Foot core strengthening: relevance in injury prevention and rehabilitation for runners

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Abstract

The human foot is a flexible structure characterized by a pronounced medial longitudinal arch (MLA) that compresses and recoils during running. That process is actively driven by the intrinsic foot muscles and requires a proper stability of the MLA. This introduces the concept of foot core stability. Because the intrinsic foot muscles are often neglected by clinicians and researchers, the purpose of this article is to provide some guidelines for incorporating foot core training in prevention or rehabilitation programmes for runners.

The intrinsic foot muscles play a key role in postural control and maintain balance during single leg stance by controlling the height of the MLA and the foot pronation. During running, these muscles lengthen eccentrically during the absorption phase and subsequently shorten as the arch recoils during the propulsive phase, functioning in parallel to the plantar fascia.

As a consequence, the dysfunction or weakness of the MLA active support may lead to injuries (e.g. plantar fasciopathy, Achilles or Tibialis posterior tendinopathy, metatarsalgia or medial tibial stress syndrome), due to numerous biomechanical cascades and mechanisms.

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 beneficiate 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. In addition we warmly recommend integrating this protocol in any lower limb injury prevention programme or strength and conditioning plan for runners.

Keywords:
Intrinsic foot muscles, medial longitudinal arch, short foot exercise, neuromuscular electrical stimulation, pronation.

Résumé

Le pied humain est une structure souple caractérisée par une arche longitudinale médiale (ALM) prononcée qui se comprime et se détend pendant la course. Ce processus est activement assuré par les muscles intrinsèques du pied et nécessite une bonne stabilité de l'ALM. Ceci conduit au concept de gainage du pied. Parce que les muscles intrinsèques du pied sont souvent négligés par les cliniciens et les chercheurs, le but de cet article est de fournir quelques lignes directrices pour intégrer les exercices de gainage du pied dans les programmes de prévention ou de rééducation destinés aux coureurs.

Les muscles intrinsèques du pied jouent un rôle clé dans le contrôle postural et le maintien de l'équilibre pendant la phase d'appui monopodal, en assurant le contrôle de la hauteur de l'ALM et de la pronation du pied. Au cours de la course, ces muscles s'allongent en mode excentrique au cours de la phase d'absorption puis se raccourcissent ensuite lorsque l'arche se détend pendant la phase de propulsion, fonctionnant en parallèle avec le fascia plantaire. En conséquence, toute dysfonctionnement ou toute faiblesse du soutien actif de l'ALM peut engendrer des blessures (ex. fasciopathie plantaire, tendinopathie Achilléenne ou tibiale postérieure, métatarsalgie ou périostite), en raison des nombreux enchaînements et mécanismes biomécaniques possibles.

Afin de corriger ou de prévenir ces déficiences, deux options existent afin d'améliorer le gainage du pied. Tout d'abord en termes de contrôle volontaire des muscles intrinsèques du pied, «l'exercice du pied raccourci» doit être pratiqué. Deuxièmement, effectuer des séances de renforcement utilisant l'électrostimulation neuromusculaire de ces muscles semble être une stratégie prometteuse pour soutenir l'ALM et contrôler la pronation chez les coureurs.

En pratique, le protocole de gainage du pied peut bénéficier non seulement aux coureurs touchés par des blessures liées à une pronation excessive, mais aussi à ceux ayant subi une blessure au long cours des membres inférieurs et étant potentiellement désentraînés. En outre, nous recommandons vivement d'intégrer ce protocole dans tout programme de prévention des blessures du membre inférieur et dans les séances de préparation physique destinées aux coureurs.

Mots clés:
Muscles intrinsèques du pied, Arche longitudinale médiale, Exercice de raccourcissement du pied, Electrostimulation neuro-musculaire, pronation

Introduction

The human foot is a flexible structure characterized by a pronounced medial longitudinal arch (MLA) that compresses and recoils. This interface allows mechanical energy to be firstly stored and subsequently released during each foot contact while walking and running [1,2]. This is accomplished through the deformation of the MLA, which is controlled by numerous structures including intrinsic foot muscles [3]. That process requires a proper stability of the MLA, which introduces the foot core concept, proposed by McKeon et al. as an extension of the concept of core stability regarding the lumbopelvic region [3]. At the foot plantar sole level, the local stabilisers are the intrinsic muscles with their small moment arms and small cross-sectional areas: they constitute the active subsystem of the foot core. It is worth noting that the extrinsic foot muscles function as the global movers of the foot core to generate the movements of the foot and provide both absorption and propulsion capabilities during dynamic tasks [3]. The passive subsystem of the foot core consists of the bones, ligaments and joint capsules that control the foot's arches. The third subsystem involved in the foot core concept is the neural subsystem which consists of the sensory receptors in the plantar fascia, joint capsules, ligaments, muscles and tendons involved in the active and passive subsystems. The interactions between these three subsystems are further detailed in the paper of McKeon et al. [3].

Because the IFM are most commonly neglected in assessments and treatments, an essential element of foot core stability is not addressed. The purpose of this article is to provide some guidelines for incorporating foot core training in prevention or rehabilitation programmes for runners. Running is a cyclic activity where between 31.6% and 84.9% for an average of 54% of individuals sustain lower extremity injuries [4]. The whole lower limbs musculature is involved during the running gait, including the foot core stabilizers, in other words the intrinsic foot muscles (IFM). It is therefore of interest to assess the role of these muscles while running, to address the potential consequences of a dysfunction of the IFM and then to consider the reinforcement of the MLA in different modes for prevention or rehabilitation.

Functions of the intrinsic foot muscles in static and dynamic modes

As mentioned by Kelly et al., the IFM play a key role in postural control and are very important to stabilise the foot and maintain balance during single leg stance [5]. In addition these muscles are active in maintaining the height of the MLA and reducing foot pronation during static stance [6,7]. The overall action of the IFM in static mode has been summarised under the concept of "active arch buttressing mechanism"; this muscle group being stretched in a similar way to that of the plantar fascia in response to MLA deformation [2].

Fifty years ago, some authors already suggested that the IFM were active stabilisers of the toes during the push off phase of gait and providing resistance to subtalar joint pronation [8,9].

More recently, it has been shown that, during running, the IFM slowly lengthen eccentrically during the MLA compression and subsequently shorten as the arch recoils during the propulsive phase[10]. Interestingly, the IFM seem to function in parallel to the plantar fascia, actively regulating the stiffness of the foot in response to the magnitude of forces encountered during the running stance phase [10]. These muscles may then contribute to power absorption and generation at the foot, act as protectors of the plantar fascia and facilitate optimal foot ground force transmission [3].

Consequences of intrinsic foot muscles dysfunction or weakness and risk of injuries for runners

As it is established that IFM play a critical role during the running stance phase, the question of the consequences of the dysfunction or weakness of these muscles must then be addressed.

From epidemiological perspectives, several authors already mentioned this topic in the past, suggesting that inefficient active support of the MLA may contribute to injuries such as plantar fasciitis (recognised as a repetitive strain injury from excessive deformation of the arch) or medial tibial stress syndrome, through a reduced ability to control foot pronation [7,11,12].

In the biomechanics community, it has been widely proposed that dysfunction of the plantar intrinsic muscles of the foot leads to an increase in foot pronation in static stance, while walking or running [6,7,13]. 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 plan. 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 [13–15].

In the same line, Novachek mentioned that the time to maximum pronation is delayed beyond 40% of stance in case of excessive pronation. Likewise, the period of pronation is prolonged delaying the onset of supination. In this case, the "excessive pronating" runner would not start supinating or reaching a neutral position until later (i.e. well after propulsion phase was to have begun). Accordingly, the foot is not an effective lever [16].

Other authors reported that a more pronounced pronation associated with MLA flattening resulted in greater contact area and maximum force in the medial midfoot in runners and caused a higher loading of the medial longitudinal arch, and may consequently overload the first and second metatarsal heads [13,17–20].

Finally, we recently showed that running-induced fatigue increased the loading under the MLA in highly trained athletes, but not necessary with a concomitant increase of pronation [21]. Then this is worth noting that MLA dysfunction or weakness leads to compliance or flattening but not automatically to global foot pronation.

A last (but not least) parameter should be taken into account here: the sensorimotor consequences of IFM default. Indeed, the intrinsic foot muscles provide sensory and motor contributions to the foot core system and their dysfunction may contribute to the development of lower extremity overuse injuries [22].

Modalities of Medial Longitudinal Arch strengthening

At this stage, it is critical to address the evidence based methods and techniques the clinicians may use in order to activate and strengthen the IFM in order to optimize the MLA control.

Short foot exercise

The main exercise in foot core training is the "short foot exercise", enhancing the volitional control of the IFM [3,23,24]. In this exercise, the patient is asked to contract the IFM in an isolated way in order to raise the MLA (Figure 1). The patient learns to activate the IFM through the short foot exercise in a seated position, the demands of the exercise should be gradually progressed to more challenging activities in double- and single-limb standing and landing. Four weeks of short foot exercise training has been shown to improve both local foot postural control (maintaining an arch during standing activities) and dynamic single-leg balance [24].

Neuromuscular electrical stimulation of the Intrinsic Foot Muscles

A complimentary modality for the volitional strengthening of IFM is neuromuscular electrical stimulation (NMES) of the IFM, which appears promising as a tool in rehabilitation and prevention [24].

First of all, this technique can be used to educate patients during the initial stages of rehabilitation or prevention programmes by allowing them to understand (and feel) the precise biomechanics of foot function with involuntary activation of the IFM rather than trying to have them figure out how to activate these muscles voluntarily.

The incorporation of this innovative modality on the IFM has been shown to enhance foot postural control and plantar pressure profiles during running [24–26].

Our former experimentations suggested that NMES of IFM can decrease the navicular drop through a 3-week program including three sessions a week or can be used in combination with other exercises during a 5-week protocol resulting in a lateral shift of the foot plantar pressure patterns, which means a decrease of the MLA loading during running [13,25,26].

In addition, Gaillet et al. reported that a single 20-minute NMES session of the abductor hallucis induced an immediate inversion in standing position, which persisted 2 months later most likely due to the plasticity of spinally mediated abductor hallucis afferent connections [27]. James et al. reported also that a single 20-minute session of high-frequency, low-intensity wide-pulse NMES over the same muscle showed interesting effects during walking, such as an increase in forefoot eversion with concomitant rearfoot inversion in the frontal plane and rearfoot-dominated adduction in the transverse plane [28].

These latter findings over a single treatment session confirm the mechanical effect of NMES as a modality of primary interest regarding its neurologic-related effect rather than the strengthening effect [22].

In terms of practical set-up, the patients should stand with the feet on the ground. The electrical stimulator should deliver NEMS as following for instance: 15 minutes duration, around 75 NEMS contractions completed during each training session. Two electrodes are placed behind the head of the first metatarsal to stimulate the medial arch intrinsic muscles (Figure 2). Biphasic symmetric regular-wave pulsed currents (85 Hz) lasting 400 ms are delivered. Each 4-second steady tetanic stimulation is followed by an active rest period lasting 8 seconds [22,25,26]. Another type of protocol is available, as prescribed by James et al.: high-frequency, low-intensity wide-pulse NMES [28].

Regarding proper strengthening programme, patients should perform an average of 9 to 12 NMES sessions throughout 3 to 5 weeks. Initially the patients begin in double-leg stance and progress to single-leg stance activities [22].

It is also recommended to integrate NMES of the IFM in dynamic tasks like hoping, bouncing or landing as soon as possible during the progression [3,22].

Relevance in injury prevention and rehabilitation for runners

This is worth reminding that the foot sole (and by extension the IFM) is the interface between the body and the ground while running. Nevertheless when examining the literature associated with treatment for "overabsorption" types of injuries, evidence for the function of IFM and targeting improvement in their function is very minimal. We hardly think that this period is over and then we recommend that foot core strengthening exercises must be a component of a multifactorial rehabilitation programme [22].

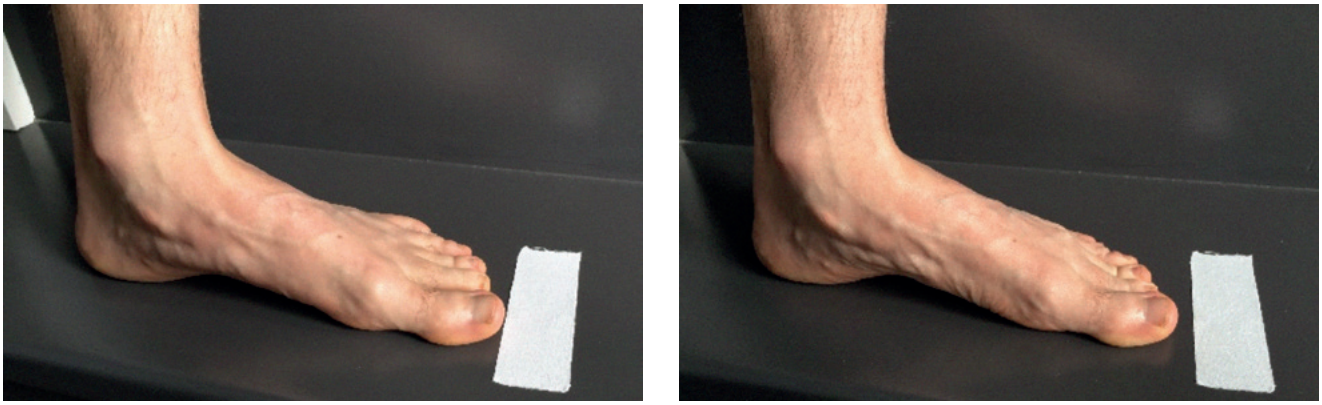

Figure 1 (A and B): The short foot exercise, A: Starting rest position and B: Intrinsic foot muscles activated. Please note the flexion of the first phalange while activating the intrinsinc foot muscles and the augmented distance between the tiptoe and the tape due to foot shortening.

Figure 2: Localisation of the electrodes for neuromuscular electrical stimulation programme of the intrinsic foot muscles.

Firstly the foot core strengthening protocol may beneficiate the runners affected by excessive pronation related injuries or in other words injuries resulting from a cascade of risk factors including MLA weakness or dysfunction as well as real overpronation. There is a large cohort of injuries that may be integrated in this subgroup (e.g. medial tibial stress syndrome, medial metarsalgia and metatarsal stress fracture, Achilles and posterior tibialis tendinopathy, plantar fasciopathy, Patello femoral pain syndrome …) [13,29–33].

In addition we know that any injury keeping the runner out of running during a relatively long period is going to result in a detraining and amyotrophy process [24]. We assume that the IFM must be stimulated and maintained during such an inactive period in order to prepare the "return to play" phase.

Nevertheless, rehabilitation is probably not the sole field where the foot core training should be applied. The widely unexplored topic of injury prevention should also take some benefit from this concept. It is proposed that the short foot exercise for instance should be integrated in any proprioception-targeted injury prevention programme or sometimes NMES of the IFM in the strength and conditioning sessions at the gym (simultaneously with squatting or dead lifting for example).

In the same line, we can notice the development of numerous running clinics or running education centres around the world; most of the time, one of the targets of the proposed sessions is to educate the runner to the midfoot strike running technique in order to prevent excessive passive impact force at the foot strike [34]. It is worth noting that very progressive protocols have been set-up in order to prepare the calves muscles that are much more solicited with that technique [34]. We assume that promoting and enhancing as well the foot core training in such transition programmes is a must, as these muscles are in the frontline in the shock absorption and in the propulsion phases.

Conclusion

Dynamic foot control is of primary interest for runners' health and performance. Overuse injuries related to medial longitudinal arch control may be related to impairments in foot stabilization at the stance phase of running, which led to increased tissue stresses or malalignments. Training the intrinsic foot muscles may offer benefit to the foot core system by increasing the medial longitudinal arch stiffness and ability to cope with changing demands of dynamic foot control. Practicing the different techniques of strengthening in rehabilitation or in training may offer an excellent strategy for reducing the incidence or preventing the effects of lower extremity overuse injuries related to poor foot control. In order to fully validate this strategy, further studies are required, assessing the effect of the foot core stability protocol on running-related injury prevalence and recurrence.

Practical implications

- 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 programme should be implemented in lower limbs rehabilitation plans and in strength and conditioning training sessions for runners.

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