

[Athletic Training]

Is There Evidence to Support a Forefoot Strike Pattern in Barefoot Runners? A Review

Daniel S. Lorenz, DPT, PT, LAT, CSCS, USAW/SPC,*† and Marisa Pontillo, PT, DPT, SCS‡

Context: Barefoot running is a trend among running enthusiasts that is the subject of much controversy. At this time, benefits appear to be more speculative and anecdotal than evidence based. Additionally, the risk of injuries is not well established.

Evidence acquisition: A PubMed search was undertaken for articles published in English from 1980 to 2011. Additional references were accrued from reference lists of research articles.

Results: While minimal data exist that definitively support barefoot running, there are data lending support to the argument that runners should use a forefoot strike pattern in lieu of a heel strike pattern to reduce ground reaction forces, ground contact time, and step length.

Conclusions: Whether there is a positive or negative effect on injury has yet to be determined. Unquestionably, more research is needed before definitive conclusions can be drawn.

Keywords: barefoot running; shod running; forefoot strike; minimalist shoes

The popularity of aerobic exercise has increased significantly since the 1970s.³³ In particular, running is a popular choice for many people because it has several positive health benefits and can be performed virtually anywhere without any special equipment or training.¹⁰ Furthermore, aerobic endurance can improve with three 30-minute training sessions per week.²⁸ As the number of individuals participating in leisurely jogging and running activities has increased, so too have injuries.^{3,10,15} In an effort to prevent, treat, and reduce running injuries, a current trend in rehabilitation has centered on modifying running technique.¹⁰ Chi running, barefoot running, evolution running, and the pose method are all running styles that aim to eliminate the initial heel strike at ground contact by promoting a forefoot strike upon impact.^{10,14,29,30} No definitive conclusions can be made that any of these strike patterns prevent or reduce injury. Several articles have shown that a significant reduction in ground reaction forces, stride length, and ground contact time can occur if the heel strike is eliminated at initial contact,⁵ but again, no definitive evidence exists that injury risk is reduced.

§References 1, 5, 9, 11-13, 15, 16, 20, 23, 26, 27, 31, 34.

One of the hottest and most contested topics currently in sports medicine is barefoot running. Regardless of which viewpoint is advocated, opinions on the efficacy as well as safety are offered with passion and fervor. Several websites exist composed of supporters and detractors alike. A recent Google search for “barefoot running” revealed an astonishing 14.6 million hits.² Despite the lack of evidence, proponents claim improved performance and reduced injuries, whereas detractors warn of the imminent risks involved.²¹ Popularity may be due to shoe companies designing shoes to mimic the barefoot condition, thus garnering the proposed benefits of barefoot running. In fact, *Time* magazine rated one minimalist shoe brand as one of the best inventions of 2008. Unfortunately, there is a paucity of data from peer-reviewed Index Medicus publications to support or refute claims of barefoot running. At this time, evidence is largely speculative and anecdotal, particularly on whether barefoot running has any effect, positive or negative, on injury rate.

The earliest humans ran while engaging in hunting long before projectile technologies were invented.²⁴ Before the invention of running shoes in the 1970s, humans ran in either no shoes or minimal footwear, such as sandals, moccasins,

From †Specialists in Sports and Orthopedic Rehabilitation, Overland Park, Kansas, and ‡Penn Therapy and Fitness at Penn Sports Medicine Center Philadelphia, Pennsylvania

*Address correspondence to Daniel S. Lorenz, DPT, PT, LAT, CSCS, USAW/SPC, Director of Physical Therapy, Specialists in Sports and Orthopedic Rehabilitation, 7381 West 133rd Street, Suite 302, Overland Park, KS 66213 (e-mail: danielslorenz@gmail.com).

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Table 1. Differences between barefoot and shod running.

	Barefoot	Shod
Foot strike	Forefoot	Heel or midfoot
Effect of shoes ^a	Not applicable	Provide cushioning/shock absorption Control mobility Affect lower extremity kinematics (pronation/supination at foot and ankle; tibia internal/external rotation)
Kinematics	Increased plantarflexion moment at strike Maximum knee flexion, 105°-130° Higher stride frequency, leg stiffness, vertical stiffness	Higher level of peak dorsiflexion Maximum knee flexion: 90°
Kinetics	Lesser impact force at foot contact Higher levels of activity in tibialis anterior as well as gastrocnemius-soleus complex throughout cycle	Larger peak impact at foot contact Lesser activity of lower leg musculature versus barefoot, also dependant on type of footwear
Economy	Improved economy (in debate)	Economy based heavily on training; some suggest decreased versus barefoot condition
Injury rates	Not elucidated versus shod	Not elucidated versus barefoot

^aFor shod running: varietal uses, dependant on type of shoe.

or running flats.²⁵ The author of *Born to Run*, Christopher Maccougall, is credited with starting the trend of barefoot running. Although barefoot running has become popular in recent years, competitive runners have run barefoot with great success long before *Born to Run* was published. In 1960, Ethiopia's Abebe Bikila, potentially the greatest marathoner of all time, won the first of his consecutive gold medals without shoes in a world-record finishing with a time of 2:15:17.⁶ Interestingly, the reason he ran barefoot is that his shoes did not fit properly. It is also worth noting that he ran the Tokyo Marathon in shoes. England's Bruce Tulloh was running European record times from 1955 to 1967, almost always in bare feet.⁶ What is not known at this time is what the health benefits are, if any, with barefoot running after races. Performance and health benefits are therefore possibly contradictory. The purpose of this review is to highlight the proposed benefits of barefoot running with emphasis on the biomechanics of both barefoot and shod running (Table 1).

NORMAL RUNNING BIOMECHANICS

As clinicians, observation of the stance phase is of most interest, secondary to the variation of mechanics exhibited. Foot strike patterns vary among runners and type of running. For example, runners tend to use a heel strike or midfoot strike, whereas sprinters typically use a forefoot strike.^{8,36}

RUNNING ECONOMY

Running economy represents an athlete's energy efficiency, and it refers to the energy demand of submaximal running,

defined by oxygen consumption and respiratory exchange ratio.³² Running economy is therefore one of the determinants of performance.¹⁹ Running economy can be affected by physiological and biomechanical factors and influenced by training strategies. The physiological factors that affect running economy include core temperature, heart rate, ventilation, and blood lactate levels.³² Biomechanical factors include those that cannot be modified, such as morphological features, but also factors that are modifiable. For example, optimal stride length is achieved through consistent training. Footwear is easily modifiable, and "light weight but well cushioned" shoes are recommended to maximize running economy, reducing oxygen consumption by 2.8% compared to stiff shoes of the same weight.¹⁹ The shoe cushioning is thought to provide adequate shock. Foot strike patterns affect running economy; more economical runners demonstrate a heel strike pattern, secondary to a heavier reliance on footwear and skeletal structures to absorb ground reaction forces. In contrast, forefoot strikers rely more heavily on musculature to aid in cushioning during stance.²⁷ Running economy appears to be linked to training (trained runners are more efficient than untrained runners)²²; it is plausible that when a runner uses his or her preferred type of foot contact, it will optimize his or her economy, unless a particular foot strike pattern has been adopted to maximize other parameters (such as speed).

The issue with the barefoot craze is that it is not only footwear changes but also the fact that distance runners are doing distance running with a forefoot strike or traditional heel strikers are changing their strike pattern. Furthermore, if running economy improves with training, an individual's

optimal economy should be reliant on her or his usual training style. Therefore, running economy may initially decrease if runners change their running style or footwear.

EFFECT OF SHOES

Bishop and others⁴ investigated whether athletic footwear affects leg stiffness in dynamic activities. Nine healthy adults hopped on force plates and ran on a treadmill under 3 conditions: barefoot, low-cost footwear, and high-cost footwear. Leg stiffness significantly increased from barefoot to the “cushioned” shoe condition during hopping. When running shod, runners landed in more dorsiflexion but had less ankle motion than when running barefoot. As running speed increased, kinematic differences surfaced. Barefoot runners landed in more knee flexion and increased ankle motion more than shod runners as speed increased.

Squadrone and Galozzi³⁴ studied the biomechanical and physiological differences among barefoot, standard running shoes, and minimalist shoes in experienced barefoot runners. The barefoot athletes landed in a more plantarflexed position at the ankle, resulting in a decrease peak vertical ground reaction force. Stride length and contact time were significantly shorter, and there was higher stride frequency. VO_2 and peak impact forces were lower with the minimalist shoes. Lower limb kinematics were similar in the barefoot and minimalist conditions.^{18,34} Additionally, heart rate and rating of perceived exertion were significantly higher in the shod condition. Divert and others¹³ and Squadrone and Galozzi³⁴ have found that barefoot running uses about 5% less energy than shod running.

INJURY RATES IN RUNNERS

The risk or lack thereof from barefoot running injuries is speculative. Barefoot-stimulating footwear was associated with metatarsal stress injury in 2 experienced runners whose only change in routine was the addition of barefoot-stimulating footwear.^{17,37} Runners using these shoes should use caution when changing from a heel strike to midfoot strike pattern.¹⁷

In a survey of runners who run between 5000- and 10 000-meter races, injury prevalence varied from 20% to 27% among males and females, respectively.²³ Running-related chronic injuries to bone and connective tissue in the legs are rare in developing countries, where many people are habitually barefooted. People in developed countries are not running marathons often, and injury rates with shod runners may be higher due to increased running.

In a recent case series¹⁰ of 2 runners with chronic exertional compartment syndrome, altering running mechanics to a forefoot striking technique was the primary intervention. Even though the subjects were not barefoot, the change in running technique resulted in increased step rate as well as decreases in impulse, ground reaction forces, and step length. Researchers hypothesized that because a heel strike pattern results in the position of knee extension and ankle dorsiflexion, a more forefoot contact at initial contact would

require less dorsiflexion. Additionally, a forefoot strike pattern may reduce the eccentric activity of the anterior compartment musculature, mitigating the increase of anterior compartment pressure and symptoms of chronic exertional compartment syndrome during running. It is not known at this time if any long-term effects are from this approach to running for people with chronic exertional compartment syndrome.

BAREFOOT VERSUS SHOD RUNNING

Lieberman and coauthors²⁴ compared the foot strike patterns in habitually barefoot versus shod runners. Barefoot runners often land on the forefoot before bringing down the heel but sometimes land with a flat foot or midfoot strike. Shod runners most often rear foot strike, facilitated by the elevated heel of the modern running shoe. Kinematic and kinetic data show that even on hard surfaces, barefoot forefoot strike runners generate smaller impact forces than shod rear foot strikers, likely resulting from a more plantarflexed landing pattern and resulting ankle compliance during impact. Forefoot and midfoot strike patterns may protect the heel and lower limbs from some impact-related injuries.²⁴ Theoretically, a forefoot running style may reduce ground reaction forces and reduce stress reactions/fractures, anterior knee pain, and low back pain.¹⁰

In a review of literature on barefoot running,²¹ notable differences were found in gait and other parameters when barefoot and shod running were compared. No evidence either confirms or refutes improved performance and reduced injuries in barefoot runners, and many claimed disadvantages are not supported by the literature. Barefoot running may be an acceptable training method for athletes and coaches who both understand and can minimize the risks.²¹

Divert and others¹² compared the mechanics of barefoot and shod running. Thirty-five subjects ran 2 bouts of 4 minutes on a treadmill. Barefoot running showed lower contact and flight times, lower passive peak body weight, higher braking and pushing impulses, and higher preactivation of triceps surae muscles. Barefoot running led to a reduction of impact peak forces.

Divert and colleagues¹³ sought to determine the mass and shoe effects on the mechanics and energetics of shod running. Twelve subjects ran on a treadmill in 6 conditions: barefoot, unloaded using ultrathin diving socks, loaded with a 150-g backpack, loaded with a 350-g backpack, shoes weighing 150g and shoes weighing 350g. Net efficiency also was decreased in the shoe conditions. The main role of the shoe was to attenuate foot-ground impact.

De Wit and others⁷ analyzed the stance phase during running shod and barefoot in 9 trained subjects at 3 different velocities. In the barefoot condition, a flatter foot placement correlated with lower peak heel pressures. Plus, a significantly higher leg stiffness during the stance phase was found for the barefoot condition. Sagittal kinematics did not vary significantly between conditions. Using skeletal markers instead of externally mounted markers, motion differences in tibial and calcaneal movement between barefoot and shod running were

small and unsystematic compared with differences between subjects.³⁵


Finally, with a forefoot strike pattern, there is an associated increase in cadence. Since a forefoot strike pattern decreases step length, a runner increases step rate to run at the same pace. What is not known, however, is if there are any consequences, positive or negative, on running kinetics or on injury rates with increased number of steps over time. Clearly, more research is needed on this topic as well.

CONCLUSIONS

Based on limited biomechanical data, there is some evidence supporting a forefoot strike pattern for improving running efficiency. However, little is known about the correlation with

injury rates, locations of injury, or the long-term effects in barefoot runners who use forefoot strike pattern. Intuitively, it is safer to use minimalist shoes to help limit exposure to sharp objects or unsanitary surfaces. A gradual increase in barefoot running volume may allow the foot to accommodate to new stresses from barefoot running.

Directions for further research are abundant at this time. Prospective studies on running injuries in those who run barefoot or with minimalist shoes would be of great benefit to the sports medicine community and should be of primary importance. Further studies on running kinematics in both shod and barefoot conditions will help substantiate current claims, and studies on kinematics of barefoot running in athletes with previous injury may also be beneficial.



Clinical Recommendations

SORT: Strength of Recommendation Taxonomy

A: consistent, good-quality patient-oriented evidence
B: inconsistent or limited-quality patient-oriented evidence
C: consensus, disease-oriented evidence, usual practice, expert opinion, or case series

Clinical Recommendation	SORT Evidence Rating
Forefoot contact, instead of heel strike contact, reduces ground reaction forces, ground contact time, and decreases step length. ^{1, 5, 9, 11-13, 15, 16, 20, 24, 26, 27, 31, 34}	A

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