MILITARY MEDICINE, 164, 2:153, 1999

The Effect of Leg Strength on the Incidence of Lower Extremity Overuse Injuries during Military Training

*Jay R. Hoffman, PhD**
*Leah Chapnik, BS**
*Ari Shamis, MD**
Uri Givon, MD†
*Benjamin Davidson, MD**

This study examined the effects of strength, aerobic fitness, and activity profile on the incidence of overuse injuries, particularly stress fractures, during military training. A total of 136 military recruits were followed during 9 weeks of basic training. Maximal strength and aerobic fitness were determined by a one-repetition maximum leg press and a 2,000-m run, respectively. An activity profile was determined by the recruit's activity history. Twelve recruits (8.8%) were diagnosed with stress fractures. Recruits who were 1 SD below the population mean in both absolute (98.4 ± 36.6 kg) and relative strength (1.72 ± 0.61 kg/kg of body weight) had a five times greater risk for stress fracture ($p < 0.05$) than stronger recruits. Poor aerobic fitness did not appear to be related to any increased incidence of stress fracture. It appears that recruits with lower body strength levels, within 1 SD of the population mean, have a reduced incidence of stress fractures during military training.

Introduction

The incidence of overuse injuries, particularly in the lower limbs, is the major cause of training days lost during military recruit training.[1,2] Stress fractures appear to be the most common problem reported during these training periods, with incidence rates ranging from 1.5 to 64%.[1,3-8] These high incidence rates have resulted in a concerted research effort to determine whether there are certain risk factors that make soldiers more prone to this type of injury.

Stress fractures are thought to occur from cyclical overuse of the bone. This overuse is considered to be consequent to the strain magnitude, the number of loading cycles, the bone's structural geometry, and its resistance to bending and torsion.[9] There have been several biomechanical factors that have been identified as potential indicators for a lower limb overuse injury.[7,8] However, these factors (i.e., tibial length, valgus knee alignment, external hip rotation, leg dominance) are genetically determined, and without using a very stringent selection process, they are most likely uncontrollable. Therefore, a different strategy needs to be used to assist in reducing the high incidence rate of stress fractures.

Because bone is a living tissue, it has the ability to remodel and adapt to physical stresses imposed on it. Participation in physical activity has generally been associated with elevated levels of bone mineral density and bone mineral content.[10-12] Increases in bone mass appear to be influenced by the type of exercise training performed. High-intensity activity appears to have a greater influence on bone remodeling than lower-intensity activity.[13] In particular, resistance training has been shown to be a very effective stimulus for increases in bone mineral density.[10,12,14,15] In addition, individuals with a lower bone density are reported to be at greater risk for stress fracture than individuals with normal bone density levels.[16] It would appear that individuals who participate in conditioning programs, which are known to increase bone mineral density, would be less susceptible to stress fractures during military training. However, some doubts have been raised concerning preinduction activity history and fitness levels and their relationship to stress fractures. Israeli clinicians [4,6-8] have reported that physical fitness levels and activity history are not related to the incidence of stress fractures in infantry recruits. However, there were several methodological problems in those studies related to how physical fitness was determined (strength was measured isometrically) and how the soldiers' activity history was defined. Further research is warranted concerning physical fitness, specifically strength, and its influence on lower limb overuse injuries. Therefore, the purpose of this study was to examine the affects of preinduction strength and fitness levels on the incidence of lower extremity overuse injuries during basic training.

Methods

A total of 136 male military recruits (mean ± SD; 18.0 ± 0.0 years, 1.76 ± 0.07 cm, 66.7 ± 12.0 kg, 13.6 ± 5.8% body fat) were followed during 9 weeks of basic training. During the first week of basic training, all recruits performed strength and fitness testing. Maximal lower body strength was determined by a one-repetition maximum (1RM) effort performed on a leg-press exercise. The 1RM leg press was performed on a Universal Gym station (Universal Gym Equipment, Cedar Rapids, Iowa). The leg press was performed with the subjects in a sitting position and the knees positioned at 90°. Subjects warmed up with a light resistance and then, within three to five attempts, achieved a 1RM effort.

Aerobic fitness was determined by a maximal-effort 2,000-m run. This fitness test is part of the standard Israel Defense Force fitness test. The 2,000-m run was performed on a dry dirt road. All recruits were required to wear T-shirts, shorts, socks, and running shoes. The fitness instructors administrating the test emphasized the importance of performance times in the briefing before the run.

Anthropometric assessments included body weight and body fat content. Body weight was measured to the nearest 0.1 kg. Body fat content was estimated from skinfold caliper measures using the method of Durnin and Wormersley.[17]

All recruits completed an activity history questionnaire. If relevant, recruits were asked to describe their physical condi-

*Aeromedical Center, Israel Air Force, Israel.
†Israel Defense Force Medical Corps, Israel.
This manuscript was received for review in November 1997. The revised manuscript was accepted for publication in June 1998.

tioning program before their induction. In addition, each recruit was asked to detail any competitive sport that he participated in within 1 year before his induction and at what level (i.e., local, national, or international) of performance. Based on the answers to these questions, an activity profile score was assigned. The activity profile score ranged from 1 to 5. A score of 1 indicated that the recruit did not participate in any physical conditioning program before induction. A score of 2 indicated that the recruit participated in a preparatory conditioning program but was not a competitive athlete. Scores of 3, 4, or 5 indicated that the recruit was active and had also competed in a sport on the local, national, or international level, respectively.

All recruits had free access to the base medical staff. All complaints concerning possible overuse injuries were recorded. The type of complaint, its location, and the treatment plan (days of rest or limited duty) were also noted. In instances in which clinical symptoms suggesting a stress fracture were apparent, the recruit was referred to an orthopedic surgeon for further evaluation and bone scintigraphy. All bone scans involved an intravenous dose of 20 mCi of ^{99m}Tc-methyldiphosphonate with imaging by an Elscint Dynmax camera (Elscint, Haifa, Israel). All scans were read using a grading system from 1 to 4.[18] Stress fracture was diagnosed when a focal area of increased uptake was found. Irregular areas of increased uptake were not considered to be indicative of stress fracture.

Statistical Analysis

Mann-Whitney *U* tests were used to compare the means of groups with and without stress fractures, clinical visits, and days of limited duty. χ^2 tests were used to determine the relative rate of risk for stress fracture in recruits who were 1 SD below the population mean in strength, relative strength, and endurance run time. In addition, the relative rate of risk for stress fracture was determined between recruits who were active (activity profile between 2 and 5) and those who were inactive (activity profile of 1) before their enlistment. Significance for all statistical analyses was set at $p \leq 0.05$. All data are reported as means ± SD.

Results

A total of 58 recruits (43%) visited the base clinic with complaints suggesting possible overuse injuries. These visits resulted in 32 of these recruits (24%) being placed on limited duty for periods ranging from 1 to 38 days. Twelve of these recruits (8.8%) were diagnosed with stress fractures, and several of them had multiple sites of injury. The locations and grades of these injuries are shown in Table I. The tibia had the highest incidence of injury (53%), followed by the foot (35%) and the femur (12%).

The activity profile and incidence of stress fracture for the recruits is shown in Table II. Eighty-two of the recruits (58.8%) did not participate in any physical conditioning program before their enlistment. Within this group, 11% of the recruits suffered stress fractures, accounting for the highest incidence of stress fractures seen (75% of all stress fractures). In addition, those recruits who were inactive before their induction accumulated significantly more days of limited duty than recruits who were physically active before induction. Within the group of recruits who were physically active before induction but not involved in competitive sports, 7% suffered stress fractures. Recruits who had a competitive sports background (9.6%) did not suffer any stress fractures during the present study period.

The relative risks for stress fractures in recruits who were 1 SD below the military recruit mean for strength, relative strength, endurance run time, and who were inactive before induction are shown in Table III. The means and SDs for absolute strength, relative strength, and endurance run time were 98.4 ± 38.6 kg, 1.72 ± 0.61 kg/kg of body weight, and 566 ± 98 seconds, respectively. Recruits who were 1 SD below the average in both strength and relative strength were at a significantly greater risk for stress fracture than the stronger recruits. Recruits who were not as aerobically fit did not appear to be at any greater risk for stress fracture than their more aerobically fit peers.

TABLE I

LOCATION AND GRADE OF STRESS FRACTURES

	Location of Injury		
Injury Grade	Foot	Tibia	Femur
I	2	5	1
II	1	2	0
III	2	2	1
IV	1	0	0
Total	6	9	2

Grade I: small, ill-defined lesion with mildly increased activity in the cortical region; grade II: larger than grade I, well-defined, elongated lesion with moderately increased activity in the cortical region; grade III: wide fusiform lesion with highly increased activity in the cortico-medullary region; grade IV: wide extensive lesion with intensely increased activity in the transcortico-medullary region.

TABLE II

ACTIVITY PROFILE AND INCIDENCE OF STRESS FRACTURES

	Activity Profile Level				
	1	2	3	4	5
Stress fracture	9	3	–	–	–
Total number of recruits per level	82	41	10	1	2
Recruits with stress fracture per level (%)	11	7	0	0	0

Activity Profile Level: 1, not active; 2, active; 3, active and competing in a sport at the local level; 4, active and competing in a sport at the national level; and 5, active and competing in a sport at the international level.

TABLE III

THE RISK OF LOW LEVELS OF STRENGTH, AEROBIC FITNESS, AND INACTIVITY ON THE INCIDENCE OF STRESS FRACTURES

	Risk Estimate	95% Confidence Interval
Activity profile	2.1	0.6–7.4
1RM leg press (kg)	4.7[a]	1.7–13.6
1RM leg press (kg/kg of body weight)	5.2[a]	1.8–14.7
2,000-m run time	1.9	0.6–6.6

[a] $p < 0.05$.

Discussion

The major findings of this study suggest that the weaker recruits, whose lower body strength was 1 SD below the population mean, were at a significantly higher risk for stress fractures than the stronger recruits. In addition, recruits who were physically active before their induction (activity profiles greater than 2) had significantly fewer days on limited duty during basic training than recruits who were not active before induction.

The incidence of stress fractures observed in this study (8.8%) was similar to that reported by Gofrit and Livneh.[6] The anatomical locations of these injuries were also similar to those reported in previous investigations,[4,7,8] with the tibia being the prevalent site of injury, followed by the foot and the femur. In addition, the percentage of recruits (43%) presenting symptoms of overuse injuries was similar to that reported by Milgrom et al.[4]

In support of previous studies,[4,6,8] our results indicate that preinduction inactivity and poor aerobic fitness are not factors that are significantly related to an increased risk for stress fracture. Interestingly, the results of this study did show that recruits who were inactive before their induction had a significantly greater number of days on limited duty and were at two times greater risk ($p > 0.05$) to suffer a stress fracture than active recruits. Although these results may represent the normal joint and muscle soreness frequently seen in novice trainees during the initial stages of a training program, or a process of remodeling in lower limbs subjected to a new stress, it should be examined further in future studies.

The ability of aerobic training to cause increases to bone mass is questionable. Although several studies have shown increases in bone mass subsequent to aerobic training,[19,20] others have reported no differences in bone mineral density between aerobically trained athletes and sedentary controls.[11,21] In addition, long-distance running may even result in a decrease in bone mineral density.[22] These inconsistent results support the findings of this and others studies, which failed to observe any relationship between aerobic fitness and the incidence of stress fractures.

The ability to maintain the proper training stimulus (e.g., intensity of the load, rate of force application, and direction of the force) appears to be the primary determinant for new bone formation.[23,24] The inconsistency seen in the literature concerning aerobic training and increases in bone mass may be partly related to the difficulty of maintaining a constant overload on the bone. During aerobic training, the overload to the bone may be restricted because of limitations by the individual's oxygen-transport system, and not by the muscular skeletal system.[23]

Resistance training may be the most effective mode of training for improving bone strength and increasing bone mineral density.[10,11,21] Adaptations to bone mass consequent to heavy resistance training appear to be quite responsive at a young age.[14] Elite adolescent weightlifters have been reported to have significantly greater strength levels and significantly greater bone mass than both age-matched controls and untrained adults with fully mature bones.[14] Considering that muscular strength has been shown to be related to bone mineral content[25] and that low bone mineral content is related to an increased incidence of stress fractures,[16] it would be expected that stronger recruits would be at a lower risk for stress fractures during basic training. This was the basis for the hypothesis behind this study. Surprisingly, studies by Finestone et al.[7] and Milgrom et al.[4] did not show any relationship between strength and the incidence of stress fractures in military recruits. However, several methodological problems may have confounded their results. Those investigators had used an isometric knee flexion as their strength measure. This may not have been an appropriate strength test because isometric strength is specific only at the joint angle tested and does not reflect the strength of the entire muscle mass measured. In contrast, a dynamic strength test using a structural exercise (an exercise that recruits several muscle groups) may have been a better test to reflect both muscle strength and bone mineral density. In addition, because of the large difference in subject number between groups and the wide range of strength in the noninjured group, a comparison of the means test was not appropriate because of the expected large variance. As such, we decided to direct our hypothesis slightly differently. We thought it more appropriate to examine whether weak recruits (those whose 1RM leg-press strength was 1 SD below the population mean) were at a greater risk for stress fractures than stronger recruits (within 1 SD of the mean). Our results confirmed this hypothesis by showing that poor lower body strength is associated with a significantly greater risk for stress fracture. For comparison purposes, we also examined strength levels between recruits with and without stress fractures and observed results similar to those reported in previous studies.

In conclusion, military recruits with greater lower body strength appear to be at lower risk for stress fractures during military training. This is probably related to increased bone mineral density associated with the greater strength levels. Future research should consider examining whether strength training during the early stages of military training can help reduce the incidence of stress fractures.

Acknowledgments

The authors gratefully acknowledge the technical and administrative contributions of the following individuals: Ronen Spiegle, M.D., Gabi Darmon, M.D., Dov Frank, and Karen Sela.

References

1. Jordaan G: The incidence of overuse injuries in military recruits during basic military training. Milit Med 1994; 159: 421-6.
2. Ross J: A review of lower limb overuse injuries during basic military training. 1. Types of overuse injuries. Milit Med 1993; 158: 410-5.
3. Bruduig TJB, Grudger TD, Obermeyer L: Stress fractures in 295 trainees: a one year study of incidence as related to age, sex and race. Milit Med 1983; 148: 311-3.
4. Milgrom C, Finestone A, Shlamkovitch N, et al: Youth is a risk factor for stress. J Bone Joint Surg Br 1994; 76: 20-2.
5. Sahi T: Stress fracture: epidemiology and control. Rev Int Serv Sante Forces Armees 1984; 57: 311-3.
6. Gofrit ON, Livneh A: Stress fracture of bone in conscripted infantry recruits: lack of correlation to pre-army physical fitness. Milit Med 1994; 159: 339-41.
7. Finestone A, Shalmkovitch N, Eldad A, et al: Risk factors for stress fractures among Israeli infantry recruits. Milit Med 1991; 156: 528-30.
8. Giladi M, Milgrom C, Danon YL: Stress fractures in military recruits. Med Corps Int 1988; 3: 21-8.
9. Milgrom C, Finestone A, Shlamkovitch N, et al: Stress fracture treatment. Orthop Int 1995; 3: 362-7.
10. Hamdy RL, Anderson JS, Whalen KE, et al: Regional differences in bone density of young men involved in different exercises. Med Sci Sports Exercise 1994; 26: 884-8.

11. Heinonen A, Oja P, Kannus P, et al: Bone mineral density of female athletes in different sports. Bone Miner 1993; 23: 1-14.
12. Karlsson MK, Johnell O, Obrant KJ: Bone mineral density in weight lifters. Calcif Tissue Int 1993: 52: 212-5.
13. Kannus P, Sievanen H, Jarvinen TLN, et al: Effects of free mobilization and low- to high-intensity treadmill running on the immobilization-induced bone loss in rats. J Bone Miner Res 1994; 9: 1613-9.
14. Conroy BP, Kraemer WJ, Maresh CM, et al: Bone mineral density in elite Junior Olympic weightlifters. Med Sci Sports Exercise 1993; 25: 1103-9.
15. Lohman T, Going S, Pamenter R, et al: Effects of resistance training on regional and total bone mineral density in premenopausal women: a randomized prospective study. J Bone Miner Res 1995; 10: 1015-24.
16. Myburgh KH, Hutchins J, Fataar AB, et al: Low bone density is an etiologic factor for stress fractures in athletes. Ann Intern Med 1990; 113: 754-9.
17. Durnin JV, Wormersley J: Body fat assessed from total body density and its estimation from skinfold thickness: measurements on 481 men and women aged 16 to 72 years. Br J Nutr 1974; 32: 77-97.
18. Zwas ST, Elkanovitch R, Frank G: Interpretation and classification of bone scintigraphic findings in stress fractures. J Nucl Med 1987; 28: 452-7.
19. Lane ST, Bloch A, Jones HH, et al: Long distance running, bone density and osteoarthritis. JAMA 1993; 55: 1147-51.
20. Wolman RL, Faulman L, Clark P, et al: Different training patterns and bone mineral density of the femoral shaft in elite female athletes. Ann Rheum Dis 1991; 50: 487-9.
21. Heinrich CH, Going SB, Pamenter RW, et al: Bone mineral content of cyclically menstruating female resistance and endurance trained athletes. Med Sci Sports Exercise 1990; 22: 558-63.
22. Bilanin JE, Blanchard MS, Russek-Cohen E: Lower vertebral bone density in male long distance runners. Med Sci Sports Exercise 1989; 21: 66-70.
23. Conroy BP, Earle RW: Bone, muscle and connective tissue adaptations to physical activity. In Essentials of Strength Training and Conditioning, pp 51-66. Edited by Baechle TR. Champaign, IL, Human Kinetics, 1994.
24. Rubin CT, Lanyon LE: Regulation of bone formation by applied dynamic loads. J Bone Joint Surg Am 1984; 66: 397-402.
25. Snow-Harter C, Bouxsein M, Lewis B, et al: Muscle strength as a predictor of bone mineral density in young women. J Bone Miner Res 1990; 5: 589-95.