sports Med 6:* 40–50, 1978
40. James SL, Brubaker CE: Biomechanical and neuromuscular aspects of running. *Exerc Sport Sci Rev 1:* 189–214, 1973
41. Johnson LC, Stradford HT, Geis RW, et al: Histogenesis of stress fractures. *J Bone Joint Surg 45A:* 1542, 1963
42. Keats TE: Musculoskeletal stress injuries. *Curr Probl Diagn Radiol 13:* 6–49, 1984
43. Li G, Zhang S, Chen G, et al: Radiographic and histologic analyses of stress fracture in rabbit tibias. *Am J Sports Med 13:* 285–294, 1985
44. Lombardo SJ, Benson DW: Stress fractures of the femur in runners. *Am J Sports Med 10:* 219–227, 1982
45. Matin P: The appearance of bone scans following fractures, including immediate and long-term studies. *J Nucl Med 20:* 1227–1231, 1979
46. Matheson GO, Clement DB, McKenzie DC, et al: Scintigraphic uptake of ^{99}Tc at non-painful sites in athletes with stress fractures: The concept of bone strain. *Sports Medicine*, in press, 1986
47. McBryde AM: Stress fractures in athletes. *J Sports Med 3:* 212–217, 1975
48. McBryde AM: *Prevention and Treatment of Running Injuries*. D'Ambrosia R, Drez D (eds). Thorofare, New Jersey, Charles B Slack, Inc, 1982, pp 21–42
49. McBryde AM: Stress fractures in runners. *Clin Sports Med 4:* 737–752, 1985
50. McKenzie DC, Clement DB, Taunton JE: Running shoes, orthotics, and injuries. *Sports Med 2:* 334–347, 1985
51. Meurman KOA, Elfving S: Stress fracture of the cuneiform bones. *Br J Radiol 53:* 157–160, 1980
52. Michael RH, Holder LE: The soleus syndrome: A cause of medial tibial stress (shin splints). *Am J Sports Med 13:* 87–94, 1985
53. Milgrom C, Chisin R, Giladi M, et al: Negative bone scans in impending tibial stress fractures. *Am J Sports Med 12:* 488–491, 1984
54. Milgrom C, Giladi M, Kashtan H, et al: A prospective study of the effect of a shock-absorbing orthotic device on the incidence of stress fractures in military recruits. *Foot Ankle 6:* 101–104, 1985
55. Mills GQ, Marymont JH, Murphy DA: Bone scan utilization in the differential diagnosis of exercise-induced lower extremity pain. *Clin Orthop 149:* 207–210, 1980
56. Morris JM, Blickenstaff LD: *Fatigue Fractures: A Clinical Study*. Springfield, IL, Charles C Thomas, 1967
57. Moss A, Mowat AG: Ultrasound assessment of stress fractures. *Br Med J 286:* 1479–1480, 1983
58. Mubarak SJ, Gould RN, Lee YF, et al: The medial tibial stress syndrome. A cause of shin splints. *Am J Sports Med 10:* 201–205, 1982
59. Murcia M, Brennan RE, Edeiken J: Computed tomography of stress fracture. *Skeletal Radiol 8:* 193–195, 1982
60. Newberg AH, Kalisher L: Case report: An unusual stress fracture in a jogger. *J Trauma 18:* 816–817, 1978
61. Nitz AJ, Scoville CR: Use of ultrasound in early detection of stress fractures of the medial tibial plateau. *Milit Med 145:* 844–846, 1980
62. Orava S, Puranen J, Ala-Ketola L: Stress fractures caused by physical exercise. *Acta Orthop Scand 49:* 19–27, 1978
63. Orava S: Stress fractures. *Br J Sports Med 14:* 40–44, 1980
64. Orava S, Hulko A: Stress fractures of the mid-tibial shaft. *Acta Orthop Scand 55:* 35–37, 1984
65. Park CH, Kapadia D, O'Hara E: Three phase bone scan findings in stress fracture. *Clin Nucl Med 6:* 587–588, 1981
66. Pavlov H, Torg JS, Freiberger RH: Tarsal navicular stress fractures: Radiographic evaluation. *Radiology 148:* 641–645, 1983
67. du Plessis MP: Stress fractures and over-use syndromes. *South Afric Med J 25:* 670, 1980
68. Prather JL, Nusynitz ML, Snowdy HA, et al: Scintigraphic findings in stress fractures. *J Bone Joint Surg 59A:* 869–874, 1977
69. Provost RA, Morris JM: Fatigue fracture of the femoral shaft. *J Bone Joint Surg 51A:* 487–498, 1969

70. Rosen PR, Micheli LJ, Treves S: Early scintigraphic diagnosis of bone stress and fractures in athletic adolescents. *Pediatrics 70:* 11–15, 1982
71. Roub LW, Gumerman LW, Hanley EN, et al: Bone stress: A radionuclide imaging perspective. *Radiology 132:* 431–438, 1979
72. Ruff CB, Hayes WC: Subperiosteal expansion and cortical remodeling of the human femur and tibia with aging. *Science 217:* 945–948, 1982
73. Rupani HD, Holder LW, Espinola DA, et al: Three-phase radionuclide bone imaging in sports medicine. *Radiology 156:* 187–196, 1985
74. Saunders AJS, El Sayed TF, Hilson AJW, et al: Stress lesions of the lower leg and foot. *Clin Radiol 30:* 649–651, 1979
75. Scully TJ, Besterman G: Stress fracture—a preventable training injury. *Milit Med 147:* 285–287, 1982
76. Skinner HB, Cook SD: Fatigue failure stress of the femoral neck. A case report. *Am J Sports Med 10:* 245–247, 1982
77. Somer K, Meurman ROA: Computed tomography of stress fractures. *J Comput Assist Tomogr 6:* 109–115, 1982
78. Spencer RP, Levinson ED, Baldwin RD, et al: Diverse bone scan abnormalities in "shin splints." *J Nucl Med 20:* 1271–1272, 1979
79. Stanitski CL, McMaster JH, Scranton PE: On the nature of stress fractures. *Am J Sports Med 6:* 391–396, 1978
80. Sullivan D, Warren RF, Pavlov H, et al: Stress fractures in 51 runners. *Clin Orthop 187:* 188–192, 1984
81. Taunton JE, Clement DB, Webber D: Lower extremity stress fractures in athletes. *Physician Sportsmed 9:* 77–86, 1981
82. Thompson JP, Loomer RL: Osteochondral lesions of the talus in a sports medicine clinic. *Am J Sports Med 12:* 460–463, 1984
83. Torg JS, Pavlov H, Cooley LH, et al: Stress fractures of the tarsal navicular. *J Bone Joint Surg 64A:* 700–712, 1982
84. Wilcox JR, Moniot AL, Green JP: Bone scanning in the evaluation of exercise-related stress injuries. *Radiology 123:* 699–703, 1977
85. Wilson ES, Katz FN: Stress fractures. *Radiology 92:* 481–486, 1969
86. Yale J: A statistical analysis of 3,657 consecutive fatigue fractures of the distal lower extremities. *J Am Podiatr Assoc 66:* 739–748, 1976