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Biomechanical and Anatomic Factors Associated With a History of Plantar Fasciitis in Female Runners

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Objective: To compare selected structural and biomechanical factors between female runners with a history of plantar fasciitis and healthy control subjects.

Design: Cross-sectional.

Setting: University of Delaware Motion Analysis Laboratory, Newark, DE; and University of Massachusetts Biomechanics Laboratory, Amherst, MA.

Participants: Twenty-five female runners with a history of plantar fasciitis were recruited for this study. A group of 25 age- and mileage-matched runners with no history of plantar fasciitis served as control subjects.

Interventions: The independent variable was whether or not subjects had a history of plantar fasciitis.

Main Outcome Measures: Subjects ran overground while kinematic and kinetic data were recorded using a motion capture system and force plate. Rearfoot kinematic variables of interest included peak dorsiflexion, peak eversion, time to peak eversion along with eversion excursion. Vertical ground reaction force variables included impact peak and the maximum instantaneous load rate. Structural measures were taken for calcaneal valgus and arch index during standing and passive ankle dorsiflexion range of motion.

Results: A significantly greater maximum instantaneous load rate was found in the plantar fasciitis group along with an increased ankle dorsiflexion range of motion compared with the control group. The plantar fasciitis group had a lower arch index compared with control subjects, but calcaneal valgus was similar between groups. No differences in rearfoot kinematics were found between groups.

Conclusion: These data indicate that a history of plantar fasciitis in runners may be associated with greater vertical ground reaction force load rates and a lower medial longitudinal arch of the foot.

Key Words: ground reaction forces, rearfoot eversion, ankle dorsiflexion, injury

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INTRODUCTION

Plantar fasciitis is one of the most common foot pathologies with approximately one million Americans seeking medical attention for this condition each year.[1] In a retrospective study of 2002 runners, plantar fasciitis was found to be the third most common overuse injury with an incidence of 7.9%.[2] The foot–leg complex takes the brunt of impact during locomotion, making it susceptible to injury. Adults take an average of 10,000 steps per day.[3] This dosage increases with running because 10,000 steps are taken during the course of a single, hour-long run. Even with a shorter run, ground reaction forces and joint excursions are double in magnitude compared with walking, leading to greater stress on joints and soft tissues of the foot. The plantar fascia is one of the most important tissues in maintaining the structural integrity of the foot. It plays a key role in supporting the medial longitudinal arch, creating tension between the proximal and distal aspects of the foot. Plantar fasciitis has been described as an overload of the plantar fascia.[4]

Foot pronation has often been implicated with the incidence of plantar fasciitis.[5–7] The associated flattening of the medial arch with excessive pronation may place increased stress on the plantar fascia.[6] It has been postulated that greater than average pronation may occur as a result of foot structure or as a compensatory mechanism resulting from a lack of available ankle dorsiflexion.[8] Two studies have reported reduced ankle dorsiflexion range of motion in the limb affected by plantar fasciitis compared with both the unaffected limb and healthy control subjects.[7,8] In contrast, another investigation reported similar dorsiflexion range of motion in plantar fasciitis runners and control subjects.[5] Additionally, a retrospective study revealed that only 16% of the 267 patients with plantar fasciitis were deemed to have excessive tightness in the gastrocnemius/soleus complex.[9] Therefore, the relationship between sagittal plane ankle mechanics and plantar fasciitis requires further clarification.

Although hyperpronation is believed to increase the load on the plantar fascia, several comprehensive reviews have failed to distinguish a definitive link between pronation and plantar fasciitis.[10,11] This may be attributable, in part, to the differing methods of assessing pronation between studies.

Methods ranged from static quantification of the rearfoot and medial arch to dynamic measurements of rearfoot eversion during gait. Measurement of both static and dynamic indicators of foot pronation might provide a better indication of the relationship between pronation and plantar fasciitis.

Because plantar fasciitis is caused by an overload of the plantar fascia, it is worth considering the external loads that are applied to the foot. Liddle et al[12] found no difference in the impact peak or load rate of the vertical ground reaction force between the injured and uninjured foot in patients with unilateral plantar fasciitis. However, these measures were taken during walking. In a preliminary prospective study of female runners, Davis et al[13] reported greater impact peak and loading rates in individuals with plantar fasciitis compared with healthy control subjects.

In summary, both the biomechanical and structural factors associated with plantar fasciitis during running remain unclear. Therefore, the purpose of this study was to compare selected biomechanical and structural factors between female runners with a history of plantar fasciitis and healthy control subjects. In terms of structure, it was hypothesized that runners in the plantar fasciitis group would demonstrate reduced passive ankle dorsiflexion range of motion as well as increased calcaneal valgus and lower arch heights during quiet stance. During running, it was expected that individuals with plantar fasciitis would exhibit reduced ankle dorsiflexion but greater and prolonged rearfoot eversion. In addition, greater vertical ground reaction force impact peak and load rates were expected in the runners with a history of plantar fasciitis.

METHODS

Subjects

Twenty-five female runners between the ages of 18 and 45 years with a history of at least one diagnosis of plantar fasciitis by a medical professional were recruited for this cross-sectional study (PF group). Since the time of first diagnosis, a mean of 2.8 years (standard deviation, 2.4 years) had passed before data collection. To be included in the study, all subjects were required to be currently free from lower extremity injury and able to run without pain or symptoms for the preceding 2 months. This status was determined by interview by an experienced physical therapist on entry to the study. In addition, all subjects were required to be habitually running a minimum of 20 miles/week^{-1} at the time of data collection. An age- and mileage (current) -matched sample of 25 runners with no history of plantar fasciitis or heel pain were selected as T1 a control group (CON) (Table 1). Mileage was calculated as the weekly average over the 6-month period preceding the data collection. Before participation, details of the study and protocol were explained to each subject and written, informed consent was obtained. The protocol was approved by the Institutional Review Boards of the University of Delaware and University of Massachusetts.

Experimental Procedures

The structural assessment of each subject was conducted by an experienced physical therapist. Ankle dorsiflexion range of motion was measured using a goniometer with the knee both in extension and 90° of flexion to assess gastrocnemius and soleus flexibility. Calcaneal valgus, a measure of rearfoot pronation in stance, was then quantified as the angle of a posterior heel bisection line from the vertical. Finally, the arch index was calculated using the height to the dorsum of the foot at 50% of the foot length divided by the truncated foot length.[14] The truncated foot length was defined as the length of the foot from the posterior aspect of the heel to the first metatarsal head. The arch index has been shown to have excellent reliability within our laboratory with intraexaminer (2,1) and interexaminer (2,k) intraclass correlation coefficient values of 0.98 and 0.85, respectively.[14] Good reliability for ankle dorsiflexion flexibility and calcaneal alignment has also been reported in the literature with intraclass correlation coefficient values ranging from 0.81 to 0.97[15,16] and 0.88 to 0.90[17,18] respectively.

TABLE 1. Mean (Standard Deviation) Demographic Information for the Two Comparison Groups

Variable	PF	CON	*P*
Age (years)	31 (10)	31 (10)	0.49
Mileage (miles/week^{-1})	25 (7)	26 (8)	0.54
Height (m)	1.66 (0.06)	1.67 (0.07)	0.72
Mass (kg)	61.6 (6.2)	64.3 (8.7)	0.22

PF, plantar fasciitis group; CON, control group; *P*, probability of independent *t*test value.

Biomechanical data were collected during overground running using a six-camera Vicon 512 (Oxford Metrics, Oxford, UK) motion analysis system and a forceplate (Bertec Corporation, Columbus, OH). Kinetic data were sampled at 960 Hz while kinematic data were collected at 120 Hz from seven anatomic and seven tracking markers placed on the foot and lower leg (Fig. 1). Data were captured for the affected limb F1 in the PF group. In the CON group, the limb was selected to match the distribution of right and left limbs in the PF group (15 right, 10 left). After a standing calibration trial, the

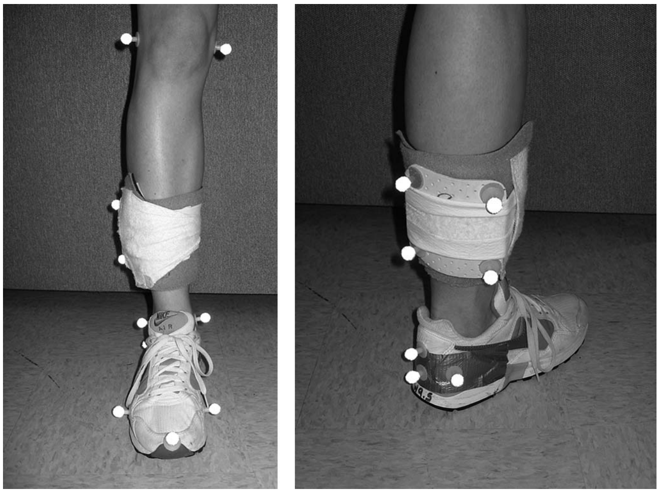

FIGURE 1. Markers reconstructed for the standing calibration trial (left) and running trials.

anatomic markers were removed. Subjects subsequently ran along a 25-m runway at a velocity of 3.7 ms^{-1} (± 5%) in standard, neutral, laboratory running shoes (Nike Air Pegasus; Nike, Portland, OR). Running velocity was assessed using custom light gates.

Data Reduction

Five running trials were selected for further analysis. Raw marker trajectory data and ground reaction force data were filtered using a fourth-order low-pass recursive Butterworth filter with a cutoff frequency of 8 and 50 Hz, respectively. Visual three-dimensional software (C-motion Inc., Germantown, MD) was used to compute the three-dimensional kinematics of the rearfoot relative to the shank. Custom Labview (National Instruments Corporation, Austin, TX) software was used to extract all kinematic and kinetic variables of interest. The rearfoot kinematic variables included peak dorsiflexion, peak eversion (EV), time to peak EV along with EV excursion (from heel-strike to peak). The vertical ground reaction force variables included impact peak and the maximum instantaneous load rate between 20% and 80% of the time to impact peak.[19] Both ground reaction force variables were normalized to body weight.

Data Analysis

Descriptive statistics were calculated for each variable, including the group mean, standard deviation, and effect size. Independent *t* tests were carried out for between-group statistical comparison using SPSS 15.0 (SPSS Inc., Chicago, IL) for the variables of interest. Effect sizes (ES) were determined for all variables to aid in the interpretation of any trends found. The ES was calculated as the difference between the two group means divided by the pooled standard deviation and was defined as small ($d = 0.2$), medium ($d = 0.4$), and large ($d = 0.8$).[20]

RESULTS

A comparison of structural measurements between groups is provided in Table 2. The PF group had a greater ankle dorsiflexion range of motion with the knee extended ($P = 0.02$, ES = 0.71) and flexed ($P = 0.01$, ES = 0.82) compared with control subjects. In standing, the PF group had a significantly lower arch index ($P = 0.01$, ES = 0.87), but there was no difference in the calcaneal valgus ($P = 0.34$, ES = −0.27) between groups.

In terms of dynamic variables during running (Table 3), experimental groups did not exhibit differences in rearfoot peak eversion ($P = 0.14$, ES = –0.52), time of peak EV ($P = 0.12$, ES = –0.45), EV excursion ($P = 0.47$, ES = –0.21), and peak dorsiflexion ($P = 0.73$, ES = –0.10). A substantially greater vertical load rate was found in the PF group ($P = 0.04$, ES = 0.34). In addition, vertical impact peak was 8% greater in the PF group with a moderate effect size ($P = 0.10$, ES = 0.45).

DISCUSSION

The purpose of this study was to compare structural and biomechanical characteristics between female runners with a history of plantar fasciitis and healthy control subjects. Results suggest that runners with a history of plantar fasciitis had greater passive ankle dorsiflexion range of motion as well as less calcaneal EV and lower arches during stance compared with control subjects. In addition, they exhibited similar sagittal and frontal plane kinematics during running. However, vertical impact peaks and loading rates were higher in the PF group.

The increased dorsiflexion range of motion seen in the PF group is in contrast to some of the findings in the literature.[4,21] However, subjects in the current study were pain-free at the time of testing, whereas the other studies included subjects who were currently experiencing plantar fasciitis. It is possible that some of our subjects may have undergone physical therapy to relieve their pain. Ankle joint flexibility training is one of the most commonly prescribed treatments for plantar fasciitis.[4,9] Chandler and Kibler[22] reported that after flexibility training, a group of patients with plantar fasciitis improved their range of motion in the affected limb to be greater than that of the unaffected limb. It would, therefore, be of value to prospectively study the incidence of plantar fasciitis in runners to determine if limitations in ankle flexibility were present before injury.

The similarity in calcaneal valgus during quiet stance was also surprising. However, the increased valgus expected in the PF group was based on the premise that these subjects would need to compensate for their limited ankle dorsiflexion. Because these subjects exhibited both normal passive ankle

TABLE 2. Comparison of Mean (Standard Deviation) Structural and Flexibility Variables Between Groups*

Variable	PF	CON	*P*	Effect Size
Dorsiflexion range of motion (extended) (°)	3.4 (6.2)	–0.4 (3.9)	0.02†	0.71
Dorsiflexion range of motion (flexed) (°)	13.8 (5.8)	9.2 (5.4)	0.01†	0.82
Standing calcaneal valgus (°)	4.1 (3.3)	3.2 (3.3)	0.34	–0.27
Arch index	0.315 (0.030)	0.344 (0.036)	0.01†	–0.87

*Ankle dorsiflexion was reported with the knee in both an extended and a flexed position.
†Significant difference between groups ($P < 0.05$).
PF, plantar fasciitis group; CON, control group; *P*, probability of independent *t* test value.

TABLE 3. Mean (Standard Deviation) Kinematic and Kinetic Variables Between Groups

Variable	PF	CON	*P*	Effect Size
Rearfoot peak EV (°)	9.4 (3.2)	11.0 (3.0)	0.139	–0.52
Time to peak EV (% stance)	49.6 (7.0)	52.6 (6.0)	0.115	–0.45
EV excursion (°)	14.2 (3.0)	14.9 (4.0)	0.467	–0.21
Ankle peak DF (°)	25.7 (2.9)	26.0 (3.6)	0.732	–0.10
Impact peak (BW)	1.84 (0.30)	1.70 (0.30)	0.093	0.45
VILR (BW/s^{-1})	100.5 (36.0)	82.9 (18.7)	0.037*	0.34

*Significant difference between groups ($P < 0.05$).
PF, plantar fasciitis group; CON, control group; *P*, probability of independent *t* test value; EV, eversion; DF, dorsiflexion; BW, body weight; VILR, maximum instantaneous load rate.

dorsiflexion range of motion as well as peak dorsiflexion during running, there was no need for compensation.

Although calcaneal valgus was not different between groups, the PF group did demonstrate a lower arch height during standing. Hence, the results suggest that plantar fasciitis may be more related to midfoot rather than rearfoot pronation. The plantar fascia has been shown, in cadaveric studies, to be crucial to the integrity of the medial arch.[23] Its supportive effect on the arch has been found to surpass the tibialis posterior and peroneus longus.[24] Therefore, a lower arch might place the plantar fascia under greater stress.

Based on the similarity of calcaneal valgus between groups, it is not surprising that the dynamic measures of rearfoot pronation were also similar. Excessive pronation has also been proposed as a compensation for reduced ankle dorsiflexion during gait.[8] Because ankle dorsiflexion during running was not limited in the PF group, there was no need for compensatory eversion to occur. Our results support the findings of Messier et al[25] who reported that rearfoot peak EV, EV excursion, and time of peak EV were not significant discriminators between control subjects and a group of runners currently with plantar fasciitis.

In contrast, Taunton et al[9] found that excessive hyper-pronation during gait was evident in 55% of the plantar fasciitis subjects they analyzed. However, pronation was determined visually by a clinician and the authors did not specify the criteria used. Subjective clinical measures often do not distinguish between subjects who pronate more in the rearfoot or midfoot. In the current study, midfoot pronation was not assessed dynamically, which could account for the discrepancy between these studies. Indeed, a limitation of our study is that only rearfoot kinematics were assessed during running. A multisegment foot model is needed to better understand the relationship between midfoot pronation and plantar fasciitis. Using such an approach, preliminary data have demonstrated that excessive midfoot motion (movement of the forefoot relative to the rearfoot) may be associated with plantar fasciitis during walking.[26] In this light, it is interesting to note that the PF group in the current study did exhibit greater static midfoot pronation as indicated by their lower arches. This may have been associated with greater dynamic midfoot motion during running if it had been measured.

Runners with a history of plantar fasciitis tended to load their lower extremities faster, as characterized by the elevated vertical ground reaction force load rates. In addition, there was a trend toward a greater vertical impact peak in the PF group compared with control subjects. These greater external loads applied to the foot may subject the plantar fascia to abnormal mechanical loading, placing the structure at greater vulnerability to injury. These findings were in contrast to those of Liddle et al[12] who reported no difference in vertical load rates during walking. It is possible that there is a threshold of loading during running, not reached with walking, that increases the risk for plantar fasciitis. Foot orthotic devices have been commonly prescribed to treat plantar fasciitis. Given that orthotics have been shown to reduce load rates in runners,[27] it is possible that this may be the mechanism by which they help to reduce symptoms. Indeed, preliminary data from a prospective study showed that runners who went on to sustain plantar fasciitis also demonstrated greater initial loading parameters compared with runners who remained free from this injury.[13]

A limitation of the present investigation is that because only females were studied, it is unknown whether the findings apply to male runners with plantar fasciitis. Indeed, there are little data concerning the structural and biomechanical differences between males and females with plantar fasciitis. Future research involving male subjects is warranted, especially given the high prevalence of plantar fasciitis in male runners.[2]

Another limitation is that the cross-sectional nature of this study makes it difficult to determine whether the differences in variables between the injured and control groups were the result of the injury or were present before injury. Indeed, any treatment that runners may have sought for the injury could have altered their flexibility or biomechanical measurements. To truly determine which of the investigated variables can be used as predictors of subsequent plantar fasciitis, prospective studies are required. In addition, cross-sectional studies involving patients with current plantar fasciitis may lend further insight into the variables associated with painful symptoms.

In conclusion, a lower arch height and greater vertical ground reaction force load rate were associated with a history of plantar fasciitis in female runners. Although both static and dynamic rearfoot measurements were similar between groups, future studies should incorporate ways of assessing dynamic midfoot motion.

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