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Altering foot progression angle in people with medial knee osteoarthritis: the effects of varying toe-in and toe-out angles are mediated by pain and malalignment

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SUMMARY

Objectives: To evaluate if altering the foot progression angle (FPA) by varying magnitudes during gait alters the external knee adduction moment (KAM), knee flexion moment (KFM), knee extension moment (KEM) and/or symptoms in people with medial knee osteoarthritis (OA). Potential influence of pain and knee malalignment on load-modifying effects of FPA was investigated.
Design: Participants ($n = 22$) underwent 3-dimensional gait analysis to measure KAM peaks, KAM impulse, KFM and KEM peaks. Following natural gait, five altered FPA conditions were performed in random order (10° toe-in, 0° FPA, 10° toe-out, 20° toe-out and 30° toe-out). A projection screen displayed their real-time FPA. Pain/discomfort at knees and feet/ankles were evaluated for each condition. Linear mixed models were used for statistical analysis.
Results: Toe-in reduced the early stance peak KAM and KEM but increased the KAM impulse, late stance peak and KFM. Toe-out reduced the KAM impulse, late stance peak and KFM ($P < 0.001$) but increased the early stance peak KAM and KEM. All effects were greater in participants with more varus knees. Pain significantly mediated the effect of altered FPA on the KAM impulse and late stance peak. In more painful individuals, toe-in was predicted to reduce the KAM impulse and late stance peak, and increase them for toe-out gait. There were no immediate symptomatic changes.
Conclusions: Effects of altered FPA vary across all medial knee load parameters and it is difficult to determine an optimal direction of FPA change. Future studies should consider Western Ontario McMaster Universities OA Index (WOMAC) pain to judge the likely effects of altered FPA.

Introduction

Knee osteoarthritis (OA), which predominantly occurs in the medial tibiofemoral compartment[1,2], imposes a large personal and societal burden[3]. Structural deterioration occurs in many people[4] and excessive medial knee compartment load during walking is a major modifiable risk factor for OA progression[5,6]. Consequently, conservative knee load-modifying treatments have been recommended by leading OA and rheumatology associations[7,8]. Gait modification strategies have received increasing interest because they have demonstrated some ability to reduce surrogate measures of medial knee joint load[9]. One strategy is altering the foot progression angle (FPA), defined as the angle made between the line of walking progression and the long axis of the foot. Specifically, both toe-in gait (internally rotating the foot with respect to the line of walking progression) and toe-out gait (externally rotating the foot) have been reported to reduce different indices of medial knee load[9].

Measured non-invasively using three-dimensional gait analysis, the external knee adduction moment (KAM) is a valid and reliable indicator of the distribution of dynamic compressive load between the medial and lateral tibiofemoral compartments[10,11]. The KAM is most commonly quantified by evaluating the peaks observed during early stance (approximately 25%) and late stance (approximately 75%), and by the adduction angular impulse (area under the KAM-time curve). Researchers investigating biomechanical interventions typically target a reduction in the early stance peak KAM

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and/or KAM impulse because these parameters have been associated with increased risk of OA progression[5,6]. The clinical significance of a larger late stance peak KAM currently remains unknown.

Modifying gait to either a toe-out or toe-in position has been proposed as a conservative biomechanical intervention for people with medial knee OA[9,12], and larger toe-out angles have been shown to protect against OA progression[13]. According to a recent systematic review of gait modification strategies in healthy individuals and those with knee OA[9], conscious alterations in toe-out angle exhibited inconsistent non-significant effects on the early stance peak KAM (55.2% reduction to 12.7% increase) but consistent significant reductions in the late stance peak (22.9–92.6%). Reported effects of toe-in gait demonstrate inconsistency particularly in the early stance peak KAM, with 13% reductions identified in two studies[12,14] and a mean 20.0% increase demonstrated in another study[15]. To date, effect of altered FPA on the KAM impulse has only been evaluated in a single healthy individual and needs to be confirmed in larger samples[16]. The variability in study findings may arise from methodological differences amongst studies, including variable magnitudes of FPA change, FPA measurement and participant characteristics. Accordingly, a more standardised FPA change in people with medial knee OA should be investigated. Implementation of specific FPA magnitudes may be achieved using real-time visual biofeedback, which was proven effective for other gait interventions in knee OA[17,18]. Additionally, efficacy of some interventions designed to alter the KAM have shown to be mediated by participant-related factors, including pain severity and malalignment[17–20], suggesting that these should be investigated with altered FPA.

Toe-out is postulated to modify knee load by laterally displacing the centre of pressure location and hence the ground reaction force (GRF), resulting in a reduced frontal plane GRF lever arm at the knee and thus a lower KAM[21]. Toe-in gait is postulated to modify the early stance peak KAM by either medially shifting the knee joint centre and/or externally rotating the heel, thereby laterally shifting the centre of pressure[12]. A change in KAM in early stance with altered FPA may be accompanied by an increase in the external flexion moment, possibly transferring joint load from being predominantly located in the medial compartment to being more evenly distributed between the two compartments[21]. Accordingly, a reduction in the KAM may be accompanied by an increase in the knee flexion moment (KFM) during early stance or knee extension moment (KEM) during the late stance, potentially counteracting the positive effects of a reduced KAM[22].

The primary aim of this study was to evaluate the immediate effect of varying FPA magnitudes on characteristics of the KAM in people with medial knee OA. The secondary aim was to investigate the effect of altered FPA on the peak KFM. Thirdly, we aimed to determine if participant characteristics, including mechanical knee alignment and pain severity, influence the load modifying ability of altered FPA gait. Finally, the immediate symptomatic effect of altered FPA gait at the knee and ankle joints was evaluated.

Methods

Participants

Individuals with medial tibiofemoral knee OA were recruited *via* community advertisements. A priori repeated measures analysis of variance (ANOVA) sample size calculation was conducted based on previous study findings of toe-out gait on the late stance peak KAM (effect size = 1.96)[23]. As several magnitudes of FPA were to be implemented in this study, analysis was conducted on a more conservative estimated effect size of 0.30 (power: 90%; alpha: 0.05) requiring 22 participants. Participants were included if they fulfilled the American College of Rheumatology clinical and radiographic criteria for knee OA[24] and reported average knee pain on most days of the previous month >3 on an 11-point numeric rating scale (NRS). Using a radiographic atlas[25], only participants with predominantly medial tibiofemoral OA were included (defined as greater medial osteophyte presence, or in cases of equal osteophytes in both compartments, greater joint space narrowing in the medial compartment was required). Exclusion criteria were: knee arthroscopy or injection in the previous 6 months, history of knee or hip surgery, neurological conditions affecting ambulation, gait aid use, other rheumatologic conditions, spinal pain with lower limb symptoms, body mass index (BMI) > 35 kg/m^2 and anatomic valgus knee malalignment (≥5°) on radiographs[26]. The most symptomatic side was considered the study limb for participants with bilaterally eligible knees. The study was approved by the Institutional Ethics Committee and all participants provided written informed consent.

Measurement of kinematics and kinetics

Participants underwent three-dimensional gait analysis under six conditions in a single session. Firstly, the natural gait condition was recorded followed by the FPA gait modification conditions, implemented under five pre-determined FPA magnitudes in toe-in and toe-out directions. Walking in their own comfortable walking shoes, participants performed ‘natural’ gait at self-selected speed along the 8 m laboratory walkway for five successful force plate contact trials. During subsequent conditions when altered FPA gait was implemented, speed was matched to the natural gait trials (±5% of mean) by use of photoelectric timing gates placed 4 m apart.

A Vicon motion analysis system captured kinematics using eight MX cameras recording at 120 Hz (Vicon, Oxford, UK), which was integrated with three Advanced Mechanical Technology, Inc. (AMTI, Watertown, MA) force plates in the laboratory floor to collect GRF data at 1200 Hz. Standard Plug-In-Gait lower body marker set was used, containing 20 retro-reflective markers adhered to anatomical landmarks[27]. Medial knee and ankle markers were included during an initial static standing trial to determine positioning of knee and ankle joint centres using a custom-written BodyBuilder program (Vicon, Oxford, UK).

The FPA was calculated as the angle between the foot vector (line joining the ankle joint centre and the marker over the second metatarsal head) and the forward laboratory axis, projected into the laboratory's transverse plane[14,28]. The FPA was calculated during foot flat (average FPA between 15% and 50% of stance). External knee moments were calculated about an orthogonal axis system in the shank segment using the Vicon Plug-In-Gait linked-segment model (v2) in Vicon Nexus software[29] using Newton-Euler inverse dynamics. The following KAM parameters were chosen to indicate medial tibiofemoral load: early and late stance peaks (the former being the maximum in the first half of stance; the latter being the maximum value after the highest positive gradient during the second half of stance), and impulse. The maximum KFM (first half of stance) and KEM (second half of stance) were measured due to their possible association with changes in medial knee load[22]. External moments were normalised to body weight and height (BW × HT%). Because of their potential to influence knee load, the following variables were evaluated: speed, step width and stride length[9]. Step width was defined as the medio-lateral distance between ankle joint centres at each foot strike[30].

Walking with altered FPA

A research physiotherapist (MS) trained participants to walk with altered FPA. Five FPA conditions were implemented, with