STRESS FRACTURES AND TIBIAL BONE WIDTH

A RISK FACTOR

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A prospective study of 295 infantry recruits has shown that the mediolateral width of the tibia measured radiographically at each of three different levels in the bone had a statistically significant correlation with the total incidence of stress fractures as well as with those in the tibia alone or the femur alone. A narrow tibial width was shown to be a risk factor, but cortical thickness was not found to be significant.

Stress fractures are a problem among military and athletic trainees (Gilbert and Johnson 1966; Belkin 1980), who can develop forces of several times their body weight at the interface between foot and ground during running (Mann et al. 1979). These forces, although modified, are transmitted proximally to the tibia and beyond. Lanyon et al. (1975) have shown by strain gauge studies that large compression and tension forces are developed in the tibia during walking and running. The magnitude of these forces varies with different surfaces of the tibia, the phase of the gait cycle, the gait pattern and cadence, and which ground-foot interface is studied. The repetitive cyclical absorption by bone of these forces and those produced by dynamic muscle action is thought to produce stress fractures (Devas 1958).

We have previously shown that Israeli recruits are similar to athletes in that the most frequent site of their stress fractures is the tibia followed by the femur (Giladi et al. 1985; Milgrom, Giladi et al. 1985). In other armies different patterns are found. Part of our prospective study at the Osteoporosis Institute of Jerusalem examined the hypothesis that tibial bone geometry and composition might be risk factors for stress fractures in Israeli recruits, and we report here the correlation between tibial bone width and the incidence of such fractures.

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0301-620X/87/2008 $2.00

MATERIALS AND METHODS

A group of 295 male infantry recruits were evaluated prospectively for possible risk factors for stress fracture. All participants gave their informed consent. Each recruit had a pre-training screening which included measurement of weight and height, clinical measurement of tibial torsion and classification of tibial alignment into genu varum, straight, or genu valgum. Tibial bone mineral content was measured 8 cm above each ankle joint by the Cameron photon absorption technique using a Norland Digital Bone Densitometer with the beam directed from medial to lateral.

Standard radiographs were taken with a tube-film distance of 90 cm. For the anteroposterior view the feet were positioned in 15° of medial rotation; standard lateral views were used. Measurements were then made, using a magnification ruler, of total tibial width and cortical widths in both anteroposterior and mediolateral planes at three levels, in each bone: at 8 cm above the ankle joint, at the point of the narrowest mediolateral width, and at the point of the narrowest anteroposterior width (Fig. 1). The six measurements for each bone are laid out and given a number in the heading of Table I.

During their 14-week basic training course the recruits were reviewed at three-weekly intervals by army doctors in the field and questioned about symptoms compatible with stress fracture. Those with complaints were examined. The recruits also had free daily access to medical staff and were encouraged to report symptoms. Those with symptoms compatible with stress fracture

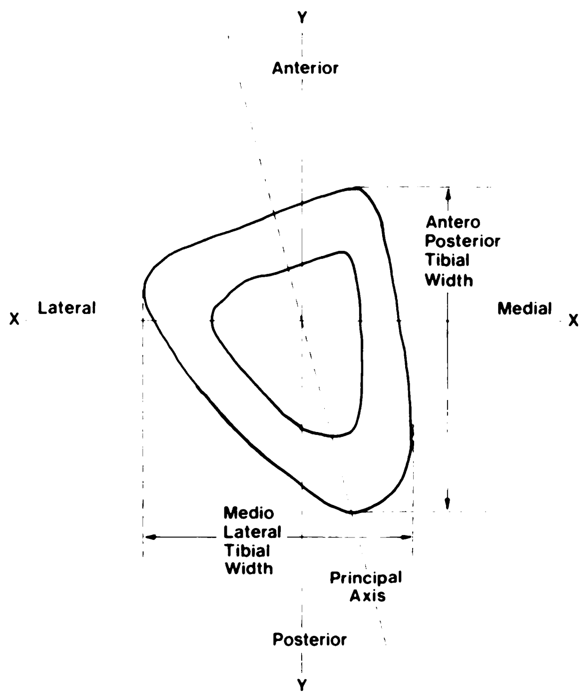

Fig. 1

Diagram of a cross-section through the left tibia.

were given three days' rest; if symptoms then persisted the recruit was sent for orthopaedic investigation in hospital.

Sites of pain were then recorded in relation to anatomical landmarks, appropriate radiographs were taken and late phase ^{99m}Tc-MDP scintigraphy was performed in all cases. A diagnosis of stress fracture was made on the basis of either a positive radiograph or a positive scintigram, using the criteria of Prather et al. (1977). Scintigraphy was considered to be diagnostic of a stress fracture when a focal area of increased uptake was found in the absence of other bony pathology (Milgrom, Chisin et al. 1985).

Results were recorded on a standard evaluation form which had been designed before the study began, and all data was processed through the IBM computer facilities of the Israeli Defense Forces Medical Corps. Statistical results including means, standard deviations and p values were calculated with the Statistical Package for the Social Sciences (SPSS) using Student's *t*-test or Yates' correction of the chi-square test.

RESULTS

During the course of basic training 91 of the 295 recruits (31%) were found to have one or more stress fractures (Milgrom, Giladi et al. 1985). Of the total of 184 stress fractures, 51% were in the tibial diaphysis, 5% in the tibial plateau, 21% in the femoral diaphysis, 9% in the supracondylar region and 4% in the femoral condyles. All of the tibial and femoral diaphyseal fractures were in the medial cortex. Only 9% of the fractures were in the feet.

Both anteroposterior and mediolateral bone widths were measured in both tibias of 288 of the 295 recruits at each of the three levels (Table I). The correlation between right and left tibial widths varied from 0.81 to 0.91, depending on the measurement site; the mean width for each level on right and left legs was used for calculation. The correlation between each of the six

Table I. The mean mediolateral (ML) and anteroposterior (AP) diameters of the tibia ± s.d. measured in millimetres at each of three levels in 286 recruits with and without stress fractures

	Level measured					
	Narrowest ML*		Narrowest AP†		8 cm above ankle	
Stress fractures	ML 1	AP 2	ML 3	AP 4	ML 5	AP 6
Femoral						
Present (n = 36)	22.8 ± 1.6	28.0 ± 2.9	24.8 ± 2.0	25.0 ± 2.3	25.3 ± 2.3	25.3 ± 2.3
Absent (n = 250)	24.5 ± 1.9	28.2 ± 2.6	26.4 ± 2.0	25.9 ± 2.0	26.9 ± 2.2	26.2 ± 2.0
Significance of difference in mean width	$p < 0.001$	$p = 0.609$	$p < 0.001$	$p = 0.016$	$p < 0.001$	$p = 0.012$
Tibial						
Present (n = 58)	23.8 ± 2.1	28.1 ± 2.7	25.7 ± 2.1	25.4 ± 2.0	26.1 ± 2.4	25.7 ± 2.2
Absent (n = 228)	24.4 ± 1.9	28.3 ± 2.6	26.3 ± 2.0	25.9 ± 2.0	26.9 ± 2.3	26.2 ± 2.0
Significance of difference in mean width	$p = 0.036$	$p = 0.578$	$p = 0.027$	$p = 0.085$	$p = 0.036$	$p = 0.101$
All						
Present (n = 86)	23.8 ± 2.1	28.2 ± 2.8	25.6 ± 2.2	25.5 ± 2.1	26.2 ± 2.5	25.8 ± 2.2
Absent (n = 200)	24.6 ± 1.8	28.2 ± 2.5	26.4 ± 1.9	25.9 ± 2.0	26.9 ± 2.2	26.9 ± 2.0
Significance of difference in mean width	$p = 0.001$	$p = 0.980$	$p = 0.003$	$p = 0.088$	$p = 0.010$	$p = 0.098$

*, mean 13.7 cm above the ankle joint
†, mean 8.7 cm above the ankle joint

measurements of mean tibial bone widths and the incidence of stress fractures is given in Table I. The mean mediolateral width at all three levels (measurements 1, 3 and 5) showed a statistically significant difference in recruits with and without any stress fractures. This difference was also significant for the smaller groups sustaining either femoral or tibial stress fractures alone. Anterolateral measurements 4 and 6 showed a statistically significant difference only in relation to femoral stress fractures, while measurement 2 was found to have no statistical significance.

No statistical correlation was found between the incidence of stress fractures and height, weight, tibial torsion, tibial alignment, tibial bone mineral content, or the radiographic width of the tibial cortex. Use of the ratio of tibial bone width to the height of the recruit rather than tibial bone width alone did not increase the statistical correlation with the incidence of stress fracture, and other ratios related to the height and weight of the recruit as well as to tibial width were shown to have no statistical significance.

DISCUSSION

Stress fractures are a problem in sports medicine (Belkin 1980), but the true incidence in athletes and joggers is not known. Brudvig, Gudger and Obermeyer (1983) suggest an incidence of less than 2% in US Army recruits, but we have reported a 31% incidence of stress fractures in a group of special infantry recruits in the Israeli Army (Milgrom, Giladi et al. 1985). One of the possible explanations for this difference could be the existence of a group with high risk for stress fractures within the Israeli Army (Giladi et al. 1985). Brudvig et al. (1983) noted sub-populations with a higher risk factor in the US Army; white men had twice the incidence of stress fractures as black men doing the same training at West Point. Protzman and Griffis (1977) showed that women had ten times as many stress fractures as men on the same course.

We found that recruits with stress fractures had tibias which were narrower mediolaterally at all three measured levels (1, 3 and 5) than recruits without stress fractures. Measurement 5 was taken at a fixed distance above the ankle joint rather than at a point of narrowing and this may be one reason why it was less statistically significant than measurements 1 and 3. These two measurements give the mediolateral diameter of the tibia at the levels of the narrowest mediolateral and anteroposterior tibial widths respectively.

The tibia has varying cross-sectional shapes, but it may be idealised as a cylinder whose cross section is an eccentric ellipse within an ellipse. For an oblate cylinder, bending strength in the mediolateral plane is related to the area moment of inertia of the cylinder about the y-axis of rotation (see Fig. 1). This area moment of inertia is proportional to a factor of the fourth power of the radius in the mediolateral plane (Frankel and Burstein 1970). Therefore wider tibias in this plane should have greater resistance to bending in this direction. Resistance to compression and tension should also be greater since a larger cross-sectional area allows these forces to be distributed over a greater unit area (Frankel and Burstein 1970). The fact that all of the stress fractures in the tibial and femoral shafts in this series occurred in the medial cortex helps explain why the tibial bone width in a mediolateral direction correlates best with the incidence of such fractures; the distribution of bone in this plane is one determinant of the resistance of the medial cortex to bending, compression and tension. Moreover, most of the tibial stress fractures occurred in the middle third of the bone; this implicates bending forces, since such forces are maximal in this region.

A wide tibia is normally associated with wide tubular bones in general and this explains why total and femoral stress fracture incidence also correlated with tibial bone width. We found, however, more correlation of tibial bone width with femoral than with tibial stress fractures. The reason for this is not readily apparent and requires further study, but the mechanism of femoral stress fractures may well differ from that of the majority of tibial stress fractures. The number of metatarsal stress fractures in this study was too small to establish any statistical correlation with tibial bone width.

The finding that tibial bone width is related to stress fracture morbidity may help to explain Protzman and Griffis' (1977) finding that women sustained many more stress fractures than men during the same training. Miller and Purkey (1980) studied paired human tibias and found that women had relatively narrower bones with lower moments of inertia.

The statistical correlation found between tibial bone width and the incidence of stress fractures is important, since it is the first physical parameter of the bone to be identified as a risk factor. Attempts can now be centred on determining the biomechanical basis for its significance and on identifying risk groups for stress fractures which will be clinically useful.

Improved correlation might result if tibial widths were measured along axes other than the simple anteroposterior and mediolateral ones used in this study. The principal axis of the tibia (see Fig. 1), that in which the tibial diameter is widest at any given cross-section, may be important, but its direction is not constant and varies at different levels of the tibia. Another possible axis for measurement is the predominant axis of occurrence of stress fractures but this axis has not yet been identified.

If clinically useful risk groups can be identified, they will help with the screening of athletes or recruits before training. High-risk subjects could be identified and either given a modified training programme or be excluded entirely from certain courses.

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