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Distribution and Natural History of Stress Fractures in U.S. Marine Recruits[1]

In a prospective study, 839 scintigraphic abnormalities that could be related to stress were detected in 250 patients (23% cortical; 77% cancellous). Only 28% had confirmatory radiographs. Of 73 patients with 2-6-week follow-up, 54% showed radiographic changes. The fractures showed definite patterns of scintigraphic and radiographic evolution dependent upon location and exercise program. Recruits with a running background suffered fewer fractures. A regular sequence of radiographic changes in cancellous bone, presumably not previously noted, includes an initial normal radiograph progressing to subtle speckles of calcium density which finally coalesce into the sclerotic band typical of cancellous bone stress fracture. In the appropriate clinical setting, a scintigraphic abnormality is diagnostic of stress fracture even if radiographs are normal.

Index terms: Extremities, fracture • Fractures, stress • Extremities, radionuclide studies • (Skeletal system, stress fractures, 4[0].415) • (Skeletal system, radionuclide exam, 4[0].1299)

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STRESS fractures are common among individuals who have recently begun exercise programs. In a prospective study of U.S. Marine recruits, 250 patients presenting with lower-extremity pain related to exercise were evaluated with bone scintigraphy and radiography of symptomatic or scan-positive locations. Follow-up examinations at 2–6-week intervals allowed quantitation of fracture evolution by both modalities. We intended to search for differences in the natural history by either modality regarding the anatomic distribution, intraosseous location, initial lesion intensity, and history of any prior regular strenuous exercise. We also sought corroboration of previous assertions that a focally abnormal scintigram with a normal radiograph is diagnostic of stress fracture in the proper clinical setting, and that scintigraphy shows a predictable superiority over radiography in early diagnosis (1–3).

MATERIALS AND METHODS

Patients were 250 U.S. Marine recruits, averaging 20.25 years of age, who presented at morning sick call between September 1979 and December 1980 with stress-related lower-extremity pain. The location and severity of pain, relation to exercise, training date of onset (T-day), as well as any prior exercise program were documented.

Patients received 15 mCi (555 MBq)^{99m}Tc-MDP intravenously with subsequent two-hour delayed scintigraphy of the lower extremities employing a standard-field 37 PM tube gamma camera with a low-energy, all-purpose collimator. Each leg was imaged for 150 seconds, while bilateral foot imaging took 240 seconds. Radiographs of the appropriate sites were obtained.

Readers sequentially evaluated the radiographs, scintigrams, and then re-evaluated the radiographs at scan-positive sites. Abnormalities were tabulated by location, lesion intensity, radiographic findings, and T-day of onset, for individual and combined sites.

In 73 patients (29%), follow-up examinations were obtained at 2–6 week intervals including a history for any interim therapy. Results were tabulated as above with additional analysis of any changes in the scintigrams and radiographs.

RESULTS

Initial scans revealed a total of 839 abnormal sites with an average of 3.4 per patient (TABLE I). Scintigraphic abnormalities were seen more frequently in trabecular bone (77%) than in cortical bone (23%) and were slightly more common in the leg (51%) than the foot (49%) (TABLE II). Of the 839 abnormal sites, 238 (28%) had positive concurrent radiographs, representing 162 of 650 trabecular sites (25%) and 76 of the 189 cortical sites (40%). TABLE II also shows the lesion intensity at the abnormal site correlated with the number of positive radiographs. Intensity of scintigraphic uptake was graded 0 to 3+. Normal and 1+ through 3+ abnormal uptake by calcaneus and tibia

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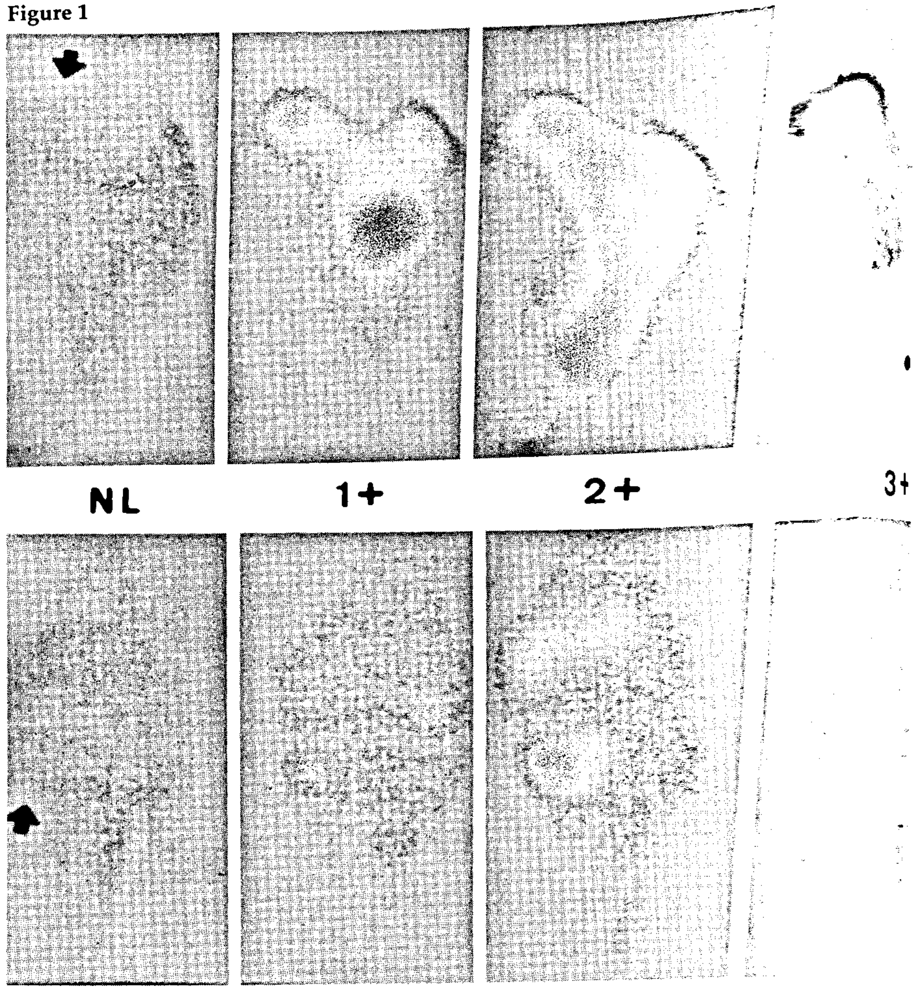
TABLE I: Distribution of Patients *vs.* No. of Abnormal Sites on Initial Scintigram

No. Abnormal Sites	Per Cent of Patients
0	12%
1	14%
2	17%
3	9%
4	12%
≥5	36%

Figure 1



Graded spectrum of scintigraphic uptake.
Top. Images of the calcaneus show normal (arrow) through 3+ abnormal uptake.
Bottom. Images of the medial fibial condyle show a spectrum similar to that above.

TABLE II: Anatomic and Intraosseous Distribution of Initial Scintigraphic Abnormalities

Site	Total No. Patients	Total No. Abnormal Sites	Total Pos. Radiographs	3+ Sites/Pos. Radiographs	2+ sites/Pos. Radiographs	1+ sites Radiogr[illegible]
Leg						
Femur (trabecular)	36	48	3	4/0	15/2	29/1
Femur (cortical)	27	48	9	3/2	15/3	30/4
Patella	8	12	0	0	6/0	6/0
Fibula	5	8	2	3/0	4/2	1/0
Tibia (trabecular)	120	192	34	50/17	65/10	77/7
Tibia (cortical)	103	124	59	54/43	34/10	36/6
Total	299	432	107	114/62	139/27	179/18
Foot						
Talus	33	46	10	18/4	21/4	7/2
Calcaneus	95	172	83	96/53	43/17	33/13
Navicular	20	28	12	9/3	17/7	2/2
Cuboid	11	13	2	7/2	5/0	1/0
Cuneiforms	6	6	2	5/2	1/0	0
MT* (trabecular)	62	133	16	58/8	65/6	10/2
MT* (cortical)	8	9	6	3/3	0	6/3
Total	235	407	131	196/75	152/34	59/22
Trabecular						
Leg	164	252	37	54/17	86/12	112/8
Foot	227	398	125	193/72	152/34	53/19
Total	391	650	162	247/89	238/46	165/27
Cortical						
Leg	135	180	70	60/45	53/15	67/13
Foot	8	9	6	3/3	0	6/3
Total	143	189	76	63/48	53/15	73/13
Total		839	238	310/137	291/61	238/4[illegible]

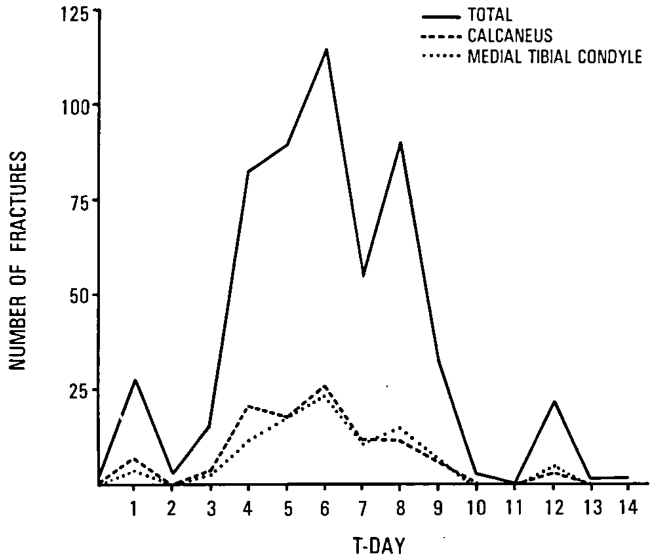
* MT = metatarsal

TABLE III: Exercise Regimen in Recruit Training for the First Two Weeks (T-Days 1-14)*

T-Day	Running (miles/min)	Marching (hr.)
1	1/8	
2	1/8	
3	1.5/14	1
4	1.5/14	2
5	1/9	1
6	2/18	1
7	2/18	1
8	2.5/22	1
9	2.5/21	1
10	3/28	2
11	3/27	
12	2/18	1
13	3/28	1
14		

* Daily PT: avg. 2 hr/day, includes calisthenics, wind sprints, & obstacle course

Figure 2



Relationship of stress fracture incidence to time in training by days.

TABLE IV: Fracture Distribution by Week in Training

Week No.	Fracture Total	Fracture Location: Trabecular	Cortical	Leg	Foot
1	386	316	70	192	194
2	151	126	25	75	76
3	34	27	7	17	17
4	29	19	10	16	13
5	50	37	13	28	22
6	59	48	11	26	33
7	76	37	39	52	24
8	50	40	10	22	28
9	4	0	4	4	0

TABLE V: Abnormal Sites on First Scintigrams Compared with Prior History of Running

	No. Patients	No. Abnormal Sites	No. Sites per Patient	
Runners	65	126	1.9	$p < 0.01$
Nonrunners	185	713	3.9	
Total	250	839	3.4	

are illustrated in Figure 1. Radiographs were positive in 44% of all and 76% of cortical 3+ scintigraphic abnormalities, while positive radiographs were seen in only 17% of all and 18% of cortical 1+ sites. There was no instance of an abnormal radiograph at a scintigraphically normal site.

The majority of injuries developed within the first two weeks of recruit training (TABLE III). TABLE IV shows the relationship of the number of patients presenting with symptoms compared to weeks in the training cycle, as well as distributing the fracture types into locations. Symptoms developed in the greatest number of patients during weeks 1 and 2. In some patients, symptoms developed as early as T-day 1, when the exercise consisted of calisthenics and a one-mile run. Figure 2 shows that large numbers of patients did not become symptomatic until T-day 4, one day following the first exercise in close-order drill (marching). Correlation of pretraining exercise with the incidence of fractures showed that recruits with a prior history of long-distance running (1 mile/day, ≥4 days/week) had significantly fewer fractures than did nonrunners (TABLE V). No other pretraining exercise regimen demonstrated a sparing effect.

TABLE VI lists the data from the follow-up examinations performed on 73 of the 250 original patients. A total of 289 abnormal sites were seen, averaging 4.0 sites per patient; 235 sites were in trabecular bone (81%) and 54 in cortical bone (19%). A total of 44 sites (15%) had positive radiographs at initial examination, while 157 (54%) showed radiographic changes on follow-up. Of the 44 sites with positive radiographs initially, 27 (11%) represented trabecular and 17 (26%) represented cortical sites, while the 157 sites with positive radiographs on follow-up examination showed that 118 (50%) were trabecular and 39 (72%) were cortical. The overall conversion rate from a negative to a positive radiograph on the follow-up examination was 46%: trabecular bone 44% and cortical bone 59%.

Comparison of the follow-up with the initial radiographs demonstrated the expected radiographic changes of stress fracture, namely, sclerotic bands at the fracture site in trabecular bone and periosteal new bone formation at cortical sites. Additional intermediate radiographic changes were discovered in trabecular bone early in the follow-up phase of the study (January 1980); these changes consisted of subtle blurring of trabecular margins and small fluffy densities of new bone in the trabecular sites that showed abnormal uptake on scintigraphy but were not present on the initial radiographs. The spectrum of these abnormalities in trabecular bone as seen in

TABLE VI: Distribution and Evolution of Scintigraphic and Radiographic Abnormalities on Follow-up Examination

Site	Total No. Patients with Follow-up	Total No. Abnormal Sites	No. Pos. Radiographs Initially	No. Pos. Radiographs on Follow-up	Per Cent Conversion
Leg					
Femur (trabecular)	9	10	0	3	30
Femur (cortical)	8	13	7	9	33
Patella	4	5	0	0	0
Fibula	0	0	0	0	
Tibia (trabecular)	45	67	1	21	30
Tibia (cortical)	26	36	7	25	62
Total	92	131	15	58	37
Foot					
Talus	13	13	0	2	15
Calcaneus	42	78	19	72	90
Navicular	7	10	3	6	30
Cuboid	1	1	0	1	100
Cuneiforms	0	0	0	0	
MT* (trabecular)	23	51	4	13	19
MT* (cortical)	5	5	3	5	100
Total	91	158	29	99	54
Trabecular					
Leg	58	82	1	24	28
Foot	86	153	26	94	54
Total	144	235	27	118	44
Cortical					
Leg	34	49	14	34	57
Foot	5	5	3	5	100
Total	39	54	17	39	59
Total		289	44	157	46

* MT = metatarsal

TABLE VII: Radiographic Evolution of Trabecular Stress Fracture

Initial Radiographic Finding	Follow-up Radiographic Finding: Normal	Subtle	Classic
Normal	120	51	35
Subtle		8	12
Classic			9

the calcaneous and medial tibial condyle of several patients may show both subtle and intermediate changes (Fig. 3). Since these findings were felt to represent early, previously unreported changes in the development of trabecular stress fracture, all previous radiographs were reviewed for this finding and the new results incorporated (TABLE VII). In a small percentage of our patients these subtle changes had been overlooked. In subsequent radiographic evaluation, these new criteria were included.

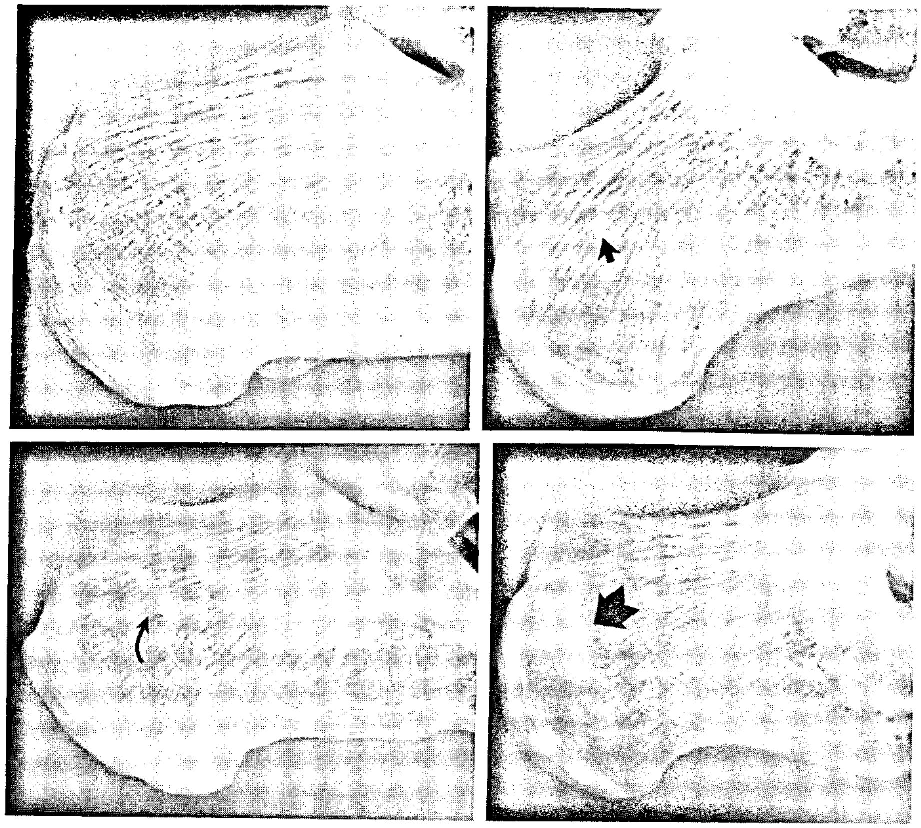
DISCUSSION

Analysis by anatomic distribution showed no predominance of involved sights in either the leg or foot. However, 73% (316/432) of the initial abnormalities in the leg did involve the tibia. Within the tibia, involvement of the medial proximal condyle, the major weight-bearing portion, predominated. In the foot, the single most common site was the calcaneus (21%), specifically the posterior tuberosity, again a major weight-bearing site. Although metatarsal fractures were quite common (17% of total), the majority showed subtle abnormalities in the trabecular bone of the base and head rather than the classic "march" fracture, contrary to currently held belief (4). On follow-up, radiographic abnormalities were present in 25% of these trabecular metatarsal fractures. While radiologists have long recognized the bone's propensity to incur stress fracture (4), no fracture could be diagnosed without a scintigram in 75% of the patients. The fracture distribution for the remaining bones in the lower extremity showed no other significant numbers at any particular site. However, any bone may be involved with fractures in unusual areas, such as the navicular (3% of total), cuboid (1.5%), and the great toe (Fig. 4).

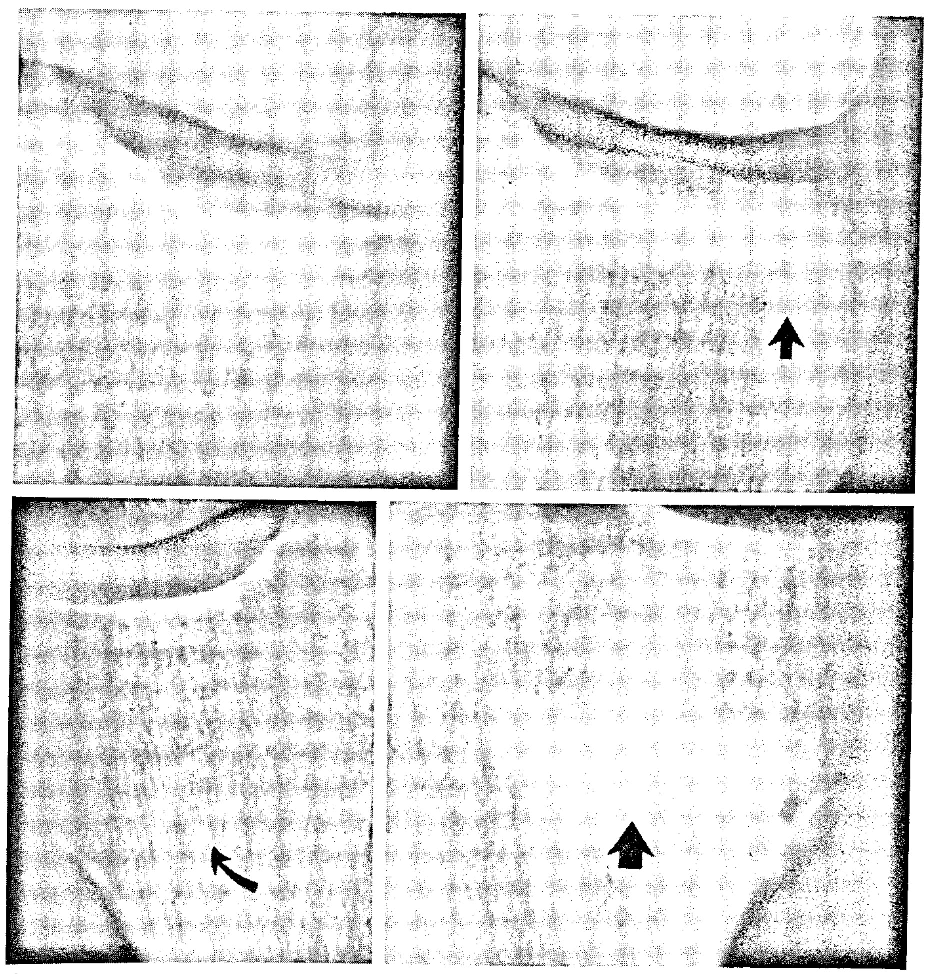
Although we initially doubted the data concerning those patients with stress-related symptoms predating training, we discovered that these recruits exercised while awaiting the formal onset of training. A large number of fractures were seen on T-day 4 (Fig. 2) one day after marching was added to the running and exercise protocol. T-day 3 is the first day on the obstacle course, which involves vertical leaps of 8–10 feet as part of the daily physical training. As expected, the majority (64%) of stress injuries occurred in the first two weeks of recruit training, 46% in the initial seven days. Since new exercise regimens may result in bone failure, this early development of stress fracture was anticipated. Following the peak within the first two weeks, the weekly distribution was relatively even, with another peak at week 7. At this time newly intensified exercise followed the return of the recruits from the rifle range where they had spent weeks 4–6.

A coincidental relationship between specific forms of exercise and stress fractures involving the calcaneus and the medial tibial condyle was noted. Sixty percent of patients with medial tibial condylar stress fractures had an associated calcaneal fracture while 52% of those with calcaneal fractures had fractures of the medial tibial condyle. Three possible mechanisms were identified: (*a*) all training was done in combat boots; (*b*) marching and run-

Figure 3



a.

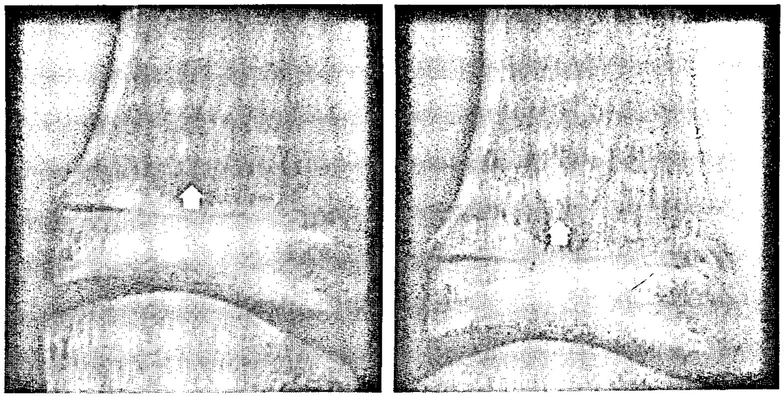


b.

Spectrum of radiographic findings.

a. Lateral views of the calcaneus illustrate the subtle progression of trabecular appearance from normal to small, fluffy speckles (small arrow), through coalescent cloud-like densities (curved arrow), to the classic sclerotic band (large arrow).
b. Similar changes as manifested in the medial tibial condyle.

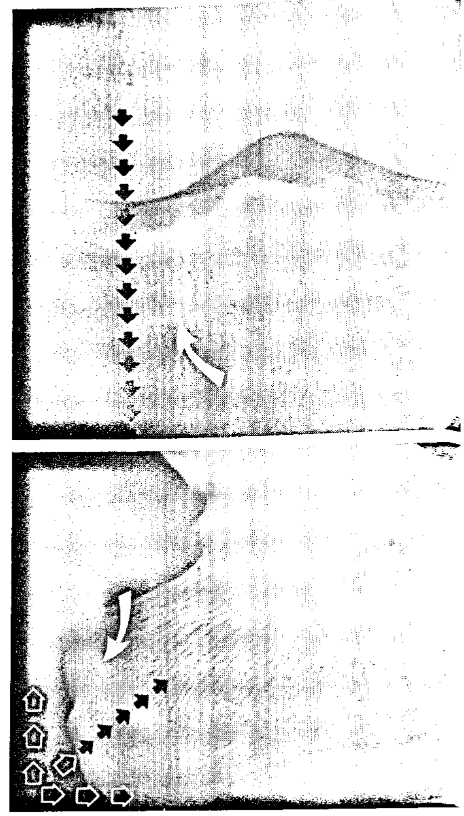
Figure 4



a. b.

a. Initial examination on 18 Dec 79 shows a questionable abnormal density in the base of the first proximal phalanx (arrow).
b. Repeat study on 7 Jan 80 reveals a classic trabecular stress fracture at the same site (arrow).

Figure 5



Straight arrows follow the vectors of force as applied and transmitted to the medial tibial condyle and calcaneus. Note that the healing stress fractures (curved arrows) are perpendicular to the axial load on the former and the net vector on the latter.

ning were done on asphalt; and (*c*) a strong heel snap was used to mark the cadence while marching (5). We formally presented this relationship to the Recruit Depot Command in June 1980. Subsequently, the program substituted running on grass in tennis shoes, and eliminated marching with the heel snap. A sharp drop was seen in the incidence of calcaneal stress fracture from 20.5 to 7%, thus patients entering the study after this change in the training routine were excluded from data analysis.

Although we were able to generate a frequency distribution of stress fractures in the lower extremities, we were unable to establish the overall incidence of stress fractures in recruits, since logistical problems prevented a longitudinal study at regular intervals utilizing scintigraphy and radiography of one or more platoons of recruits (70 men each). Additional problems included those patients who did not present for evaluation of stress fractures because of lack of symptoms or a strong desire to continue training regardless of their physical well-being. Those presenting with hip pain were usually referred to orthopedics and circumvented this study. Many patients with multiple fractures had asymptomatic sites of injury, possibly due to masking by symptoms from other sites (6). However, it is possible that asymptomatic stress fractures occur.

A review of the physiologic factors leading to the development of subacute bone failure and stress fracture is useful for relating the imaging modality to metabolic bone changes. Stress fractures may result from alternating compressive and expansile forces transmitted to the bone through ligaments, tendons, and muscles (7). Forces of intensity and duration exceeding those normally experienced by the bone result in shearing of the cortical and trabecular bone at right angles to the net force (Fig. 5). As the bone is sheared by these forces, initial healing results in some bone resorption at the site of the injury with subsequent reparative new bone formation. This results in deposition of osteonal bone seen as sclerosis on radiographs. A significant number of stress injuries require minimal new bone to support the new stress, since our data and previous reports (6, 8) have shown that approximately one-half of all lesions fail to demonstrate any radiographic change.

Skeletal scintigraphy utilizes the osseous metabolic activity to provide physiologic data. Alterations in metabolic rate may be detected as early as 24 hours after injury (9). When the stress is removed, a decrease in abnormal uptake is seen, with some cases returning to normal within 4–6 weeks (Fig. 6). Uncommonly, persistent activity at uncomplicated healed fracture sites may be seen for many months to years (9).

Conversely, standard skeletal radiography requires an approximate 50% change in bone density for delineation and diagnosis of trabecular lesions. A stress fracture of trabecular bone will appear normal on radiographs for 10–21 days (6, 10, 11) before resorption and proliferation associated with healing produce perceptible increase in density of the bone matrix. The preliminary resorptive phase of healing might be perceptible on higher detail or magnification radiography. A wide spectrum of radiographic abnormalities at injury sites associated with abnormal scintigrams was identified. These range from barely perceptible fluffy speckles of new bone, through larger cloud-like densities, to the classic sclerotic trabecular stress fracture. These radiographic changes became evident when follow-up images were compared with earlier normal radiographs, without using high-detail or magnification radiography. In those patients with follow-up studies, these subtle changes were observed initially in 20 of the 235 trabecular fractures, 1[illegible] of which progressed to more classic appearance.

Wilcox *et al.*, in an earlier report from this institution, demonstrated the clear superiority of scintigraphy over radiography in early detection of stress fracture (1). Subsequent reports (2, 1[illegible] as well as our present data (8) corroborate this assertion. We assumed the superiority of scintigraphy and used the scintigraphic findings as the primary criterion for diagnosis against

Figure 6

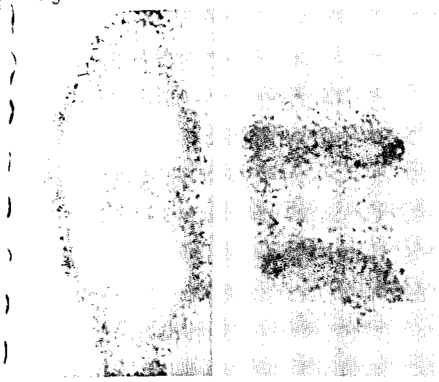
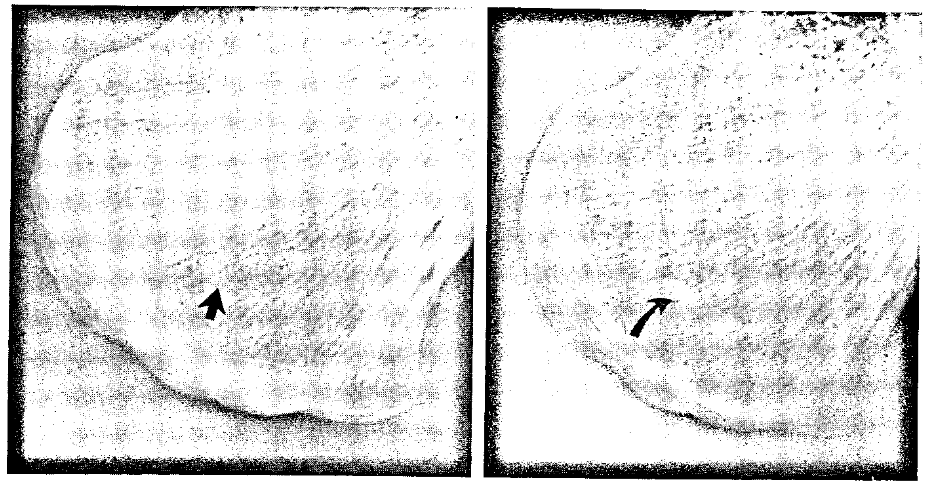


Illustration of complete resolution of a 2+ scintigraphic abnormality in the medial femoral condyle over a three-week period.

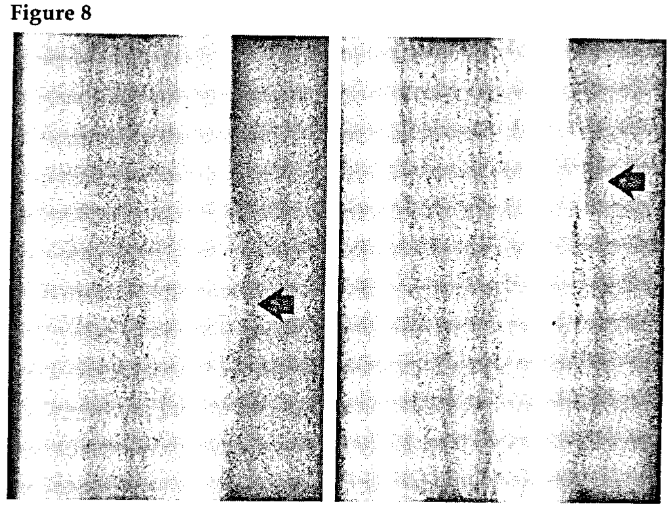
Figure 7



a. b.

21-year-old recruit with bilateral heel pain. Initial radiograph (**a**) reveals subtle changes of stress fracture consisting of several faint, fluffy densities (small arrow) which on the follow-up study six weeks later (**b**), have coalesced to become a portion of the classic sclerotic band (curved arrow).

Figure 8



a. b.

a. Subtle changes (photographically enhanced) at cortical sites consist of a blurred cortical margin and barely perceptible periosteal new bone (arrow).
b. Typical focal periosteal thickening is easily identified on a repeat study two weeks later (arrow).

which we could then compare the usefulness of radiography for either early or late confirmation of the scintigraphic diagnosis. We had not anticipated finding the intermediate radiographic abnormalities, but considered it the serendipitous outcome of the protocol design.

Data analysis showed a clear edge in the early detection of stress fractures by scintigraphy, with only 28% of scintigraphic abnormalities showing radiographic change. Follow-up examinations showed an overall incidence of 54% positive radiographs with an interval conversion rate from negative to positive of 46%. Therefore, after sufficient time is allowed for development of radiographic changes, approximately one-half of patients still show no abnormality. The necessity of a confirmatory radiograph to make a diagnosis of stress fracture as has been done in the past (1–3, 5, 7, 9, 10, 12) would, therefore, result in a large percentage of false-negative diagnoses. There were no instances of radiographic change at a symptomatic site without a corresponding abnormality on a scintigram.

The spectrum of early radiographic abnormalities could be predicted from the factors involved in altered bone physiology. There were no instances of subtle findings reverting to a normal appearance on follow-up examination. The majority showed continued progression toward the classic stress fracture (Figs. 7 and 8).

There were three instances of progression to complete fracture, all occurring in metatarsal shafts. Therapy for stress fractures diagnosed on the initial examination consisted of 1–2 weeks of limited duty, with no running but continued calisthenics. The patients were then exercised to a level of pain tolerance. This 1–2 week period of reduced exercise appeared to be sufficient for new bone formation at the injury site, apparently adequate to maintain the integrity of the bone upon reinstituting exercise. Incompletely treated stress fractures may be debilitating and have resulted in the premature termination of athletic careers, although in this context, therapeutic considerations are more complex.

SUMMARY

In a prospective study of stress injuries of the lower extremities of U.S. Marine recruits, we derived a frequency distribution of stress fractures. The most frequently fractured bone was the tibia (73%), while the single most common site was the posterior calcaneal tuberosity (21%). The natural history of stress fractures by scintigraphy and radiography has been outlined, showing the evolutionary changes on either study as a universal progression independent of injury site or type of stress. An identical spectrum of changes should be present within any group undergoing intense new exercise. The frequency distribution of stress fractures should be a function of differing forms and intensities of exercise, therefore, our figures should not be applied to other groups.

We used the presence of a scintigraphic abnormality at a symptomatic site

as the criterion for diagnosis of stress fracture. Since the distribution of skeletal radiotracer uptake is directly dependent on local metabolic activity, it is expected that a focal alteration in bone metabolism will result in a scintigram approaching 100% sensitivity for the abnormality (9). In the proper clinical setting, the specificity should approximate this figure; however, a focal, nonstress-related bone abnormality which has not manifested any radiographic change, such as early osteomyelitis, could result in a false-positive examination. Specificity cannot, therefore, be accurately determined without an actual determination of the pathologic changes within the bone, necessarily involving biopsy.

In summary, we believe that we have established bone scintigraphy as an early and accurate means for the detection of lower extremity stress fractures, even in the absence of radiographic findings (6). We feel that a focally abnormal scintigram, in the proper clinical setting, establishes the diagnosis of stress fracture, with radiography to be performed at the time of initial work-up only to rule out a nonstress injury (such as complete fracture, fibrous dysplasia, osteomyelitis, primary bone tumor).

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