The Journal of Foot & Ankle Surgery 000 (2022) 1−5

Contents lists available at ScienceDirect

The Journal of Foot & Ankle Surgery

journal homepage: www.jfas.org

Original Research

Variations in the Thickness of the Plantar Fascia After Training Based in Training Race. A Pilot Study

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A R T I C L E   I N F O

Level of Clinical Evidence: 2

Keywords:
plantar fascia
runners
tissue stress
ultrasound measurement

A B S T R A C T

Plantar fascia (PF) is a connective tissue made up of mostly type 1 collagen that is subjected to constant loads. This study evaluated the effect of continuous running on tissue stress in the PF by measuring changes in the thickness of the PF using ultrasound scans. It was a cross-sectional study involving 24 runners from the University of Valencia, recruited as volunteers between December 2018 and February 2019. A variety of data was recorded: (age, body mass index, type of footwear, number of workouts per week, KM run per week, sports injuries in the last year, pre and postrace ultrasound PF measurements). There were significant differences in the 3 postrace measurements of the left foot (<0.001). PF thicknesses were measured before and after running, with a minimal average difference of 0.4 mm in the medial and central fascicles, and 0.3 mm in the lateral fascicle. We observed PF thicknesses above 4mm in asymptomatic patients with no signs of vascularisation, proving that increased PF thickness is not the only criterion for diagnosis of plantar fasciitis.

Musculoskeletal tissues are subjected to constant workloads during daily activities (1). The tendons are commonly engaged in repetitive loading or overuse amongst both the athletic and non-athletic population (2), and there is evidence that this is closely associated with the development of tendinopathy. The plantar fascia (PF) is subjected to mechanical loads while walking or running, and degenerative changes are commonly observed in the morphology of the PF, leading to pathology characterised by an accumulation of damage (3).

Physical stress is defined as the force applied in an area of biological tissue (4,5). Mechanical theory, or Physical Stress Theory (PST), argues that: "changes in the relative level of physical stress cause a predictable adaptive response in all biological tissue" (6).

The PF plays a key role in the biomechanics of the foot; it interacts with the propulsion mechanisms distributing the forces and energies that involve the foot in conditions of repetitive load such as continuous running (7). During weightbearing exercises, the arch of the foot lowers and stretches out, then recoils when the load is removed. PF injuries due to excessive traction forces directly involve the “Windlass” mechanism, behaving like a quasi-elastic tissue (8-11). This spring-like property of the foot arch helps to attenuate impact forces and store/release elastic strain energy leading to energy saving during running (12).

Each time the foot comes into contact with the ground while running, the PF experiences repeated tension as high as 0.6 to 3.7 times the bodyweight and longitudinal tension of up to 6% (13-15). Simulation studies have shown that tension and peak stress along the PF are concentrated at the proximal points. Accumulation of such repetitive and site-specific stress on the PF can induce mechanical fatigue (i.e., reduction of stiffness and increased strain upon loading) (12). This can be a key factor leading to increased thickness of the PF in regular runners.

This affects both athletes and people with sedentary lifestyles, making up 11% to 15% of foot problems requiring professional help (16). Every day people that do all kinds of sports receive medical treatment, but the most common patients are amateur runners (17). Amateur running is growing in popularity; however, many people lack the appropriate physical preparation, which can lead to injuries. A systematic review showed a plantar fasciitis prevalence of between 5.2% and 17.5% among 3500 runners, with an incidence of 4.5 to 10 injuries per 1000 hours of running (18). Therefore, it is possible that experienced, long-distance runners may have a PF and a foot arch that are adapted

Financial Disclosure: None reported.
Conflict of Interest: None reported.
Funding for open access charge: Universidad de Málaga / CBUA.

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https://doi.org/10.1053/j.jfas.2022.02.008

to long-distance running (smaller changes in PF properties and arch deformation), compared to people that do not run. There is limited available knowledge on this issue (12).

Musculoskeletal ultrasound imaging (MSK US) is an emerging diagnostic tool in medicine and physical therapy which allows for dynamic visualisation of tissues in real time with devices that are often portable (19-21). Recent advances in ultrasound technology and the development of high-resolution ultrasound transducers have resulted in improved visualisation of soft tissues and bony structures. MSK US can be used to evaluate tissue properties such as the orientation and volume of fibres, as well as the presence of inflammatory processes, therefore it can be a valuable diagnostic and prognostic tool for the physical therapist (22). In addition, it can easily be repeated, which makes it an effective tool to monitor tissue changes over time (23).

Currently there is no consensus on average PF thickness (24-28), although there does exist an ultrasound classification that deems thicknesses greater than or equal to 4 cm as pathological (29). Sometimes asymptomatic athletic subjects exceed this thickness. A relationship has been observed between mechanical stress and the fibrous morphology of the PF. This information is of clinical assistance in understanding the pathophysiological diseases of the PF.

We sought to determine whether changes took place in the thickness of the PF as a result of physiological and mechanical adaptation after controlled exercise in the form of continuous running. We hypothesised that changes in the thickness of the PF would be observed under ultrasound. The aim of this study was to investigate the effect that continuous running has on the tissue stress generated in the PF in terms of thickness, measured under ultrasound.

Patients and Methods

Design

The design is a cross-sectional study.

Patients

The participants in this study were made up of 24 volunteer runners (male and female), who had taken part in the Picaña-Paiporta half marathon in December 2018. This study was carried out between December 2018 and February 2019 in full accordance with the provisions of the Helsinki Declaration regarding ethical principles for medical research involving human subjects and was approved by the Ethics Committee. Written informed consent was obtained from all participants before data collection.

All subjects were 18 or over and were amateur runners who took part in at least one quarter, half or full marathon per year, and who trained at least once a week. They had been running regularly for at least 10 km/week during that year, and their running experience ranged from 5 to 10 y. The exclusion criteria were heel pain and/or a history of diseases or injuries of the feet that had affected the musculoskeletal system in the previous 3 months, and neurological problems or surgical interventions in the lower limbs. All participants wore their usual sports clothing.

Sample size

The sample size was determined by application of the EPIDAT program, using the criterion of AT with a detectable difference of the mean of 0.039 to evaluate the statistical power (25). For a significance level of .05 and a power of 80%. The study was designed to detect changes exceeding 0.060 (large effect size). This calculation produced a necessary sample size of 21 subjects.

Protocol

Subjects were assessed in a foot clinic. The study was carried out in 3 phases. During the first phase, the study data (age, BMI, type of footwear (29), number of workouts per week, KM run per week, and sports injuries in the last year) was collected using a questionnaire, thus allowing the sample to be established by taking into account inclusion and exclusion criteria. In the second phase, a brief exploration was carried out using the Foot Posture Index (FPI), followed by measurements of the thickness of the medial, central and lateral fascicles of the PF, before and after race-based training. The FPI evaluates the multi-segmental nature of foot posture in all 3 planes and does not require the use of specialised equipment. Each item of the FPI is scored between −2 and +2, resulting in a total ranging from −12 (highly supinated) to +12 (highly pronated). The items of the index include talar head palpation, curves above and below the lateral malleoli, calcaneal angle, talonavicular bulge, medial longitudinal arch, and forefoot to hindfoot alignment. In all other respects, the protocol described by Redmond et al was followed. (30,31).

Ultrasound Measurements

A diagnostic ultrasound device was employed: the LOGIQ V2^{TM} (GE Healthcare, EE. UU.), equipped with a 8 to 13 MHz linear transducer probe (12L-RS), with a contact surface area of approximately 7cm in length and 1cm in width and a weight of 390 grams. A dynamic range of 69bB and a scan depth of 2.5 cm (12L-RS) were used. The linear transducer parameters were the same in all measurements in this study: a frequency of 8Khz, a low filter setting and optimisation for low flow detection. The gain was adjusted to the highest possible level without background noise. The only setting that varied was focus, which was adjusted according to the level of the PF of each subject, with fixed depth.

Each participant was assigned an identification number, which was the only information provided to the examiner. The ultrasound images were obtained by a single examiner. All participants received a standardised ultrasound on both feet. The data was recorded by a research assistant, who was unaware of the premeasurements. All ultrasound measurements are expressed in millimetres.

Care was taken to maintain the same standardised foot position, to keep the same ultrasound scanner settings and to replicate the same measurements. The participants adopted a prone position with the knee in extension and the feet lying outside the stretcher (25,27). Guide lines for the transducer were indicated on the skin using a waterproof marker in order to ensure identical points of measurement. Once the subjects were in position, the width of the heel was measured and the mid-way point was marked with a line (central fascicle). Using this cutaneous reference point, 2 more lines were drawn at a distance of 1.5cm on either side, towards the inside of the foot (medial fascicle) and towards the outside (lateral fascicle) (32). The first measurement (thickness 1) was taken: the thickness at the insertion of the PF in the heel at each longitudinal section: medial (Fig. 1*A*), central (Fig. 1*B*) and lateral (Fig. 1*C*). The probe was lined up precisely with the pen marks made on the heel. Three images were taken of each longitudinal section in the 3 fascicles of the FP and the average thickness in centimetres of each fascicle was calculated (27).

After the ultrasound measurement (pre), participants were asked to run at 12 km/h (+-2km/h; precision 98%) for 10 minutes (high-intensity exercise) on a treadmill (33). The race protocol was assumed to be identical for all runners in terms of mechanical loading as they all had a similar stature (Table 1). The foot strike pattern of participants was visually observed throughout the running task. All participants were able to complete the task without resting or walking. After running, participants underwent the same measurement to examine PF thickness (post).

Statistical Analysis

The program SPSS v.25.0 (IBM Inc, Chicago, IL) was used for statistical calculations using descriptive and inferential statistical tests. The normal distribution of the data was

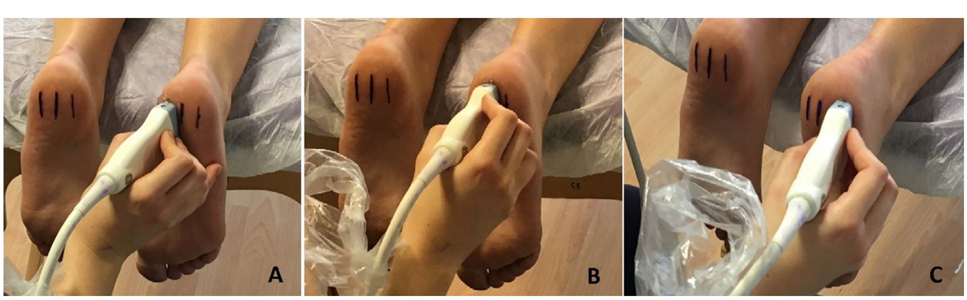

Fig. The thickness of the insertion of the plantar fascia to the heel in the longitudinal sections: medial (*A*), central (*B*), and lateral (*C*).

Table 1
Distribution of the mean, minimum, maximum and standard deviation of the variables

Characteristics	Male	Female	Total
Demographics			
Gender (n)	18	6	24
Age (y)	38 .05 (53-25) ± 7.81	38.66 (55-20) ± 14.21	38.20 (55-20) ± 9.44
Height (cm)	176.90 (167-192) ± 0.08	161.70 (158-165) ± 0.02	173.13 (158-192) ± 0.09
Weight (kg)	73.06 (58-94) ± 10.25	59 (52-67) ± 5.02	69.54 (52-94) ± 11.03
BMI /kg/m^2)	23.23 (19.59-26.32) ± 1.79	22.60 (19.10-25.53) ± 2.21	23.07 (19.10-26.32) ± 1.87
Qualitative variables		———	
Training time/week (t/w)	3.33 (2-5) ± 0.77	3.83 (3-5) ± 0.98	3.46 (2-5) ± 0.17
*Km/week (km/w)**	2.61 (1-5*) ± 1.04	2.50 (1-4*) ± 1.23	2.58 (1-5*) ± 1.06
Foot Posture Index			
Left FPI	2.61 (-1 to 5) ± 1.50	2.33 (1-3) ± 0.82	2.54 (-1 to 5) ± 1.35
Right FPI	2.56 (-2 to 7) ± 2.01	4.00 (2-6) ± 1.55	2.92 (-2 to 7) ± 1.98
Quantitative variables			
Size (EU)	43.11 (40-46) ± 1.94	40.33 (38-41) ± 1.27	43.15 (38-46) ± 2.54
Shore (HA)	42.17 (27-61) ± 10.88	43.33 (32-58) ± 9.18	42.46 (27-61) ± 10.30
Sneaker weight (g)	297.06 (200-438) ± 65.76	219.67 (145-274) ± 53.29	277.70 (145-438) ± 70.61
Drop (mm)	11 (8-12) ± 1.41	10 (8-12) ± 1.26	10.75 (8-12) ± 1.42

Abbreviations: N, number; Y, Years; cm, centimetre; Km, kilometre; BMI, body mass index; FPI, foot posture index; EU, Europe; g, grame; mm, milimetre.
* 1: 5-10 km/w; 2: 10-20 km/w; 3: 20-30 km/w; 4: 30-40 km/w; 5: + 50 km/w.

verified using a Shapiro-Wilk test and it was revealed that the ultrasound measurement data was normally distributed. The intraclass correlation coefficient was used to evaluate the reproducibility of PF thickness measurements, with a 95% Confidence Interval (95% CI) and a sample of 10 subjects measured at baseline and after 24 hours. Estimation was carried out by calculating the intraclass correlation coefficient, using a 1-way random effect model, and found to be excellent (ICC 0.94: 95% CI: 0.90-0.96) at baseline and at 60 minutes (ICC 0.87; 95% CI: 0.80-0.92). The null hypothesis (no differences between pre and postmeasurement) was tested using bivariate analysis which was performed with a non-parametric test (the Mann-Whitney U test), in view of the non-normal distribution observed in most cases (1-way ANOVA) with a significance level of 0.05. The standard error of measurement (SEM) also provides a measure of variability. SEM values were calculated as follows: $SEM = SD \times \sqrt{(1 - ICC)}$, with SD representing the standard deviation of the measure. Minimal Detectable Change MDC values, which reflect the magnitude of change necessary to provide confidence that a change is not the result of random variation or measurement error, were calculated as follows: MDC = z-score (95% CI) $\times$ SEM $\times \sqrt{2}$ [32], and it was shown as the effect size test with eta-square.

Results

This experimental intra-subject analysis is based on a study population of 24 participants (N = 24). Of these, 18 (75%) were male and 6 (25%) were female. Therefore 48 feet were available for analysis. The average age was 38.21 (9.44) years and the average body mass index was (BMI) 23.07 (1.87) kg/m2 (Table 1). The assessment of the dominant foot revealed that 93% of participants were right-footed, but we did not observe any significant differences between the right and left feet p = .871.

The average type of foot according to the FPI was 2.54 (1.35) in the left foot and 2.92 (1.98) in the right foot.

Statistically significant differences were observed in all 3 left foot measurements ($F(1;24)$ = 6.84, 9.77, 11.59, p = .015 0.005, <0.001). The difference is minimal between the base line and after physical activity, with an average difference of 0.4 mm in the central and medial fascicles, and 0.3 mm in the lateral fascicle (Table 2). In addition, high power is observed in all measurements.

Furthermore, no statistically significant differences were observed in average right foot measurements (F (1;24) = 3,60 and 3,65, p = .07 and .069) in the central and medial fascicles. However, significant changes were observed in the lateral measurements compared to the baseline, (F (1;24) = 18.18, $p \leq .001$) (Table 2), and high power was observed in all measurements.

Discussion

Tissue stress is explained in many areas with the basic premise that changes in the relative level of physical stress causes a predictable adaptive response in all biological tissue (6). When there is an increase in stress tolerance, hypertrophy appears, followed by injury (8). After exercise, tendons demonstrate an increase in matrix metalloproteinases that contributes to an increased release of products due to collagen breakdown (34−37). Over the first 24 to 36 hours after exercise, the acute response results in a net loss of collagen (38−41).

In symptomatic subjects, a PF thickness greater than 4mm has been suggested as a diagnosis for plantar fasciitis (25,29). However, studies (27) in runners show great variability in thickness, 35% of the heels analysed (27 out of 77) among 41% of runners (16 out of 39) showed an abnormally thickened fascia above 4mm, and some asymptomatic patients had measurements over 7mm.

The aim of this study was to determine the effect that continuous running has on the tissue stress generated on PF in relation to thickness. The morphological changes in the insertion thickness of the PF were determined by analysing the ultrasound images of the

Table 2
Distribution of the mean of pre-post running ultrasound measurements in both feet

	PRE-RUNNING				POST-RUNNING								
	Average (cm)	SD (cm)	CI 95% (cm)		Average (cm)	SD (cm)	CI 95% (cm)		p Value	SEM	F	MDC	Observed power
LMF	0.36	0.06	0.34	0.39	0.40	0.07	0.37	0.43	.015	0.013	6.84	0.007	0.707
LCF	0.32	0.07	0.30	0.35	0.36	0.07	0.33	0.39	.005	0.012	9.77	0.005	0.849
LLF	0.27	0.04	0.26	0.29	0.30	0.05	0.28	0.32	<.001	0.008	11.59	0.003	0.983
RMF	0.37	0.06	0.34	0.39	0.39	0.07	0.36	0.42	.070	0.011	3.60	0.006	0.444
RCF	0.32	0.06	0.30	0.35	0.35	0.05	0.33	0.37	.069	0.014	3.65	0.006	0.449
RLF	0.28	0.04	0.26	0.29	0.31	0.05	0.29	0.33	<.001	0.008	18.18	0.003	0.983

Abbreviations: LMF, Left Medial Fascicle; LCF, Left Central Fascicle; LLF, Left Lateral Fascicle; RMF, Right Medial Fascicle; RCF, Right Central Fascicle; RLF, Right Lateral Fascicle; SEM, standard error of measurement; MDC, Minimal Different Changes; CI, Confidence Interval.

participants to assess the differences in asymptomatic runners before and after a race-based training session.

Our results showed a significant difference ($p \leq .001$) between the pre and postrace measurements of the thickness of the FP in the lateral fascicle, in both feet. However, although no statistically significant differences were observed, it should be noted that a difference in thickness of at least 2mm was observed on average across the 3 fascicles analysed at the medial, central and lateral points on the feet of all the participants. According to simulation studies, the proximal site of PF is where the mechanical loading is concentrated (42-44). Such site-specific stress accumulation during a race could be the cause of site-specificity of mechanical fatigue in PF. Mechanical overload and excessive strain can produce microscopic damage in PF which eventually leads to plantar fasciitis (45). Our findings support this pathogenesis.

These results are in line with those obtained by Hall et al in their analysis of asymptomatic runners aged 20 to 67, of whom 35% had a PF thickness greater than 4 mm. As with other studies carried out on asymptomatic runners (27), where the average thickness of the PF was 3.78 mm (range, 2.4-7.0 mm) for the right foot and 3.87 mm (range, 2.3-6.7 mm) for the left, it should be noted that the right foot was dominant among the study population. One earlier study (24) assessed the influence of sports on PF thickness in a population of healthy asymptomatic young adults, not strictly runners, between 20 and 30 years of age. The authors found no difference in thickness among those subjects with a physically active lifestyle. However, other studies that analysed the plantar fat pad (46) concluded that the impact of continuous running produces a fracture in the plantar fat due to the stress suffered in the heel during exercise.

In addition, the mechanical properties (thickness and elasticity) of the heel pad in the elderly differ from those found in young people. Older people have a thicker and stiffer heel fat pad in comparison (47). This greatly reduces the shock absorption capacity of the heel fat pad and as a result, makes it more susceptible to injury (32). Our research included participants aged between 20 and 55, which is why, due to the cumulative effects of age and the repetitive load and impact of running on asphalt, the PF may be more thickened, although the average is lower, at 4 mm.

It is necessary to rethink how to begin standardising and measuring the thickness of the PF. Fede et al (48) carried out a systematic review to explore current literature on obtaining homogeneous muscle data from ultrasounds. This revealed that there is no heterogeneity in measurement methods nor protocols and therefore, normal reference values cannot be established. Currently, there are 5 studies (25,26,48,49,50) that have collected non-pathological ultrasound data on PF. The thickness measurements of the PF varied from 3 to 4mm and the position of the participants was different in each study, thus the variability in thickness is determined by the position of the patient and the resulting muscle tension. Salehi et al (50) examined reliability in subjects with plantar fasciitis and healthy control subjects, whereas most previous studies have assessed reliability of PF properties using ultrasound only in either healthy groups or in clinical populations. Our study followed other similar investigations (49) by continuing to measure the thickness of the PF with the patient in the prone position with the knee extended, and using a similar measurement tool (51). The images clearly identified thickening and degenerative changes, thus supporting the conclusion that there were structural changes in the fascia. Therefore, US images would be an appropriate intervention to clinically address these tissue changes within the PF (27,50).

There are clinical implications for our findings. First, most of the averages obtained in PF thickness are greater than 4mm in asymptomatic patients, therefore increased PF thickness is not the only criterion for diagnosis of plantar fasciitis. Second, long-distance running causes mechanical fatigue in the FP mainly at the insertion proximal to the calcaneus.

Future studies will offer a better understanding of the optimal training/conditioning that aid prevention of PF injuries while enhancing its spring function when running. Experienced runners can develop a resilient PF that minimises the risk of PF-related injuries. As clinical therapists, we must evaluate all risk factors, such as the type of patient and the stress or load supported by the PF which could lead to a possible PF injury, and act preventively whether we are dealing with biological tissue that is normal or susceptible to injury.

The main limitation of the study was the size of the sample. For this reason, there is no specific analysis according to gender or age. In the sample, the majority of subjects were men, given that they had all been recruited from the Picaña-Paiporta half marathon (Valencia, Spain) where, out of 1327 participants, less than 20.5% were women. However, previous studies have shown a link between gender and the plantar fasciitis in runners (51,52). In addition, age can be the cause of changes in the fascia. It is perhaps necessary to include other types of impact sports to ensure that the absorption of impact by the plantar fat pad can prevent an increase in the thickness of the PF.

In conclusion, despite the above-stated limitations, the findings showed the effect that continuous running has on tissue stress generated in PF in relation to thickness. The morphological changes observed in the 3 fascicles had an average difference in thickness of at least 2mm. We observed PF thicknesses above 4mm in asymptomatic patients with no signs of vascularisation, proving that increased PF thickness is not the only criterion for diagnosis of plantar fasciitis. However, our sample size limits the extent to which definitive conclusions can be drawn. Future research of this type is needed, that ensures homogeneity in the study groups by size and composition, as well as in aspects such as different sports or the follow-up period considered and the description of main outcomes, in order to minimise the risk of bias.

Authors' Contributions

Conceptualization, R.A-D; methodology, A.B.O-A and G.G-N.; formal analysis, R.A-D and P.N-G.; writing—original draft preparation, R.A-D and P.N-G.; writing—review and editing, A.B.O-A and G.G-N.; visualization, G.G-N.; supervision, A.B.O-A.

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