Gait & Posture 32 (2010) 519–523

Contents lists available at ScienceDirect

Gait & Posture

journal homepage: www.elsevier.com/locate/gaitpost

A comparison of foot kinematics in people with normal- and flat-arched feet using the Oxford Foot Model

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ARTICLE INFO

Article history:
Received 24 May 2010
Received in revised form 14 July 2010
Accepted 18 July 2010

Keywords:
Flat-arched feet
Oxford Foot Model
Gait
Foot kinematics

ABSTRACT

Foot posture is thought to influence predisposition to overuse injuries of the lower limb. Although the mechanisms underlying this proposed relationship are unclear, it is thought that altered foot kinematics may play a role. Therefore, this study was designed to investigate differences in foot motion between people with normal- and flat-arched feet using the Oxford Foot Model (OFM). Foot posture in 19 participants was documented as normal-arched (n = 10) or flat-arched (n = 9) using a foot screening protocol incorporating measurements from weightbearing antero-posterior and lateral foot radiographs. Differences between the groups in triplanar motion of the tibia, rearfoot and forefoot during walking were evaluated using a three-dimensional motion analysis system incorporating a multi-segment foot model (OFM). Participants with flat-arched feet demonstrated greater peak forefoot plantar-flexion (-13.78 ± 5.68 vs -6.58 ± 3.78; $p = 0.004$), forefoot abduction (-12.98 ± 6.98 vs -1.88 ± 6.38; $p = 0.002$), and rearfoot internal rotation (10.68 ± 7.58 vs -0.28 ± 9.98; $p = 0.018$) compared to those with normal-arched feet. Additionally, participants with flat-arched feet demonstrated decreased peak forefoot adduction (-7.08 ± 9.28 vs 5.68 ± 7.38; $p = 0.004$) and a trend towards increased rearfoot eversion (-5.88 ± 4.48 vs -2.58 ± 2.68; $p = 0.06$). These findings support the notion that flat-arched feet have altered motion associated with greater pronation during gait; factors that may increase the risk of overuse injury.

1. Background

Human foot posture is generally characterised by the alignment of the foot skeleton and varies considerably between individuals. Variation from normal foot posture has long been thought to influence function of the foot and lower limb during gait, thereby predisposing to injury [1]. While the link between altered foot posture and injury is still unclear, several studies have demonstrated that foot posture influences lower limb muscle electromyographic (EMG) activity [2] and joint kinematics [3–5] during gait.

Various postural alignments of the foot have been theoretically associated with abnormal motion of the foot during gait. Flat-arched feet, in particular, have been associated with altered foot function, including prolonged calcaneal eversion, increased tibial internal rotation, increased forefoot abduction, reduced efficiency of gait and reduced shock absorption [6,7]. As a result, greater stress might be applied to those structures involved in controlling these movements during the stance phase of gait. Additionally, abnormal motion of the foot has also been proposed to lead to greater stress on more proximal structures such as the knee joint due to coupling between the foot and the knee [7].

Several kinematic studies have compared participants with flat or pronated feet to those with normal foot posture [3–5,8]. However, the results of these studies have been inconsistent due to variations in foot posture classification and biomechanical modelling methods used. Previous foot posture classification methods used include visual observation [3], goniometric evaluation [4], arch ratio measurement [5], and the combination of static and dynamic two-dimensional measurements of the medial longitudinal arch [8]. Although these studies have provided insight into the potential influence of foot posture on kinematics, less than optimal reliability for a range of clinical foot measurements [9] limits the methodological strength of these studies. Subsequently, there remains a need to assess the influence of flat-arched feet on kinematics using more reliable and objective foot posture classification methods.

Several multi-segment foot models have been proposed to evaluate the motion of the joints of the foot [10–15]. The Oxford Foot Model (OFM) is a multi-segment kinematic model that was

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doi:10.1016/j.gaitpost.2010.07.013

1) as demonstrated by the X-ray values (29.058 for the flat-arched group compared to 8.558 for the control group) which indicates that the talus and calcaneus were more internally rotated. Consequently, the greater rearfoot internal rotation accompanied by greater rearfoot eversion and forefoot abduction might increase the effort required to resupinate and invert the foot for propulsion.

An increase in rearfoot internal rotation might also be associated with an increase in internal tibial rotation, as the talus provides an anatomical link between the rearfoot and tibia. In the present study, although not significantly different, the flat-arched group demonstrated greater peak tibial internal rotation and the tibia was generally more internally rotated throughout stance phase. Due to the coupling motion between the subtalar joint and the leg [28], altered rearfoot motion may affect tibial motion which may consequently affect the function of proximal joints, such as the knee [7]. Increase in the backward tilt of the tibia at initial contact was also found in the flat-arched feet, which may be related to trends for a greater stride length exhibited by the flat-arched group.

In order to draw more definitive conclusions about foot function of people with flat-arched feet, greater consistency in methodological design is required. Currently there is substantial variability in kinematic modelling of the foot and the methods to classify foot posture which makes comparison between studies very difficult [29]. The OFM has been frequently used in previous studies evaluating a range of populations, which enable comparison between the reported data across studies and demonstrated good between-trial repeatability for the forefoot and rearfoot segments [15,16]. Additionally, the OFM is readily available to be used by researchers and clinicians as part of the Vicon software. It is important to note however, that the OFM models the foot as rigid rearfoot, forefoot and hallux segments, based on the assumption that the midfoot joints act to transmit motion between the forefoot and the rearfoot [11]. Kinematic foot models which allow for more detailed analysis of the midfoot [30] may be of additional benefit when assessing how foot function is influenced by variations in arch structure.

5. Conclusion

Differences in foot motion between adults with normal- and flat-arched feet classified radiographically were detected using the OFM. People with flat-arched feet demonstrated greater peak plantar-flexion and abduction of the forefoot and internal rotation of the rearfoot during late stance phase. Moreover, decreased peak forefoot adduction and a trend towards increased rearfoot eversion were also found for this group. These findings support the notion that flat-arched feet have altered motion associated with greater pronation during gait; factors that may increase the risk of overuse injury. Further research combining kinematic evaluation and electromyography is required to explain the impact of these differences and any clinical implications they may have on the lower extremity.

Acknowledgements

This study was funded by the Australian Podiatry Education and Research Foundation (APERF). The authors would like to thank Gabriele Paolini from Vicon Motion System Ltd. for his assistance and support of this project. H.B.M. is currently a National Health and Medical Research Council fellow (Clinical Career Development Award, ID: 433049).

Conflict of interest statement

All authors declare no conflict of interest related to this work.

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