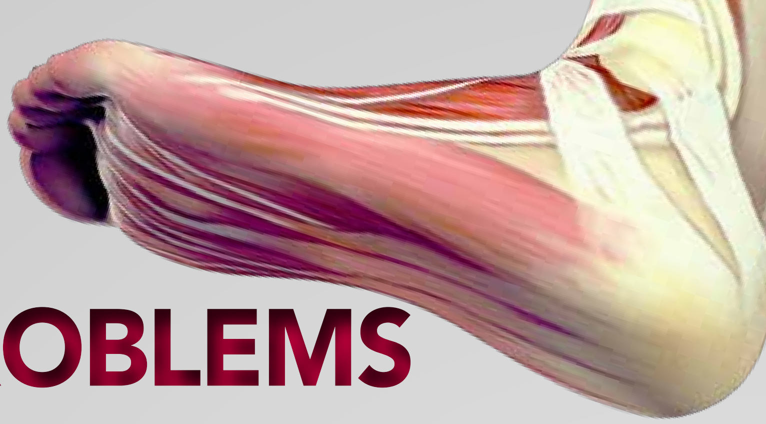
THE CORE OF YOUR FOOT PROBLEMS



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We all know that the foot is an amazing piece of anatomy and we probably all feel a bit chuffed once we've memorised the names of all the bones, know how they are held together, and understand the windlass mechanism and plantar fasciitis. But, other than their existence, what do we know about the intrinsic foot muscles (IFMs)? Well, it turns out that they are pretty crucial for proper functioning of the foot, and that strengthening them can help with many problems relating not only to the foot, but also the ankle and even the knee. This article allows you to understand the concept of the 'foot core', how to assess the IFMs and how to strengthen them. Read this article online https://spxj.nl/3kLmWSV

The human foot is a complex system with multiple degrees of freedom that play an essential role in its many diverse functions. It is our only point of contact with the 'earth'. During standing, it is our base of support. While walking or running, the foot needs to be stable during foot-strike and push-off. However, during the mid-stance phase, the foot is required to be dynamically adapting and reducing loads. It possesses spring-like qualities required for storing and releasing elastic energy. This is achieved through the deformation of the arch, which in turn is controlled by the intrinsic and extrinsic foot muscles. There is evidence that the foot arch architecture and musculature has changed with evolution in response to the increased demands of load carriage and running; wearing shoes; and changes in terrain from sandy soils, rocks, and grass to pounding concrete pavements.

So, What's the Problem?

Dynamic foot control arises from the interaction between active and passive structures and should be of primary interest in rehabilitation (or prehabilitation) of lower limb injuries. The stability of the arch, proposed to be the central 'core' of the foot, is requisite for normal foot function (1*). The concept of core stability in the lumbopelvic–hip region is well known, understood and clinically practised. So why not extend that concept to the arch of the foot? Both local stabilisers and global movers of the foot control the arch, similar to the lumbopelvic core. The local stabilisers include the four layers of intrinsic foot muscles (IFMs). These muscles originate and insert on the foot, have generally small moment arms, small cross-sectional areas and serve primarily to stabilise the arches (1*); see Further Resource 1 for more detail about the anatomy of the IFMs. The muscles that originate in the lower leg, cross the ankle and insert on the foot are the global movers; and traditionally have larger cross-sectional areas, larger moment arms, are prime movers of the foot, and also provide some stability to the arch and ankle (1*).

The IFMs form part of the active and neural subsystems that make up the foot core. These muscles eccentrically lengthen during the stance phase of running and then shorten at the propulsion phase, as they recoil with the arch. They play a key role in supporting the medial longitudinal arch (MLA) of the foot, providing flexibility, stability and shock absorption. Studies have shown that the IFMs provide an active contribution in late stance phase, in order to provide sufficient stiffness in the joints to facilitate propulsive forces for push-off (2*). It may seem obvious therefore to strengthen foot muscles, specifically the IFMs, to maintain and improve optimal capacity to generate and absorb these forces.

The arch of the foot deforms with each step and the intrinsic muscles are integral in controlling the extent and speed of these changes. Should the IFMs faulter in their function, an unstable or misaligned foundation results. Abnormal foot movement can form which over time could cause pain and injury. It seems that the value of the arch musculature in the prevalence of foot injuries is not fully appreciated. Little mention of specific foot strengthening (as a component of an intervention) is seen in clinical trials and guidelines for plantar fasciitis, as is the case with posterior tibial tendon dysfunction, medial tibial stress syndrome, plantar heel pain and chronic lower leg pain. Quite often exercise therapy is focused from the top down – for example strengthening the hips, glutes, quads, hamstring and calf. If we are to adopt the concept of the foot acting as the core to the lower limb then exercise therapy needs to be considered from the bottom up!

There are some studies that support multiple exercises to achieve greater strength in the foot, such as the 'short foot exercise' (SFE), doming, toes curl, towing exercises or the more dynamic hopping exercises, or even barefoot running. The real impact of these exercises on foot muscle strength and, more importantly, on improving foot core stability remains unclear. Despite

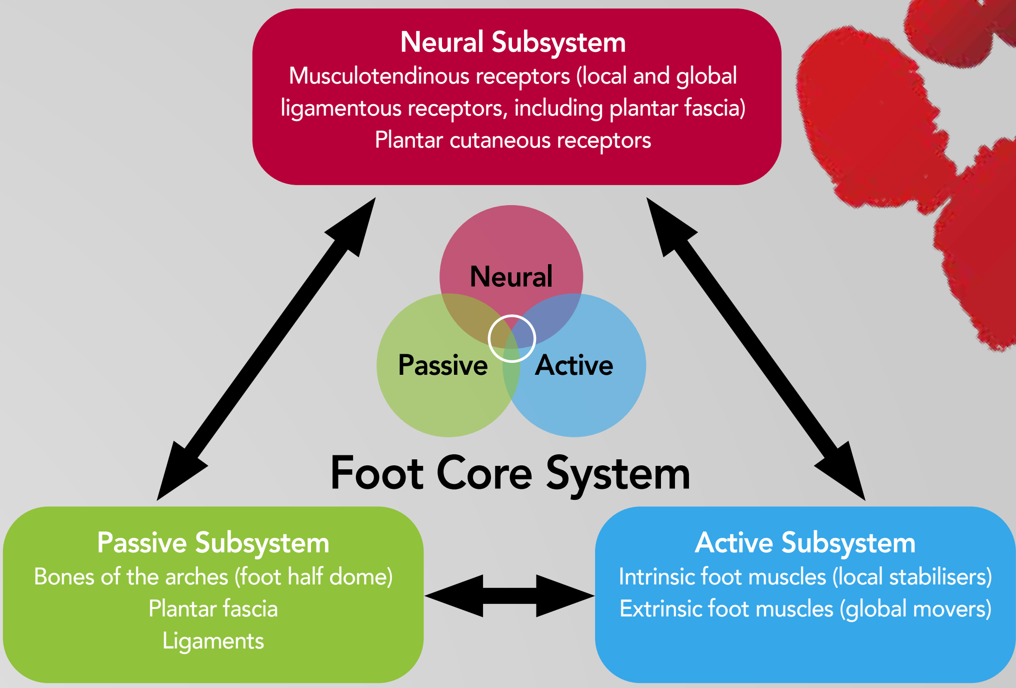

Figure 1: The foot core system. The neural, active and passive subsystems interact to produce the foot core system which provides stability and flexibility to cope with changing foot demands. *McKeon et al. The foot core system: a new paradigm for understanding intrinsic foot muscle function. British Journal of Sports Medicine 2015;49:290 (1*)*

a recognised need, data related to the assessment and efficacy of these exercises is scarce. There is emerging evidence of intervention studies focusing on improving IFM function. Two studies showed that following a programme focusing on training the intrinsic muscles of the foot resulted in improvement of dynamic stability during single limb reaching tasks (3,4). It was concluded from these studies that increasing toe flexor strength and executing the prescribed SFE improved the ability of the MLA to provide dynamical stability. However, it is unclear whether these improvements in function during relatively low-intensity static activities would translate to more dynamic high-intensity activities. Nigg et al. in 2009 (5) and 2017 (6*) showed that the smaller, intrinsic muscles are proficient in detecting inversion/eversion and/or abduction/adduction movement in the foot. It was suggested that stronger small muscles may act to minimise lower limb injuries (5,6*). Thus, it may be possible that by increasing the activity and strength of the IFMs and extrinsic foot muscles, arch function can be optimised. In turn, this may decrease the transfer of load and rotational forces to the knee and ankle, possibly decreasing ACL injury or ankle sprain risk during dynamic activities (7). Similarly, the SFE has been shown to be more effective than standard proprioceptive sensory exercises for treating patients with ankle sprains, with SFE generating significantly greater improvements in balance index, vibration sensory threshold, joint position sense and ankle stability (8*). A preliminary randomised controlled trial showed that 4 weeks of IFM strengthening resulted in improved motor performance and decreased perceived difficulty when performing the exercises (9).

A randomised clinical trial is underway that may prove interesting for patients with knee osteoarthritis (KOA) (10*). Previous research [discussed by Dantas et al. (10*)] has reported that:

- KOA patients have:
  - weak foot–ankle muscles;
  - foot muscle strength deficits directly related to increased knee pain and stiffness, decreased physical function and more severe KOA; and
  - reduced plantar grip strength, a deficit that may impact on kinetic chain during gait; and
- studies have shown that 8–12 weeks of physical therapy targeting the trunk, hip and knee muscles may be effective in reducing pain and improving function and strength, but does not reduce the knee joint loads during gait or stair climbing.

However, studies have shown that minimally flexible shoes (essentially shoes with a more rigid base of support) reduced knee joint loads during gait and stair descent (11). Also, it has been seen that the use of minimalist shoes (6 hours daily, 5 days a week, for 6 months) resulted in reduced pain and analgesic intake, and improved self-reported functionality (12*,13). These results raise the question: can an increase in the neuromuscular reflexes of IFM minimise impact and knee overload? The new study, which is underway, will focus on the fact that a decrease in knee joint loads is essential to prevent the aggravation of KOA, and therefore propose a foot–ankle strengthening programme to affect the symptoms and outcomes of KOA (10*).

It seems that there is a shift in thinking or focus about the importance of the IFMs. Training the IFMs may offer benefit to the foot core system by increasing its functional ability to control movement and load during the changing demands of dynamic foot control. Moving from targeted isolation of these muscles in a strength training programme to their global integration in movement patterns (like heel raises, hopping, running, jumping) may offer an excellent strategy for reducing the effects of lower extremity overuse injuries related to poor foot control (14).

AT DIFFERENT STAGES OF THE GAIT CYCLE, THE FOOT NEEDS TO BE EITHER STRONG AND STABLE OR DYNAMICALLY ADAPTING

●● THE CONCEPT OF CORE STABILITY IN THE LUMBOPELVIC–HIP REGION IS WELL KNOWN AND HAS NOW BEEN APPLIED TO THE FOOT ●●

Understanding the Foot Core System

Panjabi originally proposed the theoretical model of the lumbopelvic–hip core stability, which is based on the functional interdependence of the passive, active and neural subsystems controlling spinal mobility and stability (15). Hodges further described the lumbopelvic core stability approach as having 'control' and 'capacity' components (16). The control components aim to restore coordination of the muscles acting as the core. The role of the capacity components, however, is to provide sufficient muscle strength and endurance to prevent the spine from being mechanically unstable under differing loads. At the end of the day the control and capacity components must complement each other to provide a stable lumbopelvic core. Jam was the first to apply these concepts to the foot core system (17*), as shown in Figure 1 (1*).

McKeon and co-authors describe in detail the different subsystems of the foot and how they together can form a 'foot core' that ideally would provide optimal stability, mobility and function for the rest of the lower limb (1*). The movement and stability of the arch (specifically the MLA) is controlled by intrinsic (local stabilisers) and extrinsic (global movers) muscles. As mentioned earlier, the IFMs are largely ignored or forgotten by clinicians and researchers. The muscles are seldom specifically addressed in rehabilitation programmes. Interventions for foot-related problems or lower limb injuries are more often directed at externally supporting the foot rather than training these 'core stabiliser' muscles to function as they were intended. Table 1 describes the functional qualities of the IFMs (1*).

Assessment of the Foot Core

Clinical assessment of the IFMs in musculoskeletal injury has received little attention. A recent systematic review concluded "[t]here is no gold standard to measure intrinsic muscle strength in the foot" (18*). Assessment techniques have been categorised into 'direct' and 'indirect' evaluations of intrinsic muscle function (18*). Direct evaluations are methods that focus on assessing toe flexion strength. Indirect evaluations include imaging techniques (including MRI and Ultrasound) and EMG (surface and fine wire) to estimate function of the IFMs; however, these are not practical on a daily basis in a clinical setting (18*).

Testing toe flexion strength is fundamentally limited by the inability to separate the contributions of the intrinsic and extrinsic toe flexor muscles (1*). Common methods for assessing this are manual muscle testing, toe grip dynamometry and pedobarography. In addition to these, two special tests include 'the paper grip' and 'intrinsic positive tests' (18*). The limitation of all of these tests is the assumed primary role of the intrinsic muscles being toe flexion, while ignoring their more proximal functions of supporting the arches of the feet. There are additional tests that can be performed. Although they do not specifically assess the IFMs, they can be useful in identifying the strength or stiffness of the foot arch expressed by its deformation when moving between weight-bearing and non-weight-bearing postures. These tests include the arch rigidity index, the medial arch height, navicular drop (ND) and the foot mobility measurement (FMM) (2*).

Below are the most common and practical methods (based on equipment within a standard clinic setting) for assessing the IFMs and the foot core.

1. Medial Arch Height

This can be measured during gait and/or standing phase, and requires the use of the Oxford Foot Model, a 3D multi-segment foot model with a good to excellent repeatability. Although accurate, this may not be a viable option within many clinics. There is, however, also a simpler version of assessing medial arch height, which is described next.

A functional assessment of a patient's ability to maintain a neutral foot posture and MLA height during single limb stance has been proposed as a test to assess IFM integrity (17*).

Table 1: Functional Qualities of the Intrinsic Foot Muscles (IFMs)
Adapted from McKeon et al. The foot core system: a new paradigm for understanding intrinsic foot muscle function.
British Journal of Sports Medicine 2015;49:290 (1*)

Functional quality	Description
Supportive of the foot arches	● Diminished function of the IFMs leads to detrimental alterations in foot posture ● Training the IFMs enhances foot posture
Activity dependent	● IFMs are more active in dynamic activities, such as walking compared to standing
Load dependent	● As postural demands increase (moving from double to single limb stance) so the activity of the IFMs increases
Synergistic	● During the propulsive phase of gait, the IFMs work together as a unit to provide dynamic arch support
Modulating	● The IFMs support the foot in its role as a platform for standing and as a lever for propelling the body during dynamic activities

The following instructions guide you through how to perform the IFM test:

i. The clinician sets the patient's test foot in subtalar neutral with the calcaneus and all the metatarsal heads on the ground, and instructs the patient to fully extend the toes.
ii. The patient then lowers their toes to the ground and is asked to maintain the foot position in single limb stance for 30 seconds.
iii. The clinician observes for gross changes in navicular height and overactivity of the extrinsic muscles.

Evidence suggests that the IFM test can detect improvements in foot core function, but more research is needed.

2. Arch Rigidity Index

The arch rigidity index (ARI) provides an indication of the structural mobility of the MLA, and is determined by dividing the standing arch height index by the sitting arch height index. An ARI of 1 indicates low arch mobility (stiff MLA), whereas higher numbers correlate with higher arch mobility (more flexible MLA). This is explained and illustrated in more detail by Tourillon et al. (2*)

3. Navicular Drop (ND)

The most popular evaluation of longitudinal arch stability found in the literature is the sit-to-stand double-leg or single-leg ND test (2*). The patient should sit with their feet (barefoot) resting on the floor such that their hips, knees and ankles are all flexed to 90°. Palpate the inferior border of the prominent tuberosity of the navicular bone and mark with a pen. Using a steel ruler (resolution: 0.5mm), measure the distance from your pen mark to the ground. Instruct the patient to then stand up onto a 10cm box, with their full weight through the foot being assessed. The other foot rests, for balance, lightly on the box. Repeat the measurement from your pen mark to the box. The ND is the difference between the two measurements (sitting vs standing). Ideally this should be repeated three times and an average value recorded (2*). Video 1 illustrates how to perform the ND test.

4. Foot Mobility Measurement (FMM)

The FMM is a measure of both vertical and medial to lateral mobility of the midfoot. The FMM differs from the ND test, which only assesses vertical mobility, and the FMM may be a relevant test in the assessment of foot mobility differences between non-weight-bearing and weight-bearing positions (2*). A detailed description of how to perform the test can be found at Tourillon et al. (2*) and McPoil et al. (19*).

Training the Foot Core

The same training principles used for any other muscle group can be applied to the strengthening of the foot muscles. IFM strengthening can be performed in isometric, concentric, eccentric or plyometric modes (2*). Exercises traditionally prescribed for IFM training primarily involved toe flexion such as towel curls and marble pick-ups. Although these exercises may activate some of the intrinsic muscles, they also involve substantial recruitment of the extrinsic toe flexor muscles (1*).

1. Short Foot Exercise (SFE)

The SFE is a recently described method of isolating the IFMs. By pulling the first metatarsophalangeal joint towards the calcaneus, essentially shortening the foot and elevating the MLA, the IFMs are being isolated. This action is also termed 'foot doming' (1*,2*). As with lumbopelvic–hip core control, the Hodges' concept of establishing control of intrinsic foot muscle function first, before increasing capacity should be followed (1*,16) .

The SFE can often be difficult for both the therapist to teach and the patient to learn, so Tourillon et al. (2*) have described three gradual training steps:

i. Passive mode. Initially the patient should simply sit while their foot is moved by the therapist in and out of the short foot positions. This allows the patient time to feel and observe the required movement.
ii. Active-assisted mode. Here, the patient can actively start to attempt the movement and muscle contractions while still being guided and physically assisted by the therapist.
iii. Active mode. The patient performs the exercise without assistance (Video 2).

Video 1: The navicular drop test for foot overpronation (Courtesy of YouTube user Physiotutors) https://youtu.be/BejuNMmD7-Y

Video 2: Foot – short foot intrinsic muscle strengthening Courtesy of YouTube user Physical Therapy First https://youtube.com/watch?v=QnnsoOIAFm0

The SFE is illustrated at McKeon et al. (1*), Tourillon et al. (2*), and Fourchet et al. (20*). Ideally the SFE should be progressed from sitting to bipedal, to unipedal positions, followed by functional activities such as squats and single-leg hops (1*). As with rehabilitation principles for other body parts, an area should not be worked in isolation, and functional movement patterns should be integrated to ensure a successful outcome. It has been suggested that upper body active and resisted activities be combined with SFE to create cross-body movement patterns (ie. trunk and pelvis rotation and its effect on foot posture) and facilitate muscular chain action (2*).

There is an increasing body of evidence to suggest that SFE training

THE SHORT FOOT EXERCISE HAS BEEN SHOWN TO BE MORE EFFECTIVE THAN STANDARD PROPRIOCEPTIVE SENSORY EXERCISES FOR TREATING PATIENTS WITH ANKLE SPRAINS

of the foot core can improve foot function. For example, according to the literature (8*,21,22*,23*,24):

- 4 weeks of SFE training can:
  - reduce arch collapse (as assessed by ND and arch height index) and improve balance ability;
  - improve dynamic balance compared to those who performed 4 weeks of towel curl exercises;
  - significantly increase great toe flexion strength and the cross-sectional area of the abductor hallucis muscle after 4 weeks of SFE and foot orthotic intervention, compared to foot orthotic intervention alone; and
  - improve self-reported function in chronic ankle instability patients.
- 6 weeks of SFE training:
  - provided a reduction in ND, foot pronation, foot pain, and disability and increment in plantar force of medial midfoot in pes planus.
- the SFE:
  - can be used to decrease ND – particularly in individuals with a flexible flatfoot;
  - is more effective than standard proprioceptive sensory exercise for treating ankle sprain patients; and
  - creates a more active foundational posture for functional movements and dynamic activities.

Traditionally a top-down approach, targeting the muscles of the lumbopelvic–hip complex, is commonly used in addressing a number of lower limb injuries. The functional effectiveness of the SFE suggests a ground-up approach may be a feasible option. Incorporating the SFE into performance and rehabilitation training may optimise lower extremity joint alignment and kinematics for more efficient muscle activity by way of the ground-up approach (24).

Video 3: Foot intrinsic muscles activation (Courtesy of YouTube user REACH Rehab + Chiropractic Performance Center)
https://youtube.com/watch?v=Jyha3RA2UAg

Video 4: Foot & ankle exercise: towel toe curls (Courtesy of YouTube user stoneclinicPT)
https://youtube.com/watch?v=dVDMUuWtX00

2. Toe Yoga or Toe Posture Exercises

'Toe yoga' or 'toe posture exercises' have been shown to activate the IFMs in an isometric contraction (19*). Some examples of toe posture exercises are described below and shown in Video 3.

- Toe-spread-out exercise is carried out by a sequential extension of all toes, followed by hallux abduction, hallux flexion, and fifth toe flexion (2*).
- The 'first-toe extension' or 'hallux-extension' exercise is performed by extending the first metatarsophalangeal joint while maintaining the lesser toes (second to fifth) in contact with the floor (2*).
- The 'lesser-toe-extension' exercise consists in extension of toes two to five while maintaining the hallux in contact with the ground (2*).

3. Towel Curl

Although we have stressed that toe flexion exercises recruit more of the extrinsic foot musculature (such as the flexor digitorum longus) rather than focusing on the IFMs, Hashimoto et al. developed an IFM strength training programme that minimised involvement of the extrinsic muscles by bringing the ankle into plantar flexion (2*,25*). The steps for performing the towel curl are listed below and shown in Video 4.

- Have the patient spread a towel out on the floor.
- The patient can be in either a sitting or standing position and should have their feet resting flat on top of the towel.
- Then have the patient pull the towel towards themselves by grabbing it with their toes and slowly flexing (curling) their toes, and then relaxing.
- This exercise can be progressed by adding a weight to the edge of the towel.

4. Dynamic and Plyometric Foot Strengthening

As we know, isometric exercises are not reflective of how foot muscles work during locomotion. Performing low load tasks, like the SFE, would seem insufficient to take on the magnitude of load at the midfoot during running or even walking. The foot muscles would be ill equipped to generate sufficient force with SFE exercises alone. A progression from isometric (core) to plyometric exercises in order to get closer to the specific function of running, jumping or sporting activities is suggested. More progressive functional exercises incorporating SFE are illustrated in Tourillon et al. (2*).

Minimalist or Barefoot Running

The literature on the effects of running on foot muscular adaptations is relatively scarce and somewhat contradictory. It seems that you are either for or against barefoot/minimalist running. Granted, there is no conclusive data to suggest a causal link between footwear use and injury risk; however, it is believed by some that the inclusion of barefoot or minimalist training in a runner's programme would be beneficial towards injury prevention. Arguably this is due to the following:

1. An increase in sensory input to the sole of the foot improves postural stability and therefore, fine control of movement (26*). Stability progressively increased with decreasing amount of footwear support.
2. IFM size and strength improve with barefoot or minimalist activities leading to a restoration of the foot arch (2*,27*).
3. Individuals with extended lower limbs on ground contact (commonly demonstrated when wearing shoes) have an increased reliance on passive tissues for shock absorption. These individuals tend to under use the posterior muscles of the lower limb, and are associated with both traumatic and chronic overuse injuries (26*). Many habitually barefoot or minimalist shoe runners do not use these mechanics. Runners who transition to barefoot running cease to use these mechanics (26*).

Greater hip, knee and ankle flexion are required to reduce the load traditionally absorbed by passive tissues (shoes) during dynamic movement. Greater eccentric muscle work, by the posterior chain muscles, is thus required. Options to achieve this may be via neuromuscular training programmes, gait retraining or barefoot running. Evidence suggests that barefoot running (or walking to start) has a positive impact on mechanics associated with injury (26*).

The transition towards barefoot activities in daily life, especially barefoot running, needs to be managed carefully in adults who have spent most of their lives shod. Slowly increasing time spent barefoot and on variable surfaces (starting with more forgiving carpeting, sand, or grass) may provide a suitable introduction to barefoot training. In this way, adults may be able to restore innate impact moderating mechanisms without muscle–tendon strain.

Conclusion

In order to best transfer lower limb forces during propulsion, the foot core system must act as a strong and rigid lever. On the contrary, it must cope with significant amounts of constraint at the absorption phase, in the sense of impact reduction. Deficits in active foot stabilisation during running or walking, may lead to increased tissue stresses resulting in overuse injuries linked to the lack of control of the arch of the foot.

'Prehistorically' our feet were designed with the strength for unsupported endurance walking and running. Unfortunately, adding permanent support to the foot (a.k.a shoes), as opposed to strengthening the foot core, is the current standard of care. Barefoot activities or minimalist shoes can be considered in safe environments as part of a training programme as it could assist in improving foot function.

The foot core should be approached in a similar way to the lumbopelvic–hip core system, which needs to be strong, but in the right way. That means the IFMs of the foot need to provide stability not only through strength but endurance too. The global, extrinsic muscles are there to support the foot and generate gross movement. A foot strengthening programme that includes the SFE should be considered when treating a foot injury or possibly any other lower limb injury. According to the guidelines, managing a foot injury should still include the use of orthoses and other supportive devices (braces or taping), albeit temporarily where possible. Greater focus needs to be placed on static and dynamic foot core function in prehabilitation and/or rehabilitation programmes.

In summary, this article aimed at increasing the awareness of the importance of the foot core, making up the arch, and contributing to overall foot function. It is apparent that a stronger foot is a healthier foot.

Further Resources

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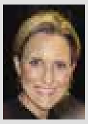
DISCUSSIONS

- What is the best test (if you have one) in your clinical practice to assess foot core function?
- Have you used or considered the use of a 'ground-up' approach to managing lower limb injuries? And if so, what was your choice of exercises and the outcome?
- What are your beliefs and attitude towards barefoot and/or minimalist footwear in rehabilitation?

KEY POINTS

- The foot core system (not unlike the lumbopelvic core) is composed of interacting subsystems that provide relevant sensory input and functional stability for accommodating the changing demands during both static and dynamic activities.
- Plantar cutaneous input from the foot can influence whole-body postural stability and kinematics during movement.
- The intrinsic foot muscles (IFMs) play a critical role in the foot core system as local stabilisers and direct sensors of foot deformation.
- Assessment of the foot core system can provide clinical insight into the ability of the foot to cope with changing functional demands, although no gold standard test exists (…yet).
- Targeting the intrinsic muscles via the short foot exercise (SFE), is the start of foot core training, slowly building on control and then capacity.
- The SFE creates a more active foundational posture for functional movements and dynamic activities.
- The functional effectiveness of the SFE suggests that a ground-up approach in managing lower limb injuries is possible.
- SFE should be incorporated into dynamic and plyometric activities to optimise lower limb performance and rehabilitation training.
- Barefoot activities or minimalist shoes can be considered in safe environments as part of a training programme as it could assist in improving foot function.
- A shift in thinking or focus about the importance of the IFMs or the foot core is needed to ensure optimal outcomes for our patients with lower limb injuries or pain.



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