

Subject-specific Effect of Foot Progression Angle On Knee Moment During Stepping On An Elliptical Trainer

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INTRODUCTION: Medial knee osteoarthritis (KOA) is a progressive joint disease with a rare chance of cartilage repair. Therefore, slowing the rate of cartilage loss is the best strategy for dealing with the condition. Peak knee adduction moment (pKAM) is an indicator of medial knee loading and a surrogate measure of the presence and progression of cartilage damage in the medial compartment of the knee (1). Previous studies have shown that gait modification strategies, including changes in the foot progression angle (FPA), can reduce pKAM (2,3). However, due to subject-to-subject variability in response to these interventions, these studies were limited in detecting the accurate FPA that induces an optimal reduction in pKAM for each subject. Therefore, the objective of this pilot study was to explore the subject specific FPA for reducing pKAM in healthy adults using a custom robotic elliptical trainer that applies various controlled slow perturbations in the transverse plane to the knee while the subject makes steps without noticing the perturbations. In addition, we explored the effect of different stepping conditions on the peak knee flexion moment (pKFM) and KAM impulse, other biomechanical measures that may affect the medial knee loading. It should be noted that elliptical stepping produces less impact on the knee than overground walking.

METHODS: This study was approved by the local institution's IRB. A customized elliptical trainer with a six-degree-of-freedom (6-DOF) goniometer and multi-DOF controlled stepping was used to determine knee moments during stepping. A 6-axis force/torque sensor was mounted underneath each footplate to measure "footplate reaction" forces and moments. The footplates of this customized elliptical trainer were modified and can rotate in the transverse plane. A total of 16 healthy subjects with no history of lower limb injury participated in this pilot study. A typical stepping session was as follows: while the footplates were fixed at a 10° external rotation (toe-out) subjects started stepping. After finishing at least 20 cycles of stepping and while subjects were still stepping, the footplates started rotating 10° inward with a slow velocity until it reached the neutral position. After completing another 20 cycles of stepping, the footplates rotated inward further until it reached 10° internal rotation (toe-in). All these modifications were made without the subjects' knowledge. These footplate perturbations were done to both footplates simultaneously. However, measurements of the knee moment were done in real-time only on the right knee. The slope of a linear fit for changes in the pKAM during footplate transition was calculated. Also, the magnitude of pKAM, pKFM, and KAM impulse was measured in each toe-in/toe-out position. Statistical analysis - The last ten stepping cycles in each condition were chosen for analysis. One-sample t-test was used to compare the slope of the linear fit with a zero-slope line. A repeated-measures analysis of variance (ANOVA) was utilized to investigate differences in pKAM, pKFM, and KAM impulse between different conditions for each subject. The significance level was set at 0.05.

RESULTS SECTION: The slope of changes in the pKAM during footplate transition was significantly different from a zero-slope line ($P < 0.05$), with a negative slope towards the toe-in position (Figure 1). Thirteen subjects (81.3%) reduced their pKAM and KAM impulse with toe-in and 3 subjects (18.7%) reduced their pKAM and KAM impulse with toe-out. For the subjects that showed pKAM reduction with toe-in, significant differences in the pKAM and KAM impulse magnitude during different footplate positions were found ($P < 0.05$, Figure 2). The pKAM values (mean±std) observed for the neutral, toe-out, and toe-in foot positioning were 1.19 ± 0.79 , 1.47 ± 0.78 , and 0.92 ± 0.72 , respectively. The KAM impulse values observed for the neutral, toe-out, and toe-in foot positioning were 0.18 ± 0.33 , 0.25 ± 0.31 , and 0.07 ± 0.33 , respectively. However, repeated-measures ANOVA did not show a significant main effect of condition in changes in the pKFM for different footplate positions ($P > 0.05$). The pKFM values observed for the neutral, toe-out, and toe-in foot positioning were 4.66 ± 3.15 , 4.89 ± 3.22 , and 4.52 ± 3.42 , respectively.

DISCUSSION: In this pilot study, we evaluated whether stepping with modified foot positioning reduces pKAM during stepping on our customized elliptical trainer. It has been reported that toe-in or toe-out gait patterns alleviate pKAM in healthy individuals and individuals with KOA during overground walking in a non-uniform pattern (3). Similarly, the transition of our elliptical footplates in transverse plane (from toe-out to toe-in position) reduction in the pKAM in a non-uniform pattern. Therefore, these subject-specific modifications in foot positionings are a useful approach for identifying optimal strategies in reducing pKAM during stepping, with the subjects walking without noticing the foot positioning changes. This is an advantage over identifying the strategies during overground walking, during which the subjects make the foot positioning changes voluntarily and thus may change the walking and knee joint loading patterns. Additionally, it is suggested that optimal KOA training should not increase the pKFM to reduce the chance of an increase in the medial knee loading as a result of an increase in the pKFM. Accordingly, our stepping modifications did not demonstrate a significant increase in the magnitude of the pKFM.

SIGNIFICANCE/CLINICAL RELEVANCE: The customized elliptical trainer and subject-specific intervention protocol can potentially be used as therapeutic and research tool to train patients with KOA for improving their lower limb function and reducing the progression of the disease.

REFERENCES:

- 1) Gupta, Dhruv, Cyril John Donnelly, and Jeffrey A. Reinbolt. "Finding Emergent Gait Patterns May Reduce Progression of Knee Osteoarthritis in a Clinically Relevant Time Frame." *Life* 12.7 (2022): 1050.
- 2) Richards, R., et al. "Gait retraining using real-time feedback in patients with medial knee osteoarthritis: Feasibility and effects of a six-week gait training program." *The Knee* 25.5 (2018): 814-824.
- 3) Uhlrich, Scott D., et al. "Personalization improves the biomechanical efficacy of foot progression angle modifications in individuals with medial knee osteoarthritis." *Journal of biomechanics* 144 (2022): 111312.

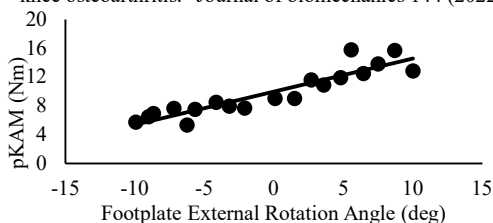


Figure 1: pKAM reduction during the slow transition of the footplate for a representative subject

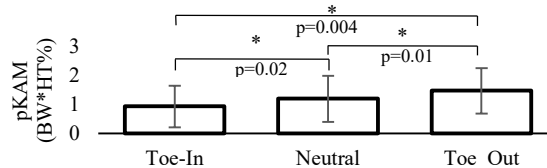


Figure 2: pKAM during stepping with toe-in, neutral, and toe-out position in the subjects with smaller pKAM during toe-in condition.