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Risk Factors for Recurrent Stress Fractures in Athletes

Raija Korpelainen,*†‡ MSc, Sakari Orava,§ MD, PhD, Jarmo Karpakka,*‖ MD, PhD, Pertti Siira,[a] PT, and Antero Hulkko,[b] MD, PhD

*From the *Department of Sports Medicine, Oulu Deaconess Institute, the †Department of Physiology, University of Oulu, Oulu, §Tohtoritalo Hospital, Turku, ‖Kainuu Central Hospital, Kajaani, the [a]Department of Physiatric Medicine and Rehabilitation, Pohjois-Pohjanmaa Central Hospital, Oulu, and the [b]Department of Surgery, Keski-Pohjanmaa Central Hospital, Kokkola, Finland*

ABSTRACT

Our aim was to identify factors predisposing athletes to multiple stress fractures, with the emphasis on biomechanical factors. Our hypothesis was that certain anatomic factors of the ankle are associated with risk of multiple stress fractures of the lower extremities in athletes. Thirty-one athletes (19 men and 12 women) with at least three separate stress fractures each, and a control group of 15 athletes without fractures completed a questionnaire focusing on putative risk factors for stress fractures, such as nutrition, training history, and hormonal history in women. Bone mineral density was measured by dual-energy x-ray absorptiometry in the lumbar spine and proximal femur. Biomechanical features such as foot structure, pronation and supination of the ankle, dorsiflexion of the ankle, forefoot varus and valgus, leg-length inequality, range of hip rotation, simple and choice reaction times, and balance in standing were measured. There was an average of 3.7 (range, 3 to 6) fractures in each athlete, totaling 114 fractures. The fracture site was the tibia or fibula in 70% of the fractures in men and the foot and ankle in 50% of the fractures in women. Most of the patients were runners (61%); the mean weekly running mileage was 117 km. Biomechanical factors associated with multiple stress fractures were high longitudinal arch of the foot, leg-length inequality, and excessive forefoot varus. Nearly half of the female patients (40%) reported menstrual irregularities. Runners with high weekly training mileage were found to be at risk of recurrent stress fractures of the lower extremities.

‡Address correspondence and reprint requests to Raija Korpelainen, MSc, Department of Sports Medicine, Oulu Deaconess Institute, Isokatu 43, 90100 Oulu, Finland.

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Although stress fractures are common in athletes, accounting for as much as 10% of all sports overuse injuries,[30] the risk factors for recurrent stress fractures have not as yet been carefully outlined, and the prevention of such injuries has proven to be difficult. The incidence of stress fractures is also increasing among recreational exercisers. People today are more concerned about physical fitness and, with the increasing popularity of running, stress fractures of the lower extremity, especially the tibia, ankle, and foot, have become common.[12]

There are many causes of stress fractures, including both intrinsic and extrinsic factors. Many characteristics have been implicated as possible risk factors, including age,[32] sex,[18,36] skeletal alignment,[17,29] low bone density,[3,4] hormonal factors,[3,4,7,11] training parameters, and footwear.[1,31] The origin of fatigue fractures of the lower extremities in athletes and military recruits is assumed in many cases to be biomechanical, with the forces acting on one element of the human locomotor system exceeding the critical limits. According to previous studies, biomechanical factors that may predispose athletes to stress fracture are a narrow tibia, a high degree of external rotation of the hip,[13,17] varus alignment in the ankle and forefoot,[29] hyperpronation of the ankle,[40] high longitudinal arch of the foot,[29] and leg-length discrepancy.[10,14]

Although stress fractures are common in athletes, recurrent stress fractures in the same athlete are a rare occurrence. To identify factors that predispose athletes to recurrent stress fractures of the lower extremities, we compiled and analyzed the data of a series of 31 athletes with at least three separate stress fractures of the lower extremities. Our emphasis in this study was on biomechanical factors.

MATERIALS AND METHODS

A series of 34 consecutive athletes with at least three separate stress fractures of the lower extremities was gathered from a series of 12,150 patients treated in the Department of Sports Medicine of the Oulu Deaconess Institute during the years 1972 through 1995. The cases studied were restricted to athletes in whom the diagnosis had been confirmed by a positive radiograph or a positive scintigram. Consecutive fractures in the same bone were classified as separate fractures if the healing of the former fracture had been confirmed by a radiograph or a scintigram. Bilateral fractures and concurrent metatarsal fractures were classified as separate fractures. Thirty-one (19 men and 12 women) of the 34 patients were available for the study, and 15 (9 men and 6 women) of them were willing to participate in the biomechanical measurements. The group of 15 patients did not differ by age, sex, body mass index, or sport distribution from the original 31 patients. Three patients could not be reached.

The mean age of the injured athletes was 20 years at the onset of the first fracture, with the women being significantly younger than the men (18 years versus 21 years). The mean body mass index was 18.8 in women and 20.7 in men. Nineteen of the patients (61%) were long-distance runners. There were few representatives of the other events, including sprinting, jumping, skiing, orienteering, ice hockey, weight lifting, and squash. The distribution of multiple stress fractures according to sports events in athletes is presented in Table 1. All the runners, except for two, were or had been competing at a national or international level. The runners trained 4 to 14 times per week and on average they ran 117 km per week (30 to 200 km). The representatives of other events had 3 to 14 training sessions per week.

A control group of 15 athletes who were treated in the same clinic for other lower extremity symptoms and who were matched by sex, age, body mass index, and sports event was formed.

All 31 patients and 15 control subjects completed a questionnaire on their demographic features, handedness, fractures, height, weight, training history (sports event, intensity and frequency of training, and, in runners, mileage at the time of injury), dietary history, hormonal history in women, consumption of alcohol and cigarettes, and general state of health. The patients were asked to recall these features from the time of the occurrence of the fractures, and they also sent us their training and food diaries. In addition, all participants were asked the same questions 3 months later either in the clinic or by telephone interview. The women were classified by hormonal status as amenorrheic (0 to 3 periods per year), oligomenorrheic (4 to 9 periods per year), or eumenorrheic (10 to 13 periods per year).[34] Body mass index was calculated by dividing weight in kilograms by the square of the height in meters. The age of the patient at the onset of each fracture was calculated.

Bone mineral density measurement (in grams per square centimeters) was performed in the lumbar spine (L2 to L4), the right femoral neck, the greater trochanter, and Ward's triangle by dual-energy x-ray absorptiometry (Dexa, Lunar Corporation, Madison, Wisconsin). The scanner was calibrated daily. Leg-length inequality of the subjects was measured radiologically in a standardized, supported erect stance as the difference between the heights of the superior surfaces of the femoral heads. The radiology nurse on duty confirmed that the patient was leaning correctly on the support with no flexion at the knee and ankle. The angle seen on the radiograph between the femoral neck and the femoral shaft was measured. All these measurements were performed by experienced nurses under the guidance of a radiologist.

The analysis of the foot structure was performed using a podoscopic mirrored table and special devices (Karhu Titan Company, Helsinki, Finland), and the results were recorded on a standardized registration form.[19,20] This method and its reliability have been reported in detail previously.[25] Briefly, we analyzed the structure of the longitudinal arch of the foot by obtaining a pedogram (footprint) on a mirrored table and then classifying the foot type as normal, pes cavus, or pes planus. We also measured the varus angle of the forefoot in a nonweight-bearing position, the pronation of the ankle in bipedal standing and squatting (the knees flexed 45°) positions, and, finally, the passive dorsiflexion of the ankle in a unipedal squatting position. The range of hip rotation was measured using a standard plastic goniometer. The reliability and the reproducibility of the method has been reported before.[6] These measurements were performed by the same physical therapist.

The protocol for the motor performance measurement and the reliability of the method have been described in detail previously.[2,22] In brief, to record motor performance characteristics of the lower extremities, a computerized Human Performance Measurement/Basic Elements of Performance 2 device (HPM/BEP) (Human Performance Measurement, Inc., Arlington, Texas) was used. The HPM/BEP 2 device is a multifunctional system designed to measure the following aspects of motor performance of lower extremities: reaction time, movement speed, foot tapping, synergy of different muscle groups, and accuracy.

TABLE 1
Distribution of Multiple Stress Fractures According to Sports Events in Athletes

Sports event	Women	Men	Total
Long-distance running	7	12	19
Sprinting	2	0	2
Jumping	1	2	3
Orienteering	1	1	2
Cross-country skiing	1	0	1
Power events	0	1	1
Ball games	0	3	3
Total	12	19	31

Statistical Analysis

Statistical analysis was performed with the Statistical Package for the Social Sciences (SPSS Inc., Chicago, Illinois). The Mann-Whitney test was used to compare the values of the patients with those of the control subjects and also when comparing the statistical significance of the difference between the values of the women and the men. Cross-tabulation and the chi-square test were used to analyze the difference between the sexes in the stress fracture incidence by bone and by sports event. The Wilcoxon signed rank test was used to compare the left side with the right side for each patient. The relationship between leg dominance and leg-length inequality was analyzed by using cross-tabulation and the chi-square test. Analysis of variance was used to compare the association between the structure of the longitudinal arch of the foot and the number of fractures.

RESULTS

The average number of stress fractures in each patient was 3.7, yielding a total of 114 stress fractures among the group of 31 patients. Sixteen athletes had sustained 3 fractures; 10 athletes, 4 fractures; 4 athletes, 5 fractures; and 1 male high jumper sustained 6 separate stress fractures. The distribution of fractures according to anatomic location in both sexes is presented in Table 2. A quarter of the fractures were located in the tarsal and metatarsal bones, followed in frequency by the distal and proximal parts of the tibia (17.5% each). The fracture site was the tibia or fibula in 70% of the fractures in men and the foot and ankle in 50% of the fractures in women. The difference in the distribution of the fractures between the sexes was statistically significant ($P < 0.01$). In the endurance runners, more than half of the fractures were located in the tibia or fibula; in the jumpers, 70% of the fractures were located in the tibia or fibula; and in orienteers, all of the fractures were located in the tibia or fibula (Table 3).

TABLE 2
Distribution of Multiple Stress Fractures According to Anatomic Location in Both Sexes

Location	Women		Men		Total	
	N	%	*N*	%	*N*	%
Metatarsal	15	34.1	13	18.6	28	24.6
Calcaneus	2	4.5	0	0.0	2	1.8
Tarsal	5	11.4	3	4.3	8	7.0
Tibia						
Distal third	7	15.9	13	18.6	20	17.5
Middle third	4	9.1	11	15.7	15	13.2
Proximal third	4	9.1	16	22.9	20	17.5
Fibula						
Distal third	2	4.5	5	7.1	7	6.1
Middle third	1	2.3	3	4.3	4	3.5
Proximal third	0	0.0	1	1.4	1	0.9
Femur						
Distal third	1	2.3	0	0.0	1	0.9
Middle third	0	0.0	0	0.0	0	0.0
Proximal third	1	2.3	3	4.3	4	3.5
Pubic bones	2	4.5	2	2.9	4	3.5
Total	44	100.0	70	100.0	114	100.0

In 83% of the cases, a leg-length inequality of at least 1 mm was established. The mean leg-length discrepancy in patients was 4.9 mm (range, 0 to 18); in controls, it was 3.6 mm (range, 0 to 8). The stress fracture was found more often in the shorter leg (49%) than in the longer one (38%). All the male patients had a leg-length discrepancy of at least 2 mm, averaging 7.1 mm (range, 2 to 18). In women with unequal leg lengths, the mean difference between the right and the left leg was 2.8 mm (range, 0 to 8). This sex difference was not statistically significant. The right side was involved in 63% of the cases, with injury occurring in the dominant leg more often (60%) than in the nondominant leg.

The characteristics of the hip, ankle, and foot structures of the patients and control subjects are presented in Table 4. A high longitudinal arch of the right foot was present more often in the patients (40%) than in the control subjects (13%). The patients in whom the forefoot varus exceeded 10° ($N = 3$) had sustained at least four separate fractures. There was no significant difference between the patients and the control subjects in external rotation of the hip and the angle between the shaft and the neck of the femur. Nor was there a difference between the groups in the balance and reaction times measured by the HPM/BEP device (Table 5).

There was no association between body mass index and the number of fractures in patients. The menstrual history was available in 10 of the 12 female athletes. Six of them had always menstruated regularly while four (40%) reported menstrual irregularities. Three women suffered from amenorrhea, two of whom had primary amenorrhea (never menstruated). The two women with primary amenorrhea were 26 and 27 years old, respectively, and were diagnosed as osteoporotic (bone mineral density ≤ -2.5 SD from the reference value). The third woman did not come in for biomechanical and bone mineral density measurements. In the control group there was 1 oligomenorrheic woman and 14 eumenorrheic women. The bone mineral density measurements were taken in six female patients and six control subjects. The results are presented in Table 6. There was no difference in the mean bone mineral density values between the patients and the controls.

One hundred seven fractures were treated nonoperatively, and seven fractures required surgical intervention.

DISCUSSION

The patient group in this study represents a population of athletes and keep-fit athletes from Northern Finland. According to previous studies on stress fractures, the origin of stress fractures in athletes is multifactoral. Although several of these factors have been assessed in large cross-sectional and prospective studies in military recruits, the results in military personnel cannot be generalized to athletes because of differences in training, footwear, and the initial fitness level.[17,33] Moreover, there are no studies

TABLE 3
Distribution of Multiple Stress Fractures by Sports Event According to Anatomic Location

Bone	Sports event								
	Long-distance running	Sprinting	Jumping	Orienteering	Skiing	Power events	Ball games	Total *N*	Total %
Metatarsal	20	3	2	0	0	1	2	28	24.6
Calcaneus	2	0	0	0	0	0	0	2	1.8
Tarsal	5	2	1	0	0	0	0	8	7.0
Tibia									
Distal third	11	1	0	0	3	2	3	20	17.5
Middle third	7	1	4	0	0	0	3	15	13.2
Proximal third	12	0	2	6	0	0	0	20	17.5
Fibula									
Distal third	5	1	0	1	0	0	0	7	6.1
Middle third	2	0	1	0	0	0	1	4	3.5
Proximal third	1	0	0	0	0	0	0	1	0.9
Femur									
Distal third	1	0	0	0	0	0	0	1	0.9
Middle third	0	0	0	0	0	0	0	0	0.0
Proximal third	4	0	0	0	0	0	0	4	3.5
Pubic bones	3	0	0	0	0	0	1	4	3.5
Total	73	8	10	7	3	3	10	114	100.0

TABLE 4
Characteristics of the Hip, Ankle, and Foot Structures of Patients and Control Subjects[a]

Variable	Patients		Control subjects	
	Right leg	Left leg	Right leg	Left leg
Hip joint				
External rotation (deg)				
Active	33 (20–42)	37 (25–48)	34 (25–47)	37 (30–50)
Passive	41 (29–51)	43 (30–55)	43 (32–57)	41 (35–53)
Internal rotation (deg)				
Active	33 (24–44)	30 (21–38)	32 (17–43)	30 (23–38)
Passive	40 (28–49)	38 (27–49)	39 (28–49)	37 (28–44)
Shaft-neck angle (deg)	130 (120–140)	130 (120–140)	130 (110–140)	130 (110–140)
Forefoot varus (deg)	6 (0–24)	6 (0–21)	3 (0–14)	5 (−3–12)
Ankle				
Pronation (deg)	6 (3–14)	7 (3–13)	6 (3–14)	7 (0–14)
Dorsiflexion/passive (deg)	38 (25–45)	38 (24–46)	40 (32–48)	40 (33–50)
Structure of the longitudinal arch (No. of patients)				
Pes planus	2	2	1	2
Normal	7	7	12	9
Pes cavus	6	6	2	4

[a] Data based on 15 patients and 15 control subjects. Values are mean (range) unless otherwise indicated.

available on the risk factors for multiple stress fractures in either military or sporting personnel.

This study showed a significant difference between men and women regarding the age at which stress fractures occur, with women being younger when sustaining the fractures. However, the fractures occurred during the most active period of their athletic career for both men and women, so perhaps it was not the age that was the risk factor but the intensity of training. The athletes with multiple stress fractures sustained their first fracture at approximately 20 years of age.

The present study shows that runners are prone to stress fractures. This is in agreement with most of the other surveys of stress fractures in athletes.[29,35,43] In the present study, there was great variation in the extent of training among the patients in the series. However, there was no association between the weekly running mileage and the frequency of fractures. Furthermore, some runners had sustained their multiple fractures with only a moderate amount of training. This is also in agreement with the findings of a previous study.[37] According to another study,[8] an increase in training mileage correlated with an increase in stress fractures. Little is known of other aspects of the training regimen except running mileage in athletes. Unfortunately, we were not able to retrospectively collect exact data concerning the weekly training of all the present athletes. It seems evident that factors other than simply running mileage are more important in determining the risk of stress fractures in runners. Most of the biomechanical factors that were included in this study have been previously suggested to be risk factors for single stress fractures.

TABLE 5
Motor Performance Characteristics in Athletes with Multiple Stress Fractures and in Control Subjects

Variable	Patients (N = 15)		Control subjects (N = 15)	
	Right leg	Left leg	Right leg	Left leg
	Mean (range)	Mean (range)	Mean (range)	Mean (range)
Reaction time				
Simple (ms)	217 (250–188)	232 (434–204)	222 (250–188)	222 (263–188)
Choice (ms)	312 (454–243)	333 (416–270)	312 (416–263)	322 (370–294)
Speed of movement				
Foot tapping (taps/s)	6.0 (4.7–7.1)	5.7 (4.4–6.8)	5.7 (3.7–7.7)	5.6 (3.5–6.8)
Speed of lateral movement (m/s)	1.8 (1.5–2.0)	1.7 (1.4–2.0)	1.8 (1.3–2.1)	1.7 (1.2–2.0)
Accuracy of lateral movement (bits/s)	6.6 (5.7–7.5)	6.3 (4.8–8.2)	6.7 (4.9–8.8)	6.3 (4.1–8.2)
Balance in standing on one foot (stability-%)	93 (87–96)	93 (86–96)	94 (91–95)	93 (90–96)

TABLE 6
Body Mass Index and Bone Mineral Density in Female Athletes with Multiple Stress Fractures and in Control Subjects

Variable	Patients (N = 6)	Control subjects (N = 6)
	Mean (range)	Mean (range)
Body mass index	18.8 (15.2–20.7)	20.3 (18.3–21.5)
Bone mineral density (g/cm^2)		
L2-L4	1.214 (0.904–1.428)	1.134 (1.106–1.224)
Percentage of reference value	101 (76–116)	99 (95–102)
Femoral neck	1.037 (0.934–1.126)	1.004 (0.941–1.133)
Percentage of reference value	108 (98–119)	109 (99–118)

According to a previous study,[17] a high degree of external rotation of the hip might be a risk factor for tibial stress fractures. Increased femoral anteversion in a closed kinetic chain is combined with external proximal tibial torsion. This may result in compensatory hyperpronation of the foot, which has been found particularly in women with a wider pelvis.[23] We measured both the hip rotation and the angle between the neck and the shaft of the femur and found no evidence to support the relationship between hip rotation and fractures.

Results of studies focusing on the relationship between the foot type and stress fractures in either military recruits or athletes have been contradictory.[3,21,29,38] A foot with a high longitudinal arch (pes cavus) is known to be more rigid, with reduced shock absorbing capacity, whereas a more flexible type of foot (pes planus) allows less force to be passed to the tibia and femur.[27,39] In contrast with that finding, one study has revealed that the presence of pes planus is often associated with prolonged pronation or hyperpronation, which may contribute to muscle fatigue and excessive torsion of the tibia.[5] Pes cavus may also be associated with an internally rotated tibia vara and prolonged pronation of the foot, and this combination could, at least theoretically, be most unfortunate when considering stress fractures.

A methodologic problem in some previous studies is that the assessment of the foot type was based on observation of subjects in a nonweightbearing position, which leads to underestimating the frequency of pes planus. It is essential to observe the foot in a functional position to get an idea of its function during locomotion, particularly since we know that the vertical ground-reaction forces increase from 70% to 80% of body weight during walking and from 275% to 300% during running.[26] In the present study, we evaluated the structure of the longitudinal arch and the degree of pronation in subjects in a standing and squatting position, and we found no statistically significant differences between the two groups.

A cavus type right foot was found in 40% (N = 6) of the injured athletes, compared with 13% (N = 2) of the control subjects, and the majority of the fractures occurred in the right leg. This may imply that a high longitudinal arch is a risk factor for multiple stress fractures, but the present sample size is too small to demonstrate statistically significant differences. We found no significant difference in the degree of forefoot varus between the fracture and control groups. The range of varus was much larger in the injured athletes than in the control subjects. All patients with measurements exceeding 10° had sustained at least four fractures.

Leg-length inequality was found to be present significantly more often in the patient group than in the control group. This has been noted previously in military recruits.[15] We further studied the relationship between the frequency of fractures and the degree of leg-length discrepancy and found no relationship. Moreover, in the male jumper with six fractures, the legs were equal in length. We found that stress fractures occurred with equal frequency in both the shorter and longer leg, which is in agreement with findings from a previous study.[3] This can be explained by alterations in the biomechanics of both the shorter and the longer leg during locomotion. In a majority of the cases (60%), the fracture was located in the dominant leg, which may be explained by a greater use of this limb. However, there was no correlation between the number of fractures and limb dominance, although it has been suggested that limb dominance is a risk factor for stress fractures of the lower extremity.[13] In many patients, the fracture side varied, and sometimes fractures were located in both legs simultaneously.

Young female athletes who train intensely are at risk of developing menstrual disturbances and consecutive stress fractures.[3,4,9,16,28,34,44] Bennell et al.[4] found a history of stress fractures in nearly half of the female track and field athletes they studied, and those with fractures were more likely to have delayed menarche, a history of menstrual irregularities, and low bone mineral density. The results from the studies that have focused on the association between low bone mineral density and stress fractures in female military recruits or athletes are contradictory.[4,11,16,24,34] Although our female fracture group was small, it is still notable that in such a small group there were two women with remarkably decreased bone mineral density.

The normative bone mineral density values have been collected in the general population, but there are no normative values specific to athletes. In one study it has been suggested that the level of bone density required by physically active people for bone health may be greater than that required by the general population, and that people at risk of stress fracture cannot be identified as being at risk based on normal dual-energy x-ray absorptiometry values.[3] The authors of that study suggest that bone density tests should have a place as a general screening tool to predict the risk of stress fracture in female athletes with multiple stress fracture episodes and menstrual disturbances, and that for more general screening, normative specific values for athletes of different sports should be provided. This is a suggestion we agree with. Our study did not reveal any association between stress fractures and bone mineral density values. However, the range in lumbar spine bone mineral density values in the fracture group was higher than in the control group.

The association between motor performance characteristics and stress fractures has not been studied previously. Taimela et al.[41,42] found in their studies that a long reaction time is associated with musculoskeletal complaints in young men and adolescent athletes. We found no significant differences between the groups in speed, accuracy, or balance. Nor was there a difference between the right and left limbs in the fracture group. It seems that mechanical factors are of more importance in athletes with recurrent stress fractures.

In conclusion, runners with a high weekly training mileage are at a high risk of recurrent stress fractures of the foot and shin. Leg-length inequality, a high longitudinal arch of the foot, forefoot varus, and menstrual irregularities may also be etiologic factors for recurrent stress fractures. An extensive, inexpensive analysis of the locomotor system may help to identify potential problems. Malalignment of the skeleton may be the origin of acute or even worse chronic injuries. Based on the knowledge currently available, this problem cannot be neglected and preventive analysis is suggested.

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