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Prospective Comparison of Running Injuries Between Shod and Barefoot Runners

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Abstract and Introduction

Abstract

Background Advocates of barefoot running suggest that it is more natural and may be a way to minimise injury risk. In contrast, opponents believe shoes are needed to adequately cushion and support the foot. However, to date, there have been no prospective studies of injury patterns in barefoot and shod runners. The purpose of this study was to compare the incidence and rate of injuries between shod and barefoot runners.

Methods A prospective survey was conducted over the course of a year among 201 (107 barefoot and 94 shod) adult runners. Information regarding injuries and mileage was logged monthly using a custom, web-based database program. The number of injured runners, number of injuries per runner and injury rates were compared between habitual barefoot and habitual shod runners. Both musculoskeletal and plantar surface injuries were assessed.

Results Statistically fewer overall, diagnosed, musculoskeletal injuries/runner were noted in the barefoot group. However, injury rates were not statistically different between groups due to significantly less mileage run in the barefoot group. As expected, barefoot runners sustained a statistically greater number of injuries to the plantar surface of the foot. The descriptive analysis suggests a greater number of calf injuries, but lower number of knee and hip injuries in the barefoot group. Additionally barefoot runners reported less plantar fasciitis than the shod group.

Conclusions Barefoot running is associated with fewer overall musculoskeletal injuries/runner, but similar injury rates. A larger scale cohort is needed to more accurately assess differences in individual injuries between these two groups.

Introduction

Barefoot (BF) running has received very little attention until recently, when the popular book, *Born to Run*, hit the press. There are now 93 chapters of the Barefoot Runners Society,[1] in 23 countries across the globe. Advocates of running BF have suggested that it may reduce injury incidence due to the reduction of impact loading, as well as promote foot strengthening. Opponents suggest BF running will be associated with increased injury incidence due to the lack of support and cushioning the modern running shoes provide. However, injuries in modern day shod (SH) runners are remarkably common with up to 79% sustaining an injury in a given year.[2] This seems exceedingly high for an activity suggested to be needed for our own survival.[3]

While the aetiology of running injuries is clearly multifactorial, modern day footwear may have played an important role. The addition of a cushioned heel dramatically changes the landing pattern during running. The majority of habitual BF runners land on their forefoot.[4–6] However, up to 89% of traditionally SH runners land on their heels.[7–9] One of the distinct characteristics of a rearfoot strike (RFS) is the initial impact transient of the vertical ground reaction force that is typically missing in a forefoot strike (FFS). This impact transient is associated with significantly higher rates of loading compared with those of a FFS. Nigg and colleagues argue that a certain amount of loading in bone is necessary. They believe that changes in the rate of loading trigger tuning in the musculoskeletal (MSK) tissues to initiate a loading response with each footfall.[10,11] However, increased impulsive loading has been associated with bony[12] and cartilaginous[13] injuries in animal studies. Increased vertical load rates have also been associated with a number of common running-related injuries in retrospective and prospective human studies.[14–18] Additionally, it has recently been reported that runners with a RFS have twice the rate of repetitive stress injuries than their FFS counterparts.[19]

BF running is also associated with a shorter stride length and higher cadence. The reduction of stride length has been shown to reduce hip and knee loads.[20] Hip adduction, which is linked to some of the most common running injuries, including stress fractures, iliotibial band syndrome[21,22] and patellofemoral pain syndrome,[23] is also reduced.

Being BF has additional benefits. It results in increased sensory feedback from the plantar mechanoreceptors, which has been shown to improve both static and dynamic stability.[24–26] BF running has also been associated with increased ankle joint

position sense[27] which could lead to a reduction in ankle sprains or other joint injuries. Finally, reducing support to the arch has been shown to result in increasing the cross-sectional area of the arch musculature.[28] Strengthening of the arch musculature has been shown to reduce arch collapse as indicated by a reduced navicular drop and increased arch height index.[29] As plantar fasciitis has been associated with weak arch muscles,[30] strengthening of these muscles should help to reduce the risk of this common injury.[31]

However, BF running is not without risk. The increased load to the calf and arch associated with a BF, FFS pattern places additional stress to these areas. The plantar surface is also at greater risk for injury. The plantar surface is designed to be protective as the foot can withstand six times more abrasive load than the skin covering the leg.[32] However, despite these protective features, exposure of the bare sole clearly increases the risk of plantar surface injuries such as cuts, bruises and blisters.

While it is a well-accepted fact that SH running is associated with a high-injury incidence, it is unclear whether injuries are actually reduced with BF running, as has been suggested. Thus, the aim of this preliminary, prospective study was to compare injury patterns between habitually SH and habitually BF runners. We expected that overall MSK injuries will be lower in the BF runners due to the reduced vertical impacts and softer landings they experience. We also expected a greater number of abrasive injuries to the plantar surface of the foot in the BF runners.

Methods

Subjects

A preliminary sample size estimate based on previous prospective injury data[14] determined that 80 runners per group were required to determine differences in overall injury incidence. In order to account for a 20% dropout, 96 runners per group were sought. Runners were solicited from online forums and running groups from across the USA, as well as internationally. All runners were between the ages of 18 and 50 years, running more than 10 miles per week, and had been running for more than 6 months prior to entry in the study. BF runners were required to run at least 50% of their yearly mileage completely BF. The remaining 50% of their mileage had to be run in true minimal shoes, each characterised by the lack of an arch support, missing a reinforced heel counter and having no midsole.

Web-based Survey

Runners were entered into an online database and were sent a link to a secured, online survey system. After providing their informed consent, approved by the University of Delaware Human Subjects Review Board, they provided information regarding their running history, mileage history and injury history. Participants then reported their monthly mileage and any running-related injuries they had experienced for a year. Along with location and diagnosis of the injury, they reported any medical attention and diagnosis received, footwear worn during injury and activity during injury. The system was automated such that the participant was notified monthly by email. If the participant failed to respond within 3 days, an automated reminder was sent. If another 3 days passed without response, an alert was sent to the study coordinator who contacted the participant directly via e-mail or phone to encourage them to fill out the required monthly information.

Analysis

For all statistical tests described below, a p value ≤0.05 was considered a significant difference. Injuries were divided into three groups. We first examined all running-related MSK injuries reported by the runners. These were also categorised by location (ie, hip, knee and foot). We then assessed the subset of MSK injuries that were diagnosed (DxMSK) by a clinician, such as a physician, physical therapist or athletic trainer, to provide a valid diagnosis. Finally, we were interested in the abrasive injuries to the plantar surface (PL) of the foot, including cuts, bruises and blisters, and assessed these as well. In each of these groups, we compared the relative number of runners injured, as well as the number of injuries reported between the BF and SH groups.

The relative proportion of BF and SH runners sustaining injuries in each subgroup was compared using a χ^2 analysis. Additionally, the total number of injuries per runner and the injury rate per 1000 miles were calculated for each person and averaged across groups. The number of injuries/person and injury rates were compared between groups using an independent t test. These tests were performed on each set of injuries including MSK, DxMSK and PL. The study was not powered for determining differences in individual injuries. Therefore, injuries by body part, such as knee or foot injuries, as well as specific diagnoses, such as tibial stress fractures or Achilles tendinitis, were compared descriptively.

Results

Subjects

A total of 450 runners contacted the study coordinator and were screened regarding their mileage, footwear, age and medical condition. Runners resided in seven different countries, in five continents. Among those in the USA, 34 different states were represented across both groups. A total of 226 qualified runners were admitted into the study, including 108 SH and 118 BF runners. Twenty-five (14 SH, 11 BF) of these runners decided not to participate, thus leaving 201 (94 SH, 107 BF) runners for the monthly follow-up. Of these runners, we experienced a compliance of 84% due to occasional missed monthly reporting. Despite efforts to balance the groups by age and sex, the BF group was 4 years older and more dominated by males (). As a result of the sex differences, the BF group was slightly taller and heavier than the SH group. At baseline, the BF group reported running less mileage and running slower based on their reported 5-kilometer race time. On average, they ran approximately 10 miles/week less throughout the study (14.9±8.8 vs 25.3±14.8 miles/week). The BF group had been running BF 1.65±1.32 years prior to entry in the study, and 63% of these runners began running BF between 6–12 months prior to the start of the study. On enrolling in the study, the BF participants reported running on average 80±23% of their mileage completely BF, and the remainder in minimal footwear. During the study, this was reduced slightly to 75±33% of their mileage being run completely BF.

Table 1. Self-reported participant characteristics of the BF and SH groups at baseline. p≤0.05 indicates a significant difference.

	SH (n=94)		BF (n=107)		p Value
Age (year)	34.6	(9.1)	38.6	(7.6)	0.001
Gender	35F	59M	13F	94M	0.000
Height (m)	1.73	(0.09)	1.76	(0.07)	0.010
Weight (kg)	68.9	(11.8)	76.0	(12.6)	0.000
Years running (year)	9.6	(7.6)	9.8	(9.5)	0.899
Premileage (mi/week)	30.0	(18.1)	16.5	(9.3)	0.000
5 km time (min)	21.37	(3.65)	24.95	(5.81)	0.000

BF, barefoot; SH, shod.

Injuries

Overall, there were 396 injuries reported, 346 of which were running-related injuries (164 SH, 182 BF). MSK injuries represented 281 of the 346, (156 SH, and 125 BF) with 136 (73 SH, 63 BF) or 48% of which were clinically diagnosed (DxMSK). Of all of the MSK (diagnosed and undiagnosed) injuries, the foot was the most commonly injured body part in both groups with percentages being similar between groups (43% for SH and 41% for BF). The number of injuries to the remaining body parts was generally lower in the BF group. The largest differences in number of injuries noted were at the hip, followed by the knee and ankle (figure 1).

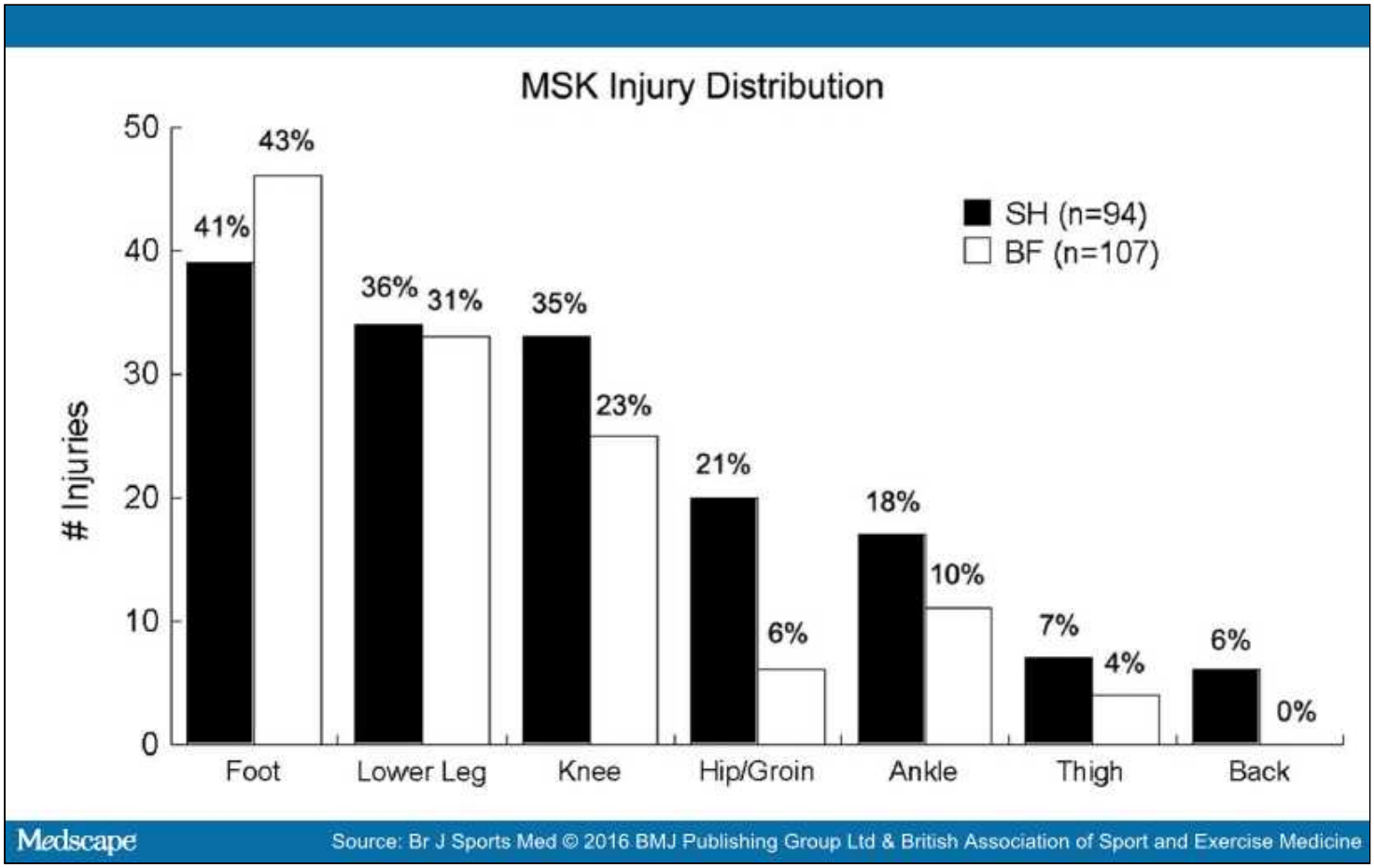

Figure 1.

Body part distribution of all musculoskeletal injuries (MSK) injuries incurred during the study for both groups (does not include plantar surface injuries of the foot). As there are unequal number of runners in the shod and barefoot groups, the number of injuries/number of runners for each group at each location are noted as % above each bar.

When grouping all reported MSK injuries (regardless of being medically diagnosed or not), there were no differences between SH and BF groups in the relative number of runners reporting a MSK injury (figure 2). Interestingly, 48% of BF runners did not sustain any MSK injuries compared to only 38% of SH runners; however, this did not reach statistical significance. There were statistically fewer (p=0.05) MSK injuries/runner reported in the BF group compared with the SH group (1.17 BF vs 1.66 SH). However, when normalised for mileage, there was no difference in injury rates between groups. In the BF group, 72% of these injuries were incurred while BF, as opposed to in minimal footwear. This is not surprising as the BF group spent about 75% of their run time BF.

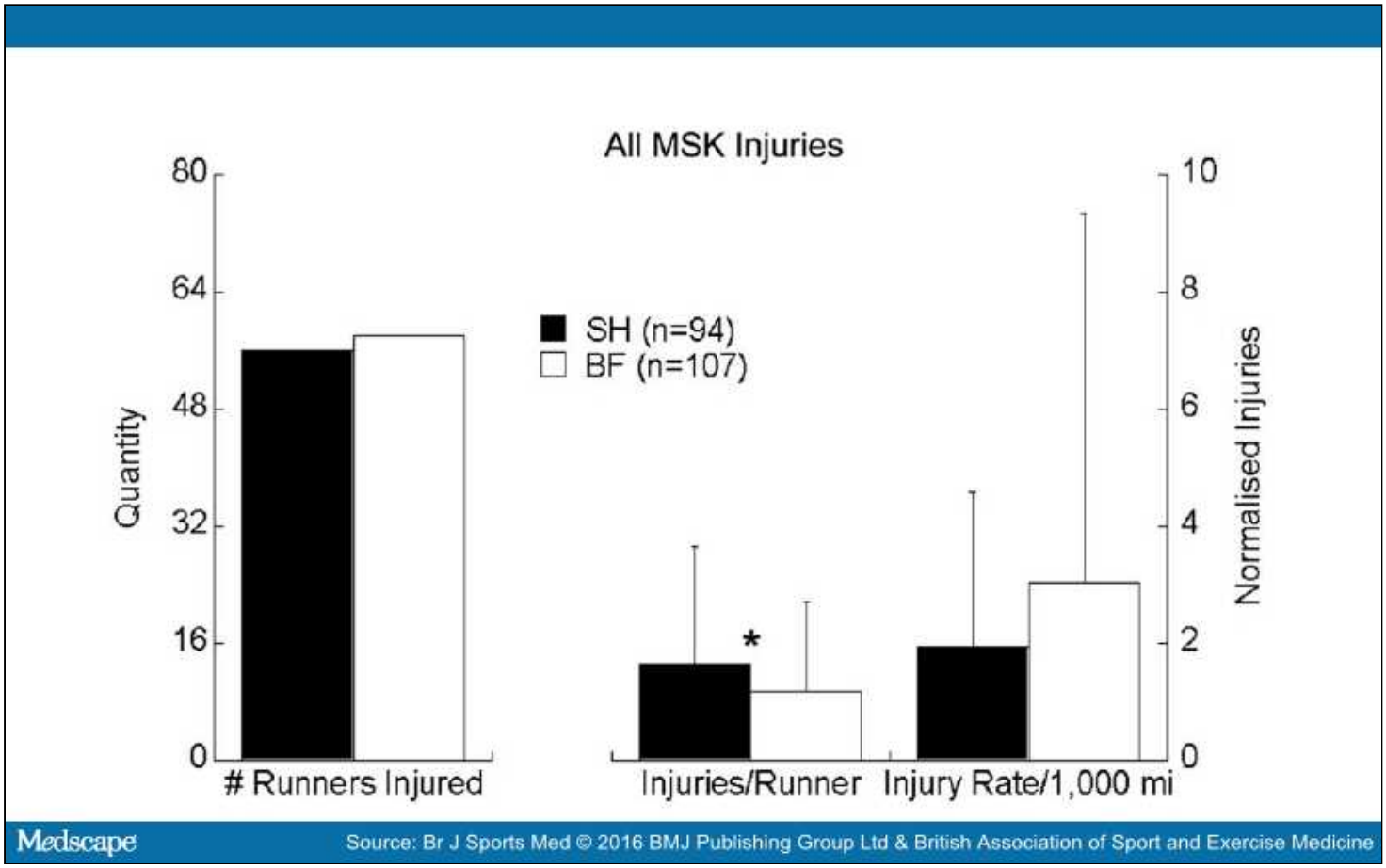

Figure 2.

Comparison of all musculoskeletal injuries (MSK) injuries sustained during the study. * indicates a significant difference p≤0.05.

The number of runners sustaining diagnosed injuries (DxMSK) was similar, with 34% of SH runners versus 32% of BF runners injured. Additionally, there were 24% fewer diagnosed injuries/runner in the BF group versus the SH group resulting from an average of 0.78 injuries/SH runner and 0.59 injuries/BF runner; however, this did not reach significance (figure 3). When normalised for mileage, DxMSK injury rates were similar between groups.

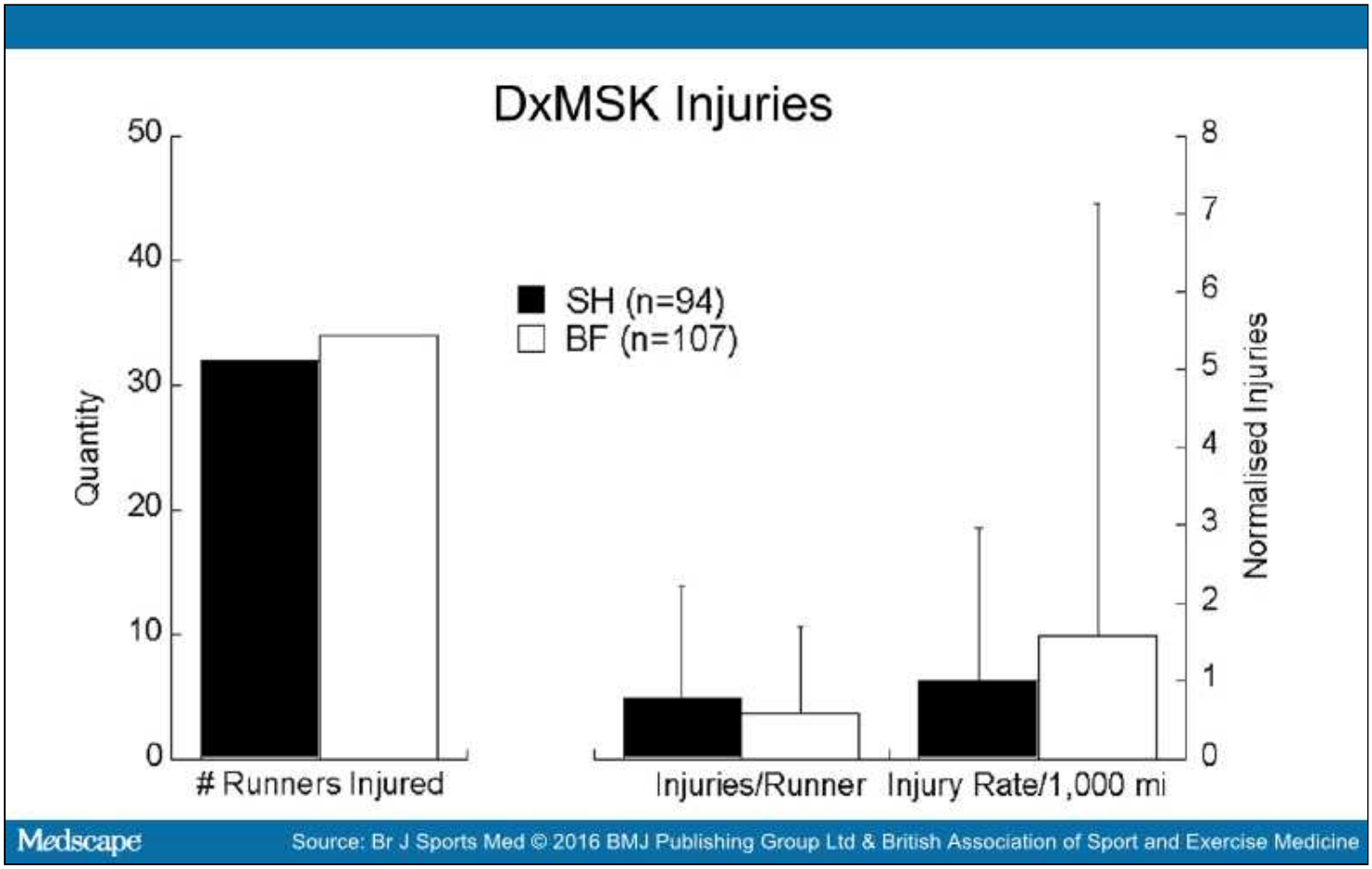

Figure 3.

Comparison of diagnosed musculoskeletal (DxMSK) injuries reported during the study.

In terms of specific injuries, the SH group had 21 diagnosed injuries to the hip and knee compared to 5 in the BF group (). The trend was reversed for lower leg injuries. BF runners had 27 lower leg injuries compared to 12 in the SH group. Interestingly, there were 11 cases of plantar fasciitis in the SH group compared to only 3 in the BF group. The majority of these diagnosed MSK injuries occurred in the lower leg, ankle and foot for both groups.

Table 2. Clinically diagnosed, musculoskeletal injuries in the SH and BF runners

Common running injury diagnoses	SH	BF
Plantar fasciitis	11	3
Iliotibial band syndrome	8	4
Gluteal strain/tendinitis	5	0
Achilles tendinitis	4	9
Anterior tibialis strain/tendinitis	4	3
Hamstring strain	4	0
Ankle sprain	4	3
Patellofemoral pain	4	1
Metatarsal stress fracture/syndrome	3	3
Peroneal tendinitis	2	5

Gastrocnemius/soleus strain	1	5
Tibialis posterior strain/tendinitis	1	5

BF, barefoot; SH, shod.

Thirty per cent of BF runners sustained some type of PL injury during the study, compared with only 6% of SH runners (figure 4). This resulted in significantly more PL injuries reported and a higher PL injury rate in BF runners. Cuts were the most prevalent PL injury in the BF group along with blisters and bruises that were also common in this group ().

Table 3. Summary of PL injuries reported by SH and BF runners during the study and the number of people to whom these injuries were sustained

Summary of PL injuries	SH		BF	
	Injuries	People	Injuries	People
Cuts	1	1	24	15
Blisters	7	5	16	14
Bruises	0	0	12	9
Stubbed toe	0	0	5	5

BF, barefoot; PL, plantar surface; SH, shod.

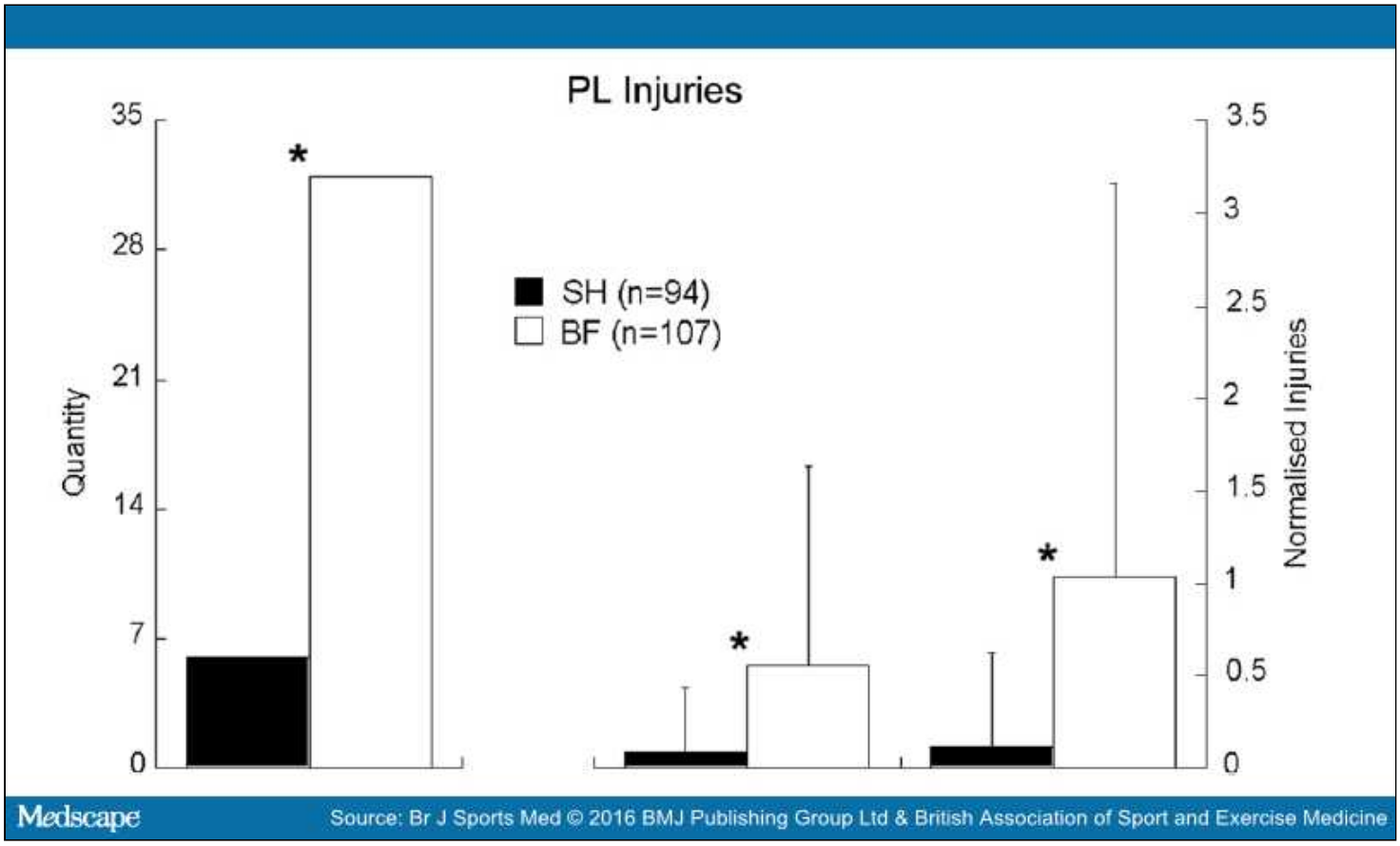

Figure 4.

Comparison of plantar surface (PL) injuries incurred during the study. * indicates a significant difference p≤0.05.

Discussion

The purpose of this prospective study was to examine the differences in injuries between habitually BF and habitually SH runners. The MSK injuries/runner (including diagnosed and self-reported) were 30% lower in the BF compared to the SH group (figure 2). These injuries were experienced by 52% and 62% of BF and SH groups, respectively. These percentages are consistent with those reported by van Gent *et al*[2] who reported that between 19% and 79% of runners are injured within a given year. Despite the number of MSK injuries/person being lower in the BF group, their overall injury rate was not different due to their lower mileage run. As some of these runners had been running BF for less than a year, they were not likely to be as well adapted to running BF as the SH group were to running wearing shoes. Additionally, it is possible that running BF, by itself, limits the number of miles run due to the tolerance of the plantar surface. It should be noted that the injury rate was associated with a very high standard deviation in the BF group. This is consistent for each of the injury rate measures. This may be due to the greater variation in running mileage in the BF versus the SH group.

In terms of MSK injury locations, the foot was the most commonly injured area in BF and SH runners. While foot injuries are common in runners, the knee is typically reported as the most common site for injuries.[2] With the greater load to the foot during BF running, it was surprising that the number of foot injuries/runner was found to be similar between groups (41% in SH group vs 43% in the BF group) (figure 1). However, injuries to all other body parts were generally lower in the BF runners. The largest differences were at the hip, knee and ankle joints. This reduction in joint injuries may be related, in part, to the reduced external joint moments reported by Kerrigan *et al*[33] during BF running as compared with SH running. BF running has been associated with reduced stride lengths, which have also been associated with reductions in hip and knee moments in a study by Heiderscheit *et al*.[20] The greatest reductions in joint loading noted in both of these studies were at the knee. This is significant, as the knee has been reported to be the most common site of running injuries in a systematic review by van Gent *et al*.[2]

BF runners incurred more abrasive injuries to the sole of the foot. Cuts were the most common PL injury and are likely to be the most serious due to the risk of infection. While BF runners ran completely BF for 75% of their mileage, they did protect their feet with minimal footwear for the remaining mileage. Ultimately, the use of minimal footwear protected the sole from many of these PL injuries, as 88% occurred while running BF. While this type of footwear removes important sensory input, most biomechanical variables are similar between BF and minimal footwear running.[4]

While the study was not powered to assess individual diagnosed injuries, there were some interesting findings that warrant further study. For example, despite the greater load to the arch with BF running, plantar fasciitis appeared to be more common in the SH group. This may be related to the fact that plantar fasciitis has been associated with increased vertical load rates.[16] It has been reported that up to 89% of SH runners are rearfoot strikers[7–9] with much higher rates of vertical loading. In contrast, 80% of BF runners are mid-foot/forefoot strikers,[4–6] which is associated with lower rates of loading. Additionally, removing support of the foot promotes strengthening of the arch muscles by increasing the demand on these muscles.[28,31,34] These muscles are critical to the eccentric control of the arch lowering with each footstrike and are protective of the plantar fascia.[28,29]

The greater number of Achilles/calf and posterior tibialis strains may be due to the anterior strike pattern of a BF runner.[35] This position places greater eccentric demands on these muscles as the foot dorsiflexes and everts in early stance. The similar number of metatarsal stress fractures/syndromes was surprising as there have been a number of reports of bony injuries to the metatarsals associated with minimal footwear running.[36–38] However, injuries in these reports were associated with a very brief transition phase into minimal footwear running. Our study only included individuals who had been running BF for at least 6 months and most likely excluded those who did not do the transition successfully. Runners in these studies were also wearing minimal footwear. It is possible that running BF provides more sensory input that may be protective of overloading the metatarsals.

Patellofemoral pain syndrome and iliotibial band syndrome are among the most common injuries in runners[2,39] and were more prevalent in the SH runners (). In prospective and retrospective studies, both of these injuries have been associated with excessive hip adduction.[21–23,40] BF running, with its shorter stride length, has been reported to result in lower hip adduction[20] and may explain this reduction in knee pain. Additionally, patellofemoral pain has been linked with high-vertical load rates[18] that are reported to be significantly reduced in habitual BF runners.[5] Patellofemoral pain has also been linked with high-patellofemoral contact stresses.[41] Bonacci *et al*[42] recently examined this relationship using a musculoskeletal model. They demonstrated that BF runners, with lower vertical ground reaction forces in early stance (due to lower rates of loading) and greater patellofemoral contact area (due to greater knee flexion), have lower patellofemoral contact stresses. The findings of these studies were supported by a recent survey of BF runners[43] who reported that knee injuries were the most common injury that had resolved with their transition to BF running. Knee injuries are the most common site for running injuries and running BF, or in minimal shoes, may have a profound effect on these injuries.

Table 2. Clinically diagnosed, musculoskeletal injuries in the SH and BF runners

Common running injury diagnoses	SH	BF
Plantar fasciitis	11	3
Iliotibial band syndrome	8	4
Gluteal strain/tendinitis	5	0
Achilles tendinitis	4	9
Anterior tibialis strain/tendinitis	4	3
Hamstring strain	4	0
Ankle sprain	4	3
Patellofemoral pain	4	1
Metatarsal stress fracture/syndrome	3	3
Peroneal tendinitis	2	5
Gastrocnemius/soleus strain	1	5
Tibialis posterior strain/tendinitis	1	5

BF, barefoot; SH, shod.

There were several limitations to this study mostly related to the differences in participant characteristics between the two groups. First, the BF participants were older on average by 4 years (38.6 vs 34.6 years). However, while significant, the clinical relevance of this age difference as related to injury is unknown. There were more males in the BF group resulting in their being taller and heavier. While sex is not a risk factor for overall injuries, it does play a role in some specific diagnoses. Therefore, studies designed to assess specific injuries should be balanced by sex. The BF group also ran less mileage than their SH counterparts. Matching runners on weekly mileage may have helped to control level of experience. However, novice runners are injured more frequently than more experienced runners.[44] Based on this, one might have expected the relatively novice BF runners to be injured more, which was not the case. While the BF runners had an average of 1.65 years of BF running, 63% of them had only been running BF for between 6 and 12 months. Thus, there is also a possibility that many in this group were still transitioning to BF running, as the time for complete adaptation is still unknown. Many of the lower leg injuries reported, such as Achilles tendinitis, might be related to the increased muscular demand of transitioning to a new running pattern. These injuries might resolve as the lower leg further adapts. Finally, a larger cohort would have allowed for the examination of statistical differences in individual injuries.

In summary, results from this study suggest that BF runners sustain fewer overall MSK injuries compared to their SH running counterparts. However, this difference is not present when running volume is considered as BF runners run less mileage. While BF runners sustained a similar number of clinically diagnosed, MSK injuries, the incidence and type appear to be different. This may be due to the difference in the loading patterns of the lower extremity between the two running conditions. Specifically, the BF condition increases the load to the calf (due to the FFS pattern) and the arch (due to the removal of support). However, it was interesting to note that while injuries to the calf were greater in the BF group, arch injuries were less. This may suggest that the arch adapts quicker than the calf to BF running; however, further studies are clearly needed to further investigate this.

Future studies should include a larger cohort so that specific injuries can be compared statistically. Additionally, studies should include runners with a longer history of BF running to avoid injuries associated with transition. Finally, many runners who desire the benefits of BF running without the exposure of the foot choose minimal footwear. Therefore, future studies of the effect of true minimal footwear on injuries should be conducted.

Sidebar 1

What are the Main Findings?

- Significantly fewer musculoskeletal injuries were reported in barefoot runners than in shod runners.

- Injury rates are similar between barefoot and shod runners due to decreased mileage in barefoot runners.
- Plantar surface injuries are significantly higher in barefoot runners than in shod runners.

Sidebar 2

How Might It Impact on Clinical Practice in the Near Future?

- These findings suggest that habitual barefoot running does not increase overall injury incidence, and may be a safe alternative for injured runners if transitioned properly.
- Barefoot running may serve as protection against knee injuries—which are the most common injuries sustained by runners.
- Gastrocnemius-soleus strains are greater in barefoot runners, highlighting the need to adequately strengthen these muscles; plantar fasciitis was less common, suggesting that barefoot running itself may strengthen the arch musculature.
- Owing to the higher number of plantar surface injuries, barefoot runners should protect their feet with minimal footwear when encountering environmental elements such as the cold, heat, darkness and sharp surfaces.

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