

Contemporary Review: The Foot and Ankle in Long-Distance Running

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Abstract

Distance runners represent a unique patient population. The cyclic activity associated with distance running leads to a high incidence of injury. Gait patterns, the extrinsic and intrinsic muscles of the foot and ankle, foot strike pattern, shoe wear considerations, alignment, and orthotics are also all important considerations that must be considered by the treating provider. The purpose of this work is to review relevant functional anatomy, recent studies on gait patterns in running, orthotics, and theory on how the body moves through space during running in order to better equip the clinician to treat long distance runners.

Keywords: marathon, ultramarathon, running, long distance running, foot and ankle injuries

Introduction

Running has been reported to be the second most popular physical activity in the world.⁴⁵ As such, foot and ankle surgeons will frequently encounter distance runners who have symptoms and/or questions about shoes, orthotics, alignment, and injury prevention. Although distance running is not a contact sport, it is associated with substantial cyclic loading that may lead to overuse injuries. The patient assessment must therefore incorporate anatomical, biomechanical, and physiological evaluations.

Although there are many health benefits of running, there is a high incidence of running injuries, especially stress reaction and tendinitis. Distance runners, because of the high demands on the ankle and feet, may also have different expectations and specific concerns than nonrunners.

The purpose of this article is to examine the evolution, biomechanics, and functional anatomy of the foot as it applies to long-distance running. In addition, the use of orthotics as well as the incidence and treatment of stress injury will be reviewed.

Epidemiology

Although distance running lacks a clear definition, the marathon has traditionally been used to define a “long” distance. The marathon (26.2 miles/42 km) has been referred

to as the “suburban Mt Everest” in popular culture. It is estimated that roughly 1.3 million people completed a marathon in 2018.³ Ultramarathons are defined as distances greater than a marathon. The participation in ultramarathons has increased by 1676% in the last 23 years to roughly 611 098 yearly participants as of 2021.⁸⁶ The health benefits of running include a 30% reduced risk of all-cause mortality and a 45% reduced risk of cardiovascular mortality.⁵⁷

Nevertheless, it has been reported that up to 79% of runners sustain an injury of some sort during any given year, of which the vast majority involve the lower limb.^{60,63,101,104,105} These are evenly distributed across the foot and ankle, knee, and lower leg. These injuries are also important to clinicians who treat nonelite runners because the injury rate for novice runners is higher than for elite runners. Per 1000 hours of running, the injury rate has been reported to be 17.8% for

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novice runners, 7.7% for recreational runners, and 3.5% for elite or professional runners.^{10,106}

VanderWorp and colleagues divided the risk factors for injuries in runners into 3 domains: (1) personal factors including sex, age, and body shape/alignment; (2) running/training factors (experience, training mileage, surface, shoe use, etc); and (3) health- and lifestyle-related factors (history of previous injury, orthotics etc).¹⁰³ In their extensive review on the topic, these authors found that a history of previous injury, training errors, and orthotic use had the strongest association with an increased risk for running-related injuries.¹⁰³ The female runner is thought to be at a particularly increased risk of injury because of a possible combination of factors described as the female athlete triad. This is characterized by menstrual dysfunction, low energy availability, and reduced bone mineral density. The prevalence of these factors in the general population is low. However, sports such as running, whose female athletes typically have lean body mass, have rates of amenorrhea as high as 69%, disordered eating as high as 49.2%, and an osteopenia prevalence ranging from 22% to 50%.^{49,51,75}

The Evolution of Running: Historical Perspective

The modern foot is thought to have evolved from an ancestor similar to the African ape, where its function is in both ground-based movement as well as arboreal movement.²³ The evolutionary transition from trees to the ground came with changes in foot shape and function. Although bipedal gait is one function that differentiates human movement from modern chimpanzees, the human ancestor *Australopithecus* is thought to have walked bipedally for several million years without otherwise looking like a modern human.¹³

Thus, although bipedal gait may not differentiate us from our ancestors, running may. The change in foot shape and function from *Australopithecus* to modern *Homo sapiens* suggests that modern humans have more demanding locomotion behaviors such as carrying heavy objects and running from predators. The modern human shape and features, especially in the musculoskeletal system, are reflective of elements necessary for distance running. Our feet are shaped and function differently than modern apes.¹³ These differences include (1) a larger and adducted first ray, (2) mobile and shortened lateral rays, (3) tarsal bone alignment that can change conformation and allows for rigidity during the toe-off phase of gait, and (4) well-defined transverse and longitudinal arches supported by strong planar tissues that are resistant to tensile loads and capable of energy storage.^{39,99,107}

When compared to walking, running requires strong ankle plantarflexion as well as a strong plantar aponeurosis and soft tissue resistance to support plantar tensile loads during late stance and the toe-off phase of gait. The underdevelopment of these structures in the human ancestor

Australopithecus provides further support that *Homo sapiens* further evolved to run.^{1,66}

Additionally, the intrinsic muscles of the foot are also important in running when compared to walking. Electromyographic (EMG) activity in the planar intrinsic muscles is greater in running than in walking and greater in higher load activities.^{7,81} Unlike most quadrupeds, humans have well-developed intrinsic foot muscles. In quadrupeds, these muscles are nearly or completely absent.⁶⁶ This is likely because human running requires careful balance on uneven surfaces as well as during single leg stance.

Intrinsic Muscles in Running

Although underappreciated, the intrinsic muscles are of particular importance in running. These structures have been likened to the abdominal and paraspinal muscles of the lumbopelvic-hip core.⁶⁶ The function of the intrinsic muscles as a group includes providing support to the arches of the foot,^{33,40,71} being responsive to applied loads,^{64,65} acting in synergy with the extrinsic muscles of the foot, and serving to regulate how forces are transmitted during gait, posture, and balance activities such as single leg stance.^{50,94}

Weakness or atrophy of the intrinsic muscles have been associated with several pathologic conditions including pes cavus and Charcot-Marie-Tooth,^{20,36} hammer toe and claw toe deformities,^{27,74} plantar fasciitis,^{18,66} hallux valgus,^{28,52,97} and pes planus.^{48,67,97} In runners, intrinsic weakness may manifest as nonspecific arch pain and fatigue, as well as unexplained metatarsalgia.

Although these muscles are not large contributors to force generation in gait, they are thought to play an important role in proprioception by providing sensory input via the stretch response. Although other contributors to sensory input such as the capsular ligaments are static, the intrinsic muscles of the foot can be modulated through training to alter sensitivity to foot loads.⁴⁷

Additionally, either through contraction, resistance to stretch, or by neuromuscular feedback, the intrinsic musculature seems to be an important contributor to foot shape. Headlee et al⁴⁰ showed that after fatigue of the intrinsic muscles of the foot, measured by a change in navicular height, pronation significantly increased and was independent of the magnitude of pronation before the fatigue test. The authors concluded that while the change in muscle force led to the change in posture, the change in muscle force may be associated with a change in sensory feedback of the muscles. This concept of muscle fatigue from repetitive contractions leading to a decrease in joint position sense has been shown elsewhere in the lower extremity.⁴¹

It has been shown that the shape of a runner's foot changes with prolonged running.^{22,31,43} As measured by navicular drop, Cowley and Marsden²² noted that there was an average of 5 mm drop in the navicular after the half

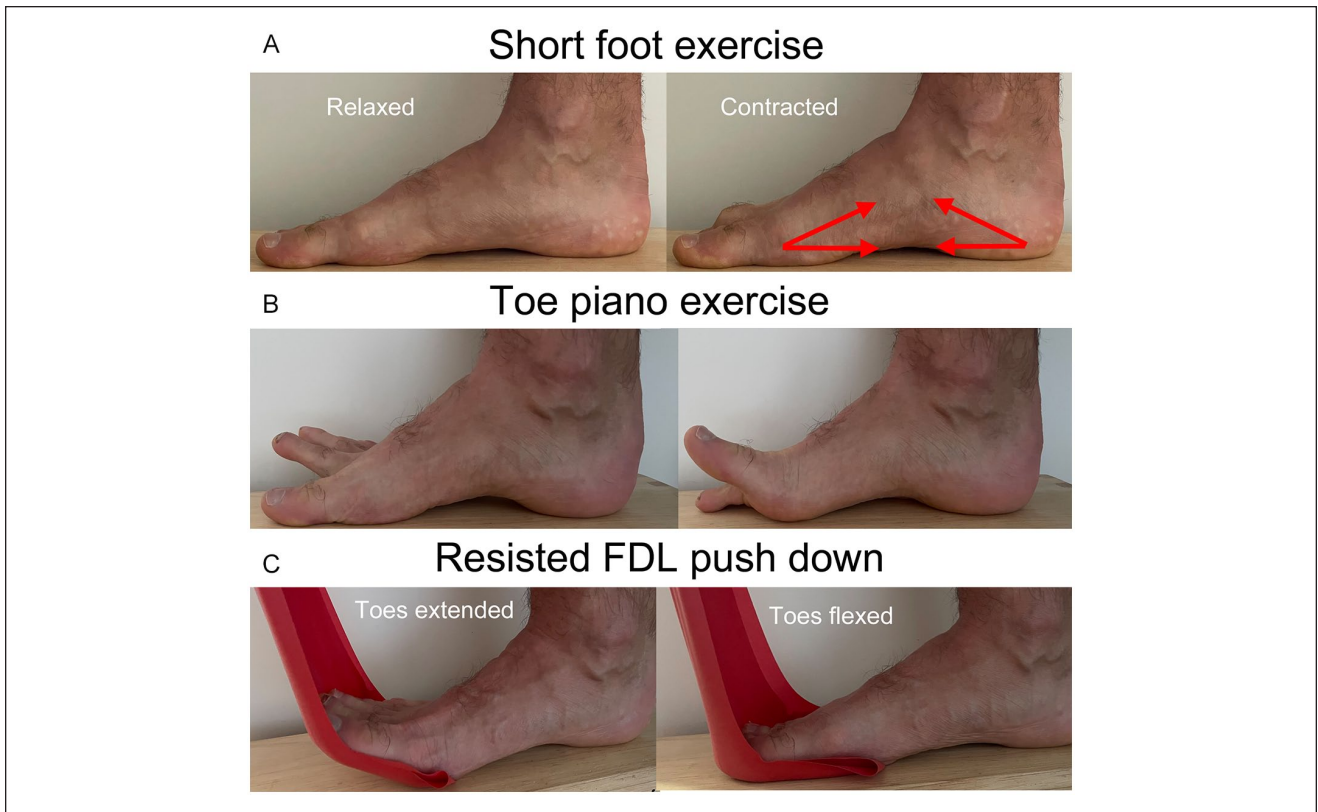


Figure 1. Three common intrinsic foot strengthening exercises: (A) The short foot exercise entails contraction of the intrinsic muscles of the foot. This causes the foot to shorten and an elevation of the medial column. This is performed by having the patient flex their toes and pull them proximally toward the heel. This should begin to lift the metatarsophalangeal joints and shorten the arch. (B) In the toe piano exercise, the goal is to build control of the lesser toes independent of the great toe by altering extension of the great toe with extension of the lesser toes in isolation from either other. (C) Resisted toe flexion exercises utilize a band to resist flexion of the toes from extension to neutral and in reverse. There are many progressions of each of these exercises.

marathon distance. Fukano et al³⁵ noted a similar navicular drop of 4.8 mm after a full marathon and noted that the drop persisted even 8 days after the race. It is thought that in addition to intrinsic fatigue, decreased stiffness of the plantar fascia may be contributory. Shiotani et al⁹⁰ performed a study measuring long-distance runners and noted a decrease in plantar fascia stiffness after a long-distance run.

Strengthening the intrinsic muscles has been a recent interest and should be considered as a conservative treatment for runners thought to have weak intrinsics. Given the function of the intrinsics, weakness in this muscle group can present as nonspecific foot pain with activities such as running that have a high dynamic demand without other identifiable cause.

Although there is no gold standard for evaluating the intrinsic muscles,⁹⁴ intrinsic strength and control can be evaluated in the office setting. The first useful test is the paper pullout test. This is performed by having the patient grip a strip of paper against the ground with a lesser toe. The examiner then attempts to pull the paper out while the patient grips the paper against the ground. With intrinsic

weakness, the examiner will generally be able to remove the paper without ripping it, a sign of poor toe flexion strength. Another test is the “short foot exercise” (SFE) (see Figure 1). If the patient is unable to easily perform the SFE while standing, this is likely due to intrinsic weakness.

Strengthening of the intrinsic foot muscles can be helpful to long-distance runners. In addition to being a diagnostic test, the SFE is also a commonly performed intrinsic strengthening exercise. The goal of the SFE is to recruit and strengthen the lumbricals and interossei of the foot. Such muscle recruitment and conditioning has been shown to be a mechanism to improve neuromuscular control, balance, and intrinsic foot strength.^{80,87} The SFE can initially be performed sitting. Thereafter, it is progressed to being performed standing on 2 legs and then 1 leg. There is increasing evidence that intrinsic strengthening improves foot function. For example, Sulowska et al⁹⁸ performed a 6-week prospective study on long-distance runners performing intrinsic strengthening exercises and noted improved functional movement patterns and foot alignment measured by the foot posture index. Mulligan and Cook⁷¹ demonstrated a

reduction in navicular drop, arch height index, and improved balance after 4 weeks of short foot exercises. Lynn et al⁶² showed short foot exercise improved balance compared to traditional intrinsic strengthening exercise in another 4-week study of healthy patients.

It has also been proposed that barefoot running strengthens the intrinsic foot muscles and may decrease injury rates. To examine this concept, Bell et al¹¹ used ultrasonography to indirectly measure the strength of the intrinsic muscles in experienced barefoot and traditionally shod runners. They found no difference between runners, which implies that barefoot running alone does not necessarily increase intrinsic strength.¹¹

Two other intrinsic strengthening exercises include the toe piano exercise and resisted toe flexion exercises (Figure 1). These exercises are also thought to strengthen and provide neuromuscular recruitment of the intrinsic muscles to stabilize the metatarsophalangeal and proximal interphalangeal joints with toe motion as opposed to the SFE, which has more effect on arch stabilization.

In summary, the intrinsic muscles of the foot have an important function in gait, and specific strengthening exercise should be considered in activities such as long-distance running that may cause muscle fatigue.

Impact Forces and “Comfort”

Over the last decade, there has been substantial focus in the running literature on foot strike pattern, minimalist shoes, impact forces, and the relationship between the 3. The discussions on various shoe designs and running forms often begin with the concept of impact forces.

To start, most runners (89%) have a heel strike gait pattern with running.⁵⁵ In this pattern, the heel strikes the ground first followed by the rest of the foot and body mass. In forefoot running, the forefoot impacts the ground before the heel while the ankle is in a more plantarflexed position.

To understand the difference in tissue stress between forefoot and heel strike running, the difference between externally measured ground reaction forces and internal tissue forces and loading rates must be appreciated. Many studies use a force-time curve, as measured by ground reaction force, to represent the forces experienced during running (Figure 2). As runner speed increases, so does the peak ground reaction force. It has been reported that increased peak ground reaction forces and peak loading rates are important considerations and may be potentially harmful to the runner.^{25,44,70,91-93,112} The externally measured peak vertical ground reaction force with walking and running is approximately 1 to 1.5 times body weight for walking and 2 to 2.9 times body weight for running.⁷⁹ Meanwhile, the joint reaction force across the ankle joint with walking and running is up to 5 times body weight and 13 times body weight, respectively.¹⁴ This conceptual model, however, is likely an oversimplification of the stress seen at the tissue level.

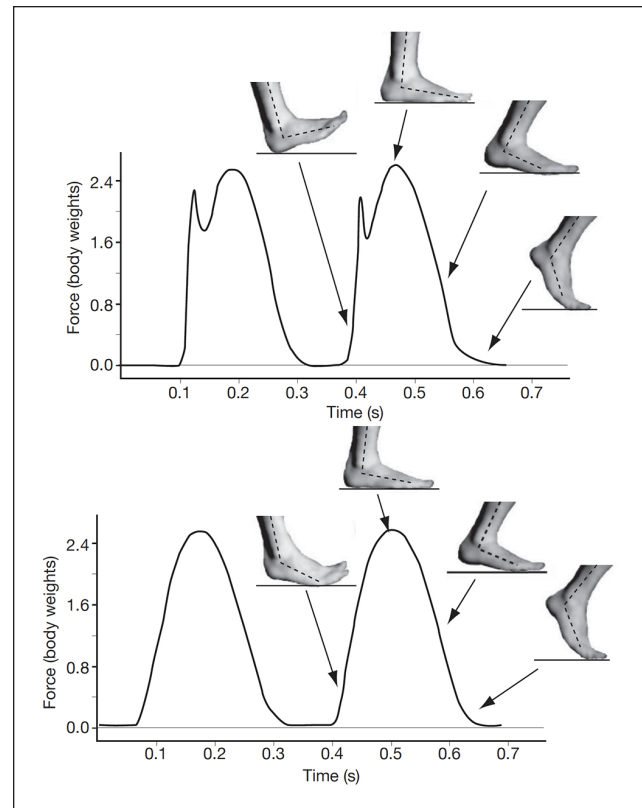


Figure 2. Vertical ground reaction forces and foot kinematics for 3 foot strikes at 3.5 m/s in the same runner. Top: rear foot striker during barefoot heel-toe running. Bottom: forefoot strike during barefoot running (reproduced with permission from Lieberman et al⁵⁸). Note the increased impact impulse (higher initial slope of the curve) in heel strike compared to forefoot strike.

Other factors such as neuromuscular control, skeletal position, as well as loading mechanism are likely important considerations as well. Forces seen at the tissue level are harder to directly measure but are likely more nuanced than what is seen at a force transducer on the running surface.

The effect that foot strike pattern and footwear has on injury rates is important to consider as well but the overall evidence is limited. In a footwear study, Altman et al² performed a prospective cohort study of traditionally shod runners and barefoot runners and noted similar overall injury rates. Daoud et al²⁵ performed a study of 52 collegiate cross-country team runners and correlated injuries to foot strike pattern. They noted that 74% of runners experienced a moderate or severe injury each year and that those who habitually rearfoot strike had approximately twice the risk of injury compared to those who habitually forefoot strike.²⁵

Comfort while running is poorly defined and understood, but it seems to be important in selection of running footwear. Although not definitively proven, running comfortably may be a sign of low tissue stress and subsequent

decreased injury risk. Different people experience comfort differently and shoes that may be comfortable for some may be uncomfortable for others.⁶⁹ Wearing the most comfortable shoes may reduce injury. Mundermann et al⁷² performed a study of military personnel and offered them 6 different shoe orthotic types that varied in arch and heel cup shape, hardness, and elasticity. The recruits then wore the insert they found most comfortable and were monitored for injury during military training exercise and compared these recruits to a control group. The authors found that the orthotic group sustained less overall stress fractures and foot pain than the control group (8.8% vs 22.2%). This study supports that if orthotics are considered, then subjective comfort should be taken into consideration.

Meanwhile, Basford and Smith⁶ performed a study on women who stand at work and showed that subjectively comfortable noncustom orthotics improved comfort while reducing back, leg, and foot pain when standing at work. They noted that 40% to 50% of participants preferred the insoles to standard footwear whereas the others had no preference or felt the orthotics made their pain worse.

Finally, shoes that are more comfortable have been associated with decreased oxygen consumption while running.⁶¹ In this study, Luo et al⁶¹ asked a group of proficient runners to try 5 different pairs of shoes and select the most comfortable and the least comfortable. They then measured the runners' mean oxygen consumption with VO_2 data collection equipment while running on a treadmill and found a 0.7% improvement in running economy when the runners used the most comfortable compared with the least comfortable shoes.

Foot Alignment, Shoes, and Custom Orthotics

Foot alignment is a common concern among runners. Foot pronation has been described as a risk factor for running injuries, and running shoe design has been a suggested intervention to prevent injuries, despite a lack of evidence.⁸³ In fact, mild pronation may be protective against injury. Neilsen et al⁷⁶ performed a study of 730 runners (all wearing the same neutral shoes) to correlate foot posture to running-related injury in shoes in order to determine if foot posture increased the risk of injury. Interestingly, they found that, overall, pronated feet were the least likely to be injured (0.63 relative incidence rate per 1000 km compared with neutral feet). However, highly pronated feet were the more likely to be injured (3.25 relative incidence rate per 1000 km compared to neutral feet). Supinated and highly supinated feet did not reach a statistically significant increase in injury rate (1.03 and 1.24 relative incidence rate per 1000 km compared with neutral feet, P value .83 and .49, respectively). These results support the notion that mild pronation may actually be protective against injury, likely secondary to hindfoot suppleness at heel strike.

The mechanism of action of orthotics, the indications for orthotics, the appropriate orthotic design, and the effectiveness of orthotics are complex issues. Orthotics have several potential mechanisms of action. First, there may be a placebo effect. Second, orthotics may change kinematics. For example, they may alter hindfoot alignment. Third, orthotics may work kinetically by altering muscle demands. With an orthotic in the shoe, the muscle(s) firing may be different than without an orthotic. This may increase or decrease muscle activity and the stress placed on particular tissues. Fourth, orthotics may change neuromuscular control by altering proprioceptive feedback.

Although orthotics may be beneficial for some runners, the evidence is unclear regarding who may benefit and in which way. The published studies on orthotics in runners are generally difficult to generalize because most lack a control group and have a small sample size.³⁷ In addition, orthotic fitting is highly practitioner dependent.¹⁹

Runners themselves believe that orthotics and shoe design matter. Enke et al³⁰ performed a study and found that 73% of runners believe that the shape of their foot should be the most important factor when choosing a running shoe. Up to 80% of runners report positive outcomes from orthotics despite no standardization of indication, orthotic shape, material, type, or orthotist.^{38,46} To the authors' knowledge, however, there are no high-level controlled trials investigating orthotics in runners. Several controlled studies on *nonrunners* including patients with Achilles tendinitis, rheumatoid arthritis, and other causes of foot pain have not shown a compelling benefit of orthotics over sham or placebo.^{21,54,73}

D'Ambrosia retrospectively reported on 200 runners with injuries treated with orthotics, mostly for pronation with forefoot varus, and noted that 73% of patients improved from posterior tibial tendonitis, 86% from metatarsalgia, 82% from plantar fasciitis, and 66% from iliotibial band syndrome.²⁴ There was a poor response in patients who had a cavus foot deformity. Banwell et al⁵ performed a systematic review of foot orthotics for flexible pes planus and found no high-level evidence supporting the use of foot orthoses in flexible pes planus. They found good to moderate evidence that foot orthoses improve medial to lateral sway during standing and energy cost during walking and low evidence that foot orthoses improve pain or alter loading and impact forces. Zammit et al¹¹¹ in 2007 performed a study on hindfoot motion with and without orthotics and found a small but statistically significant effect on hindfoot motion but no significant correlation with pain and function scores.

The change in neuromuscular control from an orthotic has been shown to be difficult to quantify.³² The effect of orthotics on the kinematics is also difficult to quantify, with several studies measuring hindfoot motion in orthotics demonstrating inconsistent results. Some authors have found a difference in hindfoot motion with orthotic intervention,^{100,110}

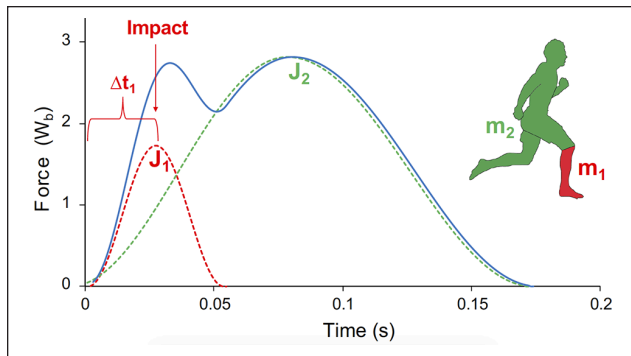


Figure 3. Two-mass model of the ground reaction force during running. In this model, the ground reaction force modeled as the sum of mass 1 and mass 2. Changing the timing of when mass 1 contacts the surface (later in heel strike), explains the increase in impact impulse in heel strike runners compared with forefoot strikers (used with permission).¹⁰²

whereas others have not.^{8,29,78,85} These studies generally use skin markers, which are known to overestimate the true effect on the motion of the underlying bone.^{17,82} To clarify this effect, Stacoff et al⁹⁶ performed a study using pins placed in the tibia, calcaneus, and shoes of subjects who then ran with and without orthotics. The authors noted that orthotics did not significantly change the movement of the tibia or calcaneus during the stance phase of running. Using similar techniques, Stacoff et al⁹⁵ performed a study comparing barefoot running to running with shoes with and without an orthotic. They showed the difference between barefoot running and running with shoes to be not clinically significant. These studies both support the notion that changing the shoe type or introducing orthotics does not change the movement path of the skeleton during running.⁷⁷

The extension of this concept to barefoot running is also demonstrated in the literature. In 2010, Lieberman et al⁵⁸ published a study demonstrating that heel strike in barefoot running results in increased vertical loading rates compared to a forefoot strike pattern. This drove a rise in popularity of barefoot running as most barefoot runners tend to adapt a forefoot strike pattern.

More recently, however, Udofa et al¹⁰² performed a study to look more closely at the relationship between footwear and ground reaction forces when ground reaction forces are modeled in a more complex way (Figure 3). Specifically, the authors modeled the ground reaction force during running as 2 masses rather than a single mass, and showed that a runner's gait changes with a change in footwear. They noted that with barefoot running, the runner more commonly has a more plantarflexed ankle and therefore a forefoot strike pattern. When there is a large heel cushion, the runner more commonly has a less plantarflexed ankle and therefore a heel strike pattern.¹⁰² This is consistent with the conceptual model that gait patterns change with footwear. Without a heel cushion, the gait will adapt a plantarflexed foot (forefoot

Table 1. Risk Factors for Bone Stress Injuries.

Biological factors
Female sex
Genetics
Smoking
Medications (anticonvulsants, steroids, antidepressants, antacids)
Female athlete triad (interrelationship between energy availability, menstrual function, and bone mass)
Diet and nutrition
Calcium and Vitamin D deficiency
Biomechanical
Running experience, distance, frequency
Training pattern
Bone characteristics (bone density)
Gait characteristics
Anatomic characteristics

strike) to minimize impact force. In the presence of a heel cushion, the gait pattern will trend toward a heel strike pattern. These data support the notion that runners will adapt their running style to avoid high heel impacts.⁶⁸

Stress Injuries in Runners

The 1-year incidence of bone stress injuries in runners has been reported to be as high 21%.¹² There are several risk factors for injury (Table 1). Low serum vitamin D has been frequently cited in the foot and ankle. In athletes in general, it has been found that those with a lower serum vitamin D level have a higher risk of stress fractures.^{15,26,89} Horas et al⁴² performed a study in a group of patients with MRI findings of bone marrow edema (BME) of the foot and ankle. They found that 84% of the patients had low vitamin D levels; 61% were vitamin D deficient, and 23% were vitamin insufficient.

Conversely, it has also been shown that an increased serum vitamin D level is associated with a reduced risk of stress fracture.⁴ Serum vitamin D levels lower than 30 ng/mL may lead to defects in bone mineralization as well as impaired muscle function, whereas levels greater than 40 ng/mL may have a protective effect on the development of stress fractures.¹⁶ Williams et al¹⁰⁹ recently performed a study demonstrating that almost half of the tested NCAA Division 1 athletes (including cross country runners) were either vitamin D insufficient or deficient. They also showed that vitamin D₃ supplementation of deficient athletes reduced the stress fracture rate by a statistically significant amount from a historical rate of 7.51% to 1.65% in the study group.¹⁰⁹ In a study of female Navy recruits, Burgi et al¹⁵ demonstrated that recruits with a serum vitamin D level below 20 ng/mL had twice the risk of stress fracture compared with those above 40 ng/mL, and thus recommend this as a target level.

The diagnosis of a bone stress injury should be clinically differentiated from a finding of bone marrow edema itself on MRI, which can sometimes be a confusing image finding. Bone marrow edema (BME) has been shown to be a sign of bone turnover, which may be either adaptive or a sign of overuse injury. Kornaat et al⁵³ performed a study in which 16 asymptomatic professional runners were followed for a 7-month running season after getting preseason MRI studies. Fourteen of the 16 runners had BME lesions before the season started. Sixty-nine percent of the lesions were located in the foot and ankle. Lesions came and went throughout the season with 20% developing new lesions and 22% of the lesions resolving, without clinical correlation. The authors concluded that incidental BME lesions in professional runners should not necessarily alter clinical care or running behavior.⁵³

Lazzarini et al⁵⁶ found that 16 of 20 (80%) collegiate cross-country runners had BME in the foot and ankle. This was higher than the 4 of 12 nonrunners. They noted that an average of 3.4 bones had edema in the runner group and 0.7 in the nonrunner group. Ridge et al⁸⁴ performed a study on BME before and after a 10-week transition to minimalist running shoes in experienced recreational runners. Thirty-six runners participated (17 in a control group, 19 in the transition group). Although they reported no difference in bone signal pretraining, they noted that 10 of 19 demonstrated an increase in BME in the minimalist transition group whereas only 1 of 16 showed lesions in the control group.⁸⁴

Lohman et al⁵⁹ performed an MRI study in 19 marathon runners and 19 matched controls. In the marathon group, who each had completed a mean of 60 previous full-length marathons, subjects underwent an MRI within 3 hours of running a marathon. Four of 19 runners demonstrated BME (1 severe and 3 slight). This was similar to the control group, in which 3 of 19 subjects demonstrated slight BME lesions. The reduced incidence of BME in these athletes may be attributed to the fact that the MRIs were obtained within 3 hours of the race as it is ultimately unknown how long BME takes to become visible on MRI. It also could be the case that because these runners had completed a mean of 60 previous marathons, that this length of run was not a significant tissue stress for these runners.

Importantly, Freund et al³⁴ studied a group of 22 ultramarathon runners participating in a 4487-km (2789-mile) multistage ultramarathon. The average mileage in these participants was 1.7 marathons per day for 64 consecutive days. They underwent foot and ankle MRIs at the beginning of the race and then roughly every 1000 km throughout the run. The authors noted that the peak intraosseous signal intensity as well as the number of BME lesions increased from baseline to 1000 km into the race, but thereafter the maximal intraosseous signal intensity actually decreased compared with the final MRI for a mean of 3667 km into the race from 411.7 to 399.9. They also noted that the number of bone lesions stayed relatively constant from 3.2 to 3.6 from 1000 km to 3669 km. None of these lesions coincided with

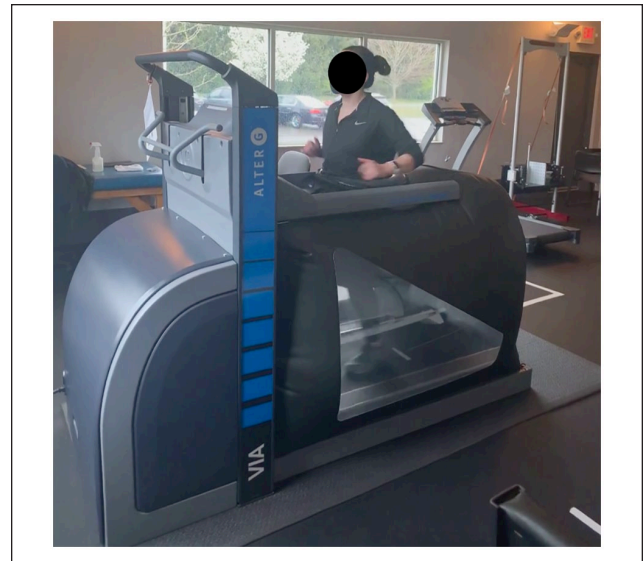


Figure 4. Commercially available offloading rehabilitation treadmill that allows preservation of running mechanics while offloading tissues (AlterG).

stress fractures or were correlated with dropping out of the race. These data support the notion that BME is a result of stress response and evidence of adaption, given that it seems to have increased to the 1000-km mark, but it was not found to be progressive or pathologic.

The treatment of bone stress injuries depends on several factors and should be individualized. When injured, the athlete should initially reduce activity to a pain-free level of function. Immobilization in a boot or hard-soled shoe should be continued for a short period of time. The treating physician must identify and address associated risk factors for stress injury while also creating a program to maintain physical conditioning and, when appropriate, a return to running program.¹⁰⁸ In the author's experience, once symptoms allow, deep-water running and antigravity treadmill work under the direction of an experienced physical therapist are the most specific activities that may help to reproduce the running mechanics while offloading the tissues (Figure 4).

Accelerating tissue healing is often a goal of runners, and there is growing interest in both electrical and ultrasonic bone stimulation. Although the risk profile is low for noninvasive treatments, the effectiveness in the published literature is lacking. Rue et al⁸⁸ performed a randomized controlled trial of 26 patients treated with low-intensity ultrasound and showed no decrease in healing time of tibial stress fractures. Similarly, Beck et al⁹ performed a randomized controlled trial of 44 patients using electrical stimulation on tibial stress fractures and demonstrated no benefit. Given these findings, although bone stimulators are generally well tolerated by patients, there is a lack of high-level evidence to support their use.

Summary

The current work provides a background and summary of the foot and ankle in distance runners. Runners are a unique patient population and involvement of an experienced athletic trainer and physical therapist can be useful.

Several important considerations include the following:

- Distance running is increasingly common, and evidence supports that humans have evolved to be runners.
- The intrinsic muscles of the foot play an important role in running. Despite a runner's footwear or gait pattern, strengthening the intrinsic muscles may be an important component of preventing or treating running injuries.
- Runners will adapt their running style to minimize internal impact forces despite the type of footwear.
- Ground reaction forces may oversimplify the understanding of internal forces and the way the skeleton moves during running.
- There is a high treatment effect of placebo/sham orthotics. There is little evidence to support the routine use of orthotics in runners.
- Running with shoes and a gait pattern that optimizes "comfort" may prevent injury and be most efficient.
- Bone marrow edema on MRI may be adaptive. In the setting of symptoms, however, treatment includes rest, activity modification, and vitamin D supplementation as needed. Thereafter, return to running is based on symptoms.
- There is no high-level evidence to support the routine use of bone stimulators for stress-related injury.

Ethical Approval

Ethical approval was not sought for the present study because it is a contemporary review article.

Declaration of Conflicting Interests

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