[Sports Physical Therapy]

The Risks and Benefits of Running Barefoot or in Minimalist Shoes: A Systematic Review

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Context: The popularity of running barefoot or in minimalist shoes has recently increased because of claims of injury prevention, enhanced running efficiency, and improved performance compared with running in shoes. Potential risks and benefits of running barefoot or in minimalist shoes have yet to be clearly defined.

Objective: To determine the methodological quality and level of evidence pertaining to the risks and benefits of running barefoot or in minimalist shoes.

Data Sources: In September 2013, a comprehensive search of the Ovid MEDLINE, SPORTDiscus, and CINAHL databases was performed by 2 independent reviewers.

Study Selection: Included articles were obtained from peer-reviewed journals in the English language with no limit for year of publication. Final inclusion criteria required at least 1 of the following outcome variables: pain, injury rate, running economy, joint forces, running velocity, electromyography, muscle performance, or edema.

Study Design: Systematic review.

Level of Evidence: Level 3.

Data Extraction: Two reviewers appraised each article using the Downs and Black checklist and appraised each for level of evidence.

Results: Twenty-three articles met the criteria for this review. Of 27 possible points on the Downs and Black checklist, articles scored between 13 and 19 points, indicating a range of evidence from very limited to moderate. Moderate evidence supports the following biomechanical differences when running barefoot versus in shoes: overall less maximum vertical ground reaction forces, less extension moment and power absorption at the knee, less foot and ankle dorsiflexion at ground contact, less ground contact time, shorter stride length, increased stride frequency, and increased knee flexion at ground contact.

Conclusion: Because of lack of high-quality evidence, no definitive conclusions can be drawn regarding specific risks or benefits to running barefoot, shod, or in minimalist shoes.

Keywords: barefoot; minimalist; running

The popularity of running in the United States has grown considerably in the past decade.[21] While many enjoy running as a recreational activity, others participate to maintain and improve cardiovascular-pulmonary health, body composition, and overall fitness.[34] As participation in running has grown, so has the number of reported running-related injuries (RRIs).[36] The overall incidence of RRI is estimated to be between 19.4% and 79.3% annually.[36] Despite efforts to reduce the incidence of RRI, injury rates have yet to decline.[7] The modern running shoe may have a negative effect on foot

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The authors report no potential conflicts of interest in the development and publication of this article.

DOI: 10.1177/1941738114546846

function despite added cushion and stabilizing features.[28] Hence, the efficacy of the modern-day running shoe has been called into question.

Barefoot running has recently increased because of claims of injury prevention, enhanced running efficiency, and improved performance.[16,18,19,32] Advocates of barefoot running suggest that humans should run with bare feet as ancestors did thousands of years ago.[23] The development of "minimalist" footwear has evolved with the barefoot running movement as a way to mimic barefoot running yet offer foot protection.[19] These newer running practices have prompted researchers to investigate injury mechanisms, physiological effects, biomechanical differences, and performance effects of running barefoot versus in shoes.[19]

Much of the recent literature is anecdotal and unclear as to the specific risks and benefits of running barefoot or in minimalist shoes.[19] A related systematic review investigated the influence of stride frequency and length on running mechanics; however, it did not consider the effects of footwear and potential outcomes that may ensue.[33] Sustaining an RRI is multifactorial and may not result from shoe wear alone; demographic characteristics must be considered.[36] Furthermore, there is no single factor such as shoe design that will explain more than a fraction of RRIs.[22] Physicians, physical therapists, and athletic trainers may face difficulties in advising a patient to run with or without shoes.

METHODS

Data Sources

In August and September 2013, Ovid MEDLINE, SPORTDiscus, and CINAHL databases were searched to identify studies examining running barefoot or in minimalist shoes using the following keywords independently and in combination: *barefoot, running*, and *minimalist*. The search was restricted to articles from peer-reviewed academic journals, published in the English language, and conducted with human subjects. Reviews, commentaries, case studies, and case series were excluded from the review.

Study Selection

Studies were initially included if the keywords were found in the title or abstract and the article met the inclusion criteria. Criteria for final selection included reporting on at least 1 of the following outcome variables: pain, injury rate, running economy, joint forces, running velocity, electromyography muscle performance (EMG), or edema. A consensus meeting between the 2 reviewers was held to determine whether the study met the predetermined criteria. Should the 2 reviewers disagree on article selection, a third reviewer would be consulted for mediation. The 2 reviewers fully agreed on the 23 articles included in the systematic review for quality assessment; therefore, arbitration by a third reviewer was not required (Figure 1).

Quality Assessment

The methodological quality of each study was independently assessed by the reviewers using the Downs and Black checklist. The checklist includes 4 categories of assessment: reporting, external validity, internal validity/bias, and internal validity/confounding. The checklist has good interrater ($r = 0.75$) and good test-retest ($r = 0.88$) reliability, as well as high internal consistency (KR-20 = 0.89).[11] Each study was further evaluated for significant results ($P < 0.05$) in the outcome categories of kinetics, kinematics, EMG, and running economy. These results were pooled, and overall quality of evidence for each outcome grouping was further classified by "level of evidence" (see Appendix 1, available at http://sph.sagepub.com/content/suppl).[37]

RESULTS

The initial search of Ovid MEDLINE, SPORTDiscus, and CINAHL resulted in 656, 343, and 110 publications, respectively. After applying the inclusion criteria and omitting duplicates, 23 articles were identified, from which all articles investigated kinetic, kinematic, running economy, or EMG differences or a combination of these 4 variables (see Appendix 2, available at http://sph.sagepub.com/content/suppl).

Quality Assessment

With a maximum total score of 27 points on the Downs and Black checklist, all articles scored between 13 and 19 points (mean, 17.4 points), indicative of moderate methodological quality among the included studies (see Appendix 3, available at http://sph.sagepub.com/content/suppl). The appraisal of level of evidence in the outcome categories of kinetics, kinematics, EMG, and running economy yielded evidence ranging from conflicting to moderate (Table 1).

Under the reporting section of the Downs and Black checklist (Table 1), at least 26 of 27 articles scored points from all items except 3, 8, and 10. In the external validity section, all articles scored zero points. Items 16 through 20 of the internal validity (bias) section scored points to all 27 articles, while items 14 and 15 scored none. Finally, items 21, 22, and 26 of the internal validity (confounding) section scored points to all articles, items 23 and 27 scored partial points, and items 24 and 25 scored none.

DISCUSSION

The differences between barefoot and shod running have been increasingly studied in the literature.[2,6,9,18,20,23,25,28,31] Runners typically contact the ground with the heel first: a rear foot strike (RFS). In contrast, barefoot runners tend to display a midfoot strike (MFS) or a forefoot strike (FFS), which may allow for absorption of collision forces with the ground and avoidance of excessive pressure at the heel.[23] The difference in strike patterns may be related to potential kinetic and kinematic changes in ground reaction forces (GRFs), loading rates, joint moments and

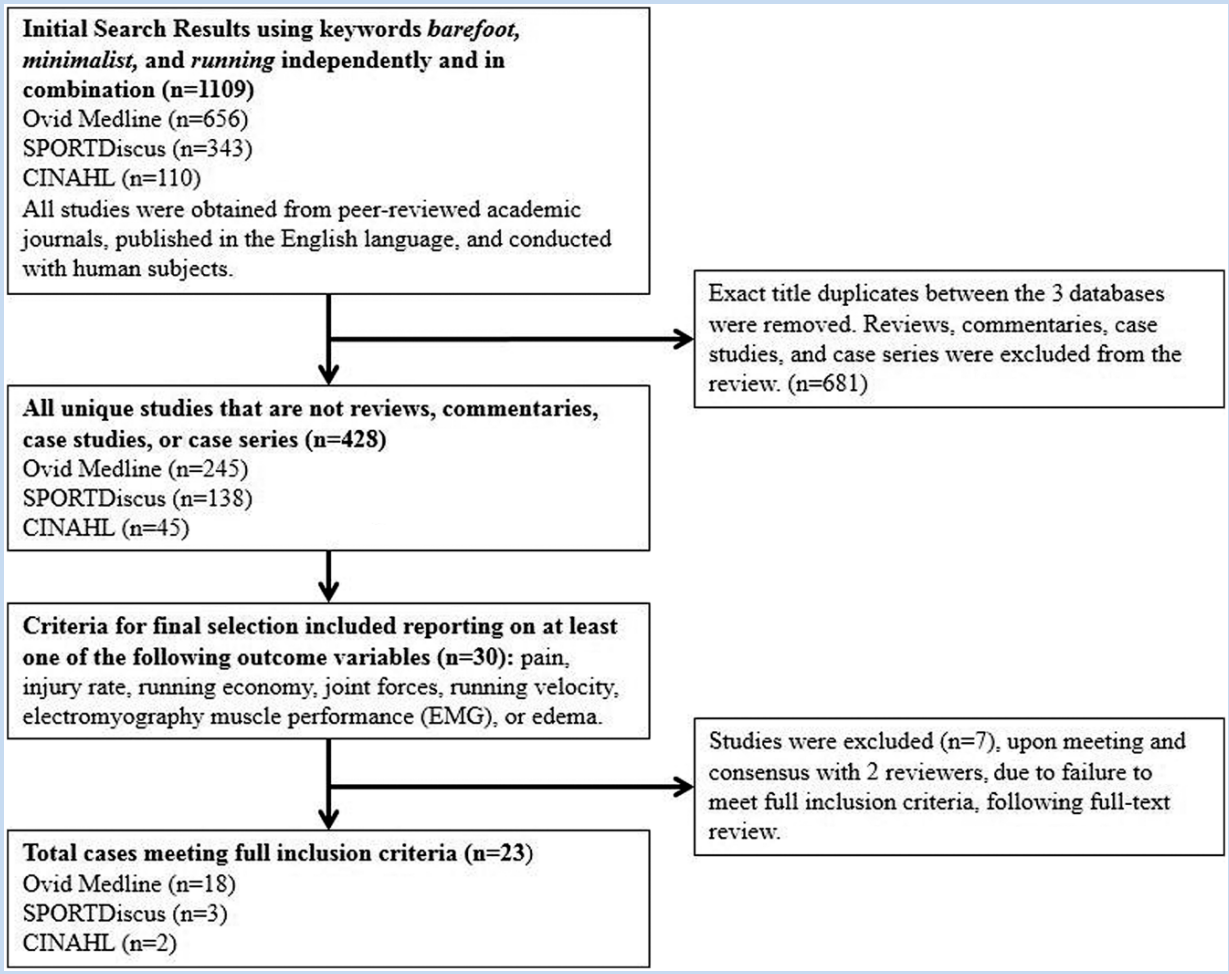

Figure 1. Summary of search and selection process.

powers, joint range of motion, muscle activation patterns, and running economy. These alterations in biomechanics and joint forces while barefoot or in minimalist shoes may protect against RRI[20,29-31] and/or enhance running performance.[13,26]

Kinetics

Moderate evidence suggests an association between barefoot running and lowered maximum vertical GRFs.[5,6,8,9,17,20,23] This decrease in peak vertical GRF at initial contact may be associated with the FFS pattern observed while running barefoot.[8,23] Kinetic analysis of the vertical GRF during the 3 running strike patterns revealed that an RFS yields a defined impact peak on contact with the surface.[6] Forefoot striking eliminated this impact by loading the posterior calf musculature.[6] Added cushioning found in the modern running shoe serves to attenuate shock and reduce impact forces; however, this may influence RFS pattern and ultimately increase forces to the lower extremity.[23,28] Moreover, the length and direction of the GRF moment arm may be altered by the geometry of the modern shoe and the thickness of the foot-ground interface by compression of the midsole.[5] Further kinetic analysis reveals a decrease in the moment arm of both the vertical and mediolateral GRFs when forefoot striking, which reduces the tendency to evert during RFS.[2]

Related to impact force is the impulse, which is equal to the force times the duration of the collision with the ground. Impulse represents the effective mass times its change in velocity over the duration of the impact.[23] Very limited evidence suggests higher braking and pushing impulses as well as higher preactivation of the triceps surae in forefoot strike runners.[9] Very limited evidence also confirms a difference in peak vertical or medial-lateral impulses while barefoot.[27] There is moderate evidence to support that a runner may experience lower peak GRFs during barefoot running.[18] Whether the absence of an impact peak in barefoot running correlates with a benefit of decreased injury rate is not known.

The limited evidence indicating a decreased extension moment and increased power absorption at the knee when

Table 1. Level of evidence for outcome categories

	Studies Included	Conclusion/Level of Evidence
Kinetics		
Ground reaction forces	5,6,8,9,17,20,23	Moderate evidence suggestive of lowered maximum vertical GRF when barefoot
	8,17	Limited evidence suggestive of lowered max vertical GRF only during barefoot FFS
	20	Very limited evidence suggesting decreased medial-lateral and increased anterior-posterior GRF when barefoot
Impulse	9,27	Very limited evidence suggesting greater breaking and pushing impulses of plantar flexors during FFS Very limited evidence suggestive of differences in peak vertical or medial-lateral impulses while barefoot
Rate of loading	1,6,40,41	Very limited evidence suggestive of differences in loading rates when running barefoot, in minimalist shoe, or shod
Joint moments and power	3-5,20,39	Limited evidence suggesting less extension moment and power absorption at the knee when barefoot
	3,39	Limited evidence suggesting increased power generation and absorption at the ankle when barefoot
Kinematics		
Foot-strike pattern	8,17,26,27,39,41	Limited evidence suggesting FFS is associated with barefoot running
Stride	3-6,10,13, 20,24,26,38,41	Moderate evidence suggesting barefoot running is associated with increased stride frequency, shorter stride length, and less ground contact time
Joint range of motion	3,18,39,41	Moderate evidence suggestive of decreased foot and ankle dorsiflexion at initial contact when barefoot
	41	Very limited evidence suggesting decreased ankle eversion at ground contact
	5,6,18,28	Moderate evidence suggesting increased knee flexion at ground contact and less knee flexion during stance when barefoot or in minimalist shoes
Running economy	10,13,16,27,35,38	Very limited evidence suggestive of significant difference in running economy between barefoot, shod, and minimalist shoes
EMG	1,26,39	Limited evidence suggests decreased peak tibialis anterior activity when barefoot FFS

EMG, electromyography; FFS, forefoot strike; GRF, ground reaction force.

barefoot may have implications for knee injuries because of the increased length of the GRF moment arm.[3,5,20,39,40] As a tradeoff to less knee extension, limited evidence shows an increase in power generation and absorption at the ankle in barefoot running[3,39] may be associated with ankle overuse injuries such as Achilles tendinopathy.[15] Hence, the alterations in joint moments and power may be considered a possible risk factor in ankle overuse pathology.

Kinematics

Limited evidence supports a forefoot strike pattern when barefoot, resulting in a flatter foot placement at contact[25] and a more plantarflexed ankle position.[18] Moderate evidence does support decreased foot and ankle dorsiflexion at initial contact when barefoot. Runners may adopt this position during barefoot running[3,4,18,39,41] to reduce local pressure underneath the heel.[6] In the shod condition, this local pressure is eliminated by cushioning through an elevated heel, which enables runners to land with a dorsiflexed ankle.[23] The resulting increase in ankle plantarflexion moment during barefoot running implies the need for increased eccentric work of the triceps surae muscles.[4] Ultimately, this could lead to an increased risk for pathology in the Achilles tendon and may be considered a risk of running barefoot.

At the knee, moderate evidence shows an increase in knee flexion at ground contact and a decrease in knee flexion during stance when barefoot or in minimalist shoes. An increased knee flexion angle at ground contact[5,6,23,28] and less knee flexion during stance[3,4,27,41] may reduce the resultant knee extension moment arm and perhaps lessen the stress across the patellofemoral joint. Running barefoot with a forefoot strike pattern may therefore be beneficial for runners suffering from knee pain and injury.

Other kinematic differences that have been observed with barefoot running include an increased stride frequency (cadence), a shorter stride length, and less ground contact time.[3-6,10,13,20,24,26,38,41] Even though the decreased contact time with the ground may influence a reduction in force, the increased cadence may actually have a cumulative effect of joint forces over time. Very limited evidence suggests a decrease in stride length may reduce the probability of a stress fracture by 3% to 6%.[12]

Running Economy

For every 100 grams of mass added to the shoe, the volume of oxygen in the body increases by approximately 1%.[14] Other studies suggest that the additional weight of the shoe is irrelevant and that other significant factors such as barefoot running experience and shoe construction may affect the metabolic cost of barefoot and shod running.[13] Limited evidence suggests that barefoot running may result in lower metabolic demand (Vo_2, heart rate, and rating of perceived exertion) when barefoot or in minimalist shoes.[16] This may be because of the longitudinal arch of the foot permitting more elastic energy storage and recoil.[27] The longitudinal arch stretches until the heel makes contact with the ground, and then it recoils until take off.[27] An RFS, however, does not stretch the longitudinal arch until both the rear foot and forefoot make contact with the ground.[27] The foot then recoils until take off.[27] Whether running barefoot benefits running economy and potentially improves performance is unknown.

Electromyography

Limited evidence suggests decreased peak tibialis anterior activity in the barefoot FFS condition. Very limited evidence associates preactivation of the gastrocnemius and soleus when barefoot.[9] The preactivation of these muscles supports the reduction of heel impact by switching to the FFS technique.[9] The resultant increase in muscle activity required by the plantar flexors may be considered a risk of barefoot running.

Methodological Limitations

The low scores from the quality assessment using the Downs and Black checklist suggest that improved methodological quality is necessary to provide strong evidence for minimalist and shod running.

Common attributes were identified in each of the rated articles that yielded low scores. First, each study failed to report all adverse events that may be a consequence of the intervention. Second, subjects were not randomly selected and therefore were prone to selection bias. With regard to the internal validity bias section, subjects and examiners were not blinded except in 1 case.[28]

Only 10 studies reported actual probability values for their data.[3,4,6,16,17,20,26,35,40,41] Since all of the studies had a relatively small sample size (between 9 and 68), finding statistically significant results is less likely.

Clinical Relevance

Changing the foot-ground interface (eg, shoes, no shoes, heel heights, lateral flares, rocker soles) changes the kinematics and kinetics of runners in different ways and might also change the direction of the GRF vector and therefore, the moment arm length of the GRF.[5] Whether this change is beneficial or increases risks depends on the subject.

CONCLUSION

The mechanisms underlying the modification of stride frequency, stride length, foot strike pattern, lower extremity mechanics, and how they relate to running performance and injury are not yet fully understood.[39] Despite the different technologies available, minimalist shoe designs cannot entirely replicate barefoot running, possibly because of differences in mechanics and economy in barefoot running. No definitive conclusions can be drawn on the risks or benefits to running barefoot, shod, or in minimalist shoes.

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