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Biomechanical Aspects of the Static and Dynamic Patterns of the Feet of Runners with Plantar Fasciitis and Their Relationship with Sports Shoes

Ana Paula Ribeiro

Abstract

The purpose of this literature review was to evaluate studies that have investigated static and dynamic biomechanical patterns of the feet in runners with plantar fasciitis, as well as their relationship with sports shoes and insoles prescription. Original articles with different design on this theme were considered. In general, the increase plantar load rates in runners with plantar fasciitis may be directly related to changes in the plantar arch (elevated) and the rearfoot alignment in pronation, as well as the effect of shoes or insoles to reduce heel pain. In summary, the clinical support of the literature review was showed that a decrease in the medial longitudinal arch induces greater mobility of the foot, which promotes a greater angle of rearfoot pronation to maintain the stability of the subtalar joint during static and dynamic feet support in activities, such as running. This results in a greater overload on the medial region of the calcaneus, producing greater stress on the plantar fascia, contributing to the development and progression of plantar fasciitis in runners. In addition, treatment of acute plantar fasciitis was associate to insoles while chronic phase associated for shoes ultra-flexible intermediate midsole for heel pain reduction and improvement foot biomechanics in runners with plantar fasciitis.

Keywords: plantar fasciitis, foot, runner, plantar load, shoes, insoles

1. Introduction

Millions of people take part in sports activities that involve running as it is an activity available to all ages, and is low cost, versatile, and brings health benefits [1]. Currently, running is one of the most popular sports in the world, having experienced substantial growth over the past decades [1–3].

At the end of the 20th century, the considerable increase in running practice resulted in a higher prevalence of injuries in the lower limbs [2, 4, 5], with percentages of reported injuries of 5.7 to 39.3% over a period of one year in those who practice sports [1, 2]. Among the most frequent injuries, a retrospective study with 2002 runners revealed that plantar fasciitis is the third most common musculoskeletal injury in runners [6], reaching approximately 10% of them [3, 6, 7]. According to

Tauton et al., [7], of the 267 cases of plantar fasciitis analyzed in various sports, 160 of these cases involved only the running modality. In addition, it is the most common cause of acute and chronic calcaneus pain [8]. These facts have led to growing interest in research regarding the causal factors of plantar fasciitis in runners.

Plantar fasciitis is characterized by a musculoskeletal disorder of inflammatory and degenerative origin of the plantar fascia. The most common clinical symptom of plantar fasciitis is pain in the lower and medial region of the calcaneus, most typically close to its insertion in the medial tubercle of the calcaneus [9, 10].

There are several intrinsic and extrinsic factors related to the disease [11]. However, some specific intrinsic factors related to the development of plantar fasciitis have been further explored in the literature. Among them, obesity [12], decreased ankle dorsiflexion [12, 13], the type of medial plantar longitudinal arch [6, 7, 14–16], rearfoot pronation [11, 7], and increased plantar load stand out [17–20]. However, these factors still remain controversial, especially with regard to their involvement to a greater or lesser extent with the etiology of this injury [11].

The majority of studies report that the factors most strongly associated with the development of plantar fasciitis are biomechanical factors directed to the type of longitudinal plantar arch, excessive pronation of the rearfoot [6, 7, 14, 15], and increased pressure on the surface of the feet [17–20]. Thus, it is evident that changes in the plantar arch and in the rearfoot alignment can directly or indirectly influence the functionality of the plantar fascia and, consequently, in the redistribution of the plantar load.

Generally, the most accepted theoretical and scientific reasoning is that plantar overload, resulting from possible biomechanical imbalances in the structure of the feet, would result in greater pressure and increased force rates on the plantar fascia, inducing microtrauma and inflammation, characterizing the acute phase of the injury [21, 22]. Throughout the period of the disease, the repetitive support of the feet in contact with the ground would evolve to the fragmentation and degeneration of the plantar fascia, characterizing the chronic phase of plantar fasciitis associated with degeneration and fragmentation in the thickness of the plantar fascia [22, 23].

However, even though plantar fasciitis is the third most prevalent injury in runners [6, 7], the majority of studies that investigated calcaneus overload were directed to walking [17–19]. Another fact worth noting is that the presence or absence of the painful stimulus, common in the different phases - acute and chronic plantar fasciitis - has been the subject of studies on plantar loads in walking and running [16–19, 24, 25]. In addition, Ribeiro et al., [24] and Hong et al., [26] emphasize the importance of studying the distribution of plantar load during running in a training and competition environment, since running on a treadmill can influence the foot support pattern of runners affected by the disease.

According to the biomechanical studies carried out to date, it is likely that the plantar loads undergo changes during the acute (with pain) and chronic (without pain) phases of plantar fasciitis, especially in the running population [20, 24]. In addition, this possible increase in plantar load rates in runners with plantar fasciitis may be directly related to changes in the plantar arch, which remains elevated [6, 25, 27] and with the alignment of the rearfoot that maintains greater pronation of the feet [16, 25].

In this chapter, we aim to provide better understanding of scientific studies regarding the static and dynamic biomechanical patterns of the plantar support of the feet of runners with plantar fasciitis as well as their relationship with sports shoes and the prescription of orthoses and insoles, in order to assist in the clinical parameters of health professionals working in the conservative treatment of plantar fasciitis in runner athletes.

2. Static and dynamic biomechanical patterns of plantar support in runners with plantar fasciitis

2.1 Plantar load during foot support and plantar arch in runners with plantar fasciitis

Understanding of the plantar arch comes from pioneering [28, 29] and more recent studies [24, 25, 30, 31] that emphasize the importance of the plantar fascia for greater stabilization of the medial longitudinal arch, especially during mechanical support of the foot with the ground for better absorption and dissipation of forces received during walking and running sports activities [24, 25]. The plantar fascia associated with the medial longitudinal arch has the function of supporting up to 14% of the total impact forces of the foot in contact with the ground [29], thus allowing the best redistribution of plantar loads and, consequently, the appearance of plantar fasciitis.

Part of the clinical literature supports the theory that a decrease in the medial longitudinal arch induces greater mobility of the foot, which promotes a greater angle of rearfoot pronation to maintain the stability of the subtalar joint during static and dynamic support in activities such as running and walking [24, 25]. This results in a greater overload on the medial region of the calcaneus, producing greater stress on the plantar fascia [14–16, 20, 32, 33].

Another line of thought, consistent in most studies, is the theory that an elevated medial longitudinal arch induces greater rigidity and shortening of the plantar fascia [34], resulting in inefficiency in the ability to dissipate the impact forces of the foot in contact with the ground. Thus, the plantar fascia is placed under greater mechanical stress in the calcaneus region [15, 35]. In contrast, studies that evaluated the medial longitudinal arch [11, 36], rearfoot static alignment [11], and calcaneus pain in long distance runners, did not observe significant differences in these factors when compared to healthy runners.

Despite the lack of consensus in the literature on the question of the plantar arch in runners, studies have shown that in plantar fasciitis both types of plantar arch: increased and decreased can be causative factors of the condition [11, 16, 24, 25]. However, the majority of the literature is based on the reasoning of an increase in the plantar arch in runners with plantar fasciitis [7, 20, 24, 25].

Another risk factor of notable importance linked to the pathophysiological and etiological framework of plantar fasciitis, and which may be associated with changes in the conformation of the medial longitudinal arch or decreased ankle dorsiflexion, is excessive rearfoot pronation, usually caused by valgus alignment of the calcaneus [37]. This excessive pronation would result in decreased rearfoot stability, producing excessive stress on the lower-medial part of the calcaneus, related to plantar fasciitis [6]. This instability of the subtalar joint would hinder the transition from the medium support phase to the final support phase, which would promote greater plantar load in the medial region of the calcaneus, generating greater tension in the plantar fascia and, consequently, making it more vulnerable to repetitive microtrauma [14]. According to some authors [16, 24, 25] runners with plantar fasciitis present valgus alignment of the rearfoot. According to Lee et al., [38] the association between the maximum eversion angle of the rearfoot (pronation) and the height of the plantar arch can induce an indirect effect of tension in the plantar fascia that could result in overload on the plantar surface of the feet.

Thus, it is evident that changes in the plantar arch and in the rearfoot alignment can directly or indirectly infer the functionality of the plantar fascia and, consequently, in the redistribution of the plantar load. However, there are no studies in the literature that infer the direct relationship of these clinical variables of the

feet with calcaneus overload, in injuries such as plantar fasciitis, especially in the population of runners where the prevalence of these injuries is high [3, 6].

The scientific relevance of this chapter is justified on the theme of runners with plantar fasciitis, since much of the literature, directed to runners without previous injury, observed that the elevated plantar arch is positively associated with the increase in vertical force load rates [35, 39, 40]. Thus, the increase in rates of force on the plantar fascia can induce microtrauma and inflammation, characterizing the acute phase of the injury [21, 22] and following the circle character of the condition, the repetitive support of the feet in contact with the ground, would evolve to fragmentation and degeneration of the plantar fascia, characterizing the chronic phase of plantar fasciitis without pain [22, 23]. Despite this understanding, and even though plantar fasciitis is the third most prevalent injury in runners [3, 6, 7], the majority of studies carried out on the increase in vertical force rates on the calcaneus were directed to walking [17–20].

The presence or absence of pain stimulus on the calcaneus during the period of plantar fasciitis (phases - acute and chronic) has been investigated by some authors [17–20, 24, 25]. When these plantar loads were investigated, specifically in the gait of individuals with plantar fasciitis, a confounding factor in the results was associated with the pain present in the acute inflammatory phase of the disease. The results observed were greater overloads in anterior regions of the plantar surface (midfoot, forefoot, and toes) and not in the calcaneous region, as expected by the pathophysiology of plantar fasciitis [17–19]. The authors justified these findings by a momentary mechanical adaptation during the rolling of the foot in gait to promote the reduction in rearfoot loads, due to the mechanism of protection against pain in the calcaneous region. However, as the pain factor was present in plantar fasciitis, it cannot be inferred whether these increases in plantar loads in the anterior regions of the feet are related to an analgesic mechanism present in the acute phase of the disease, or whether it can be considered an intrinsic factor of the etiology of plantar fasciitis that would promote stretching of the plantar fascia, stressing its insertion in the medial tuberosity of the calcaneus.

The effect of different phases of the disease (with and without pain) on the mechanical overload of individuals with plantar fasciitis was the focus of three studies during running [16, 20, 24, 25]. However, the results of both studies are still contradictory and remain inconclusive. The first study revealed that runners with a history of plantar fasciitis, without the presence of pain, have higher peak vertical strength and impact rates (0 to 100% and 20 to 80% of support) during running compared to control runners. The second study found that recreational runners with plantar fasciitis in the acute (with the presence of pain) and chronic phases (history of plantar fasciitis without pain) have similar distribution of plantar pressure in relation to control runners [20]. The third study, carried out by Ribeiro et al., [20], aimed to verify this effect of the presence and absence of pain according to the stages of plantar fasciitis in recreational runners. The authors concluded that the estimated impact rates and rearfoot plantar loads are higher in runners with plantar fasciitis compared to control runners. In addition, the authors found that the different clinical phases of plantar fasciitis promote runners in the acute phase of plantar fasciitis (with the presence of pain in the calcaneus) to have lower impact rates and plantar loads in the rearfoot compared to the chronic phase, likely due to the mechanism of pain protection in the calcaneous region. It is possible the contradiction in the results of these studies lies in the difference in the variable used to infer overload and in the environment in which the runners were evaluated. The first study inferred overload through the vertical force obtained by a force platform in a laboratory environment [16] and the third study using plantar pressures obtained by insoles when runners ran in natural training and competition environments [20].

The importance of studying plantar loads during running in training and competition environments, as performed by Ribeiro et al., [20] was recently highlighted by Hong et al., [26] who found that the distribution of loads during running on a treadmill is not the same as during running on fixed surfaces, like the ground. According to the authors, treadmill running can be used in rehabilitation programs to help reduce plantar load, however, for patients with injuries in the lower extremities, the change in the research paradigm from the treadmill to the fixed floor, and in an ecologically valid environment is of fundamental importance to better understand the causal factors involved in the daily life of the runner.

Understanding the pattern of these plantar loads during running in a natural environment would be of great therapeutic benefit for rehabilitation programs for lower limb injuries, such as plantar fasciitis. According to Giddings et al., [41] the running activity provides a load stress with a magnitude of approximately 3.7 to 4.8 times the body weight on the fascia and plantar ligament. Thus, considering running as a cyclical modality, with great magnitude impacts on the heel and plantar fascia, its continuous practice could be directly related to the appearance and progression of plantar fasciitis. Another point of understanding is in relation to the synchronization of the foot, ankle, and tibia, corroborated by the study of DeLeo et al., [42], where the foot eversion peak occurred between 39 and 54% of the support phase, and the knee flexion peak between 36 and 45%. Thus, the attenuating function of the foot resulting from this synchronization is evident.

The movement of pronation and supination of the rearfoot has been intensively investigated in the literature [43–46], due to the strong relationship of these movements with the generation of plantar overload and the appearance of some injuries, one of which is plantar fasciitis. A condition of hyperpronation is considered to be an important factor that predisposes to injury to the feet segment in runners. Viel et al., [33] suggests that rearfoot pronation may arise from the original position of the calcaneus, which is not projected vertically and the projection of the body weight medially in relation to the support point of the calcaneus. It is believed that the control of hyperpronation, through an adequate analysis of the distribution of loads on the plantar surface and the subsequent use of appropriate footwear, reduces this incidence of injuries [47].

Thus, plantar pressure, when properly distributed, must be symmetrical between the lower limbs, as well as between the anterior and posterior parts of the foot. When body weight support is normal, all foot is in contact with the ground and support 50% of the total load, while the heel is responsible for the remaining 50%. On the other study, Marsico et al., [48] report that the plantar load must be transmitted to the entire plantar surface, 40% of which is distributed on the anterior part of the foot and 60% on the posterior part.

In view of this context, it is clear that the possible increase in plantar load rates in runners with plantar fasciitis may be directly related to changes in the plantar arch [7, 20, 49], and with the alignment of the rearfoot that maintains a more pronated posture [16, 24, 25]. Better understanding of these dynamic patterns of plantar load in runners with plantar fasciitis and their relationship with the plantar arch and rearfoot alignment could be useful for prescriptions or interventions through insoles, orthoses, and footwear aimed at runners with plantar fasciitis, demonstrating the great clinical and scientific relevance of this study.

2.2 Intrinsic foot muscles dysfunction and risk of injuries for runners: relevance in rehabilitation process

Several authors suggesting that inefficient active support of the medial longitudinal arch (MLA) may contribute to injuries such as plantar fasciitis (recognized as

a repetitive strain injury from excessive deformation of the arch) or medial tibial stress syndrome, through a reduced ability to control foot pronation [18, 19, 50]. Studies in biomechanics, has revealed that dysfunction of the plantar intrinsic muscles of the foot leads to an increase in foot pronation in static stance, while walking or running [50, 51]. This may result in a less rigid foot as the midfoot remains “unlocked” and therefore, generates less torque leading to inefficient force transmission through the foot lever and insufficient foot stiffness adaptation in transverse plane. In addition, with excessive pronation, the angle of pull of the Achilles tendon and the plantar flexors would be less than ideal such that some of the force generated by the muscles would pull medially as well as upward [51–54].

According to Fourchet and Gojanovic [51] In order to counteract or prevent these impairments, there are two ways for enhancing the foot core stability. Firstly in terms of volitional control of the intrinsic foot muscles, the “short foot exercise” must be practiced. Secondly strengthening sessions using neuromuscular electrical stimulation of these muscles seem to be a promising strategy in order to support the MLA and control the pronation during running. Practically, the foot core strengthening protocol may benefit not only the runners affected by excessive pronation related injuries but also those who sustained a long-term lower limb injury and may be affected by a detraining process. Dynamic foot control is of primary interest for runners’ health and performance. The medial longitudinal arch actively controlled by the intrinsic foot muscles allows mechanical energy to be stored and subsequently released during each foot contact while running. Four weeks of short foot exercise training improve both local foot postural control and dynamic single-leg balance. Intrinsic foot muscles strengthening using neuromuscular electrical stimulation enhances foot postural control and plantar pressure profiles during running. Foot core strengthening program should be implemented in lower limb rehabilitation plans and in strength and conditioning training sessions for runners.

In addition, recent study performed in 2020 [55], has showed the effect of body mass and ankle muscle strength on the dynamic foot-pressure distribution before and after running. Second the authors the body mass index and percentage fat mass were correlated positively to all components of foot-pressure distribution. Plantar flexor muscle strength significantly predicted plantar pressure and impulse underneath the midfoot area and the dynamic arch index. After running, plantar flexor and inverter muscle strength predicted from 30% (for metatarsal 2) to 58% (for metatarsal 1) of peak foot-pressure and impulse underneath the different foot zones. Thus, the obesity was associated with excessive plantar loading that is aggravated after running by fatigue-related reductions in plantar flexor and inverter muscle strength. To prevent foot pain and injuries related to excessive foot pressures, at the start of the weight control process non-weight bearing rather than weight-bearing exercise is advisable.

2.3 Biomechanical aspects of feet for treatment with insoles and shoes in runners with plantar fasciitis

In an attempt to prevent the progression of plantar fasciitis or even to eliminate the periods of recurrence of the disease, most therapeutic approaches directed to runners with this pathology occur through insoles, with the purpose of supporting the medial longitudinal arch and reducing overload in the rearfoot region, as well as footwear to minimize excessive rearfoot pronation [20]. However, few studies have aimed to understand the effect of these factors on plantar fasciitis [56, 57], especially in running [58, 59].

One explanation for the few studies on treatment with insoles or shoes in runners may be due to the treatment time for plantar fasciitis. According to Young *et al.*, [60]

the treatment lasts around six to 18 months, a fact which can lead to frustration of the therapist and the patient [61]. Although conservative therapy (drugs, physiotherapy, and orthosis resources) is still the mainstay of treatment, there are several controversies about the effectiveness of the therapeutic program that best provides symptom relief [62]. Thus, when conservative treatment is unsuccessful, a percentage of 5 to 10% of those affected progress to surgical treatment for removal of the plantar fascia [63].

The purpose of most of the treatment strategies for plantar fasciitis described in the literature is to reduce pain symptoms and overloads imposed on the calcaneus. In this direction Landorf *et al.*, [57], evaluated 135 individuals with plantar fasciitis, non-athletes, in a longitudinal follow-up treatment with insoles. The objective was to evaluate the effectiveness of three types of insoles on the plantar surface, after three, six, and twelve months of treatment. The authors concluded that, in the long run, none of the insoles promoted a reduction in symptomatology and improved foot function. This may explain the cycles of relapse and remission of plantar fasciitis [64].

This study is important, since one of the most commonly used resources by runners in their running practice is the insole, as a corrective factor for a better mechanical performance of the feet, as it is low cost when compared to recognized brand footwear in the market. According to some authors [65–67], the support of the longitudinal plantar arch is one of the most common treatments used in the population of athletes with plantar fasciitis.

Another study aimed at conventional footwear in triathlete runners with plantar fasciitis found that many have manufacturing defects that possibly contributed to the development of plantar fasciitis. Evaluating the construction of sports shoes (in terms of flexibility and the sole) can prevent injuries from overuse of the lower extremities [58].

In another study, the authors aimed to verify the effect of traditional footwear in relation to footwear with an ultra-flexible intermediate midsole (Nike 5.0) for the treatment of chronic plantar fasciitis associated with diverse exercises for 12 weeks and a 6-month follow-up after intervention. The conclusion of this study revealed that the shoes with an ultra-flexible intermediate midsole (Nike 5.0) promoted pain reduction earlier than conventional shoes [59].

Given the biomechanical studies carried out to date, it is likely that the way the loads are distributed on the surface of the feet of individuals with plantar fasciitis is different depending on the type of insole and footwear used by runners, especially when considering the acute and chronic phase of the pathology. However, there is still a scarcity of studies that address the effects of footwear and insoles on heel pain in runners with plantar fasciitis and their relationship with the plantar arch and load imposed on the feet during running and static postures.

3. Conclusion

In conclusion, the clinical support of the literature review was showed that a decrease in the medial longitudinal arch induces greater mobility of the foot, which promotes a greater angle of rearfoot pronation to maintain the stability of the subtalar joint during static and dynamic support in activities such as running. This results in a greater overload on the medial region of the calcaneus, producing greater stress on the plantar fascia, contributing to the development and progression of plantar fasciitis in runners. In addition, treatment of acute plantar fasciitis was associate to insoles while chronic phase associated for shoes ultra-flexible intermediate midsole for heel pain reduction and improvement foot biomechanics in runners with plantar fasciitis.

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Conflict of interest

“The authors declare no conflict of interest.”

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