YOUTH IS A RISK FACTOR FOR STRESS FRACTURE

A STUDY OF 783 INFANTRY RECRUITS

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We report a prospective study of 783 male Israeli recruits aged from 17 to 26 years. The risk of stress fracture was inversely proportional to age on both univariate and multivariate analysis. Each year of increase of age above 17 years reduced the risk of stress fracture by 28%.

J Bone Joint Surg [Br] 1994; 76-B:20–2.
Received 19 October 1992; Accepted after revision 2 June 1993

Study of the epidemiology of stress fractures has yielded some insight into the causes of these injuries (Giladi et al 1991). In engineering structures it is clear that strength derives from mass, density, three-dimensional arrangement and the quality of the component material (Heaney 1992), but the role of these factors in resisting the repetitive high strains which lead to stress fracture in bone is not known. Study is made more difficult by the strong age-dependency of bone architecture (Lindahl and Lindgren 1967; Garn 1970; Wall, Chatterji and Jeffery 1979; Cohn et al 1982).

The basic training of Israeli Army infantry offers an almost laboratory-like environment for the creation and study of stress fractures (Lancet 1986), and previous studies have identified some of the risk factors (Giladi et al 1991). We have hypothesised that bone age may be important, and as part of our ongoing research we have prospectively evaluated the effect of the age of recruits on the incidence of stress fracture among them.

MATERIALS AND METHODS

In a prospective study we followed 796 male élite infantry recruits during 14 weeks of basic training. Of these 13 did not complete training for reasons unrelated to stress fracture, or had incomplete data. The remaining 783 recruits all gave their informed consent to our study.

Before starting training all recruits were interviewed regarding previous sports activity and any history suggestive of stress fracture. They all had an orthopaedic examination designed to reveal stress fractures (Milgrom et al 1993). Records were made of weight, height, tibial length, tibial intercondylar distance, external rotation of the hip, and isometric quadriceps strength at 85° knee flexion. Physical fitness was assessed by the time of a 2 km run, the maximum possible number of chin-ups, and the number of sit-ups in one minute. The date and place of birth of each recruit were recorded, and the country of origin of each parent. For immigrants, the date of arrival in Israel was recorded.

The recruits were followed during training by a team of army doctors and an orthopaedic surgeon, and had free access to the medical staff. Examinations for stress fractures were made every two to three weeks. Suspected cases, with symptoms suggesting stress fracture to the orthopaedic surgeon, had appropriate radiographs and a bone scan within ten days of the orthopaedic examination. This involved an intravenous dose of 20 mCi of ^{99m}Tc-methyldiphosphonate with imaging by an Elscint Dynmax camera (Elscint, Haifa, Israel). Spot views of the pelvis, femora, tibiae and feet were taken 120 minutes after injection and evaluated on a grading system of 1 to 4 (Zwas, Elkanovitch and Frank 1987).

All data were recorded on a specially designed evaluation form and processed through the computer facilities of the Israel Defence Medical Corps. Statistics were calculated using the Statistical Analysis System (SAS, Cary, North Carolina), with standard univariate analysis using unpaired t-tests for comparison of the means of groups with and without stress fractures. For comparison of rates of morbidity we used the chi-squared or the Fisher exact test. To determine the interdependence of the results of univariate analysis we used multiple logistic regression models of the variables that were significant on univariate analysis. The results for these models were summarised by odds ratios for the factors of interest, including 95% confidence intervals.

RESULTS

The mean age of the 783 recruits was 18.6 years (17 to 26). Only 26 were over 19 years of age or older at the start of basic training. A total of 351 recruits presented with symptoms suggestive of stress fractures and all had scinti-

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0301-620X/94/1684 $2.00

Table I. Variables related to incidence of stress fracture (mean ± SD, significance by the *t*-test)

Variable	All sites		Tibia		Femur	
	Fracture (n = 190)	None (n = 593)	Fracture (n = 140)	None (n = 643)	Fracture (n = 60)	None (n = 723)
Age (yr)	18.58 ± 0.44	18.70 ± 0.74	18.59 ± 0.44	18.69 ± 0.72	18.58 ± 0.43	18.68 ± 0.69
	(p = 0.009)		(p = 0.041)		(p = 0.126)	
Height (mm)	175.4 ± 6.9	176.6 ± 6.6	175.4 ± 0.8	176.6 ± 6.6	175.9 ± 7.2	176.4 ± 6.6
	(p = 0.027)		(p = 0.054)		(p = 0.588)	
Tibial length (mm)	38.5 ± 2.2	38.9 ± 2.4	38.4 ± 2.1	38.9 ± 2.4	38.8 ± 2.3	38.7 ± 2.5
	(p = 0.049)		(p = 0.009)		(p = 0.804)	
External hip rotation (degrees)	62.8 ± 12.0	60.9 ± 12.0	63.4 ± 12.0	61.0 ± 12.0	60.7 ± 12.0	60.5 ± 12.0
	(p = 0.059)		(p = 0.026)		(p = 0.626)	

Table II. Summary of multiple logistic regression analysis for stress fractures at all sites

Variable	Odds ratio	95% confidence limits
Intercept	999.000	4.839 to 999.000
Height (mm)	0.976	0.938 to 1.015
External hip rotation (degrees)	1.013	0.999 to 1.028
Tibial length (mm)	0.986	0.881 to 1.103
Age (yr)	0.716	0.531 to 0.965

Table III. Summary of multiple logistic regression analysis for tibial stress fractures

Variable	Odds ratio	95% confidence limits
Intercept	629.533	0.147 to 999.000
Height (mm)	1.000	0.958 to 1.045
External hip rotation (degrees)	1.018	1.002 to 1.034
Tibial length (mm)	0.905	0.802 to 1.022
Age (yr)	0.754	0.541 to 1.050

graphy. This was never performed on asymptomatic recruits. On the basis of these results 190 (24%) were diagnosed as having stress fractures, but none was seen in those over 19 years of age. The most common site was the tibia, followed by the femur and then the metatarsals. None of the scintigraphs or radiographs taken showed evidence of open physeal plates. Table I gives the results for the variables shown to have a statistically significant relationship to incidence by univariate analysis.

The results of multiple logistic regression studies are summarised for all stress fractures in Table II and for tibial stress fractures in Table III. For each year of increase in recruit age from 17 to 26 years the risk for stress fracture at all sites decreased by 28%. For each 1° increase in external rotation of the hip, the risk for tibial stress fracture increased by 2%. The multiple logistic regression models showed no other factors with significant effects on the incidence of femoral, tibial, or all-site stress fractures.

Within our study group 87% of the recruits were Israeli-born and 13% were born overseas, including 18 (2.3%) of Ethiopian origin. Ethiopian recruits had no stress fractures, giving a statistically significant reduction in their incidence compared with Israeli-born recruits (Fisher's exact test; $p = 0.006$). There was no significant difference between Israeli-born and non-Israeli-non-Ethiopian recruits.

DISCUSSION

Our results indicate that age is a strong predicting variable for the likelihood of the development of stress fractures during infantry training. In this context, the biomechanics of long bones can be viewed as a combination of their overall geometry which governs their ability to withstand bending and torsional forces, and the mechanical properties of the bone tissue (Heaney 1992). Both factors may be implicated in the age dependency which we found.

Milgrom et al (1989) showed that stress fractures of the tibial diaphysis are usually due to repetitive bending forces in the mediolateral plane. The bending strength of the tibia in this plane is related to the cross-sectional area moment of inertia, which is proportional to the fourth power of the radius of the tibia. A narrow tibia with a low cross-sectional moment of inertia in the mediolateral plane was shown to be a risk factor; this accords with engineering principles.

Bone density is a measure of the mass density, which is related to material strength (Heaney 1992). It has been shown, however, to be a relatively poor predictor of fractures in the elderly and is only a risk factor (Ott 1992). This may be because bone porosity, rather than density, is directly related to bone fragility (Schaffler and Burr 1988). In Israeli infantry recruits bone density does not correlate with stress fracture risk (Leichter et al 1989), perhaps because the bone density in this population is within the normal range.

Bone quality also contributes to the strength of bone (Grynpas 1992; Heaney 1992) and factors in this include its micro-architecture, matrix, mineralisation and the influence of microfatigue damage. We could find no studies of the relationship between bone quality and stress fracture.

We found an incidence of scintigraphic stress fracture of 24%, corresponding to that in previous Israeli studies, with most in the tibia. All 351 recruits (45%) who had scintigraphy had closed tibial and femoral epiphyses. In this population, both univariate and multivariate analysis showed that age was an important risk factor, with a decrease in incidence of 28% per added year of age. Although the long bones studied were mature, the decreasing risk may be related to the fact that bones of younger recruits had probably not reached full structural maturity. Garn (1970) studied 25 000 radiographs and showed that there is a continued gain in cortical bone width well into the third decade. Margulies et al (1986) showed that a 14-week period of basic infantry training increased bone mineral content by 8%, and Leichter et al (1989) also reported an increase in bone density during infantry training. In horses, Nunamaker (1986) showed that stress fractures of the third metacarpal of North American thoroughbreds were more common in younger animals. In a subsequent study, Nunamaker, Butterweck and Provost (1990) used strain gauges to demonstrate that compressive strains were higher in younger racehorses during running.

It is unknown whether the decrease in risk for stress fracture of 28% per annum for recruits aged 17 to 26 years is due to increased bone density, increased cross-sectional moment of inertia, changes in bone quality or a combination of these factors. We did not measure tibial bone width (Giladi et al 1987) but our measurement of another factor, high external rotation of the hip, confirmed the results of Giladi et al (1991).

Our study indicates that Ethiopian recruits had a lower risk for stress fracture than their Israeli-born counterparts. We know of no recorded case of stress fracture in an Ethiopian recruit in the past four years. These Ethiopians are generally shorter, lighter, able to run 2 km in less time, but have lower upper-body strength than Israeli-born recruits. They also have less external rotation of the hip, which has been shown to be protective for tibial stress fractures. Further study of these racial differences may help to identify and clarify other factors related to stress fracture.

No benefits in any form have been received or will be received from a commercial party related directly or indirectly to the subject of this article.

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