CLINICAL SCIENCE

Rearfoot alignment and medial longitudinal arch configurations of runners with symptoms and histories of plantar fasciitis

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OBJECTIVE : To evaluate and compare rearfoot alignment and medial longitudinal arch index during static postures in runners, with and without symptoms and histories of plantar fasciitis (PF).

INTRODUCTION: PF is the third most common injury in runners but, so far, its etiology remains unclear. In the literature, rearfoot misalignment and conformations of the longitudinal plantar arch have been described as risk factors for the development of PF. However, in most of the investigated literature, the results are still controversial, mainly regarding athletic individuals and the effects of pain associated with these injuries.

METHODS: Forty-five runners with plantar fasciitis (30 symptomatic and 15 with previous histories of injuries) and 60 controls were evaluated. Pain was assessed by a visual analogue scale. The assessment of rearfoot alignment and the calculations of the arch index were performed by digital photographic images.

RESULTS: There were observed similarities between the three groups regarding the misalignments of the rearfoot valgus. The medial longitudinal arches were more elevated in the group with symptoms and histories of PF, compared to the control runners.

CONCLUSIONS: Runners with symptoms or histories of PF did not differ in rearfoot valgus misalignments, but showed increases in the longitudinal plantar arch during bipedal static stance, regardless of the presence of pain symptoms.

KEYWORDS: Plantar fasciitis; Pain; Rearfoot; Plantar arch; Runners.

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INTRODUCTION

At the end of the 20th century, the practice of running increased considerably [1,2] and, as a result, there were increases in the incidence of injuries in the lower limbs.[3] A retrospective study with 2002 runners, showed that plantar fasciitis (PF) was the third most common injury in runners[4] for about 20% of the athletes.[5] Tauton et al.[4] reported that out of 267 cases of investigated PF in various sport modalities, 160 involved only running. This finding resulted in an increased interest in investigating causal factors of this injury.

PF is characterized by musculoskeletal disorders of the plantar fascia from inflammatory and degenerative origins, such as in the medial tubercule of the calcaneus, the most common clinical symptoms of which are typical pain of the inferior and medial calcaneal areas.[6,7] According to Greve et al.,[8] morning pain is an important evaluation criterion. There are several intrinsic and extrinsic factors related to PF.[9] However, some specific intrinsic factors have been explored more thoroughly for the development of PF, among them obesity,[10] decreases in the range of motion of ankle dorsiflexion,[10–12] plantar longitudinal arch configurations,[6,13–15] rearfoot pronations[4,9,16] and increased plantar loads.[17–19] However, some controversies regarding these factors still remain, mainly regarding their involvement in the etiology of this injury.[9]

Some studies attributed the influences of plantar longitudinal arch and rearfoot pronation to the development of PF.[6,14,20–22] The pioneering research of Hicks [23,24] demonstrated that the height and length of the plantar longitudinal arch could be implicated in the development of PF. Hicks studied a model in different lower limbs of cadavers which characterized the tension forces absorbed by the plantar fascia and found important functions of the longitudinal arches for plantar load distributions. Most previous gait studies observed that the pain stimulus for the feet of individuals with PF promoted changes in foot roll-over patterns, thus causing load reductions in the rearfoot and load increases in other plantar regions, such as the midfoot, possibly owing to the protective mechanisms of pain.[19] However, during bipedal static support, studies which evaluated athletes with PF still have contradictory results concerning the types of the longitudinal arch and rearfoot angles, especially when the pain stimulus is under consideration.

Using subjective static evaluations, Tauton et al.[4] observed that the plantar longitudinal arch was more elevated in runners with PF and that 55% demonstrated excessive rearfoot pronation; other studies also reported similar findings.[6,14,25] An elevated arch could induce greater stiffness of the feet, which would result in an inefficient capacity to dissipate foot impact forces with the ground and, thus, place the plantar fascia in a position of greater mechanical stress.[14] Excessive pronation, for instance, could lead to greater loads on the medial areas of the calcaneus and greater tensions in the plantar area;[6,14,25] however, pain was not quantified in theses studies. On the other hand, studies which evaluated the plantar longitudinal arch,[9,11] rearfoot alignment[9] and calcaneal pain with long-distance runners did not demonstrate significant differences regarding these factors when compared to controls.

In a study of non-athletes, Prichasuk and Sbhadrabandhu[26] observed that 82 individuals with symptomatic calcaneal spurs had lower plantar arches, which were considered important factors for the development of PF. In a retrospective review of 1000 X-rays of subjects with calcaneal pain, Shama et al.[16] found that 81% demonstrated rearfoot pronation.

A more recent study by Pohl et al.,[15] revealed that female runners with a history of PF had lower medial longitudinal arches and rearfoot valguses, similar to control runners. However, they pointed out the need for future studies to evaluate runners with pain symptoms, as their subjects had over two years of diagnoses, which is a phase for possible remissions of these symptoms. It is well known that complaints of pain most often occur during the acute phase. According to Wearing et al.,[19] symptomatic feet make some adaptations during gait to reduce the loads on the rearfoot. Karr[27] also reported that the adaptations of the foot could be demonstrated not only by the lowering of the arch, but also in its elevation, associated with the onset of micro-traumas of the plantar fascia.

Considering the controversial results regarding the effects of the presence or absence of pain on the rearfoot and longitudinal plantar arch configurations in runners with PF, the present study was conducted. The importance of these results relies on a better understanding of the rearfoot angles and medial longitudinal arch indices during the static posture of runners with pain symptoms and histories of PF. Another question which motivated the present study was: would pain caused by PF induce postural adaptations of the feet and ankle? The hypotheses were that the conditions of symptomatic PF would be associated with decreases in rearfoot pronations and elevated longitudinal arches. It was expected that lower arches and excessive rearfoot pronations in runners with histories of PF, compared to control runners, would be found.

MATERIALS AND METHODS

Participants

One hundred and five recreational runners of both genders, ranging in age from 20 to 55 years,[18] were evaluated over the period of 1 year. For inclusion in this study, the runners had to have been running at least 20 km weekly for at least one year,[28] had to be experienced in running long distance competitions, had to have regular rearfoot strike patterns, and had to have maximum leg length discrepancies of 1 cm. The exclusion criteria for both groups included histories of previous foot surgeries, trauma or fractures of less than three months previously, neuropathies, obesity and musculoskeletal disorders, such as arthritis, tendinitis, bursitis, ankylosing spondylitis and heel spurs.

The control runners were recruited after reading the study proposal published in electronic media. The PF runners were recruited from the Rehabilitation Center in Sport Rheumatology of the University Hospital in Sao Paulo, Brazil. Diagnoses were made by the same experienced physician, which were confirmed by ultra-sound images taken by an experienced technician. All runners signed a term of informed consent approved by the Local Ethics Committee (protocol 1227/07).

Forty-five runners had diagnoses of unilateral PF confirmed by ultrasonography to verify thickening of the plantar fascia, hypoechoic changes, perifascial fluid collection and bony spurs.[29] Thirty runners had symptoms of heel pain; the PF group with symptoms (PFS) of more than four months' duration was considered to be in the acute phase of injury, which was also clinically diagnosed by ultra-sound. They must have had pain from palpation of the plantar fascia, complaints of pain in the morning during standing and after assuming sitting and standing positions for long durations.[18,30] Fifteen runners had previous histories of PF (PFH group), with the time of the first diagnosis within a mean (SD) of 1.5 (3.3) years. These runners were free from pain symptoms in the heel for more than two months and were considered to be in the remission phase of the injury.

The control group (CG) was composed of 60 runners with no histories or symptoms of PF. The mean weekly training volumes were 40 (12) km for the PFH group and 45 (10) km for the PFS group, whereas their mean time practice running was 7 (5) and 6 (5) years for the PFH and PFS, respectively. For the CG, the mean weekly training volume was 45(6) km and the mean weekly time of training of 4 (3) years. The mean running speed reported by the subjects, regarding their last 10-km competition, was 11.7 (0.6) km/h.

Initial assessments

All runners were interviewed using a previously developed questionnaire to characterize their histories and clarify their exclusion criteria. This questionnaire was divided into four items: personal data, anthropometric characteristics, PF data and physical activity data for running.

Pain assessments

The level of pain in all subjects was assessed by a 10 cm visual analogue scale (VAS). Before the plantar pressure measurements, the subjects rated the pain they felt at the moment of evaluation, ranging from none to unbearable. According to Jensen et al.,[31] the scale is valid and reliable and has already been used in several PF studies.[18,19]

Rearfoot alignment assesments

To evaluate the alignment of the calcaneal tendons in the posterior view of the frontal plane, the runners stood over a 45 cm platform, keeping their feet 7.5 cm apart. With a dematographic pen and white marks of 9 mm, the following anatomical points were identified on the inferior and posterior aspects for both legs: 1) the posterior calcaneal tuberosity; 2) the second point above the calcaneus; and, 3) the lower third of the leg.[32,33] (Figure 1A). The center of each marker in the medial-lateral axis was obtained with a digital caliper, a metallic device with graduations in cm, used to measure the distances between the two symmetrically opposing sides with a ruler. The images were then obtained with a digital camera positioned anterior and perpendicular to the subjects at a distance of 90 cm and at a height of 45 cm.

AutoCAD 2005® software was used to quantify calcaneal tendon alignments. To obtain these measures, a line was first drawn from the first (3 cm) to the second (7 cm) markers. Then, another line was drawn from the highest marker to the floor (22 cm), which passed through the center of the third marker (13 cm; Figure 1B).[32,33] The intersections of the extensions of these lines resulted in angles which were classified as normal (0˚–5˚), varus (<0˚) and valgus (>5˚) alignment values.[34]

Medial longitudinal plantar arch assessments

To assess the plantar arch, the runners were positioned barefoot on a podoscope (Carci®) with a distance of 7.5 cm between feet. Footprints were captured with a digital camera which was positioned in front of the podoscope at a distance of 24 cm and a height of 45 cm (Figure 2A), following valid and reliable procedures described by Ribeiro et al. and Mall et al.[35,36] The distance of 7.5 cm between feet to scale the image in AutoCAD 2005® was taken as a reference and used for the measurements.

With the AutoCAD 2005® software, a vertical straight line (L) was drawn from the second metatarsal to the center of the calcaneus. Then, the (L) line was divided into three parts for the delimitation of the forefoot, middlefoot and rearfoot areas. To measure the medial longitudinal arch, the middlefoot area was divided by the total foot area: forefoot + middlefoot + rearfoot (Figure 2B). For values between 0.22 and 0.25, the foot was classified as normal; values <0.21 indicated varus foot; and >0.26 valgus foot.[37]

Statistical analyses

The sample power was calculated by GPower 3.0 software. The sample size calculation was based upon the two outcome measures (plantar arch and rearfoot angles), considering a statistical design of the F test for repeated measures (between and within effects), with a moderate size effect ($f = 0.25$), a power of 80% and an alpha error of 5%.

The rearfoot angle and medial longitudinal arch index data were normally distributed (Shapiro-Wilk) and the variances were homogeneous (Levene's tests). For statistical purposes, the rearfoot angle and arch index data of only one foot per subject were randomly selected for the analyses of the differences between groups. ANOVAs followed by Tukey post-hoc tests ($p<0.05$) were employed to investigate differences between groups.

Intra- and inter-rater reliabilities

To analyze the intra-rater reliability of the rearfoot angle, measurements were obtained by the same examiner in two evaluation moments, at a one-week interval, and the intra-class correlation coefficients ($ICC_{3,1}$) were calculated.[38] To investigate the inter-rater reliability, $ICC_{2,1}$ were calculated using the data collected during the first week by two independent examiners.[38] The intra- and inter-rater reliability analyses for the anatomical marker data were performed only by the first examiner, following previous recommended procedures.[35,36]

RESULTS

No differences between the groups were found for demographic and anthropometric characteristics (Table 1). The symptom plantar fasciitis (SPF) group of runners reported mean times since the onset of pain of seven (two) months, and pain levels on the VAS of five (two) cm.

As shown in Table 2, all three groups demonstrated rearfoot valgus, and no significant differences were found between the groups regarding rearfoot alignments ($0.93<p<0.98$). However, regarding plantar medial longitudinal arch index, significant differences were observed between the PFS, PFH, and CG groups. The plantar arches

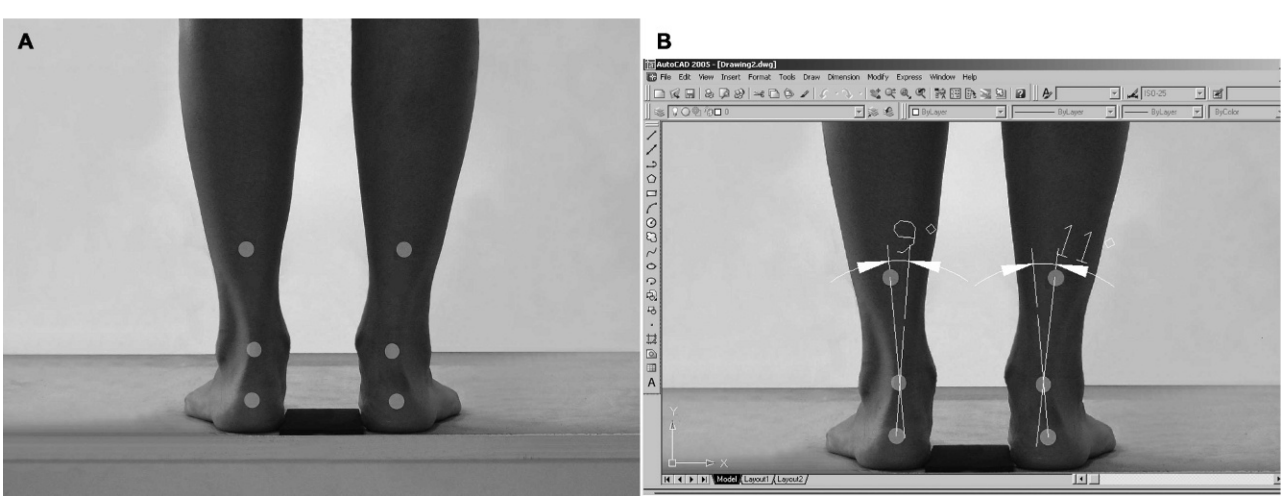
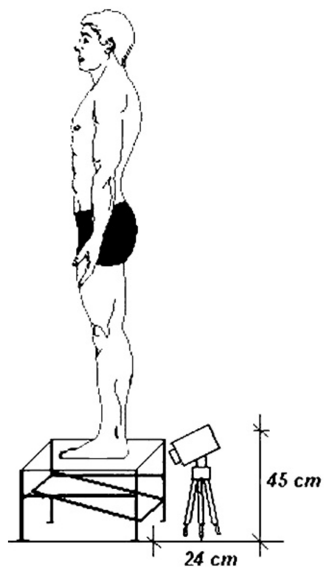


Figure 1 - Positioning of the markers (A) and quantification methods of rearfoot alignment (B).



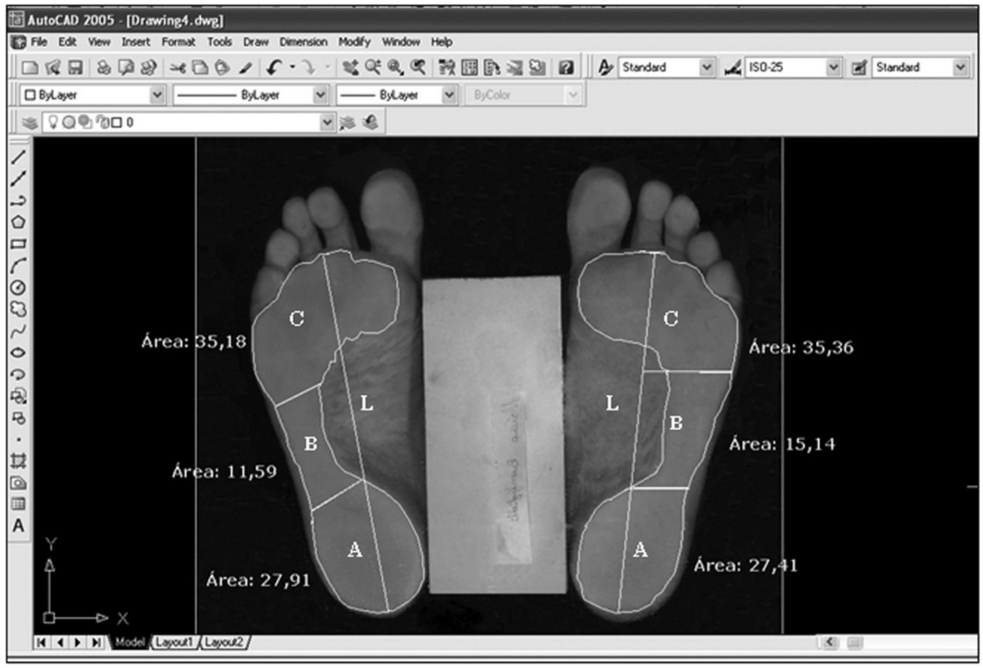


Figure 2 - Positioning of the subject on the podoscope (A). Description of the calculation of the medial longitudinal arch index. L: vertical straight line, A: rearfoot area, B: midfoot area. C: forefoot area (B).

were more elevated in both groups with PF (PFS and PFH), compared to the controls ($p = 0.008$). The reliability analyses for the rearfoot alignment angles for the PFS group resulted in ICC values of 0.96 and 0.98, respectively, for the intra- and inter-rater reliabilities.

DISCUSSION

The purpose of the present study was to evaluate and compare rearfoot alignment and medial longitudinal arch indices during static postures in runners with and without symptoms and histories of PF. The results indicated that all groups demonstrated similar rearfoot valgus misalignments. However, the plantar medial longitudinal arch indices were higher for both the PF groups (PFS and PFH), compared to the controls, but no differences were found between the PF groups.

The similarity of the valgus misalignments for runners with PFS and PFH corroborated the findings of Pohl et al.,[15] who, besides doing static evaluations, also performed dynamic analyses during running. They did not find differences regarding the valgus misalignments of the calcaneus or the variables related to the peaks, times and movement excursions of calcaneal eversion in a group of female runners with PF histories. However, they emphasized the importance of studies which investigated pain symptoms, which could have invariably affected the results.

In the present study, the aspects of pain were considered and, as a result, it was observed that valgus misalignments remained the same for the PF and control groups. It was expected that the symptom of pain would lead to less support on the medial heel as an analgesic strategy during bipedal standing positions. Consequently, the reduction in weight bearing on this region of the calcaneus would decrease the effects on the rearfoot valgus. However, similarly to controls, the presence of pain in the symptomatic runner group was not enough to reduce natural support that caused this static valgus rearfoot behavior.

Rome et al.[9] also reported similar findings when evaluated runners with complaints of calcaneal pain were compared to control groups. They did not observe

Table 1 - Descriptive statistics. Means (SD) of demographic and anthropometric data.

Variable	Gender	PFS group (n = 30; 11 F; 19 M)	PFH group (n = 15; 5 F; 10M)	Control group (n = 60; 20 F; 40M)	p-value
Age (years)	Female	44.0(9.1)	34.0(4.0)	38.0(8.0)	0.188
	Male	46.0(7.0)	40.0(6.0)	36.0(5.0)	0.200
Body mass (kg)	Female	57.8(9.5)	62.0(9.5)	55.8(7.0)	0.579
	Male	78.0(9.2)	75.4(8.3)	71.9(9.4)	0.236
Height (m)	Female	1.56(6.1)	1.76(7.8)	1.71(9.0)	0.167
	Male	1.75(4.6)	1.66(5.6)	1.79(5.6)	0.100
Body mass index (kg/ m^2)	Female	23.43(1.8)	22.3(3.2)	21.7(1.7)	0.304
	Male	25.5(2.3)	23.3(1.8)	23.5(2.6)	0.082

*ANOVAs two-way. $p < 0,05$ statistically significant.
PFS: plantar fasciitis with symptoms, F: female, M: male, PFH: previous history of plantar fasciitis.

Table 2 - Descriptive statistics [mean (SD)] for the measures of alignment of the rearfoot and plantar medial longitudinal arch index between groups of runners with symptoms and histories of plantar fasciitis.

Measure	1 PFS group (n = 30)	2 PFH group (n = 15)	3 Control group (n = 60)	p-value*
Rearfoot angle	6.9(3.2)	6.7(4.2)	7.2(5.5)	0.971 (1-2) 0.982 (1-3) 0.931 (2-3)
Plantar medial longitudinal arch index	0.17(0.08)	0.17(0.07)	0.22(0.05)	0.984 (1-2) 0.009 (1-3) 0.008 (2-3)

*ANOVAs two-way. Post-Hoc de Tukey. $p < 0,05$ diferença estatística significante.
PFS: plantar fasciitis, PFH: previous history of plantar fasciitis.

differences in rearfoot alignments; however, a limitation of this study was that they did not assess the level and duration of pain associated with PF.

The innovative aspects of the present study were to better understand how runners with pain levels of 5 (2) cm, over a duration of seven months, did not show differences in their rearfoot alignments compared to runners with histories of PF and controls. These findings suggest that valgus misalignments of the rearfoot do not appear to be a risk factor involved in the development of PF in runners. In contrast, Tauton et al.[4] reported excessive rearfoot pronation in 55% of athletes with PF. However, their assessments only included subjective clinical measures of alignment which were visually determined and were less valid and reliable.

Prichasuk and Sbhadrabandhu,[26] employed quantitative X-ray measures to investigate the calcaneal lateral tilt angles in non-athletic subjects with symptomatic calcaneal spurs. They found that, compared to controls, the symptomatic group demonstrated decreases of tilt angles and their results corroborated those of Shama et al.[16] One possible explanation for the differences between their results and those in the present study could be the sample selection, as only runners without diagnoses of calcaneal spurs were evaluated. It is possible that the presence of spurs in the chronic stages of PF could result in excessive rearfoot valgus misalignments during static postures.

One limitation of the present study was that dynamic analyses of the rearfoot and midfoot were not carried out. Even though, Pohlet al.[15] had already reported that rearfoot movements did not change in female runners with a history of PF, the inclusion of dynamic measures would be important for the demonstration of movements of these segments with the presence of pain. Also, these authors did not try to assess the relationships between midfoot pronation and PF, as previously reported by Chang et al.[39] The inclusion of these assessments could have explained the dynamic involvement of the rearfoot and midfoot during conditions of pain in runners with PF. According to Riddle et al.,[10] there are potential relationships between the increases in pain and decreases in ankle range of motion, which are of extreme importance for the foot rocking mechanisms during running.

Cornwall and McPoil[40] postulated that excessive pronation could occur as a result of structural changes in the plantar arches, or to compensatory mechanisms, which could result from decreases in dorsiflexion. However, as in the diabetic neuropath, the literature is not yet clear regarding the relationship between the smaller ankle range of motion and the foot roll-over mechanism.[41] This study also evaluated the behaviors of the plantar arch with the presence of pain in runners with PF. According to Huang and Kitoaka,[42] the crucial function of the plantar fascia is to maintain the integrity of the plantar arch. Thus, the literature hypothesizes that lowered plantar arches could induce greater stretching of the plantar fascia.[6,15,21,43,44]

In the present study, the initial hypothesis was that the presence of pain would result in increases of the plantar medial longitudinal arch index. However, it was observed that plantar arch configurations appeared to be more related to the genesis of PF and not specifically to pain symptoms. Compared to the CG, arches were more elevated in the groups with PF, both symptomatic and with histories. A possible explanation for these findings could be the fact that the elevation of the plantar arch would lead to greater strains of the plantar fascia to maintain arch architecture during static positions. The maintenance of this posture for long periods could lead to micro-traumas of the plantar fascia and, consequently, to the onset of PF, which is characterized by periods of crises and remissions.[45]

It is well documented that individuals with PF have decreases in their ankle dorsiflexion range of motion[10,12] associated with less flexibility of the triceps surae muscular group,[12] and decreases in extension of the toes.[46] These changes could suggest that the plantar fascia would be kept in a more shortened position and, thus, would be exposed to greater tensions to be able to support the plantar arch, as found in the present study. Based on this, the majority of treatments for PF recommend the use of shoe wedges with the objective of supporting the plantar medial longitudinal arch and to relax the plantar fascia, which could result in relief of the pain symptoms.[47–50]

Another proposed intervention which reinforces the previous idea, is the support of the plantar medial longitudinal arch by means of functional bandages.[51] According to Wearing et al.[19], the thickening of the plantar fascia and the levels of pain associated with PF are factors which could impose stresses on the static structures of the plantar arch. However, the present findings demonstrate that the presence of pain in the group with PF, did not promote changes in the configuration of the plantar arch, which suggests that more elevated plantar arches could be better related to the development of PF.

Messier and Pittala[52] evaluated the plantar arch of 15 runners with PF by means of plantar impressions and did not find statistically significant differences, compared to the CG. However, they reported the tendency of more elevated plantar arches in the PF group. In the present study, 45 runners, 30 with symptoms and 15 histories of PF were evaluated and the plantar impressions were obtained with podometry, whose reliability[35] and validity[36] are well established. With a larger sample size, the results demonstrated more elevated arches in both groups of runners with PF, as was reported by Messier and Pittala.[52]

According to Krivikas,[14] a more elevated arch, besides promoting greater stresses on the plantar fascia, whose function is to provide support to the plantar arch, would reduce the attenuation of the impact forces of the calcaneus on the ground. This mechanism would lead to greater loads on the medial and posterior areas of the feet. Taking into consideration the fact that running could cause high repetitive impacts on the calcaneus and, that if these impacts were repeated about 625 times/km,[53] elevated plantar medial longitudinal arches would cause greater tensions and micro-traumas on the plantar fascia in runners.

According to Karr,[27] both elevated and lowered arches could predispose individuals in the development of PF. In the present study, the runners with symptoms and histories of PF demonstrated higher elevated configurations of the plantar medial longitudinal arch, compared to the controls. These findings are in disagreement with those reported by Pohl et al.,[15] who found lower plantar longitudinal arches in female runners with PF, although they did not take pain symptoms into consideration. Two factors could explain the differences between these results. First, they only evaluated runners with histories of PF with a mean onset time of 2.5 years. Second, they did not provide data regarding the applied interventions. This could explain if the plantar medial longitudinal arch was being re-structured and, thus, the differences between the present results, in which the subjects in the PF groups received treatments over a shorter period of time (mean = 6 months).

Based on these findings, the relevance of this study was that it attempted to clarify that the presence of pain did not affect rearfoot misalignments and plantar medial longitudinal arch configurations of runners with PF. Wearing et al.[19] observed that pain symptoms promoted adaptations in the foot roll-over mechanisms during gait in individuals with PF. However, Ribeiro et al.[54] observed that pain symptoms did not promote any adaptations in foot roll-over mechanisms during running in recreational runners with PF. In the present study, the evaluations were carried out in bipedal static support and did not find any effects of pain on plantar arch shapes or rearfoot alignments. It is important to note that the elevated architecture of the plantar arch in runners with PF could lead to greater strain on the plantar fascia during static and, mostly, dynamic activities, such as running, because of the repetitive foot impacts with the ground during practice. Chronically, these stresses could cause micro-traumas in the plantar fascia and probably lead to the progression of symptoms, or even to the onset of PF.

A limitation of this study was that dynamic analyses of the rearfoot and midfoot were not included; thus, future studies are necessary for a better understanding of PF in runners. Regarding the plantar arch, studies evaluating interventions employing wedges, functional bandages and other physical therapy resources are necessary for a better understanding of the mechanical effects on the plantar medial longitudinal arch configurations in individuals with PF.

CONCLUSIONS

Runners with symptoms or histories of PF did not differ in their rearfoot valgus alignment but showed increases in longitudinal medial plantar arches during bipedal static support, regardless of the presence of pain.

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