Epidemiologic Reviews
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Vol. 24, No. 2
Printed in U.S.A.
DOI: 10.1093/epirev/mxf011

Prevention of Lower Extremity Stress Fractures in Athletes and Soldiers: A Systematic Review

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Received for publication July 3, 2002; accepted for publication November 27, 2002.

Abbreviations: CI, confidence interval; CSMI, cross-sectional moment of inertia; IDF, Israeli Defense Force; RR, relative risk.

INTRODUCTION

Stress fractures represent one of the most common and potentially serious overuse injuries (1–5). The first cited reports on stress fracture were case studies of soldiers incurring such fractures in the 19th and early 20th centuries (2, 4, 6–9). By the mid-1900s, the condition was being reported in nonmilitary populations with increasing frequency (10–15). Although almost any athlete or exerciser who engages in frequent, repetitive activity may develop a stress fracture (3, 16), repetitive weight-bearing activities such as running and marching are the most frequently reported causes of stress fracture (2, 3, 6, 16, 17). Stress fractures have been reported in most bones of the extremities, as well as the ribs and the spine (3), but the most common location is the lower extremities (2, 3, 16). Among runners, the tibia is the bone most commonly injured (1, 3, 18–20). Early military reports of stress fractures among recruits described march fractures of the foot (7, 21–24). However, during World War II, increasing numbers of military studies described march fractures in other bones of the lower extremities, primarily the tibia (25, 26) and femur (26–28). Recent military papers have shown increasing numbers occurring in the tibia (29–31).

Stress fractures occur among persons with normal bones and no acute injury who are undergoing physical activity to which they are unaccustomed (6, 14, 32). The underlying pathophysiology is believed to relate to repetitive mechanical loading of bone secondary to physical activity that stimulates an incomplete remodeling response (9, 33, 34). According to this view, stress fractures occur when the early stage of remodeling, osteoclastic resorption of bone, outstrips the osteoblastic formation of new bone, resulting in a weakened bone that is vulnerable to injury. Bone remodeling can be stimulated in anyone being exposed to a level of physical stress or activity to which he or she is not adapted. Furthermore, stress fractures can occur, even among fit athletes, if remodeling occurs in an unbalanced fashion, with the resorptive process exceeding new bone formation to an extent that weakens the bone. Stress fractures can lead to frank fractures, which may heal slowly or incompletely (1, 2, 5, 35–37).

People with stress fractures typically appear for treatment complaining of localized pain that gradually worsens, most commonly in the lower extremity (5, 6, 9, 14, 35). Patients give a history of pain that is aggravated by physical activity and relieved by rest (14, 32, 35, 36). They usually recount a history of a recent increase in physical activity or the beginning of a new activity or some other change in their routine. Palpation elicits localized tenderness over bone. Additionally, swelling and erythema may be observed. If positive, radiographs are diagnostic. However, radiologic signs depend on the time from onset of symptoms and the type of bone affected. Radiographic findings may include early lucent zones, periosteal new bone formation, focal sclerosis, endosteal callous, or later fractures or cortical cracks (35, 36). At the onset of symptoms, radiographs may be negative, and radiologic signs, if they become evident, may take several weeks to evolve (35, 36, 38, 39). While they are very specific, radiographs are not sensitive. Bone scans, on the other hand, are very sensitive but not very specific (3, 40, 41), and they should not be used alone to make the diagnosis

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of a stress fracture (40). The patient's history and the physical examination provide the foundation for making a diagnosis of stress fracture.

Strategies designed to prevent stress fracture are not well understood. Proposed strategies include gradual progressive initiation of vigorous physical training (5, 6), recovery periods with no running or marching after 2–3 weeks of training (9, 42, 43), use of proper running shoes (9), use of shock-absorbent insoles, use of orthotic shoe inserts, adherence to an appropriate diet, and treatment of abnormal menses (5). While a number of prevention strategies have been recommended, few have been evaluated adequately. The purposes of this review were: 1) to review the reported research on the causes of and risk factors for stress fracture; 2) to determine what is known about the prevention of stress fracture; and 3) to make recommendations for a systematic approach to future research and prevention.

REVIEW PROCESS

We identified relevant citations from the reference sections of 19 textbooks on sports medicine, family practice and other primary care specialties, orthopedics, and general surgery. Using Ovid, version 2, we searched the following electronic databases: MEDLINE (1966–July 2001), Current Contents (1996–July 2001), Biomedical Collection (1993–1999), and Dissertation Abstracts (in all languages) using Internet Grateful Med and the following subject terms: "stress fractures," "shin splints," and "sports injury." We then limited the search using the terms "etiology," "epidemiology," and "injury prevention and control." We identified further citations from the reference sections of papers retrieved, contacting experts in the field (including the first authors of papers on randomized controlled trials or cohort studies addressing stress fracture prevention) and the Centre for Sports Science and History (Birmingham, United Kingdom), a part of the Cochrane Collaboration, an international network of experts who manually search the medical literature. We excluded papers from the qualitative evaluation that did not provide primary research data relevant to stress fractures, that addressed treatment and rehabilitation rather than prevention, or that provided previously published data. All candidate articles were screened independently by two of the authors (B. H. J. and S. B. T.).

To evaluate identified intervention trials, we modified a scoring instrument previously used to evaluate the methodological quality of cohort studies and randomized controlled trials (table 1) (44). The scoring instrument was applied only to research papers that described tests or evaluations of interventions intended to prevent stress fracture. Reviewers/scorers were blinded to the primary authors' names and affiliations but not to the study results. Weights for scored items (statement of purpose, randomization, etc.) were established in a manner consistent with guidance for quality scoring (45). Confounding factors that needed to be addressed were determined through consultation with training injury researchers. Each citation was then evaluated independently by three reviewers. After independent evaluation, the reviewers met to reconcile substantive differences in interpretation.

Two of the authors (S. B. T. and B. H. J.) independently extracted data from the analytical studies and randomized controlled trials to determine whether pooling of results was appropriate. Because of differences in the interventions used, we elected not to pool any of the individual study-effect estimates. Since none of the studies showed a consistently significant effect size, estimates of publication bias were not calculated.

This systematic review identified 423 scientific publications, including 176 relevant to the epidemiology and prevention of stress fracture. Of these, 20 were diagnostic case series (10 military, 10 civilian), 66 were clinical case series (27 military, 39 civilian), 52 were epidemiologic studies (42 military, 10 civilian), nine were intervention trials (all military), and 25 were review articles (seven military, 18 civilian) (table 2).

CASE SERIES

Diagnostic case series

A number of studies have examined and compared the results of different diagnostic approaches to stress fracture (38, 39, 41, 46–61) (table 2). In diagnostic case series examining clinically suspected cases of stress fracture, bone scans were positive in 50–91 percent (39, 41, 46–51). In these diagnostic series, radiographs were positive in only 14–53 percent of suspected cases (39, 41, 46–51), while 7–50 percent had neither positive bone scans nor radiographs. Investigators ruled out stress fracture when both diagnostic tests were negative. In large diagnostic case series of 100 or more cases in which only bone-scan-positive stress fractures were evaluated, initial radiographs were found to be positive in only 18–28 percent of cases (38, 51). One investigator reported three cases of clinically suspected stress fracture that were initially negative upon bone scan but became positive 29–32 days later (52). The larger diagnostic case series that examined clinically suspected stress fractures indicated that bone scans were positive in 70–90 percent of persons with clinical signs and symptoms of stress fracture (46, 51, 59). Other diagnostic tests evaluated included thermography and ultrasonography (53).

One investigator found bone scan sensitivity to be 100 percent but specificity to be only 76 percent, while radiograph sensitivity was only 29 percent, with 100 percent specificity (48). A study of asymptomatic Army trainees found that 98.4 percent of "normal" basic trainees with no signs or symptoms of stress fracture had positive bone scans during the seventh week of basic training (41, 54). Positive bone scans at asymptomatic sites also occur frequently among athletes, which may represent active but normal remodeling of bone (55).

A study of 250 Marine recruits with lower extremity pain found that 54 percent of 839 clinically symptomatic scintigraphic abnormalities became radiographically positive 2–6 weeks after positive bone scans (38). Among 21 symptomatic patients diagnosed by bone scan, 86 percent developed positive radiographs in 1–3 weeks (50). In a series of 35 symptomatic patients, 14 (40 percent) developed positive radiographs 2–17 weeks following the onset of symptoms,

TABLE 1. Layout of quality review score sheet used to assess published articles on stress fracture prevention

Study name: ____________________	Maximum no. of points available	Score	Comments
Experimental design categories rated			
Statement of research question (prior hypothesis)	4		
Source of sample	5		
Inclusion/exclusion criteria	6		
Randomization	10		
Examiner/analyst blinding	4		
Selection bias addressed	2		
Information bias addressed	2		
Description of intervention	7		
Comparison of participants to eligible decliners	3		
Comparison of participants to dropouts	3		
Independent validation of data	1		
Power calculations (sample size requirements)	3		
Clear method to evaluate outcome variable defined	3		
Appropriateness of method	3		
Addressed possible confounders			
Age	2		
Gender	2		
Race	2		
Prior physical activity/sports participation	2		
Prior lower extremity injury	2		
Current type and amount of training	2		
Appropriateness of method of adjustment	4		
Data presentation and statistical analysis			
Description of tests	6		
Use of relative risk or odds ratio	2		
Use of confidence intervals or *p* values	3		
Multivariate techniques	4		
Regression coefficients (if multivariate techniques used)	3		
Presentation of data: demographic data	2		
Confounders	2		
Comparability groups	2		
Collinearity	2		
Addressed issues of multiple testing	2		
TOTAL	(possible 100)		

with a median time of 7 weeks (39). Radiographs of 26 sites in 21 patients became positive 3–60 days (median, 19 days) after the onset of stress fracture symptoms and 4–28 days (median, 8 days) following a positive bone scan with an initially negative radiograph (48). Other researchers reported that with bone scans of grade level III or higher, 76 percent of radiographs were positive (38, 51). Other investigators found asymptomatic positive bone scans for 10–46 percent of sites (30, 51, 55).

The different sensitivity and specificity of bone scans and radiographs in detecting stress fractures are relevant not only to clinicians but also to researchers. Bone scans are more sensitive but are also likely to yield more false-positive results, while radiographs are highly specific but may miss some cases. In addition, the delayed confirmation of stress fracture diagnoses by radiographs must be factored into both clinical and research protocols.

Clinical case series

The most common type of stress fracture study reported is the clinical case series (7, 10–13, 15–31, 37, 62–101) (table

TABLE 2. Distribution of published studies of stress fracture by type of study, population studied (military vs. civilian), and date of publication

Year of publication	Case series		Diagnostic series		Analytical epidemiologic studies		Intervention studies		Reviews	Total*
	Military	Civilian	Military	Civilian	Military	Civilian	Military	Civilian		
Before 1940	1	5	0	0	0	0	0	0	1	7
1940–1949	16	3	0	0	0	0	0	0	0	19
1950–1959	1	3	0	0	0	0	0	0	0	4
1960–1969	3	2	0	0	0	0	0	0	5	10
1970–1979	2	10	4	2	2	0	1	0	5	26
1980–1989	4	14	5	7	18	4	5	0	7	64
1990–2000	0	2	1	1	22	6	3	0	7	42
Total	27	39	10	10	42	10	9	0	25	172*
Reference nos. (see reference list)	7, 21–31, 62–67, 70–79	1, 3, 10–13, 15–20, 37, 68–71, 81–101, 185	38, 41, 46–48, 50–52, 54, 60, 61	39, 40, 49, 53, 55–59	103–105, 107–121, 128–139, 142–149, 156, 157, 177, 181	122–127, 140, 141, 183, 184	43, 102, 106, 158–163		2, 4–6, 8, 9, 14, 32–36, 164–176	

* Does not include one letter (civilian) and three abstracts (two military and one civilian).

2). The first military studies reported clinical cases of stress fracture affecting predominantly the metatarsals and the calcaneus (7, 21–24, 62–64). During and following World War II, military studies identified stress fractures in other bones in the lower extremities, particularly the tibia and femur (26, 27, 31, 63, 65–67). The increased incidence of stress fracture of the tibia and femur observed among military recruits in the 1970s has been attributed to a greater emphasis on running during training (30).

The civilian sports medicine literature reports stress fractures occurring during a wide variety of sport or exercise activities, such as running, fitness classes, basketball, baseball, volleyball, soccer, dancing, orienteering, and other activities (3, 16, 20, 68). Running, however, appears to be the most commonly reported sport or exercise activity associated with the occurrence of stress fracture (1, 3, 13, 20). Stress fractures account for 4–16 percent of running injuries (18, 19, 69). The tibia, the most common site, accounts for 41–55 percent of stress fractures in most large case series (1, 3, 18, 20, 68, 70, 71).

The case series studies reviewed provide information of more than historical interest. They provide insights into the development and diagnosis of stress fractures that investigators may need to consider when conducting future research or designing prevention programs. In addition, the changing patterns of bones affected and activities associated with the occurrence of these fractures provide useful clues about the nature and causes of stress fracture.

EPIDEMIOLOGY AND RISK FACTORS

Stress fractures occur frequently among persons routinely engaged in vigorous weight-bearing activities such as running or marching. A number of military studies have reported the incidence of stress fracture among recruits, cadets, trained soldiers, and Marines (102–121). For the 8-week duration of US Army basic combat training, the reported incidence of stress fracture for male trainees has ranged between 0.9 percent and 5.2 percent (102, 104, 105, 107–111), while for female trainees the incidence has ranged from 3.4 percent to 21.0 percent (102, 104, 105, 107, 109–111). Stress fracture incidence among Marine recruits over the 12 weeks of basic training has been reported to be 0.8–4.0 percent for males (106, 109, 112–114) and 3.0–5.7 percent for females (109, 115, 116). Reynolds et al. (117) reported the incidence of stress fracture among male infantry soldiers to be 6.9 percent over the course of 1 year. Fewer studies have reported the incidence of stress fracture among civilian athletes and exercise participants. The annual incidence of stress fracture among male and female collegiate track athletes was reported to be 21 percent in one study (122). In another study, 1.9 percent of college athletes from a wide range of sports experienced stress fractures annually (123). A survey of recreational runners reported stress fracture prevalences of 8 percent and 13 percent among male and female respondents, respectively (124).

To prevent stress fractures, modifiable causes and risk factors must be identified. Risk factors for exercise and sports-related injuries, including stress fractures, are commonly categorized as intrinsic or extrinsic (table 3). Intrinsic factors are characteristics of the individual exercise or sports participant, including demographic characteristics, anatomic factors, bone characteristics, physical fitness, and health risk behaviors. Extrinsic risk factors are factors in the environment or external to the individual participant that influence the likelihood of being injured, such as equipment used or type of sport. Table 3 lists common intrinsic and extrinsic risk factors for which stress fracture research was identified. The table provides citations for each risk factor.

TABLE 3. Potential intrinsic and extrinsic risk factors for stress fracture

Type of risk factor	Reference nos. (see reference list)
Intrinsic factors	
Demographic characteristics	
Female sex (amenorrhea, menstrual irregularity, etc.)	102–105, 107, 110, 111, 120–128
Increased age	104, 106, 114
Race other than White	104, 106, 114, 126, 128
Anatomic factors	
High foot arches	129–131
Knock-knees	132, 133
High quadriceps angles	132
Leg length discrepancies	124, 132
Bone characteristics	
Geometry	113, 115, 134–136, 139
Low density	138–141
Physical fitness	
Lower aerobic fitness	105, 107, 114
Lower muscle strength and muscle endurance	115, 130, 141
Lower flexibility	130, 131, 138, 144
Body composition and stature	113, 128, 133, 138
Health risk behaviors	
Sedentary lifestyle	106, 114, 131, 142, 145
Tobacco use	128, 146
No estrogen use	125–127
History of injury	114, 147, 148
Extrinsic factors	
Type of activity/sport	116, 123, 149
Physical training	
High amount total	109, 112, 156, 162
High duration, frequency, intensity	114, 150
Equipment	
Shoes	106, 133
Boots	102, 158
Insoles, orthotic inserts	106, 159, 161
Environment (roads, trails, tracks, etc.)	124, 157

STUDIES OF INTRINSIC RISK FACTORS

The reviewed studies of potentially modifiable intrinsic risk factors, such as physical fitness, sedentary lifestyle, or oral contraceptive use, should generate interest because of their obvious potential application to prevention of stress fractures. However, possible risk factors that cannot be modified, such as sex, age, or race, should not be overlooked, since not only may they influence degree of risk for persons engaged in exercise, sports, or military training but they may also need to be considered in study design and analysis.

Demographic factors

Sex. Among demographic factors, female sex was the most commonly identified intrinsic risk factor for stress fracture. Some of the studies identifying gender as a risk factor have already been enumerated above. A number of military studies of Army basic training show that women performing the same prescribed physical activities as men incur stress fractures at incidences 2–10 times higher than those for men (102–105, 107, 110, 111, 120, 121). Two civilian studies reported higher incidences of stress fracture among female distance runners (124) and women engaged in collegiate sports (123); however, another study (122) found no difference between female and male track athletes. Generally, civilian studies can be misleading, since they examine women and men who are not training together on the same team, and they do not control for the different amounts or intensities of running or other sport and exercise activities.

Studies of female runners with amenorrhea and irregular menses have shown greater risks of stress fracture. A retrospective review of medical records for 207 female collegiate athletes found that women with a history of menstrual irregularity experienced an incidence of stress fracture 3.3 times higher than that of women with regular menses (95 percent confidence interval (CI): 1.2, 9.3) (125). A survey of 241 female collegiate distance runners reported that prevalences of stress fracture among female distance runners with very irregular and irregular menses were 1.7 and 1.3 times higher, respectively, than the prevalence among women with regular menstruation (126). A low response rate and scant descriptions of the methods and survey questions used limit our ability to generalize from those results (126). A study of female college athletes found that seven of 25 women with cases of stress fracture had a history of menstrual irregularity, while none of the 25 uninjured controls had such a history (127). A survey of 1,630 women in the US Army showed that those with a history of amenorrhea lasting more than 6 months were more likely to have experienced one or more stress fractures in their lifetime (prevalence ratio = 1.7, 95 percent CI: 1.2, 2.1) (128). While all of the civilian and military studies examining the association of amenorrhea and irregular menses with risk of stress fracture had some weaknesses in design and analyses, in the aggregate they strongly suggest that such an association exists.

Age. Several military studies have examined the association of older age with risk of stress fracture. A study of 15,994 male and 4,428 female Army trainees found that rates of stress fracture during 8 weeks of Army basic training were significantly higher for successively older age groups (104). Among more than 3,000 male Marine recruits, during 12 weeks of basic training the cumulative incidence of stress fracture was found to be 1.7 times higher among men over the age of 21 years (95 percent CI: 0.92, 3.21) (106). A separate study of 1,296 male Marine recruits demonstrated a relative hazard of 1.07 per year of greater age (95 percent CI: 0.92, 1.24), after data were controlled for potentially confounding factors such as race, physical fitness, and physical activity level (114). The military studies reviewed indicated that older age may heighten the risk of stress fracture, starting at an early age, and that age should be adjusted for when other risk factors are being assessed.

Race. Four military studies examined race as a potential risk factor for stress fracture. An Army study documented that during 8 weeks of basic training, the cumulative incidence of stress fracture was higher for White male Army trainees (1.1 percent) than for Black (0.6 percent) or other non-White (0.1 percent) trainees (104). In this study, White female trainees had the highest rates of any group—11.8 percent, as compared with 1.4 percent for Black women and 4.3 percent for other non-White women—during basic training. A study of more than 3,000 male Marine recruits followed during 11 weeks of basic training showed that White recruits experienced 2.5 times as many stress fractures as non-White recruits (95 percent CI: 1.1, 5.7) (106). A multivariate analysis of data from 1,296 male Marine recruits that controlled for age, physical fitness, physical activity level, and other factors found no significant differences between White and non-White racial groups (relative risk (RR) = 1.04, 95 percent CI: 0.58, 1.88) (114). A survey of 1,630 women in the Army found the lifetime prevalence of self-reported stress fractures among White or Asian women to be 1.6 times higher (RR = 1.6, 95 percent CI: 1.2, 2.1) than that for Black women (128). These military studies suggest that White recruits and soldiers may incur more stress fractures than their non-White peers.

A survey of female collegiate distance runners documented that White runners had a higher career prevalence of stress fractures diagnosed by radiograph or bone scan—a prevalence that was 2.4 times higher than that of Black runners (95 percent CI: 0.7, 8.4) and 1.9 times higher than that of other non-White runners (95 percent CI: 1.0, 3.5) (126). Although the study had a low response rate, the results suggest that White race may be a risk factor among collegiate athletes as well as among military personnel. White race as a potential risk factor for stress fracture deserves further study, using techniques that account for potentially confounding factors such as age, physical fitness, physical activity, and bone characteristics.

Anatomic factors

A number of the papers reviewed examined anatomic factors that potentially could influence the risk of stress fracture. Three military studies evaluated foot morphology (arch height) and stress fracture risk. Among 287 Israeli Defense Force (IDF) trainees, persons with the highest foot arches sustained 3.9 times as many stress fractures as those with the lowest arches (pes planus or flat feet) (95 percent CI: 1.02, 15.38) (129). A 25-week prospective study of 449 trainees at the US Naval Special Warfare Training Center classified trainees into three equal-sized groups with high, normal, or low arch height but found no significant differences between groups (130). The results of the third study of naval special warfare trainees were inconclusive (131). Available research suggests that foot arch height may influence the risk of incurring stress fractures associated with vigorous physical training, but more research will be needed to define the nature of the association between arch type and stress fracture risk, particularly for women.

A prospective study of 294 male infantry recruits demonstrated a significant trend in stress fracture risk, increasing from persons with varus knees (bowed legs) to persons with the most valgus knees ("knock-knees") (132). A second measure of knee alignment, quadriceps angle, showed that persons with quadriceps angles greater than 15 degrees experienced a cumulative incidence of stress fracture 4.3 times higher than that of persons with quadriceps angles of 10 degrees or less (95 percent CI: 1.4, 13.4) (132). A multivariate logistic regression analysis of IDF data on 392 trainees showed that greater valgus alignment of the knee was a significant risk factor for tibial stress fractures (133). Additional research on knee morphology and leg alignment including women is needed.

Two papers studied the association between differences in right and left leg length and risk of stress fracture. A survey of distance runners found that the self-reported prevalence of stress fractures was 2.4 times higher among men reporting leg length differences than among men without them (95 percent CI: 1.6, 3.6); among women with leg length differences, the prevalence was 2.3 times higher (95 percent CI: 1.4, 4.1) (124). In a study of 294 Army trainees, no difference in stress fracture incidence was found between persons with measured leg length discrepancies and persons without them (132). More research is needed to determine the effect of leg length discrepancies on stress fracture risk.

Bone characteristics

A number of military and civilian studies have examined the relation between bone characteristics (geometry or density) and the occurrence of stress fractures. Several geometric measurements of lower limb bones (femur, tibia, fibula) provide indices of different parameters of bone strength and potential resistance to injury. These measures include: the cross-sectional area of long bones, an indicator of the axial strength and resistance to compressive and shear forces; the cross-sectional moment of inertia (CSMI), a measure of bones' resistance to bending along either the anterior-posterior axis or the mediolateral axis of the bone; the section modulus; and other, more common measures of bone strength, bone mineral density, and bone width.

In a prospective study of 626 male Marine recruits conducted during 12 weeks of basic training, 23 (3.7 percent) developed radiographically confirmed or bone-scan-confirmed stress fractures (113). Investigators found that mean values for the cross-sectional area, the section modulus, and the width of the tibia were significantly lower among trainees who developed stress fractures. Unfortunately, the authors analyzed comparisons of mean values and did not examine the incidence of stress fracture among groups of recruits exhibiting different levels of the potential bone risk factors measured. Thus, these findings are suggestive but inconclusive with regard to stress fracture risk.

A prospective study performed in 295 IDF trainees reported that 91 (31 percent) developed 184 stress fractures confirmed by bone scan (134). A multivariate analysis identified the anterior-to-posterior axis of the CSMI to be the variable most highly associated with stress fracture occurrence. In a follow-up analysis of these data, cumulative incidences of tibial, femoral, and total stress fractures were found to be significantly higher in the low-CSMI group, with risk ratios 1.8–3.6 times higher than those in the high-CSMI group (135). The fact that Army trainees with high tibial CSMIs around the anterior-posterior axis experienced a lower incidence of stress fracture suggests that bending in the mediolateral direction is a cause of stress fracture (134, 135). This may also explain why the most common location of tibial stress fractures is the medial cortex.

A number of military and civilian studies have examined the relation between stress fractures and both bone mineral density and bone width. A prospective study of 693 female Marine recruits found that mean bone mineral density and cortical bone thickness of the tibia were significantly lower among the 37 women (5.3 percent) who incurred stress fractures than among those who did not (115). Among 626 male Marine recruits, those with stress fractures had significantly lower mean bone mineral densities and narrower tibial widths. Another study reported that bone mineral density was significantly lower among 41 stress fracture patients than among 48 recruits from the same units matched for age, height, and weight, and that mean bone mineral content increased significantly during 12 weeks of military training among 35 uninjured recruits (136). Israeli researchers, likewise, reported that mean tibial bone width was significantly lower among 86 soldiers who developed stress fractures than among 250 who did not (137). In a multivariate analysis of these data, investigators reported that lower tibia width prior to basic training was associated with increased odds of stress fracture; however, bone mineral density was not (138). Another study of IDF trainees demonstrated that mean bone mineral content increased significantly during 14 weeks of basic training for both the 105 persons whose training was interrupted by stress fractures and other conditions and the 144 persons who completed training, but tibial bone width did not increase (139). In these studies, the mean bone mineral content of persons with stress fractures was lower before training than that of persons who completed the training, but not significantly so.

The results of several of the military studies of bone mineral density, bone width, and other bone parameters would have been much more meaningful and powerful if the investigators had determined the risk or incidence of stress fracture in recruits exhibiting different levels of bone strength. Nevertheless, these studies strongly suggest an association between lower measures of bone strength and higher risk of stress fracture.

Results of civilian studies of the relation between stress fractures and bone mineral density among athletes are mixed. A study that examined nine female athletes with stress fractures and nine controls found no differences in mean bone mineral density (140). A second study reported that six female runners with a history of stress fracture had higher mean bone mineral densities in the lumbar spine and femoral neck than eight runners without stress fractures (141).

Physical fitness

Aerobic fitness. Studies of US military recruits have consistently shown significant associations between low aerobic fitness levels and higher risk of stress fracture during basic training (table 4). A study of 1,078 Marine recruits found that lower aerobic fitness, as measured by longer running time on a 1.5-mile (2.4-km) run, was strongly associated with higher cumulative incidence of bone-scan- or radiographically confirmed stress fractures (table 4) (114). A similar association was reported for female Army recruits, with the slower half of women on an initial entry 1-mile (1.6-km) run test experiencing significantly more clinically identified stress fractures than the faster women (table 4) (107). In the same study, investigators observed that among male Army trainees in the slower half on the initial entry 1-mile run test, 4.8 percent developed stress fractures as compared with none of the faster recruits. A later study of Army trainees reported almost identical results (table 4) (105).

Several IDF studies have reported finding no significant association between aerobic fitness and risk of stress fracture. Two separately reported analyses based on data from 295 infantry trainees reported that mean estimated maximal oxygen uptakes for persons with stress fractures were not different from those of persons who did not have stress fractures (138), and the incidence of stress fracture for groups with higher aerobic fitness was not significantly different from that of groups with lower fitness levels (142). The difference between these findings and those of other studies may be partially explained by the use of a non-weight-bearing submaximal bicycle test for estimation of aerobic capacity and a much more sensitive definition of stress fracture that included asymptomatic stress fractures. Data from another study relating stress fractures to 2,000-m run times were reported in a manner that made interpretation difficult (143).

Muscle strength and endurance. A report on 626 male and 693 female Marine recruits indicated that male recruits who sustained stress fractures had lower mean calf girth measurements and performed lower mean numbers of sit-ups on a timed test, indicating lower muscle strength and endurance, respectively (115). Female recruits with stress fractures also performed fewer sit-ups, on average (115). A prospective study of 289 Israeli infantry trainees found that persons who developed stress fractures performed fewer leg thrusts on a timed test, indicating lower muscle endurance (138). In another study, six female runners who had sustained stress fractures exhibited higher impact and propulsive forces on a force plate than did eight runners who did not have stress fractures (141). The effect of muscle strength and endurance on stress fracture risk in military and athletic populations needs further study.

Flexibility. Few investigators have studied the association between flexibility and stress fractures. An IDF study prospectively assessed hip range of motion among 289 infantry trainees, of whom 89 subsequently developed stress fractures (138, 144). Recruits with external rotation of the hip greater than 65 degrees experienced an incidence of stress fracture 1.8 times higher than that of recruits with lower degrees of rotation (95 percent CI: 1.3, 2.5) (144). Hip

TABLE 4. Results of studies of the association between aerobic physical fitness and risk of stress fracture

Authors and year of publication (reference no.)	Study design, duration, and location	Population and sample size	Risk factor studied	Risk factor level or category (no. of subjects)	Outcome risk (% incurring stress fracture)	Risk ratio	95% CI*	*p* value
Jones et al., 1993 (107)	Prospective cohort study; 8 weeks of Army basic training; Fort Jackson, South Carolina	391 Army trainees (124 men, 186 women)	Aerobic fitness (1-mile (1.6-km) run times of initial physical fitness test comparing slowest half to fastest half; median run time (minutes:seconds) for men = 7:00; median run time for women = 9:46)	Men				
				Slowest times ($n = 38$)	4.8			Fisher's exact $p = 0.22$
				Fastest times ($n = 41$)	0.0			
				Women				
				Slowest times ($n = 68$)	17.6	2.5	1.0, 6.8	0.05
				Fastest times ($n = 72$)	6.9	1.0		
Canham et al., 1997 (105)	Prospective cohort study; 8 weeks of Army basic training; Fort Leonard Wood, Missouri	250 Army trainees (155 men, 95 women)	Aerobic fitness (2-mile (3.2-km) run times on initial physical fitness test; median run time (minutes:seconds) for men = 15:42; median run time for women = 20:46)	Men				
				Slowest times ($n = 47$)	9.9	7.7	1.0, 57.8	0.02
				Fastest times ($n = 48$)	1.3	1.0		
				Women				
				Slowest times ($n = 79$)	25.5	2.5	1.0, 6.4	0.05
				Fastest times ($n = 76$)	10.4	1.0		
Shaffer et al., 1999 (114)	Prospective cohort study; 12 weeks of Marine Corps basic training; San Diego Marine Recruit Depot, California	1,078 male Marine recruits	Aerobic fitness (1.5-mile (2.4-km) run times on initial entry physical fitness test, median time (minutes:seconds) = 11:19)	Quartiles				
				Quartile 4 (slowest) ($n = 267$)	7.0	3.1	1.3, 7.7	
				Quartile 3 ($n = 255$)	3.9	1.7	0.7, 4.6	
				Quartile 2 ($n = 284$)	1.9	0.9	0.3, 2.8	
				Quartile 1 (fastest) ($n = 272$)	2.3	1.0		Trend $p = 0.002$

* CI, confidence interval.

range of motion persisted as a risk factor in a multivariate analysis of the data (138). Two studies of more than 400 Navy special warfare trainees each investigated the association of several measures of lower extremity flexibility with stress fractures, but neither found associations (130, 131). Note that comparisons of mean values, as employed by several of these studies of flexibility (131, 138), can be misleading for factors like flexibility, which may have a bimodal rather than a linear relation with risk of injury (108).

Body composition and stature. A few military studies have investigated the relation between the occurrence of stress fractures and body composition and body stature. A number of prospectively measured indicators of body stature, including weight, height, neck girth, waist girth, thigh girth, and calf girth, were smaller among 23 Marine recruits who developed stress fractures during 12 weeks of basic training than among the 587 recruits who did not develop stress fractures (113). Body mass index (weight (kg)/height (m)^2), a surrogate measure for percentage of body fat, was also significantly lower among stress fracture patients. The authors concluded that "both small body weight and small diaphyseal dimensions relative to body weight are factors predisposing to development of stress fractures" (113, p. 645).

An IDF study of 392 infantry trainees prospectively assessed height, weight, and thigh and calf girths and found no association with stress fracture incidence (133). Similarly, body mass index was not significantly associated with the odds of injury in a multivariate analysis of data from another study of Israeli recruits (138). Percentage of body fat and body mass index could have a bimodal association with injury risk, with both the least "fat" and the most "fat" persons being at greater risk of incurring a stress fracture (107). Therefore, comparisons of mean values for injured and uninjured persons will be especially misleading, as will multivariate analyses that treat body mass index as if its association with injury risk were linear.

Health risk behaviors and medical history

Sedentary lifestyle. Several military studies have examined the association between previous levels of physical activity and risk of stress fracture during military training (table 5). Before the start of training, 3,010 Marine recruits completed a survey on past health and health behaviors, rating their previous physical activity level in five categories from inactive to very active. The study documented a significant trend of higher cumulative incidence of radiographically confirmed stress fractures among those recruits with successively lower levels of previous activity (table 5) (106). Another study of Marine recruits also showed higher rates of stress fracture among those least physically activity prior to basic training (table 5) (114). Marine recruits who reported never or only occasionally sweating experienced significantly more stress fractures, along with those with fewer months of running before entering basic training. A survey of 449 Navy special warfare trainees (table 5) (131) and a study of Finnish army recruits (145) reported similar find-

TABLE 5. Results of studies of the associations of past physical activity and amount of current training (running) with risk of stress fracture

Authors and year of publication (reference no.)	Study design, duration, and location	Population and sample size	Risk factor studied	Risk factor level or category (no. of subjects)	Outcome risk (% incurring stress fracture)	Risk ratio	95% CI*	p value
Shaffer et al., 1999 (114)	Prospective cohort study; 12 weeks of Marine Corps basic training; San Diego Marine Recruit Depot, California	1,286 male Marine recruits	Past physical activity (number of times exercised per week during previous 2 months)	Weekly exercise				
				<3 times/week (n = 658)	6.9	2.7	1.3, 46	
				3 times/week (n = 300)	3.2	1.2	0.5, 2.7	
				>3 times/week (n = 328)	2.6	1.0		Trend p = 0.00
			Frequency of sweating during exercise	Sweating frequency				
				Occasionally/never (n = 283)	8.3	5.1	2.4, 10.8	
				Fairly often (n = 408)	3.6	2.3	1.0, 5.2	
				A lot/all the time (n = 595)	1.6	1.0		
Montgomery et al., 1989 (131)	Prospective cohort study; 25 weeks; Naval Special Warfare Training Center, California	449 Navy special warfare trainees	Past physical activity (miles run per week over the year before special warfare training)	Miles run per week				
				<4 (<6.4 km) (n = 96)	11.5	3.8	1.1, 13.3	
				4–25 (6.4–40 km) (n = 279)	5.0	1.7	0.5, 5.7	
				>25 (>40 km) (n = 100)	3.0	1.0		Trend p = 0.01
Gardner et al., 1988 (106)	Prospective cohort study; 12 weeks of Marine Corps basic training; Parris Island Marine Recruit Depot, South Carolina	3,025 male Marine recruits	Physical activity	Activity level				
				Inactive (n = 25)	12.00	19.6	4.6, 81.5	
				Below average (n = 224)	2.20	3.6	1.0, 13.2	
				Average (n = 924)	1.82	1.8	0.8, 3.8	
				Active (n = 1,197)	0.91	1.5	0.5, 4.6	
				Very active (n = 638)	0.61	1.0		Trend p = 0.0004
Shaffer and Almeida, 1996 (181) and Jones et al., 1999 (109)	Prospective cohort study with historical controls; 11–12 weeks; San Diego Marine Recruit Depot, California	US Marine Corps basic training; 3,350 male recruits	Current physical training (lower amounts of running and marching (55 km running) vs. moderate training (66 km running) vs. normal (higher) recruit training (89 km running))	Total distance run				
				Low (n = 1,097)	1.7	0.50	0.27, 0.80	<0.05
				Moderate (n = 1,117)	2.7	0.79	0.46, 1.15	0.17
				High (n = 1,136)	3.7	1.00		
Brunet et al., 1990 (124)	Cross-sectional survey of civilian runners	1,505 runners (1,126 men, 375 women)	Current physical training (miles run per week)	Men (miles run/week)				
				<20 (<32 km) (n = 540)	6.7	1.0		
				20–30 (32–48 km) (n = 287)	8.0	1.2	0.7, 1.9	
				>30 (>48 km) (n = 299)	11.5	1.8	1.1, 2.7	0.01
				Women (miles run/week)				
				<20 (<32 km) (n = 214)	4.7	1.0		
				20–30 (32–48 km) (n = 78)	20.3	4.4	2.1, 9.3	<0.05
				>30 (>48 km) (n = 83)	28.0	5.9	2.9, 11.9	<0.05

* CI, confidence interval.

ings. An IDF study found no relation between duration of training or amount of running prior to basic training and stress fracture risk (142).

The preponderance of the data from military studies indicates that persons who engage in more physical activity, particularly running, will experience fewer stress fractures when beginning a physically demanding training program. Additionally, suggesting that previous activity is protective, a college sports medicine clinic reported that over a 3-year period, 67 percent of stress fractures treated occurred among freshmen, while only 17 percent occurred among sophomores, 9 percent among juniors, and 7 percent among seniors (123).

Smoking. A pretraining survey of 915 female Army trainees determined that those who smoked one or more cigarettes during the year prior to 8 weeks of basic training incurred stress fractures or stress reactions of bone more frequently than those who did not smoke (RR = 2.2, 95 percent CI: 1.4, 3.6) (146). Among 1,087 male Army trainees in the study, the risk was higher for those who smoked (RR = 1.4, 95 percent CI: 0.7, 2.9). A survey of 1,630 women in the Army found that current smokers had increased risk of stress fracture (RR = 1.7, 95 percent CI: 1.2, 2.1) (128). Similarly, several studies of male Army trainees and soldiers in operational units found a statistically significant association between cigarette smoking and overall risk of training-related injuries in general (108, 117).

Oral contraceptives. A survey answered by 241 female collegiate distance runners found that women taking oral contraceptives had a decreased risk of stress fracture confirmed by radiograph or bone scan in comparison with those who did not use oral contraceptives (RR = 0.40, 95 percent CI: 0.40, 1.2) (126). In another study, the odds of taking birth control pills were lower among 25 female collegiate athletes with stress fractures as compared with 25 female athletes who did not have stress fractures (odds ratio = 0.32, 95 percent CI: 0.1, 1.3) (127). Although the results of these studies are consistent with the known relation between estrogen use and increased bone mass and suggest that oral contraceptive use may reduce the incidence of stress fracture in female runners and athletes by more than 50 percent, the weaknesses of study design in both of these investigations suggest the need for more and larger studies of the impact of estrogen-containing oral contraceptives on the incidence of stress fracture.

Past injuries. Milgrom et al. (147) and Giladi et al. (148) reported the results of a 1-year medical follow-up study of 66 of 91 IDF recruits who had sustained one or more stress fractures during 14 weeks of basic training. Their study found that 10.6 percent of persons with a previous stress fracture developed a new stress fracture during the year after basic training, a risk considerably lower than the original risk of 31 percent (147, 148). However, Milgrom et al. (147) reported that only 1.7 percent of 60 controls in the study sustained stress fractures. Thus, both groups had lower incidences of stress fracture during the year after basic training, but the previous stress fracture group experienced a significantly higher risk than the controls. A study of Marine recruits observed that those who had sustained a previous injury but had not fully recovered were at greater risk of sustaining an injury during 12 weeks of basic training than those who had sustained an injury but did completely recover (114). Interestingly, investigators also found that those recruits who had never sustained an injury were at greater risk of developing a stress fracture during basic training than recruits who had experienced a previous injury but completely recovered (RR = 2.8, 95 percent CI: 1.4, 5.6). The authors speculated that this might indicate that a past training injury is a marker for past physical activity and that past physical activity is more protective against stress fractures. Future research into the influence of past injuries on current risk should determine the adequacy of recovery from past injuries and the level of past physical activity. These studies indicate that the association of past injuries with current risk is not simple and that it may be confounded by other factors such as adequacy of recovery and levels of past activity.

STUDIES OF EXTRINSIC RISK FACTORS

Although it would seem that extrinsic risk factors would be of great interest because of their potential impact on risk of injury and their applicability to prevention, few studies have examined this category of factors. Several of the extrinsic risk factors covered in this review, such as type of sport, physical training, and footwear, should be modifiable and of value for prevention.

Type of sport or activity

Although a number of clinical case series describe the relative frequency of stress fractures from different sports or exercise activities, we found only one study that quantified the rates for different sports (123). In that study, the top 10 sports evaluated and the percentage of athletes per season (year) who had stress fractures were as follows: softball, 6.3 percent; track, 3.7 percent; basketball, 2.9 percent; tennis, 2.8 percent; gymnastics, 2.8 percent; lacrosse, 2.7 percent; baseball, 2.6 percent; volleyball, 2.4 percent; crew, 2.2 percent; and field hockey, 2.2 percent.

Military studies indicate that different types of units and different types of training may place military personnel at different degrees of risk. A study of 120 Finnish male military recruits suggested that paratroopers may be at greater risk of incurring stress fractures than regular or light infantry soldiers (149). A medical surveillance report on the incidence of stress fracture among women undergoing Navy basic training, Marine Corps basic training, or officer candidate training indicated higher risks among Marine recruits and officer candidates (116).

Current physical training

Few military or civilian studies have examined the association between amount of physical training or exercise and incidence of stress fracture (table 5). This review found one survey that examined the effect of amount of running on the risk of stress fracture (124). That survey showed that male and female runners who ran more miles per week experienced an increased risk of radiograph- or bone-scan-diagnosed stress fracture (table 5) (124). Although the survey design had limitations, these findings are consistent with studies of runners indicating that higher amounts of running are associated with higher incidences of training injuries in general (150–155). A preliminary report on alterations in the amounts of running and marching performed by Marine recruits showed that training units that reduced running mileage experienced lower incidences of stress fracture (table 5) (109). Also of note is the finding that trainees doing the least running not only experienced a 50 percent lower incidence of injuries but performed as well on a final physical fitness test (109).

An IDF study of marching mileage and risk of stress fracture reported finding that less marching did not result in lower stress fracture rates (156). The study did not control for the amount of running by recruits in the high and low marching mileage units, however. This hinders interpretation, because stress fracture risks are probably proportionate

TABLE 6. Results of field studies carried out to determine the effectiveness of strategies designed to prevent lower extremity stress fractures* and stress reactions†

Author(s) and year of publication (reference no.)	Study design, duration, and location	Population and sample size	Prevention strategy or intervention	Study or prevention groups (no. of subjects)	Outcome risk (% incurring stress fracture)	RR‡	95% CI‡	*p* value	Median score
Bensel, 1976 (158)	Randomized trial; 12 weeks; Marine Recruit Depot, San Diego, California	US Marine Corps basic training; 786 male recruits	1) Leather combat boot vs. 2) hot-weather, tropical boot	1) LB‡ (n = 414) 2) HB‡ (n = 372)	Stress fracture	1.2	0.42, 3.42	0.735	44
					1) n = 8 (1.9%)				
					2) n = 6 (1.6%)				
					Clinical stress reaction	1.11	0.59, 2.07	0.743	
					1) n = 21 (5.1%)				
					2) n = 17 (4.6%)				
Scully and Besterman, 1982 (43)	Unknown study design; 8 weeks; Fort Knox, Kentucky	US Army basic training; 880 male Army trainees	1) Gradually progressive training with no running during week 3 (out of 8) vs. 2) normal training	1) GT‡ (n = 440) 2) NT‡ (n = 440)	Stress fracture	0.33	0.14, 0.78	<0.05	16
					1) n = 7 (1.6%)				
					2) n = 21 (4.8%)				
Bensel and Kish, 1982 (102)	Randomized trial; 8 weeks; Fort Jackson, South Carolina	US Army basic training; 2,074 male trainees	1) Standard leather combat boot vs. 2) hot-weather, spike-resistant boot	Men: 1) LB (n = 1,347); 2) HB (n = 728)	Stress reactions				43
					Calcaneal:	0.69	0.41, 1.18	0.178	
					1) n = 31 (2.3%)				
					2) n = 24 (3.3%)				
					Metatarsal:	1.0	0.50, 1.85	0.915	
					1) n = 25 (1.9%)				
					2) n = 14 (1.9%)				
					Medial tibial:	0.90	0.58, 1.40	0.644	
					1) n = 50 (0.37%)				
					2) n = 30 (0.41%)				
Bensel and Kish, 1982 (102)	Randomized trial; 8 weeks; Fort Jackson, South Carolina	US Army basic training; 767 female trainees	1) Standard leather combat boot vs. 2) hot-weather, spike-resistant boot	Women: 1) LB (n = 425); HB (n = 342)	Stress reactions				43
					Calcaneal:	0.69	0.46, 1.05	0.08	
					1) n = 38 (8.9%)				
					2) n = 44 (12.9%)				
					Metatarsal:	0.71	0.41, 1.22	0.218	
					1) n = 23 (5.4%)				
					2) n = 26 (7.6%)				
					Medial tibial:	1.22	0.2, 7.18	0.836	
					1) n = 3 (0.71%)				
					2) n = 2 (0.58%)				

Table continues

to total weight-bearing training miles (running, marching, drilling, ceremonial activity, etc.). Apropos of this latter point, a prospective study of 1,296 male Marine Corps recruits showed that weekly overall injury rates were significantly correlated with "high total volumes of vigorous physical training and the most hours of running and marching" (112, p. 1176).

Equipment and environmental factors

Most studies of the impact of exercise equipment, such as shoes and boots, on the risk of stress fracture have involved intervention trials (discussed below). One study of Marine recruits reported that use of running shoes more than 1 month old at the onset of basic training appeared to be associated with greater risk of stress fracture, while the price of running shoes was not associated with risk (106). No civilian studies investigating the effect of shoe type, age, or quality on risk of stress fracture have been identified. In addition, little information on the influence of environmental factors on risk of stress fracture is available. A survey of distance runners found that among those who had been injured, 13 percent of men and 13 percent of women attributed the injury occurrence to a change in the type of running surface; 6 percent of men and 7 percent of women attributed their injuries to running on hilly terrain (124). An investigation of an "epidemic" of stress fractures among female IDF advanced course trainees documented an incidence of stress fracture of 11.4 percent in the unit. Usual incidences of 1.0–3.5 percent were reported. The only change in physical training that could be identified by the investigation was a switch to marching on hilly, rocky terrain instead of the usual flat,

TABLE 6. Continued

Author(s) and year of publication (reference no.)	Study design, duration, and location	Population and sample size	Prevention strategy or intervention	Study or prevention groups (no. of subjects)	Outcome risk (% incurring stress fracture)	RR‡	95% CI‡	*p* value	Median score
Milgrom et al., 1985 (161)	Randomized trial; 14 weeks	Israeli Defense Force training; 295 male infantry trainees	1) Orthotic boot insoles vs. 2) no orthotics (normal boot insoles)	Boot inserts: 1) OI‡ (n = 113); 2) NO‡ (n = 152)	Femur stress fractures	0.54	0.28, 1.06	0.065	39
			Note: 30 (21%) of the 143 subjects in the test group quit wearing the orthotics.		1) *n* = 11 (9.7%)				
					2) *n* = 27 (17.8%)				
					Tibial stress fractures	0.77	0.47, 1.26	0.29	
					1) *n* = 20 (17.7%)				
					2) *n* = 35 (23.0%)				
					Metatarsal stress fractures	0.34	0.07, 1.55	0.14	
					1) *n* = 2 (1.8%)				
					2) *n* = 8 (5.3%)				
Gardner et al., 1988 (106)	Randomized trial; 12 weeks; Parris Island Marine Recruit Depot, South Carolina	US Marine Corps basic training; 3,025 male recruits	1) Shock-absorbent viscoelastic polymer boot insoles vs. 2) normal mesh boot insoles	Boot insoles: 1) VEP‡ insole (*n* = 1,557); 2) no insole (*n* = 1,468)	Stress fractures 1) *n* = 21 (1.35%) 2) *n* = 17 (1.13%)	1.2	0.62, 2.20	0.638	55
Schwellnus et al., 1990 (163)	Randomized trial; 9 weeks; South Africa	South African army basic training; 1,388 male trainees	1) Shock-absorbent neoprene boot insoles vs. 2) no insoles	Boot insoles: 1) neoprene insole (*n* = 237); 2) no insole (*n* = 1,151)	Stress fractures 1) *n* = 0 (0.0%) 2) *n* = 16 (1.4%)			<0.1	52
Finestone et al., 1992 (133)	Randomized trial; 14 weeks; Israel	Israeli Defense Force infantry training; 390 recruits	1) Basketball shoes vs. 2) infantry boots	1) Basketball shoes (*n* = 187); 2) infantry boots (*n* = 204)	"The overall incidence of ...stress fractures was the same in both groups" (133, p. 490)				30
Popovich et al., 2000 (162)	Prospective cohort study with convenience controls; 8 weeks; Fort Bliss, Texas	1,357 male US Army trainees	No running during the 1) second, 2) third, or 3) fourth week of basic training vs. controls with normal training; 4) control group 1 and 5) control group 2; 6) high-mileage running group	Training groups§	Stress fractures and stress reactions	(NR2–4)/ (C1 + C2): RR = 1.25	0.75, 2.10	0.39	37
				1) NR2 (*n* = 213)	1) *n* = 17 (8.0%)				
				2) NR3 (*n* = 262)	2) *n* = 8 (3.1%)				
				3) NR4 (*n* = 200)	3) *n* = 14 (7.0%)				
				4) C1 (*n* = 248)	4) *n* = 17 (6.9%)				
				5) C2 (*n* = 208)	5) *n* = 4 (1.9%)				
				6) R5 (*n* = 226)	6) *n* = 14 (6.2%)				

* Stress fracture = radiograph- or bone-scan-confirmed diagnosis of stress fracture.

† Stress reaction = clinically assessed stress fracture pending confirmation.

‡ RR, risk ratio; CI, confidence interval; LB, leather boot; HB, hot-weather boot; GT, gradual training; NT, normal training; OI, orthotic insoles; NO, no orthotics; VEP, viscoelastic polymer.

§ NR2, NR3, or NR4, no running during the second, third, or fourth week of basic combat training; C1, control group 1; C2, control group 2; R5, high-mileage running group.

predictable terrain (157). When marching returned to flat, smooth terrain, the incidence of injuries returned to 2.5 percent. While these reports may be suggestive, much more research is needed on the impact of equipment and environmental factors on stress fracture risk.

INTERVENTION TRIALS FOR STRESS FRACTURE PREVENTION

This review found nine studies that compared interventions intended to prevent stress fractures with fracture incidence among control subjects (43, 102, 106, 158–163) (table 6). All nine studies were carried out in military populations, and all examined strategies designed to prevent lower extremity stress fractures. The strategies tested involved modifications of either the physical training program or the footwear of Army or Marine Corps recruits.

Modifications of training

One approach to modifying training programs has been investigated. Two studies evaluated the effect of periods of recovery from weight-bearing stress during the early weeks of Army basic training (43, 162). The first of these studies, a "field trial" conducted at Fort Knox in 1974, divided 880 male trainees into equal-sized test and control groups and compared normal training with training interrupted by a recovery week, with no running, marching, or jumping taking place during the third week of the 8 weeks of US Army basic training (43). A 67 percent decrease in stress fractures in the group given recovery time suggested a possible benefit from this intervention (table 6).

In the second study, a nonrandomized controlled trial involving six companies (1,357 male trainees), Popovich et al. (162) tested the effect of recovery weeks, with no running during the second to fourth weeks of the 8 weeks of US Army basic training. The study compared the stress fracture incidence of persons from three test companies that provided a period of recovery from running during the second, third, or fourth week of basic training with the stress fracture incidence of persons from two control companies conducting normal, uninterrupted physical training. A sixth company performed more running than usual in the early weeks of training and then had a hiatus in running during the fourth and fifth weeks. The results suggested that a recovery period with limited vigorous weight-bearing training (i.e., no running) is not likely to make a significant difference in stress fracture incidence. However, the variation in stress fracture rates among units within the test and control groups was large enough to mask apparent differences between the training modification group and the controls (table 6).

Modifications of footwear

The most studied type of intervention identified by this review was modification of footwear (table 6). Two studies examined the effect of using different types of military boots on the incidence of stress fracture and other training injuries among Marine and Army trainees (102, 158). Three trials investigated the potential benefits of wearing shock-absorbent insoles in military boots (106, 159, 163). One study investigated the efficacy of wearing orthotic inserts in military boots to prevent stress fractures (161), and one study examined the effect of using athletic shoes versus boots during Army basic training (160).

A randomized trial of 879 US Marine recruits conducted by Bensel (158) showed a nonsignificant increase in rates of stress fracture at different sites among recruits wearing standard leather boots as compared with hot-weather (tropical) mesh-upper combat boots (RR = 1.1–1.2) (table 6). "Clinical" stress fractures were identified on the basis of clinical symptoms and signs, and "stress fractures of the lower extremity" were radiographically confirmed. A second study followed 2,841 male and female US Army trainees (2,074 men and 767 women) randomly assigned to wear either the standard leather combat boot or the hot-weather boot (102). Rates of calcaneal stress fracture were lower for the standard leather boot in both men (RR = 0.69) and women (RR = 0.45). Additionally, metatarsal fractures were lower among women (RR = 0.71) (table 6). Of those starting the study, 89 percent of men and 81 percent of women completed the study. Randomization was compromised by the unavailability of appropriate-sized hot-weather boots for some recruits and by an unreported number of switches made in boot assignments. Although the findings of these two studies of boots found opposite outcomes in terms of the effects on stress fracture incidence, the results suggest that any potential effect of different types of boots is likely to be small.

In another trial, Bensel and Kaplan (159) randomized 555 female US Army recruits into three groups to compare two types of insoles (urethane foam and lever action) to the standard multilayered plastic-mesh military insole and documented a nonsignificant protective effect of shock-absorbent urethane insoles. Another randomized controlled trial by Gardner et al. (106) involving 3,025 US Marine recruits approximately equally distributed between test (n = 1,557) and control (n = 1,468) groups found that shock-absorbent sorbothane insoles did not reduce the incidence of radiographically confirmed stress fractures (RR = 1.17) (table 6). A multivariate analysis controlling for the effects of race, previous physical activity, and age of the running shoes did not affect this outcome. A third randomized controlled trial conducted by Schwellnus et al. (163) among South African military recruits (250 test subjects and 1,151 controls) found a nonsignificant reduction in stress fractures in the test group wearing shock-absorbent neoprene insoles (table 6). Clinical assessments and radiographs, all of which were reviewed by a panel of eight physicians, were used to establish the diagnosis of stress fracture. The investigators also reported that the control group experienced more overuse injuries (27.5 percent) than the test group (20.6 percent) and twice as many traumatic injuries as the test group (4.3 percent vs. 2.1 percent). The fact that both the incidence of overuse injuries and the incidence of traumatic injuries were increased in the control group suggests that some factor other than the insoles might explain the higher incidence of stress fracture among the controls. The findings of these three studies of insoles, at most, suggest that some types of shock-absorbent materials may help protect the feet and lower extremities from stress fractures.

In an IDF study, Milgrom et al. (161) randomly assigned 143 of 295 persons to wear orthotic inserts during 14 weeks of infantry training. Clinical assessment and bone scans were used to establish the diagnosis of stress fracture. In this study, asymptomatic "hot spots" were also interpreted as stress fractures, a broader definition than that used by other investigators. Use of orthotics reduced the incidence of femoral stress fracture by 46 percent, but the overall reduction in stress fractures was not statistically significant (table 6). Thirty persons, 20 percent of the 143 randomly assigned to the orthotic group, "failed to accommodate to the orthotic" and were removed from the study. The injury experience of those lost to follow-up was not reported.

In another IDF study, investigators randomly provided basketball shoes to 187 (47.8 percent) of 391 Israeli infantry recruits to wear during training instead of the standard infantry boots and found that the overall incidences of stress fracture and total overuse injuries (e.g., plantar fasciitis and patellofemoral syndrome) were the same for both groups (160). Recruits wearing basketball shoes did report a decrease in overuse injuries (metatarsal stress fractures, plantar fasciitis) of the foot (17.6 percent vs. 34.0 percent; $p = 0.0001$).

QUALITY OF REPORT INTERVENTIONS

Quality scores for the randomized controlled trials ranged from 12 to 59 (out of a possible 100) for the individual rater scores; the median scores for the nine studies ranged from 16 to 55 (table 6). The design or reporting of the randomization process employed in most of the studies was inadequate. In military studies, particularly if randomization is by unit, the randomization should include enough units of test and control groups to account for interunit variation in injury rates, which may be greater than the effect size expected from the intervention. The case definition of a stress fracture and the manner in which diagnostic tests are employed should be reported for all studies.

Statistical methods were reported incompletely in all nine studies. Most of the studies reviewed did not indicate whether sample size estimates or power calculations had been performed in advance of the study. Sample sizes should be calculated while taking into account the sensitivity of the diagnostic approach employed. For instance, if only radiographically confirmed clinical cases are included in the analysis, much larger sample sizes will be necessary than if bone scan confirmation is employed. Sample size estimates should take into consideration the subpopulation being studied. For instance, studies of women will probably require fewer subjects than studies of men because of the higher incidence of stress fracture women experience given comparable exposures. Investigators should do a better job of tracking and reporting on persons lost to follow-up, documenting possible differences in personal characteristics, risk factors, injury incidence, and reasons for dropping out. In addition, interpretation of results was hampered by the lack of attention to possible confounding factors and by both information and selection biases. In a number of the studies reviewed, multivariate analysis controlling for potential confounders would have been instructive.

DISCUSSION

Our review identified more than 400 papers on stress fractures and related overuse injuries. Of these, 150 addressed the etiology, epidemiology, or prevention of stress fractures (table 2). In addition to the research papers cited, 25 were review articles (2, 4–6, 8–9, 14, 32–36, 164–176). Only nine of the reports reviewed examined interventions aimed at preventing stress fractures. All nine were military studies. Fifty-two papers studied the epidemiology of and risk factors for stress fracture, and 42 of these were military studies. Most of the 10 civilian risk factor studies focused primarily on the role of menstrual irregularity and bone density on stress fracture risk among female runners and athletes. The military studies were more diverse and identified a number of significant risk factors, including female gender, age, lower bone density and indices of bone strength, low aerobic fitness, low past physical activity levels, cigarette smoking, and greater amounts of running. The risk factors and general principles of stress fracture prevention discovered through military studies should be applicable to similarly physically active civilian populations.

The amount of research on stress fractures conducted by the military reflects the armed forces' concern about the high incidence of and amount of training time lost due to this injury (2, 177). The civilian exercise and sports communities are concerned for similar reasons (2, 4, 6). While stress fractures in military populations result in lost duty time and, in some cases, discharge from the military, among civilians these injuries result in decreased physical training and sometimes cessation of exercise. Thus, finding ways to prevent stress fractures would benefit both the military and civilian exercise and sports participants. Unfortunately, the greatest weakness of the stress fracture literature for both groups is the limited number of studies, even studies of those interventions most commonly recommended by sports medicine experts.

The nine intervention trials identified in this review examined only two of the many possible strategies for preventing stress fracture suggested by the literature—alterations of training and modifications of footwear. The one training intervention involved providing military trainees with a week-long break from running in the early weeks of training, and results did not appear to be promising enough to warrant further research. Of the interventions involving footwear, the trial of orthotic inserts appeared to be the most promising. In addition, intervention trials on some of the shock-absorbent boot insoles indicated that this approach might also be fruitful. Thus, further research into the efficacy of preventing stress fracture through modification of footwear is recommended.

Perhaps the most important insights gleaned from this quality review of stress fracture prevention studies pertain to the design and implementation of future military and sports medicine intervention trials. Other investigators have also suggested that careful attention to study design, execution, and reporting is critical (178, 179). Subjects in both intervention and control groups should be subject to uniform, consistent, and ongoing monitoring for the occurrence of injuries. Randomization should be blinded when possible, and the method of randomization used should be described clearly. Whereas a double-blind study is often not feasible for studies of athletic injuries (for example, users of orthotic devices know they are wearing them), blinded allocation of subjects is essential in order to minimize bias. Case definitions must be explicit and easily replicable. In calculating rates of injury, careful consideration must be given to the choice of denominators (e.g., person-time of exposure). Appropriate statistical methods should be used for data analysis, and these methods should be described clearly in published arti-

TABLE 7. Recommendations for research on the prevention of stress fractures, by category of intervention

Category and recommendations
Physical training and exercise interventions
Determine which parameters of physical training (frequency, duration, intensity) most affect the incidence of stress fracture.
Investigate approaches to optimize the amount of training that reduces stress fracture incidence while maintaining (or enhancing) fitness.
Study the effect of gradually enhancing physical fitness prior to intensive weight-bearing training on risk of stress fracture.
Conduct randomized controlled trials in both civilian and military populations to demonstrate whether reduced amounts of weight-bearing activity decrease the incidence of stress fracture.
Determine whether physical training can be tailored to improve bone strength and physical fitness.
Equipment and environmental interventions
Undertake biomechanical studies on footwear and running surfaces to elucidate the effect on stress fracture incidence of the interaction of impact forces, stability, and shock absorption.
Health risk behavior interventions
Determine the effect of smoking cessation on risk of stress fracture.
Ascertain the behavioral factors associated with sports injuries that present challenges of access to data and compliance of study subjects (e.g., will coaches or platoon leaders give priority to injury prevention?)
Determine effect of oral contraceptive use on risk of stress fracture among women with amenorrhea and other female athletes with risk for stress fracture.
Anatomic and biomechanical interventions
Test the effects of different types of materials in shock absorbent footwear (shoes or insoles) on the incidence of stress fracture.
Determine whether the risk of stress fracture associated with anatomic factors such as knock-knees or high arches can be reduced through the use of corrective devices such as orthotics.
Document which subgroups of persons exhibiting varying degrees of intrinsic risk factors such as high arches or leg-length discrepancies are at greatest risk.
General approaches to prevention
Conduct an in-depth analysis of the scientific literature on risk factors for stress fractures and quantify the potential magnitude of effect a modification of identified risk factors would have on the incidence of stress fracture.
Quantify the incidence of stress fracture (per unit of time) for different sports and exercise activities.
Design intervention trials to test the effectiveness of modifying the risk factors with the largest effects on risk.
Determine whether interventions are equally effective for women as they are for men.
Determine which interventions are effective for athletes with a history of previous stress fractures.

cles. Among other things, investigators should avoid comparing mean values for risk factors, such as bone density, flexibility, or percentage of body fat, in injured versus uninjured persons when it is possible to determine and compare the risks or incidence rates of stress fracture among persons exhibiting different degrees of the risk factors. Finally, the reporting of results should be improved so that the methods employed can be understood and replicated by other investigators, and published study conclusions should be supported by the data presented.

Better information on how to prevent stress fractures will depend on valid and reliable results from intervention trials. In turn, the success of future trials will depend not only on the application of improved methodology but also on knowledge of modifiable causes and risk factors. This review has identified a number of potentially modifiable risk factors that could be used to design prevention strategies.

Of the strategies for preventing stress fracture suggested by this review, modulation of amounts of running and other weight-bearing activities to reduce the total amount of activity performed is one of the most promising. Stress fractures of the lower extremities occur most commonly in association with weight-bearing sports, physical training, and exercise, so it makes sense that modifications of training or exercise programs would reduce the incidence of such injuries. One of the studies on runners reviewed indicated that persons who run more miles experience a higher incidence of stress fracture (124). In assessing running-related injuries in general, injury incidence can be 1.5–6 times higher among persons running greater distances, depending on the amount of increased running mileage (152–155, 180). If reductions in training mileage could reduce stress fracture incidence in proportion to the degree to which higher mileage elevates overuse injury risk, reductions of 50–80 percent could be achievable. A study of Marine recruits suggested that reductions in running mileage can produce decreases in stress fracture on this order of magnitude (table 5) (109, 181). A recent study of Army trainees confirmed the validity of this approach, showing that a 50 percent reduction in total running miles resulted in a 40 percent reduction in overall injury rates, with no decrease in performance on a final 2-mile (3.2-km) run (182). A classic study by Pollock et al. (180) suggested that research designed to identify thresholds of training duration and frequency above which fitness benefits diminish and injury risks increase would be valuable. Such research would benefit competitive and recreational runners, track athletes, fitness program participants, other sports participants, and military personnel.

Several studies reviewed showed that persons who have led more sedentary, physically inactive lifestyles in the past are more likely to suffer stress fractures when they begin to engage in physically demanding military training (106, 114, 131). A number of studies also indicate that higher levels of aerobic fitness protect military trainees from stress fractures and other training injuries (105, 107, 114). Research should be conducted to determine whether gradually increasing physical fitness prior to initiating a vigorous physical training program prevents stress fractures, not just in military recruits but in civilian populations as well. Those who might benefit in addition to military recruits include novice runners, first-time sports participants, and persons beginning fitness or aerobics programs.

The literature reviewed also suggested several other potentially promising approaches. Bone research suggests that it may be possible to design physical training programs not just to increase aerobic fitness and muscle strength but also to increase bone strength and dimensions (113, 115, 138). Milgrom et al. (134) has suggested that footwear might be designed to dampen the damaging bending moments of inertia of bone. Several civilian investigators have studied the associations among amenorrhea, menstrual regulatory hormones, and bone density because of the suspected association between menstrual irregularity and stress fractures (183, 184). On the basis of an extensive sports medicine review, Nattiv and Armsey (34) suggested that, while a relation is not proven, oral contraceptives may exert a protective effect for female athletes that deserves further research. Table 7 lists other recommendations for research suggested in the papers reviewed.

As a general strategy, it may be helpful to focus research on the sports and activities in which stress fractures occur most frequently and on the bones where they occur most frequently. The larger clinical case series (1, 3, 59) and some epidemiologic studies (123) suggest that stress fractures occur more frequently among runners than among participants in other weight-bearing sports such as basketball, soccer, field hockey, or tennis. Research is needed to determine whether this is the result of greater numbers of runners, greater exposure of runners, or some other possibly protective factor in other sports, such as a more varied plane of motion that distributes forces more widely over bone. A number of studies of weight-bearing physical activity and sports have shown that the tibia is the bone most commonly reported to undergo stress fracture (3, 16, 20, 185). The greater relative frequency of tibial stress fractures observed among runners as compared with military recruits suggests that the type and nature of the activity engaged in may influence the location of a stress fracture. Future prevention research focused on specific bones and high-risk sports or exercise activities might have a greater chance of success.

This review summarizes an extensive body of literature on stress fractures. It also highlights how little we know about what works to prevent one of the most common and potentially serious sports- and exercise-related overuse injuries. The available research suggests that for many persons, stress fractures and other physical training-related injuries can be prevented by reducing the amounts of weight-bearing exercise performed without sacrificing fitness. The data also suggest that the most sedentary and least physically fit persons are most vulnerable to stress fractures when starting a vigorous exercise program and that they would benefit most from starting exercise gradually and reducing training volume. Until more definitive solutions become available, a common-sense approach to training and overuse injury prevention must be recommended (151).

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