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Barefoot vs shod running: An analysis of lower limb joint forces

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ABSTRACT

Objectives
The aim of this study was to measure the magnitude of forces in the joints of the lower limb whilst running barefoot and compare them to the forces generated whilst wearing running shoes with a thick midsole.
Methods
Twenty-three volunteers who utilised running as their main sport or a training aid ran as training aid were included in this study. Each volunteer would run down a fourteen-meter-long corridor both barefoot and with running shoes. Forces for joints of the lower limb were collected using a Vicon motion analysis system and force plates. The joint forces for the ankles, knees and hips were taken as the largest joint force experienced during the stance phase and then averaged over five running trials.
Results
There was significant reduction in the joint forces for the ankles, knees, and hips when barefoot running compared to the shod condition.
Conclusion
Barefoot running could be utilised to prevent both acute and degenerative injuries of the lower limb.

INTRODUCTION

Running today remains a popular activity across the globe and has only gained popularity over time. Once considered a strange activity [1], the increase in the prevalence of running over the years can be attributed to a multitude of factors including the recognition of associated physical and mental health benefits [2] and, recently, an increase in a demand of those benefits as a result of the restrictions implemented during the COVID-19 pandemic.

The change in attitude towards running occurred around the same time as the development of the what is recognised as the modern running shoe [3]. Utilising a thick, deformable midsole, the design of the modern running shoe has not change much since its inception. This may be the reason that running injuries have been at a constant level over the last thirty years [4].

There has been a recent surge in popularity of barefoot and using minimalist running shoes as a way of injury reduction and prevention [3], with evidence suggesting barefoot running can reverse injuries of the lower limb that developed when running with shoes with a thick midsole and improve race times [5] Given that both acute [6] and degenerative injuries in some groups have been associated with larger magnitude joint forces [7-10], the purpose of this study was to establish if transitioning to barefoot running could play a role in injury prevention by reducing the joint forces across the lower limb.

OBJECTIVES

The prevalence and burden of osteoarthritis has been well documented and has social and economic implications not only for the individual, but also the wider society [11-13]. Given that the physical impairment of ankle OA is equivocal to congestive heart failure and end-stage kidney disease [14], much research has been conducted to determine the pathophysiology of joint degeneration. One area that has been widely studied is the relationship between running and OA.

The theory that the repetitive impacts of running over time may contribute to the degeneration of joints is not a new concept and has been successfully demonstrated in animal studies [15, 16]. However, the evidence that running alone is a risk factor for the development of OA in the lower limb joints of humans is still hotly debated with some research suggesting high levels of physical activity leads to joint degeneration [17, 18]. Whilst other research suggests that a definitive link cannot be made [19], and some stating running may even play a protective role [20]. The current consensus regarding the development of OA is that lifelong loading through the normal activities of living with a normal joint will not cause joint degeneration, but excessive loading through a normal joint will [8]. Joint degeneration may also occur due to normal loading through and abnormal joint [9, 10, 21]. Excess loading can occur for several reasons including increased frequency of load or increased load due to factors like obesity [22, 23]. This correlates with the fact that the development of OA has been recorded in groups such as elite level runners who have run high milage at fast paces frequently for years [24]. The most common joint of the lower limb to be affected by OA is the knee [25] and can develop due to a multitude of factors.

The knee

Osteoarthritis of the knee is extremely prevalent with over one in three adults over the age of 65 suffering from the condition [26]. There are several groups who are at higher risk of developing knee OA because of factors that increase either the total load or alter the load distribution in the knee. One such group includes individuals who have sustained a previous knee injury including anterior cruciate ligament (ACL) rupture [10] and meniscal injury [27]. This is strong risk factor for the development of OA with nearly half of individuals who suffer both an ACL rupture with associated meniscal injury going on to experience joint degeneration as a result [21]. People with malaligned knees, whether due to injury or genetic and development factors, are also shown to have a higher prevalence of OA due to the abnormal load distribution across the joint [28]. The symptoms of knee OA can also be exacerbated due to larger magnitude joint forces during activities like running [29], this may lead to poorer engagement with rehabilitation programs that incorporate running as a conservative measure, weakness is surrounding muscles [30] and, therefore, a worsening symptoms further. A reduction in the forces across the joint would reduce symptoms on OA and improve function to and further engagement with exercises to minimise progression of joint degermation [31]

Obesity is another factor that can increase the forces across the knee joint and leads to an increased prevalence of OA with a more rapid progression [22]. The pain associated with knee OA is often triggered by physical activities that load the knee joint. Footwear modifications that effectively reduce the joint force through the knee have shown symptomatic relief and may slow progression on the condition [32]. The definitive surgical management for symptomatic OA of the knee is a knee arthroplasty. Even after this, the force across this prosthetic joint is important.

Similarly, to native knee joints, the magnitude of forces affecting the implant are highly significant in both its longevity and survival. The wear of prosthetic knee joints is proportional to the force transmitted through it [33] and malalignment during insertion of the prosthesis generates greater strains in the proximal tibia which can lead to bone fatigue and failure [34].

Thus, reducing the force through the knee when running could help prevent both development and progression of knee OA as well as symptom reduction during exercise [35]. The hip is another joint that is commonly affected by OA.

Hip

The hip joint is another that can be detrimentally affected by running. Although there is not a general consensus regarding the relationship between recreational running and OA [36, 37], there is an established link between degeneration of hip joint and high intensity, high milage running with an increase in both radiological evidence and symptomatic OA [38-40]. This is thought to be due to excessive loading of the joints over time. Adaptations to running technique are made by those who suffer from hip OA in a bit to reduce the force across the joint and relieve symptoms [41]

Runners with weak hip abductors are at a higher risk of hip OA development and progression [42]. It is proposed that the hip abductors play a role in attenuating forces when running and, therefore, decreased abductor activity increases hip joint force [43] and may predispose to degeneration of the joint. Weak hip abduction strength has also been linked with patellofemoral pain amongst novice runners [44]. A decrease in hip force when running in individuals with weak hip abductors may result in a reduced risk of developing OA.

Running may also contribute to tears developing in the acetabular labrum which has been associated with anterior hip pain [45]. It is thought that this too develops as a result of larger magnitude joint forces affecting the hip [46, 47]. Another condition that contributes to anterior hip pain is the development of stress fractures. These don't tend to arise due to acute trauma, and instead as a result of abnormal forces on normal bone. Abnormal forces tend to be the result of training errors or excessive milage [48]. Stress fractures may also develop or normal forces on abnormal bone [49]. Women suffering from amenorrhoea, disordered eating or osteoporosis are considered to be at the highest risk [50]. A reduction in joint force across the hip whilst running by changing the footwear used could be a simple intervention to reduce the risk of stress fracture development in at-risk groups. Another joint where the magnitude of force acting across it is important is the ankle joint.

Foot and Ankle
Overuse injuries at the ankle and foot account for almost 40% of all overuse injuries of the lower limb [51]. Overuse injuries arise as a result of multitude of factors including training, anatomical variation and biomechanical factors such as impact force [52]. The magnitude of forces affecting the ankle is also important in those with chronic ankle instability (CAI). Osteoarthritis is apparent in approximately 70% of people with CAI [53]. This likely due to a change in the magnitude of joint forces affecting the ankle during mobilisation as a result of ligamental injury and joint malalignment [54, 55]. Modern footwear has also led to weakening of the muscles of the feet which can contribute to running related injuries [56].

Given the negative impacts of larger magnitude joint forces whilst running, this study set out to investigate whether changing the footwear used when running could reduce the forces acting across the joints of the lower limb.

METHODOLOGY

Volunteers
Prospective volunteers had to conform to a set of inclusion criteria prior to selection. They had to be aged between 16 and 30, have no form of gait abnormality, no lower limb injury in the preceding four weeks and ran regularly as either their main sport or a training aid. The experimental procedures were reviewed and approved by the approved by the University of Dundee school of Medicine and Life Sciences Research Ethics Committee (approval code: (UREC) (SMED REC 090/18)). Written consent was obtained from each volunteer prior to commencing the running trials.

Experimental procedure
All data was collected using a VICON 3D motion capture system (Vicon Motion Systems Ltd., Oxford, UK at the Institute of Motion Analysis Research (IMAR) centre of the Tayside Orthopaedic & Rehabilitation Technology centre, Ninewells Hospital and Medical School.

Selected volunteers were allotted time for a self-directed warm up prior to the initiation of the running trials. Anthropometric data including height, weight, leg length, ankle width and knee width were collected for each individual.

The VICON 3D motion system consisted of sixteen VICON FX14 cameras and two AMTI BP600400 force plates operating at 200 Hz and 1000 Hz respectively. This system utilised Nexus 2.8.1 for gait analysis and data extraction. The above anthropometric data was input into the Nexus software after calibration. Sixteen 14mm retroreflective markers were applied to the volunteers in accordance with the IMAR lower body marker placement guide (Figure 1) prior to the running trials [57].

Running trials
A set of trials for both the barefoot and shod conditions were carried out. A new pair of Nike Dart 7 running shoes (figure 2) were utilised for the shod condition. The order of testing of the conditions was random to minimise the effects of fatigue.

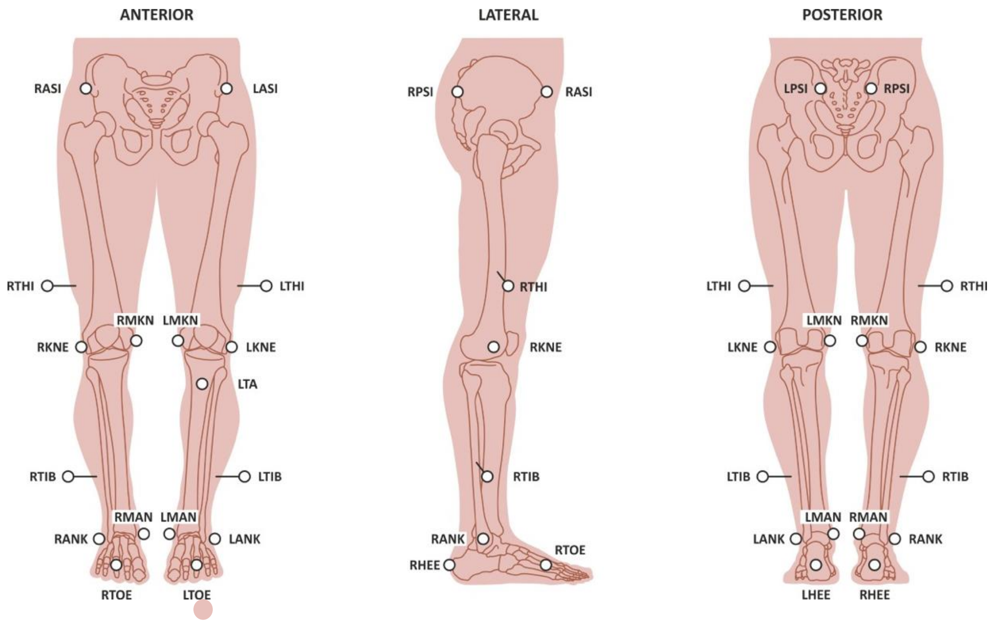

Figure 1 Lower body marker placement in accordance with the IMAR guide

Volunteers were asked to run along a 14-meter corridor at the pace they would adopt for a 5km run. This pace was chosen to allow the all the trials to be completed with minimal fatigue. Initial trials were undertaken to find a starting point that would ensure a force plate would be struck each time without gait modification. Once this starting point had been identified, the volunteer ran until five foot strikes with the same leg had been achieved [58]. After this, the same protocol was completed for the other running condition with volunteers resting for as for as long as they felt was appropriate to allow them to continue to the same pace during the next condition.

Joint force data

Each running trial was formulated by manually marking the reflective markers using the Nexus 2.8.1 and any gaps were filled with the gap filling tools provided by the Nexus 2.8.1 software. The trials were then cut to focus on the stance phase. Once this was done, a pipeline was used which applied the process Dynamic Plug-in Gait model, Export C3D and export ASCII. Each trial was screened to ensure full contract with the force plate. Any trials where the force plate was not centrally struck, or reflective markers had fallen off were excluded from the study.

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Figure 2: a comparison of the footwear conditions tested

The value for joint force was taken as the largest force experienced during the stance phase in the knee, hip, and ankle and measure in Newtons per kilogram (N/Kg).

Data analysis

Data were analysed using IBM Statistical Software of Social Science (SPSS) Version 22. Differences between the barefoot and shod conditions were analysed using paired T-tests. The α level was set at 0.05. The mean difference and effect size were calculated for significant results. The effect sizes were calculated and can be interpreted according to the following: small effect 0.2, medium effect size 0.5 and a large effect size 0.8.

Results

A total of twenty-three volunteers with the following physical characteristics were included in this study: 21 male, 2 female, Age 21.7 ± 1.5 years, Height 178.2 ± 5.0 cm, Mass 75.8 ± 6.3 kg (mean ± standard deviation)

The results of this study show that running barefoot significantly reduces the forces affecting all the joints of the lower limb. A significant reduction in force affecting the knee (-5.29%, P=0.0017), hip (-4.32%, P=0.0004) and ankle (-5.23%, P=0.0003) was recorded as a result of running barefoot. All results are summarised in table 1.

	Barefoot	Shod	Mean difference	P Value	Effect size
Knee joint force (N/Kg)	23.96 ± 0.34	25.30 ± 0.25	-0.0529	P = 0.0017	0.5
Hip joint force (N/Kg)	23.51 ± 0.26	24.57 ± 0.28	-0.0432	P = 0.0004	0.4
Ankle joint force (N/Kg)	23.66 ± 0.25	24.97 ± 0.24	-0.0523	P = 0.0003	0.6

Discussion

The results above show that running barefoot reduces joint forces for hips, knees and ankles when compared to running with running shoes. There are several kinematic changes that occur as a result of running either barefoot or with running shoes that cause the difference in joint forces. One such change is the transition from a rear-foot strike to a mid-foot strike. This is as a result of increasing plantar-flexion running barefoot [61]. Another kinematic change that occurs is an decrease joint compliance during impact when running with shoes in comparison to barefoot running [62]. The increase in joint stiffness in the ankle and knee results in a greater decelerated mass during each footfall, thus contributing to a higher peak vertical force and joint forces in the lower limb [63]. As well as a transition from rear-foot strike to mid-foot strike and increased joint compliance when running barefoot, a decrease in stride length has been documented when running barefoot when compared to shod running [64, 65]. Increasing stride frequency reduced stride length plays a protective role in joint loading by reducing the flexion moment in joints as well as reducing posterior braking forces [62, 66].

A switch from traditional running shoes to barefoot running could benefit the runner in several ways. Firstly, it may reduce the chance of developing knee OA as well as reducing the symptoms of knee OA exacerbations by decreasing the force across the joint during each footfall. Runners who have abnormal loading across the joint could also benefit from making this transition as well as those who suffer from patella-femoral pain. Given joint loading also plays a large factor in the lifespan of a knee prosthesis, a change to barefoot running may also be beneficial to reduce the rate of wear and complications.

A significant reduction in the joint forces affecting the hips when running barefoot when compared to shod running means there is a potential for reducing the rate at which degenerative joint disease occurs. It can also reduce the symptoms in those who already suffer from it. Switching to barefoot running or using minimalist shoes may also be an effective way to reduce the symptoms of anterior hip pain as well as reduce the likelihood of stress fractures occurring especially in those of high-risk groups. The same applies to those who suffer from ankle injuries whether it be due to overuse of previous injuries.

Conclusion

A transition to barefoot running is a cheap and effective change that can be made to reduce the joint forces of the lower limbs. This change may reduce the likelihood of developing OA and might play a role in reducing symptoms of those who already suffer from it. It may also protect prosthetic joints and reduce the rate of overuse injuries by reducing joint forces whilst running.

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