FOOT PRONATION AND STRESS FRACTURES OF THE FEMUR AND TIBIA: A PROSPECTIVE BIOMECHANICAL STUDY

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The relation between foot pronation and stress fractures has been suggested. However, evidence based literature is lacking and contradictory. The purpose of this study was to examine whether dynamic parameters of foot pronation are related to the development of stress fractures of the femur and tibia. 2 weeks prior to beginning of 14 weeks of basic military training, 473 infantry recruits were inrolled into the study. 2D analysis was performed to measure foot pronation during treadmill walking. The soldiers were examined during the training course at two weeks intervals for stress fractures. The odds ratio was calculated for each dynamic pronation parameter in relation to the stress fractures. 10% of the 405 soldiers who finished the training were diagnosed with stress fractures of the femur and tibia. Longer pronation time was related to risk reduction for the development of stress fractures and may have a protective effect during an extended period of training.

KEY WORDS: Subtalar joint, Stance phase, Stress fracture, Foot pronation

INTRODUCTION:

Despite an increased focus on the prevention of running injuries, overuse injuries are still rather frequent. Stress fractures of the lower extremity are disturbing overuse injury of young healthy athletic populations, affecting primarily runners (1,2). Infantry recruits frequently serve as a classic model for the investigation of this injury (3,4,5), as they are subjected to continuous physical efforts (mainly walking and running) during their training programs, and manifest similar incidence and distribution of stress fractures as those found in sports clinics.
Despite their high incidence, the etiology is not completely resolved. Foot pronation, occurring primarily at the subtalar joint, has been suggested to be associated with stress fractures. The rationale for this hypothesis is based on the assumption that pronation through the subtalar joint is important in attenuating lower limb acceleration created by the ground reaction force (6). Additionally, as pronation through the subtalar joint is coupled with internal rotation of the tibia during the first half of the stance phase, abnormality in this motion may produce abnormal tibial torsion torques, resulting in abnormal stresses along the entire lower limb (7,8). However, despite these apparent rational assumptions the literature is contradictory regarding the association between foot pronation and these injuries.
The purpose of this prospective study among a population of military infantry recruits is to study the hypothesis that there is a relationship between dynamic parameters of foot pronation and the development of stress fractures of the femur and tibia.

METHODS:

This study included 473 military infantry male recruits, all aged 18 yr, which were examined two weeks prior to the commencement of 4-month basic training. 2-D measurement of the subtalar joint displacement angle was performed as a measure of foot pronation.(9). All soldiers were filmed at 60 Hz, walking barefoot on a treadmill. Measurements were performed at 5 kmh^{-1}, a velocity which represents mean velocity chosen for the majority of all strenuous long distance marching (40- 90 km) during the basic training period. Four reflective markers were placed on the posterior aspect of the leg and foot after identifying clinically the level of subtalar motion. The inferior two markers, representing the rearfoot segment, were placed distal to the level of subtalar motion - the most distal marker at the tuber calcani, and the other marker placed 1 cm distal to the level of subtalar motion. The superior two markers, representing the leg segment, were placed 2 and 8 cm proximal to the level of subtalar motion, in the midline of the Achilles. The angle formed between the rearfoot and leg segments represented the subtalar joint displacement angle, i.e the foot pronation angle. Five dynamic parameters were used to measure foot pronation during the stance phase : bilateral maximal foot pronation angle(degree), pronation range of motion (degree), time to maximum pronation from heel strike (seconds), pronation mean angular velocity (degree/seconds), and time to maximum pronation as a percent of total stance time (%). The measurements were made using the computerized Ariel Performance Analysis System. For each subject, the mean value of four walking strides for each pronation parameter was selected for analysis. Soldiers were examined for the presence of stress fractures and other lower limb injuries every two weeks during their 4-month basic military training. All examinations were done by a single orthopedic surgeon. Diagnosis of stress fracture was considered positive only when proven by x-ray or scintigraphy.

In order to assess the risk of stress fracture associated with each of the five dynamic parameters of foot pronation, subjects were divided into three sub-groups. The first group (Q1) was defined as the lower quartile, i.e. all subjects with the lower 25% values of the measured parameter. The middle-group (IQR) included subjects with values within the inter-quartile range, and the third group (Q4) included those with values in the upper quartile. The classification was based on the mean value of four consecutive walking cycles and was applied separately to the right and left lower extremities for each parameter. An increased risk for injury or conversely, a protective effect from injury, was expected to be manifested in a significant odds ratio (OR) of injury incidence between an extreme group and the middle-group or between the two extreme groups.

RESULTS:

Of the 405 subjects who were in the final analysis, 42 (10%) had diagnosed stress fractures of the femur and tibia. Among those who did not suffer stress fractures, 49 were diagnosed with other lower extremity injuries (i.e, Achilles tendinitis, plantar fasciitis, exertional anterior knee pain, ankle sprain, etc.). These subjects were excluded from the computation of the ORs. This procedure ascertained that risk factors for stress fracture were assessed in relation to healthy status, or at least in relation to undiagnosed status. Injured and non-injured subjects did not differ significantly in BMI (means = 21.8±3.5 and 22.2±2.7 respectively, p=0.52). Limb length difference did not exceed 1.5 cm in any of the subjects.

Descriptive statistics of the pronation parameters are presented in table 1. The 25th and 75th percentiles define the cut off values between Q1 and IQR and between IQR and Q4, respectively. Intraclass correlation coefficients (ICC) for these parameters over four cycles ranged between 0.74 and 0.96, indicating acceptable reliability.

Table 1 Descriptive statistics of the pronation parameters

	R			L		
Variable	Mean±sd	P_{25}	P_{75}	Mean±sd	P_{25}	P_{75}
Max. pronation angle (degree)	8.3±4.4	5.5	10.9	6.9±4.2	4.6	9.6
Pronation range of motion (degree)	7.8±2.5	6.0	9.2	7.8±2.6	6.0	9.1
Time to max.pronation (sec)	0.17±0.06	0.13	0.20	0.17±0.06	0.13	0.20
Pronation velocity +deg/sec)	49.4±20.1	33.5	62.7	49.7±21.6	33.4	62.0
Time to max. pronation / stance time +%)	29.8±10.4	22.2	34.1	29.5±10.2	21.8	34.4

The incidence of stress fractures in the three groups is presented as percentage in table 2. The ORs are presented in table 3. None of the ORs was significant neither for pronation angle nor for pronation range of motion. However, longer pronation time was associated with reduced risk for stress fracture in both lower extremities. Although the OR of 0.47 between

Q4 and Q1 on the left side, indicating risk reduction, did not reach statistical significance as the upper limit at 95% confidence interval exceeded the value of 1, the same trend of risk reduction for stress fracture was found in the other ORs of pronation time, and its size indicates a practically significant reduction in risk. These observations were further supported by the ORs for the relative pronation time as a percent of the stance time. The ORs to develop stress fracture as well as the 95% confidence interval limits were all below than 1 and statistically significant, implying that patients with longer pronation time as percent of the total stance time had lower odds to develop stress fracture. As for pronation velocity on the left foot, significant higher OR to develop stress fracture was demonstrated in Q4 compared to Q1 and borderline significant OR in Q4 compared to the IQR groups. However, these trends were not supported by the data of the right foot.

Table 2 Stress fracture incidence as percentage of the subgroups (%)

	R			L		
VARIABLE	Q1	IQR	Q4	Q1	IQR	Q4
Max. pronation angle (degree)	12.0	17.2	14.9	11.0	11.3	14.9
Pronation range of motion (degree)	11.4	12.1	13.1	12.9	10.2	15.3
Time to max. pronation (sec)	10.7	16.6	5.4	18.5	13.7	2.3
Pronation velocity (deg/sec)	4.3	17.1	10.8	5.7	11.4	20.5
Time to max. pronation / stance time (%)	13.3	16.0	4.3	20.7	12.9	2.3

Table 3 Odds ratios between groups and 95% confidence interval for stress fractures. Significant ORs are marked in bold

		R			L		
VARIABLE	Groups	OR	Lower limit	Upper limit	OR	Lower limit	Upper limit
Max. pronation angle (degree)	Q4 vs. Q1	1.53	0.66	3.55	1.38	0.65	2.92
	Q4 vs. IQR	1.97	0.92	4.20	1.42	0.57	3.54
Pronation range of motion (degree)	Q4 vs. Q1	1.18	0.47	2.93	1.21	0.51	2.89
	Q4 vs. IQR	1.10	0.50	2.40	1.58	0.74	3.41
Time to max. pronation (sec)	Q4 vs. Q1	0.47	0.15	1.47	**0.11**	0.02	0.47
	Q4 vs. IQR	**0.29**	0.11	0.77	**0.15**	0.03	0.65
Pronation velocity (deg/sec)	Q4 vs. Q1	2.71	0.80	9.14	**4.22**	1.48	12.05
	Q4 vs. IQR	0.59	0.27	1.31	2.01	0.99	4.08
Time to max. pronation / stance time (%)	Q4 vs. Q1	**0.29**	0.09	0.95	**0.09**	0.02	0.40

DISCUSSION:

In the current study we used a large size homogeneous sample (i.e, sex, age, BMI) of a classical model for lower limb overuse injuries (the young healthy military recruit), and followed prospectively each subject during an extended period of extreme physical effort. All subjects were subjected to the same effort, and were examined by the same single orthopedic surgeon. In addition, they wore the same shoe design, thereby eliminating different shoe construction and viscoelastic properties as possible confounders. They were filmed prior to the commencement of their basic training, walking barefoot on a treadmill at a velocity which represented the mean velocity chosen for the majority of the most strenuous and long-endurance efforts taking place during the basic training period. We believe these efforts (i.e. long distance marching and running), as a repetitive trauma to the lower limbs, contribute a significant part to the external etiologic factors responsible for the development of stress fractures. The measurements were performed while barefoot and not with shoe-on, as we assumed that any difference in foot pronation among the subjects while walking with their shoes during the training, should be related mostly to inherent foot characteristics, since shoe design was similar. In addition, we thought that placing markers on the shoes would not reflect the true foot motion inside the shoes.

In our study, neither maximum pronation angle, nor pronation range of motion were found to be associated with risk of stress fracture. However, a different picture was seen regarding time taken to maximum pronation. A protective effect for subjects who were characterized by a longer time to maximum pronation, as well as a higher value of time to maximum pronation as a percent of the total stance time, is indicated by a significantly lower odds to develop a stress fracture among subjects who belong to the upper quartile (Q4) than the odds among those who belong to the other three quartiles. As for the time to maximum pronation, the odds of experiencing a stress fracture among those in the upper quartile were only 11% - 47% of the odds among those in the other three quartiles. Similarly, with regard to time to maximum pronation relative to stance time, the odds of experiencing a stress fracture among those in the upper quartile were only 9%-29% of the odds among those in the other three quartiles. As for pronation angular velocity, since it is a range of motion divided by time, and since the odds of injury were not different for the range of motion subgroups, the single significant OR for mean pronation velocity and the trend for two other high ORs may reflect the association between injury risk and time to maximum pronation. A significant OR between Q4 and Q1 and a borderline significant OR between Q4 and the IQR groups on the left foot, is in line with the notion that higher mean pronation velocity is a risk factor for stress fractures. However, these trends are not supported by the data of the right foot. It is quite possible that higher pronation velocity is not by itself a significant risk factor for stress fracture, and that time taken to maximum pronation as a percent of the total stance time is a better predictor of such a risk. Another possible explanation is that the inherent measurement error in mean pronation velocity, being calculated as the ratio between two measured variables (i.e. range of motion and time of pronation) is larger than for each of the single variables, thus masking a possible stronger true relationship between pronation velocity and incidence of injury.

In conclusion, longer pronation may have a protective role in reducing the risk to develop stress fractures of the femur and tibia during an extended period of training. Thus, evaluating dynamically parameters of foot pronation may promote the identification of individuals at risk for these injuries, further implementing prevention programs.

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