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Altered dynamic foot kinematics in people with medial knee osteoarthritis during walking: A cross-sectional study

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ABSTRACT

Background: Footwear and insoles are used to reduce knee load in people with medial knee osteoarthritis (OA), despite a limited understanding of foot function in this group. The aim of this study was to investigate the differences in foot kinematics between adults with and without medial knee OA during barefoot walking.
Methods: Foot kinematics were measured during walking in 30 adults; 15 with medial knee OA (mean age was 67.0 with a standard deviation (SD) of 8.9 years; height was 1.66 with SD of 0.13 m; body mass was 84.2 with SD of 15.8 kg; BMI was 30.7 with SD of 6.2 kg/m^2; K–L grade 3: 5, grade 4: 10) and 15 aged and gender matched control participants with 12 motion analysis cameras using the IOR multi-segment foot model. Motion of the knee joint, hindfoot, midfoot, forefoot and hallux were compared between groups using clustered linear regression.
Results: The knee OA group displayed reduced coronal plane range of motion of the midfoot (mean 3.8° vs. 5.4°, effect size = 1.1, $p = 0.023$), indicating reduced midfoot mobility. There was also a reduced sagittal plane range of motion at the hallux in the knee OA group compared to the control group (mean 29.6° vs. 36.3°, effect size = 1.2, $p = 0.008$). No statistically significant differences in hindfoot or forefoot motion were observed.
Conclusions: People with medial knee OA display altered foot function compared to healthy controls. As foot and knee function are related, it is possible that altered foot function in people with knee OA may influence the effects of footwear and insoles.

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1. Introduction

Knee osteoarthritis (OA) is one of the leading diseases responsible for physical disability in older adults [1]. Higher knee joint loading, estimated using surrogate measures such as the external moments, is implicated in both the development of knee pain and radiographic progression of medial knee OA in older adults [2,3]. Higher knee loading during walking is also related to greater levels of subchondral bone damage [4] and cartilage loss over 12 months in those with established disease [5]. Non-invasive interventions aimed at modifying knee load during walking are therefore an attractive option to slow disease progression in people with medial knee OA.

The foot is the link between the supporting surface and the lower extremity and plays an important role in the dynamic function of the lower limb. This includes the attenuation of impact forces and transmitting motion up the lower extremity during walking [6,7]. Due to the relationship between foot function, knee motion [8] and knee loading [9], speculation on the role of foot function in knee OA is growing [9,10]. Also, interventions acting at the foot–ground interface such as laterally wedged insoles are able to modify knee load by reducing the external knee adduction moment and have been investigated as treatments for knee OA [11]. Despite the importance of foot function in the dynamic function of the lower limb and investigation of the effectiveness of footwear and insoles as interventions for knee OA, foot function in people with knee OA has received little attention in the literature.

Only one previous study has investigated how foot kinematics are altered in people with knee OA and reported the presence of a more everted and less mobile hindfoot during walking [12]. The extent of changes to other aspects of foot function including that of the midfoot and hallux has not been investigated. Midfoot motion is critical for adaptation and stability of the foot during ground contact and is an important functional link between the hindfoot and forefoot [13]. Flexion at the hallux assists the foot to become a stiff structure during terminal stance via the windlass mechanism and allows smooth progression of the body during walking [14]. Without understanding the complexities of foot function in people with knee OA it is difficult

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to optimally design footwear and insole interventions that act at the foot–ground interface. Identifying the characteristics of foot function in people with knee OA may also inform strategies to prevent adverse symptoms such as foot pain when insole interventions are administered to reduce knee joint loading [15].

Therefore, the aim of this study was to compare foot kinematics during walking in people with and without medial knee OA. It was hypothesised that individuals with knee OA would exhibit kinematic differences indicative of a flatter and less mobile foot type, characterised by increased peak eversion of the hindfoot; increased forefoot abduction and reduced midfoot and hallux range of motions.

2. Materials and methods

2.1. Participants

Thirty adults (n = 30) participated in this cross-sectional study; 15 participants with medial knee OA and 15 asymptomatic controls. Participants with medial knee OA were recruited from the clinic population of the Department of Orthopaedics at The Queen Elizabeth Hospital in Adelaide, Australia. All fulfilled the American College of Rheumatology classification criteria for clinical and radiographic knee OA [16]. Participants were on the waiting list for knee arthroplasty surgery. Individuals with knee OA had to be aged over 50 years and have predominantly medial compartment disease (concomitant lateral tibiofemoral or patellofemoral OA were not excluded) with medial joint space narrowing greater than lateral [17] and a varus knee alignment (mechanical axis < 180°) [18]. Mechanical axis alignment (to determine eligibility) was determined from weight bearing short anteroposterior (A-P) knee radiographs (knees extended) using Image-J software [19] using a previously published regression equation [18]. This method avoids unnecessary and extra radiation exposure and has shown excellent correlation with mechanical axis alignment from full-limb radiographs (r = 0.88) [18]. Exclusion criteria were: a history of previous lower limb joint replacement, major orthopaedic surgery of the back or lower limbs (including high tibial osteotomy); corticosteroid injection to the knee within the past 6 months; systemic arthritic condition; cardiac complications; neurological or musculoskeletal condition affecting gait; and a cognitive disorder or inability to understand English.

Control group participants were recruited via advertisements placed in community newspapers and were matched by age and gender to individuals in the knee OA group. All control group participants reported no history of knee pain, injury or pathology and were free of any neurological or musculoskeletal conditions affecting gait. There was also no structural abnormality of the lower limbs screened by physical examination. This study was approved by The Queen Elizabeth Hospital and University of South Australia Human Research Ethics Committees. All participants provided written informed consent before participation.

2.2. Instrumentation

A 12 camera 3D motion analysis system (VICON MX-F20, Oxford, UK) was used to capture kinematic data at a sampling frequency of 100 Hz. The linear accuracy error of this system is below 1% [20]. Ground reaction forces were captured at 400 Hz with two floor-embedded force platforms to define the gait events of initial contact and toe-off (9281B, Kistler Instrument Corp, Switzerland). Walking speed was measured by two infrared photocells (Speed Light V2, Swift Performance Equipment, Queensland, Australia).

2.3. Gait analysis

Participants attended the biomechanics laboratory where kinematic and kinetic data were acquired during walking along a 15 m walkway. Retro-reflective surface markers (10 mm diameter) were placed on anatomical landmarks of the foot and leg [21] to allow measurement of hindfoot, midfoot, forefoot and hallux motion. Markers were placed on the following landmarks: medial and lateral malleoli, posterior calcaneus, sustentaculum tali, peroneal trochlea, navicular tuberosity, bases of the first, second and fifth metatarsals, head of the first, second and fifth metatarsals and the proximal phalanx of the hallux. Markers were also placed on the medial and lateral femoral epicondyles, greater trochanter, posterior and anterior superior iliac spines and rigid four-marker clusters on the thigh and shank (Fig. 1). We have previously demonstrated the reliability of foot kinematics using this method in older adults with coefficient of multiple correlations of 0.621–0.975 [22]. The position and orientation in space of each body segment were defined from a static trial with the participant standing in relaxed bipedal stance with both feet aligned with the long axis (y) of the laboratory [23]. Each participant completed walking trials at a comfortable, self-selected speed along the walkway. Three walking trials were retained where gait was unperturbed and both left and right limbs contacted the middle of separate force platforms.

2.4. Data processing

Data were exported to Visual3D for processing (v 4.0, C-motion Inc., USA). Marker trajectory data were filtered at 6 Hz [24]. Spatiotemporal gait data including walking speed, cadence, gait cycle time, stance and swing time (% gait cycle), stride and step length (% body height) were computed. A kinematic model was constructed based on that described by Leardini et al. [21] which included the following five segments: (1) shank, comprised of the tibia and fibula; (2) calcaneus; (3) midfoot, comprised of the navicular, cuneiforms and cuboid; (4) metatarsus, comprised of the metatarsals 1–5; and (5) hallux, comprised of the proximal and distal phalanges. The 3D joint angles were computed with an XYZ cardan sequence using the joint coordinate system [25] for the knee joint, hindfoot, midfoot, forefoot and hallux. All joints were considered to have six degrees of freedom, except the hallux (sagittal plane motion only). The selection of kinematic variables to be compared between groups was based on the known kinematic coupling relationships between motions of the hindfoot, midfoot, forefoot and hallux [26]. This included the peak angular motion and range of motion (ROM) of the knee, sagittal and coronal plane hindfoot and midfoot motions, transverse plane forefoot motion and sagittal plane hallux motion. Dynamic alignment of the limb in the coronal plane was calculated as the mean knee varus angle (tibia relative to the thigh) over the stance phase. Data were time normalised to 0 to 100% of the gait cycle.

2.5. Clinical and radiographic data

In addition to gait analysis data, clinical and radiographic data were used to describe the knee OA group. The Western Ontario & McMaster Universities Osteoarthritis Index (WOMAC) (5 point Likert-type format) was completed by participants in the knee OA group to assess the degree of self-reported knee pain and functional limitation [27]. Radiographic severity of tibiofemoral OA in the knee OA group was also assessed from weight-bearing X-rays using the Kellgren–Lawrence (K–L) grading scale [28,29].

2.6. Statistical analysis

Prior to statistical analysis, Shapiro–Wilks tests for normality and Levene's test for equality of variances were performed to determine if parametric or non-parametric tests were appropriate. Differences in physical characteristics (age, height, body mass and BMI) and spatiotemporal gait variables (walking speed, cadence, gait cycle time, stance and swing time, stride length and step length) between the knee OA and control groups were assessed with Student's t-tests or Mann–Whitney U tests, as appropriate. Differences in foot kinematics between the knee OA and control group were compared using clustered linear regression and adjusted for walking speed [30]. A Holm–Bonferroni

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