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Stress fractures

Identifiable risk factors

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ABSTRACT

To answer the question why such large differences in stress fracture morbidity rates (2% to 64%) exist in different countries, we prospectively evaluated 312 recruits for possible risk factors for stress fractures. Prior to training, each recruit underwent an evaluation including the following: orthopaedic examination, foot and tibial radiographs, measurements of tibial bone width, bone mineral content, bone density, aerobic physical fitness and leg power, assessments of somatotype and smoking habits, and evaluation of sociological and psychological factors. Using a multivariate analysis, two risk factors were identified: recruits with stress fractures had significantly narrower tibiae ($P < 0.001$), and a higher degree of external rotation of the hip ($P = 0.016$). These two variables were independent and cumulative. Stress fracture morbidity was 17%, 29%, and 45% when neither, one, or both risk factors were present, respectively ($P < 0.001$). Identification of these risk factors might explain the susceptibility of some people to stress fractures.

Millions of people worldwide participate in regular recreational running or other exercise programs.[23] For many of these participants the motivating factor is the popular notion that exercise can help keep one young and healthy. Indeed, exercise training has been demonstrated to be inversely related to many of the risk factors of coronary heart disease: body weight, percent body fat, serum cholesterol, triglycerides and glucose, and systolic blood pressure.[7] Morris et al.[21] stated that "vigorous exercise is a natural defense of the body with a protective effect on the aging heart against ischemia and its consequences."

As a result of this mass participation in sports, large numbers of overuse injuries are occurring.[17] Determining the causes and incidence of these injuries in recreational sports participants is difficult since they are an individualistic population and as such do not fall under any form of central control. Most studies therefore have investigated overuse injuries in military basic training, which provides a situation in which a large number of healthy subjects of the same age perform similar training under the same conditions and close monitoring.[10, 15, 28, 30]

One type of overuse injury, stress fractures, has been found to reach extremely high proportions among certain military trainees: up to 64% among a group of Finnish soldiers.[27] In contrast, the incidence rate among British paratroop recruits was only 5%,[14] and rates of less than 2% were reported in the United States Army.[28] Because of a high incidence among Israeli recruits,[19] we decided to investigate why some people doing the same training develop stress fractures while others do not. We prospectively evaluated, prior to basic training, the variables that might bear relationship to stress fractures to identify possible risk factors for this injury.

MATERIALS AND METHODS

Patient population

A group of 312 male military recruits were evaluated during 14 weeks of basic training. Seventeen recruits dropped out at an early stage of training; follow-up data was incomplete for another 6 recruits. The study population therefore consisted of 289 soldiers. All participants in the study gave their informed consent.

Study design

Each of the recruits underwent an evaluation before basic training as described below. The recruits were followed

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during the course of their training by three army doctors in the field. The recruits had free access to the medical staff, as well as mandatory stress fracture physical examinations every 3 weeks during training. Soldiers with symptoms suggesting stress fractures were given 3 days of rest and, if symptoms persisted, were seen by an orthopaedist. The stress fracture physical examination of all recruits was repeated by the same orthopaedist again at the end of their training.

Diagnosis of Stress Fractures

Recruits suspected of having a stress fracture on the basis of the orthopaedic stress fracture examination underwent the following evaluation. Appropriate radiographs were taken. A bone scan was done, usually on the date of the orthopaedic examination, but no later than 5 days after the examination. A standard intravenous dose of 20 mCi of Technetium-99 MDP was given. An Elscint Dynmax gamma camera (Elscint, Haifa, Israel), plus whole body imaging table, was used. Anterior and posterior whole body scans were performed 120 minutes after injection with information density of 4000 counts per centimeters. Additional delayed spot views of the pelvis, femurs, knees, tibiae, and feet were done. All scans were read separately by two examiners without knowledge of the recruits' sites of pain, using a 1 to 4 grading system.[6] Scintigraphy was considered to be diagnostic of stress fracture when a focal area of increased uptake (Grade 3 or 4) was found. Irregular areas of increased uptake (Grade 1 or 2) were not considered to be stress fractures.

The diagnosis of stress fractures was made on the basis of either positive radiographs or a positive scintigram; scintigraphic evidence was accepted even if radiographs showed no stress fracture. Details of the clinical radiographic and scintigraphic findings have been published elsewhere.[19] In brief, 181 recruits had scintigrams because of suspicion of stress fracture. Of them, 91 recruits (50%) were found to have 184 stress fractures; 52% of the fractures were in the tibial diaphysis, 30% in the femoral diaphysis, 9% in the metatarsals, and the rest distributed in the tibial plateau, medial femoral condyle, and ilium.

Pretraining evaluation

All measurements were performed on both legs. The mean value between the right and left legs was used for subsequent calculations. The protocol of the pretraining evaluation included the following:

Orthopaedic stress fracture examination. Recruits were questioned as to the presence of exertionally related bone pain or other musculoskeletal pain consistent with stress fracture. Each bone of the lower extremity was individually palpated for signs of tenderness. Recruits' places of pain were recorded and measured from anatomical landmarks.

Orthopaedic examination. The following measurements were made according to standard orthopaedic texts[1, 26]: range of internal and external rotation of the hip with the hip flexed to 90° (Fig. 1), tibial torsion, plantar flexion and dorsiflexion of the ankle with the knee in extension, dorsiflexion of the ankle with the knee in 45° of flexion, and hindfoot inversion and eversion from the neutral subtalar position.

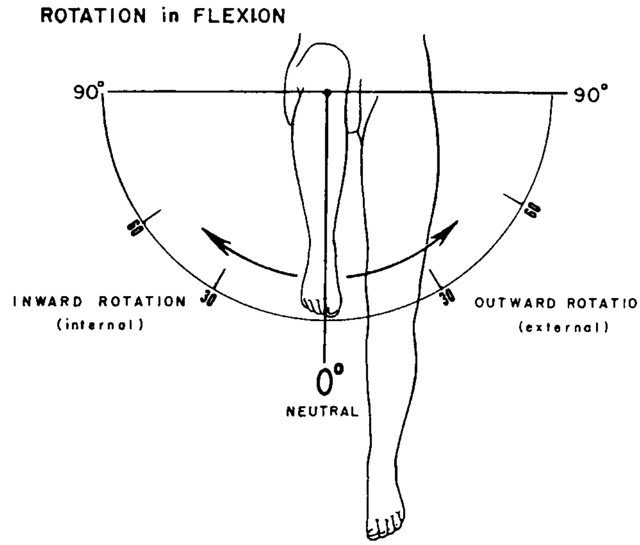

Figure 1. The measurement in flexion of hip rotation. The patient lies supine on a large protractor with the hip to be measured positioned over the center of the protractor. The hip and knee are both flexed 90°, with the thigh perpendicular to the transverse line across the anterior superior spines of the pelvis. External rotation is measured by rotating the leg toward the midline of the trunk with the thigh as the axis of rotation, thus producing external rotation of the hip. The angle that the tibia subtends on the protractor is the amount of external rotation. Internal rotation is measured similarly to external rotation, except that the leg is rotated away from the midline of the trunk.

Height and weight. Measurements were made with the subjects in underwear and without shoes. Obesity was estimated with the use of the body mass index (weight in kilograms divided by the square of the height in meters).

Foot and tibial radiographs. Standard radiographs were taken with a tube/film distance of 90 cm. For the AP view of the tibiae, the feet were positioned in 15° of medial rotation; standard lateral views were used. Standing AP and lateral views of the feet were also taken.

Tibial bone width. Measurements of tibial width were taken in 286 recruits using two dimensions on the radiographs: AP axis and the mediolateral axis at Level 1 (the point of the narrowest tibial width in the frontal view), and at Level 2 (the point of the narrowest tibial width in the lateral view). Measurements were taken twice, by two examiners, the correlation between the two measurements was 0.95.

Bone mineral content. The bone mineral content was measured by single-beam photon absorptiometry. The legs were scanned twice at a level 8 cm above the ankle mortise in the posterior-anterior direction, perpendicular to the long axis of the bone. The exact location was determined by an

AP radiograph, with the aid of a thin metal wire placed on the skin as a reference point.

Bone density. The overall mass density of bone was calculated using Compton bone densitometry. This technique measures the overall mass density of bone (grams per cubic centimeter) for a cancellous window in the center of the bone. Measurements were taken at the same level and direction as for bone mineral content.

Somatotyping. The Heath-Carter anthropometric somatotype method[5] was used to classify 246 recruits by body type according to components of endomorphic (a measure of body fatness), mesomorphic (a measure of musculoskeletal development), and ectomorphic (a measure of body slenderness). Classification was based on weight (in kilograms); standing height (in centimeters); skinfold thickness at the triceps, subscapular, anterior suprailiac, and calf (in millimeters); the epicondyle diameter of the femur and humerus (in millimeters); and the calf and flexed biceps girths (in millimeters).

Aerobic physical fitness. The aerobic fitness was assessed in 270 recruits by calculating the VO_2 max indirectly, using the Astrand nomogram of heart rate.[2]

Leg power. Leg power was assessed in 270 recruits by calculating the number of leg thrusts that could be performed in a 30 second interval.[8]

Smoking habits. There were three categories of cigarette smoking: nonsmokers (82.4%), less than 10 cigarettes a day (9.3%), and more than 10 cigarettes a day (8.3%). (Only two recruits smoked more than a pack daily.)

Quality index. This is a well-established index used in the Israeli Defence Forces and known to have a good predictive value as to future success of recruits in their army service. It is composed of three assessments: education, personality, and psychometric evaluation. (The quality index ranged from 41 to 56 points.)

Data analysis

Data was analyzed according to three separate groups: stress fractures (all anatomical sites), femoral stress fractures, and tibial stress fractures.

Univariate analysis. Means of continuous variables were compared using the two-tailed t-test (Table 1).

Multivariate analysis. Multiple logistic regression analysis was performed using the Statistical Analysis System (SAS Institute Inc, Cary, NC) (Table 2).

The variables that were found to be significant in the multiple regression analysis were tested as to their influence on stress fractures. Each variable was divided into two parts at the midpoint of the range. This created two subgroups for each variable of 30% and 70% of the total population. The trend of stress fracture morbidity was assessed by assigning a quantitative value to each subgroup (0 = no risk, 1 = risk), as shown in Table 3. Mantel Henszel chi-square statistics was used to test the existence of linear trends among risk levels (Table 4).

RESULTS

Univariate analysis

Table 1 shows the variables examined among recruits with and without stress fractures. Two variables were found to have a significant difference between the stress fracture and nonstress fracture groups. The first was the degree of external rotation of the hip joint. Recruits with stress fractures (all anatomical sites) and tibial stress fractures had a significantly greater hip external rotation than their counterparts without stress fractures. The second variable was the tibial width in the mediolateral axis. Recruits with stress fractures in all three groups had significantly narrower tibiae than their counterparts without stress fractures.

Multivariate analysis

Using multiple logistic regression, tibial bone width in the mediolateral axis at Level 2 and external rotation of the hip joint remained as the only significant variables for the group with tibial stress fractures and the one with stress fractures at all sites. As for femoral stress fractures, only tibial bone width was found to be a significant variable (Table 2).

Table 4 shows the proportion of recruits with and without stress fractures (at all sites and in the tibia) according to risk score. The proportion of recruits with stress fractures was lowest when neither of the risk factors were present (risk score = 0), intermediate when one risk factor was present (risk score = 1) and highest when two risk factors were present (risk score = 2).

DISCUSSION

Several works have proposed intrinsic risk factors for stress fractures.[13,24,28] Physical fitness, motivation, and body habitus have been mentioned. These, however, have not been investigated in controlled, prospective studies, rendering this issue controversial. We have previously identified possible risk factors for stress fractures.[11,12] These were identified in separate works, but a comprehensive, multifactorial analysis of all the possible risk factors for stress fractures has never been done.

In this study we prospectively evaluated multiple variables that might be related to risk for stress fracture. These included factors that have been previously proposed, plus others that we considered might have a role. Of the many variables studied, only two were found to have a statistically significant relationship to the incidence of stress fractures: tibial bone width and external rotation of the hip joint.

The finding that recruits with wider tibiae sustained less tibial, femoral, and total stress fractures than those with narrow tibiae conforms to biomechanical concepts.[9] For any structural material, the development of fatigue or stress fractures is an imbalance between the strength of the material and the loading demands. In the case of stress fractures, it is not a single overload that causes fracture, but a large number of repetitive loads. The stresses that develop

TABLE 1
Relevant variables among soldiers with and without stress fractures[a]

Variable	Stress fractures (at all sites)		Femoral stress fractures		Tibial stress fractures	
	With (N = 89)	Without (N = 200)	With (N = 39)	Without (N = 250)	With (N = 60)	Without (N = 229)
Age (years)	19.0 ± 0.5	19.1 ± 0.7	19.1 ± 0.6	19.0 ± 0.7	19.0 ± 0.4	19.1 ± 0.7
Body mass index (kg/m^2)	22.3 ± 1.9	22.4 ± 2.1	22.1 ± 1.9	22.5 ± 2.0	22.4 ± 2.1	22.4 ± 2.0
Heath-Carter somatotype[i]	(N = 76)	(N = 170)	(N = 36)	(N = 210)	(N = 50)	(N = 196)
Endomorphic	2.9 ± 1.1	2.8 ± 0.9	2.8 ± 1.0	2.8 ± 1.0	2.8 ± 1.1	2.8 ± 1.0
Mesomorphic	4.7 ± 1.0	4.9 ± 1.0	4.6 ± 1.0	4.8 ± 1.0	4.7 ± 1.0	4.8 ± 1.0
Ectomorphic	2.8 ± 1.0	2.8 ± 1.1	2.8 ± 0.9	2.8 ± 1.1	2.8 ± 1.1	2.8 ± 1.0
Measurements of joints motion (deg)						
External rotation of the hip joint; hip flexed 90°	58.5 ± 8.7[b]	55.9 ± 8.7[b]	58.4 ± 9.8	56.6 ± 8.9	58.8 ± 8.8[c]	56.2 ± 9.0[c]
Internal rotation of the hip joint; hip flexed 90°	53.4 ± 11.0	52.4 ± 10.4	52.4 ± 11.5	52.7 ± 10.4	54.1 ± 11.2	52.3 ± 10.4
Tibial torsion	16.5 ± 2.1	16.5 ± 1.9	16.9 ± 3.0	16.3 ± 2.5	16.5 ± 3.1	16.4 ± 2.4
Plantar flexion of the ankle; knee in extension	31.9 ± 4.1	32.3 ± 4.0	31.2 ± 3.9	32.6 ± 4.5	32.7 ± 5.2	32.4 ± 4.2
Dorsiflexion of the ankle; knee in extension	7.8 ± 3.3	8.1 ± 3.3	8.0 ± 3.7	8.2 ± 3.6	8.2 ± 3.6	8.2 ± 3.6
Dorsiflexion of the ankle; knee in 45°	18.5 ± 2.7	18.6 ± 3.0	18.6 ± 2.7	18.7 ± 3.4	18.8 ± 3.4	18.7 ± 3.5
Hindfoot eversion; from the neutral subtalar position	6.4 ± 4.0	6.6 ± 3.6	7.1 ± 4.3	6.5 ± 3.7	6.4 ± 3.6	6.6 ± 3.4
Hindfoot inversion; from the neutral subtalar position	18.3 ± 4.8	18.4 ± 5.0	18.1 ± 5.0	18.4 ± 4.9	18.4 ± 4.4	18.4 ± 5.1
Tibial bone width[j] (mm)	(N = 86)	(N = 200)	(N = 58)	(N = 228)	(N = 36)	(N = 250)
Level 1						
Mediolateral axis	23.7 ± 2.1[d]	24.6 ± 1.8[d]	22.8 ± 1.6[d]	24.5 ± 1.9[d]	23.8 ± 2.1[e]	24.4 ± 1.9[e]
Anteroposterior axis	28.2 ± 2.8	28.2 ± 2.5	28.0 ± 2.9	28.2 ± 2.6	28.1 ± 2.7	28.3 ± 2.6
Level 2						
Mediolateral axis	25.6 ± 2.2[f]	26.4 ± 1.9[f]	24.8 ± 1.9[d]	26.3 ± 2.0[d]	25.6 ± 2.1[g]	26.3 ± 2.0[g]
Anteroposterior axis	25.4 ± 2.1	25.9 ± 2.0	25.0 ± 2.3[h]	25.9 ± 2.0[h]	25.5 ± 2.1	25.9 ± 2.0
Bone mineral content	(N = 75)	(N = 177)	(N = 34)	(N = 218)	(N = 53)	(N = 199)
(gr/cm^2)	1.056 ± 0.106	1.079 ± 0.118	1.034 ± 0.100	1.077 ± 0.116	1.045 ± 0.103	1.074 ± 0.117
Bone density	(N = 72)	(N = 163)	(N = 30)	(N = 205)	(N = 48)	(N = 187)
(gr/cm^3)	160.1 ± 11.7	161.0 ± 12.4	158.9 ± 10.0	160.9 ± 12.4	159.4 ± 11.7	161.0 ± 12.2
Aerobic physical fitness	(N = 84)	(N = 186)	(N = 36)	(N = 234)	(N = 57)	(N = 213)
(ml O_2/kg·min)	42.8 ± 8.0	43.1 ± 8.0	42.3 ± 8.4	43.1 ± 9.4	42.7 ± 7.6	43.1 ± 8.1
Leg thrust	(N = 84)	(N = 186)	(N = 36)	(N = 234)	(N = 57)	(N = 213)
(number/30 seconds)	34.1 ± 9.3	33.3 ± 9.3	34.4 ± 8.2	33.4 ± 9.5	33.8 ± 9.4	33.5 ± 9.3
Smoking habits (%)						
nonsmokers	**83.3**	**82.0**	94.8	80.4	**81.9**	82.6
<10 cigarettes/day	**6.7**	10.5	2.6	10.4	**6.6**	10.0
>10 cigarettes/day	**10.0**	7.5	2.6	9.2	11.5	7.4
Quality index (points)	53.1 ± 2.3	53.1 ± 2.2	53.6 ± 1.4	53.0 ± 2.4	52.8 ± 2.3	53.2 ± 2.2

[a] Values denote means ± SD. P values: [b] = 0.016; [c] = 0.034; [d] < 0.001; [e] = 0.013; [f] = 0.003; [g] = 0.014; [h] = 0.009.
[i] Only 246 recruits had somatype testing.
[j] Level 1, narrowest point of frontal width; Level 2, narrowest point of lateral width. Only 286 recruits had tibial bone width measurements.

TABLE 2
Summary of the logistic regression analysis (P values presented)

Measurement	Stress fractures (all sites)	Femoral stress fractures	Tibial stress fractures
Tibial bone width[a]	0.003	<0.001	0.036
External rotation of the hip	0.039	0.296	0.048

[a] Tibial bone width at Level 2 at the mediolateral axis.

within a structural material and eventually cause it to fracture depend on the type of load (tensile, compression, bending, torsion, or combinations) and the geometry of the loaded structure. For a tubular structure, such as long bones, compression strength is proportional to the square of the radius, while torsional and bending strengths are proportional to the fourth power of the radius. Thus, on the basis of geometric properties alone, an increase in tibial bone width of only 4 mm, from 24 to 28 mm, increases the bone's compression strength by 36% and bending and torsional strength by 86%. Since bone size throughout the skeleton is proportional, the risk factor of tibial width can be conceptually simplified to mean that narrow bones are biomechanically weaker than wide bones; hence, they are more likely to sustain stress fractures.

No normal values are available comparing tibial bone width between recruits in this study with their English or American counterparts. If our population, however, does have relatively narrower bones, then this may be one factor that can explain why the reported incidence of stress fracture among our population is higher when compared to

TABLE 3
Quantitation of risk factors for stress fractures, using a 0 or 1 grading

	Risk factor	
	External rotation of the hip (deg)	Tibial bone width[a] (mm)
Range	30–90	20–30
Midrange point	60	25
Grouping	<60(70%); >60(30%)	<25(70%); >25(30%)
Risk score[b]	0; 1	1; 0

[a] Tibial bone width at Level 2 at the mediolateral axis (see text for details).
[b] In accordance with the above grouping.

TABLE 4
Proportions of stress fractures according to risk score

Risk score	Stress fractures (at all sites)		Tibial stress fractures	
	Without	With (%)	Without	With (%)
0	50	10 (16.7)	54	6 (10.0)
1	112	45 (28.7)	128	29 (18.5)
2	33	27 (45.0)	40	20 (33.3)
P values	<0.001		0.001	

British[14] or American[28] studies. Anthropomorphic data indicates that women have relatively narrower bones than men.[20] This finding can help explain the observation by Protzman and Griffis[24] that women at West Point, as compared to men, had more than 10 times the incidence of stress fractures when exposed to a similar training regimen.

The second risk factor identified was the degree of external rotation of the hip joint. Recruits with greater passive external rotation of the hip joint had a higher incidence of tibial stress fractures than those with lower extent of rotation. This correlation was limited to tibial stress fractures and was not found for femoral ones. The biomechanical or physiological basis for this risk factor has not yet been identified. It is not, however, related to joint motion in general, since no correlation was found between the range of motion of other leg joints and the incidence of stress fractures.

Excessive external rotation of the hip as a risk factor for tibial stress fractures might also explain the lower incidence of stress fractures in the American army. Boone and Azen[3] have found that the mean range of external rotation of the hip joint among American males was 50.5° ± 6.1°. In the present study the mean was 57.0° ± 9.0°, almost 1 standard deviation higher. This indicates that among our study population a substantially large subpopulation exists with this risk factor.

The two risk factors, decreased tibial bone width and increased external rotation of the hip, were found to be independent and cumulative. When neither risk factor was present, stress fracture incidence was 17%; when both were present, it increased to 45%; and in the presence of one risk factor, incidence was intermediate (Table 4). In view of these findings, screening recruits for tibial bone width and external rotation of the hip joint before they begin demanding training can identify a population at risk for stress fractures. Such recruits can then be monitored closely or given modified or alternative training programs.

This study is also important for its negative results, namely for the many variables that were found not to be related to increased frequency of stress fractures. One of these variables is pretraining level of physical fitness. This variable is an example of a highly modifiable characteristic. Extensive training of recruits prior to basic training can definitely increase their level of fitness. However, our study showed that aerobic physical fitness was not related to the incidence of stress fractures. This is supported by a similar observation by Mustajoki et al.[22]

Motivation has been mentioned as another risk factor for stress fractures. Hallel et al.[16] speculated that recruits with high motivation were more prone to stress fractures. In our study, however, no relationship was found between a pretraining evaluation of motivation (assessed by The Quality Index) and stress fracture incidence. Sociological and demographic parameters such as ethnic origin (Ashkenazi, or Sephardi), city living, or farm living were not related to stress fracture incidence.

Gilbert and Johnson[13] indicated that body type affects stress fracture incidence. They stated that obese recruits with poor muscle tone sustained the most stress fractures, whereas the asthenic and underdeveloped recruits composed the second highest risk category. These findings were based on impression rather than formal investigation. In this study, we did not find a relationship between stress fractures and either body somatotype or any other bodily characteristics such as weight, height, or body mass index.

A possible link between stress fractures and osteoporosis has been previously suggested.[30] The possibility was raised that stress fractures are more likely to occur in those who will suffer from osteoporosis in later life. There might be several explanations for such a link. One is that people with osteoporosis are more prone to stress fractures.[25] The second is caucasian predominance; white recruits have been found to be more susceptible to stress fractures than black recruits.[4] This parallels similar findings in osteoporosis. The third factor is female predominance. In a West Point study,[24] 10% of female recruits sustained stress fractures, as opposed to only 1% of the male recruits doing the same training. Similarly, osteoporosis affects women more than men.[25] The fourth reason might be related to hypoestrogenism. In a group of young ballet dancers the incidence of secondary amenorrhea was twice as high among dancers who sustained stress fractures as compared to dancers without stress fractures.[31] Likewise, osteoporosis is related to hypoestrogenism.[25]

In our study, we found no evidence to support the relationship between stress fractures and osteoporosis. Two common indicators for osteoporosis, bone mineral content and bone density, were measured in the tibiae. Bone mineral content measures just one component of bone, namely the mineral content. Bone density measures the overall mass density of bone, accounting for minerals, water, and fat, as well as collagen. It does not, however, reflect the physical properties of the collagen. No relationship was found between the bone mineral content or bone density measurements and the incidence of stress fractures. Since there are no comparable values in the literature for females or older populations,[29] comparisons between populations cannot be made.

The fact that no relationship was found between bone mineral content or bone density and stress fracture incidence is not surprising from a biomechanical perspective. Bending forces, rather than compression or torsion ones, were found to be the most important in the pathogenesis of the majority of stress fractures.[18] With regard to bending forces, two factors seem to be critical: the geometric distribution of the bone mass (rather than the bone mass itself) and the collagen composition. Neither of these two factors are assessed by measurement of either bone mineral content or bone density. These two measurements, however, are related to stress fractures caused by compressive loading, such as those commonly seen in the vertebral bodies of the elderly with osteoporosis.

CONCLUSIONS

We identified two easily measureable risk factors for stress fractures, narrow tibial bone width and high degree of external rotation of the hip joint. By early evaluation of these factors, training regimens in the high risk group can be modified, possibly lowering the incidence of stress fractures. The existence of the risk factors in different populations might further explain major differences in the occurrence rates in different countries.

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