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Foot posture and function have only minor effects on knee function during barefoot walking in healthy individuals

Andrew K. Buldt [a,b,*], Pazit Levinger [c], George S. Murley [a,b], Hylton B. Menz [b], Christopher J. Nester [d], Karl B. Landorf [a,b]

[a] Discipline of Podiatry, College of Science, Health and Engineering, La Trobe University, Bundoora, VIC 3086, Australia
[b] Lower Extremity and Gait Studies Program, College of Science, Health and Engineering, La Trobe University, Bundoora, VIC 3086, Australia
[c] Institute of Sport, Exercise & Active Living, College of Sport and Exercise Science, Victoria University, Footscray, VIC 8001, Australia
[d] School of Health Sciences, University of Salford, UK

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ABSTRACT

Background: Foot posture has been postulated as a risk factor for overuse injuries of the knee, however the link between foot posture and knee joint function is unclear. The aims of this study were to: (i) compare knee adduction moment and knee joint rotations between normal, planus and cavus foot posture groups, and (ii) to determine the relationship between rearfoot and midfoot joint rotations and knee adduction moment magnitude.
Methods: Rotation of the knee, rearfoot and midfoot was evaluated in 97 healthy adults that were classified as normal ($n = 37$), cavus ($n = 30$) or planus ($n = 30$) for the Foot Posture Index, Arch Index and normalised navicular height. One way analyses of variance were used to compare tri-planar knee joint rotation, knee adduction moment peak variables and knee adduction angular impulse between foot posture groups. Pearson's correlation coefficient was used to investigate the association between rearfoot and midfoot joint rotation during initial contact phase and the magnitude of 1st knee adduction moment peak.
Findings: The planus group displayed significantly greater external rotation angle at heel contact compared to both normal and cavus groups. The planus groups also displayed greater extension at heel contact and sagittal plane flexion range of motion during propulsion and early swing compared to the cavus group. Otherwise, differences between groups were characterised by small effect sizes. There was no association between rearfoot or midfoot joint rotations and knee adduction moment.
Interpretation: These findings suggest that in healthy individuals, foot posture and foot joint rotations do not substantially influence knee joint rotations and knee adduction moment while walking at a comfortable pace.

1. Introduction

The knee is the most common site of injury in the lower extremity (Jordaan and Schwellnus, 1994; Taunton et al., 2002). Variations from normal foot posture kinematics or plantar foot pressure have been postulated to be important risk factors for the development of knee disorders (Powers, 2003; Tiberio, 1987). For example, increased rearfoot eversion velocity and greater lateral centre-of-pressure position during propulsion have been associated with patello-femoral pain syndrome (Barton et al., 2011), and cross-sectional studies have found that planus (low arched) foot posture is associated with both patello-femoral pain (Barton et al., 2009) and medial compartment knee osteoarthritis (Levinger et al., 2010).

Despite these observations, the underlying mechanism linking foot posture and foot function to knee injury is unclear. Theoretically, abnormal rearfoot motion leads to altered transverse plane tibial rotation due to the coupling that occurs at the subtalar and ankle joints (Powers et al., 1999). The subsequent changes in transverse and frontal plane knee joint rotations that are assumed to occur (Eng and Pierrynowski, 1993; Kernozek and Greer, 1993) have been associated with patello-femoral pain (Salisch and Perman, 2007).

In addition, knee adduction moment (KAM) is a significant predictor of medial knee osteoarthritis progression (Miyazaki et al., 2002; Bennell et al., 2011) and may be sensitive to variations in coupling between the rearfoot and tibia. Our recent work identified several differences in joint rotations at the foot and ankle between cavus and planus foot types, including less rearfoot and midfoot abduction/adduction range of motion (peak to peak segmental excursions), and greater midfoot inversion/eversion range of motion in cavus feet (Buldt et al., 2015). Variations of this nature might be associated with differences in centre-of-pressure position under the foot (Hillstrom et al., 2013; Teyhen et al., 2009) or the relative stiffness/compliance of cavus and planus feet. Differences in foot stiffness may affect peak loads and loading rates that are transferred to the knee, perhaps elevating KAM and affecting knee joint rotations associated with patello-femoral pain.

* Corresponding author at: Discipline of Podiatry, College of Science, Health and Engineering, La Trobe University, Bundoora, VIC 3086, Australia.
E-mail address: a.buldt@latrobe.edu.au (A.K. Buldt).

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The available literature does not allow for definitive conclusions to be drawn about the effect of foot posture on knee joint function. A recent systematic review (Buldt et al., 2013) identified three main issues in the literature, including: inconsistencies in foot classification methods, variation in models to measure foot joint rotation, and only one article investigated structures proximal to the foot (Reischl et al., 1999).

With this in mind, the aims of this study were to: (i) investigate the differences in KAM and triplanar knee joint rotations in healthy individuals with normal, cavus (high medial longitudinal arch) or planus (low medial longitudinal arch) foot postures, and (ii) determine the relationship between rearfoot and midfoot joint rotations and the magnitude of KAM.

2. Methods

2.1. Participants

Ninety-seven adults, aged between 18 and 47 years were recruited primarily from the student and staff population of La Trobe University via a general call for volunteers. Participants were excluded if they reported any current lower limb musculoskeletal injury, biomechanical abnormality or neuromuscular disease that may affect the ability to walk. A screening protocol to determine foot posture of both feet was carried by using the 6-item Foot Posture Index (FPI) (Redmond et al., 2008), Arch Index (AI) (Cavanagh and Rodgers, 1987) and normalised navicular height (NNHt) (Cowan et al., 1993). Participants were allocated to one of three foot posture groups based on the screening protocol, and qualified for the normal group if static foot measurements were within one standard deviation of the mean of normative data for the FPI (Redmond et al., 2008), and either the AI or NNHt (Murley et al., 2009). Participants were assigned to the pes cavus or pes planus group if static foot measurements were greater or less than one standard deviation of the mean of normative data for the FPI and either the AI or NNHt. Boundaries for the inclusion into foot posture groups appear in a Supplementary file. If both feet of a participant satisfied the selection criteria, one foot was randomly selected for testing (using the random number generator function in Microsoft Excel®, Microsoft Corporation, Redmond, WA). Otherwise, if only one foot of a participant satisfied the selection criteria for a group, then this foot was tested. The normal foot posture group consisted of 37 participants (18 male, 19 female), the pes planus group consisted of 30 participants (15 male, 15 female) and pes cavus group consisted of 30 participants (13 male, 17 female).

Ethical approval was granted by the La Trobe University Human Ethics Committee (ID number: HEC11-097) and all participants signed informed consent.

2.2. Instrumentation

Foot and knee rotations and KAM were captured and analysed using a three-dimensional motion analysis system comprising ten Vicon cameras (eight MX2 and two MX40, Vicon motion system Ltd, Oxford, England) with a sampling frequency of 100 Hz. Ground reaction forces and gait cycle events were detected using two force plates (Kistler, type 9865B, Winterthur, Switzerland and AMTI, OR6, USA; 1000 Hz). The kinematic and force plate data was captured and synchronised using the Vicon Nexus software package.

2.3. Kinematic procedure

Motion of the rearfoot segment (calcaneus) was measured relative to the leg segment, thus representing ankle and subtalar joint rotation. The motion of the midfoot segment (navicular and cuboid) relative to the rearfoot segment represented talonavicular and calcaneocuboid joint rotations. 9 mm retro-reflective markers were placed on the foot in accordance with the 5 segment marker set described in Nester et al. (2007). Three-dimensional joint rotations of the knee and KAM were detected using a conventional lower limb model (Vicon Plug-in-Gait) (Kadaba et al., 1990). For calibration purposes, the height, weight, distance between anterior and superior iliac spines, anterior superior iliac spine to greater trochanter distance, knee width and ankle width for each participant were recorded. Retroreflective markers (12 mm) were placed over the following landmarks: midpoint of the sacrum between the posterior and superior iliac spines, bilaterally on anterior superior iliac spines, lateral aspect of the femur (using a 5 cm wand), lateral aspect of the tibia (using a 5 cm wand), lateral and medial malleoli, posterior heel, and dorsal midfoot over the 2nd metatarsal. Marker placement is illustrated in Fig. 1.

A relaxed standing calibration trial was captured using a knee alignment device (KAD, Motion Lab Systems Inc., LA, USA) in situ to calculate knee joint centre. The KAD is a spring loaded metal jig on which three equidistant markers are mounted. The KAD was placed on the knee, with the lateral pad of the KAD placed directly over the lateral intersection of the knee flexion axis, and the medial pad placed on the medial epicondyle. Following the static trial, the KAD was replaced with knee joint marker on the location of the lateral pad of the KAD. The medial malleoli markers were removed following the static trial.

Practice walking trials were undertaken until the participant was comfortable with the testing instrumentation and was walking at a consistent velocity. Participants were asked to walk at a comfortable walking pace along a flat 12 m walkway. Five acceptable walking trials (whereby the foot being investigated landed within the first force plate) were recorded. To avoid targeting, participants were not notified of the force plate, and the starting position of the participant was adjusted to allow for an acceptable trial. Walking speed was calculated using heel contact timing data, and trials that were within a range $\pm$0.1 m/s were processed. Gait trial events were determined using vertical ground reaction force data.

2.4. Data reduction

Prior to analysis of walking trials, the frontal plane knee joint angle for each participant was recorded during a static trial. For analysis of the walking data, each acceptable trial was reconstructed, and both the foot joint rotation model and Plug-in-Gait model were applied to identify markers using Vicon Nexus software. All variables of interest were normalised to the gait cycle, exported to Excel templates and the average of the five acceptable trials used for analysis. In relation to knee joint rotation (tibia relative to the femur), the following variables were extracted:

(i) Sagittal plane: joint angle at heel strike, peak flexion during load acceptance, peak extension during midstance and peak flexion during swing.
(ii) Frontal plane: joint angle at heel strike, peak adduction during load acceptance/midstance and peak abduction during propulsion/early swing.
(iii) Transverse plane: joint angle at heel strike, peak external rotation during midstance and peak internal rotation during propulsion/early swing.

Range of motion (RoM) refers to changes in knee joint angle over a period of time. For the sagittal, frontal and transverse planes respectively, RoM1 refers to change in knee joint angle between heel contact and peak flexion (load acceptance), peak adduction and peak external rotation. Likewise, RoM2 refers to change in knee joint angle between the previously mentioned peak angular measurements and peak extension, peak abduction and peak internal rotation. In the sagittal plane, RoM3 refers to change in knee joint angles between peak extension and peak flexion (swing). External KAM (normalised to percentage of body weight $\times$ height) was analysed and 1st and 2nd peak values