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Brief report

Biomechanical mechanisms of toe-out gait performance in people with and without knee osteoarthritis

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ABSTRACT

Background: Toe-out gait modification (increased toe-out angle) has been proposed to decrease medial knee joint loading and slow disease progression in patients with knee osteoarthritis. However, the manner in which toe-out gait modification is performed is unknown. The purposes of this study were to assess the biomechanical strategies of achieving a toe-out gait, and to compare these strategies between older individuals with knee osteoarthritis and young, healthy individuals.

Methods: Lower limb biomechanics were evaluated for ten patients with knee osteoarthritis and for ten young, healthy individuals during treadmill walking. Two trials, consisting of natural gait followed by a ten degree increase in toe-out angle were performed. Transverse plane rotations of the thigh, shank and foot segments were calculated and compared between walking conditions and groups.

Findings: External rotation changes with toe-out were significantly different between the thigh and shank, and thigh and foot ($P < 0.001$), but not between the shank and foot ($P = 0.48$). External rotation at each segment was not significantly different ($P > 0.05$) between groups, with the exception of thigh rotation during natural gait ($P = 0.04$).

Interpretation: Current findings suggest that increased toe-out gait is primarily achieved through rotation of the shank and foot, with less contribution from the thigh, and those individuals with knee osteoarthritis perform a toe-out gait biomechanically similar to young, healthy individuals. Gait modification programs should address individuals' limitations, such as joint stiffness, to ensure functional performance of toe-out gait modification.

1. Introduction

The role of high joint loading in the pathogenesis of knee osteoarthritis (KOA) is well recognized. In particular, high knee joint loading, as quantified by the external knee adduction moment (KAM), has been shown to be related to KOA severity as well as rate of KOA progression (Hurwitz et al., 2002; Miyazaki et al., 2002). Accordingly, recent research has focused on treatment approaches to combat high knee joint loading in people with KOA. Gait modification, for example walking with an increased toe-out angle, has been proposed as a conservative strategy to achieve this (Simic et al., 2013; Teichtahl et al., 2006). Indeed, a recent systematic review has shown consistent reductions in the KAM with gait modifications such as lateral trunk lean and toe-out gait modification (Simic et al., 2011).

A toe-out gait modification involves increased external rotation of the foot beyond the individual's typical self-selected stance phase orientation. Walking with intentionally increased toe-out has been shown to decrease the magnitude of the late stance peak KAM during walking within the same testing session (Guo et al., 2007; Lin et al., 2001; Lynn et al., 2008). Additionally, individuals who naturally self-select a toe-out gait have been shown to have reduced risk of disease progression in a longitudinal cohort study (Chang et al., 2007), indicating the importance of toe-out angle in the study of KOA. However, despite the evidence illustrating the beneficial biomechanical effects of a toe-out gait on the knee joint, the manner in which individuals with KOA can achieve this gait remains unclear. Performance of a toe-out gait can theoretically result from any combination of increased external rotation of the thigh, shank, or foot segments.

Understanding how individuals perform an increased toe-out gait would allow therapists to address specific barriers to achievement of this particular gait modification such as joint stiffness. Further, given that other age- and disease-related factors may play a role in the ability or inability to increase toe-out by a clinically-relevant amount (Chang et al., 2007) comparing strategies of achieving toe-out gait between those with and without KOA will also help inform clinical delivery of this gait modification. As a result, the purpose of the present study was to explore the biomechanics of toe-out gait, as well as the differences between older individuals with KOA and young, healthy individuals without KOA.

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2. Methods

2.1. Participants

Individuals with KOA and young, healthy individuals were recruited for this study from the university and surrounding community using advertisements and a laboratory database of previous study participants. The presence of medial compartment osteoarthritis was determined for the KOA group using the Kellgren and Lawrence classification scale (grade 2 or higher) (Kellgren and Lawrence, 1957) based on standing, semi-flexed posteroanterior knee radiographs. Individuals were excluded if they had a history of lower limb joint replacement, knee surgery or injections in the past six months, rheumatoid arthritis, self-reported osteoarthritis in other lower limb joints, or were unable to walk on a treadmill unaided for 15 min. This research was approved by the university's clinical research ethics board and all participants gave informed consent prior to testing.

2.2. Procedures

All participants attended one testing session. Twenty-two passive reflective markers were placed on each participant according to a modified Helen Hayes marker set (Kadaba et al., 1990) and kinematic data were collected using ten high-speed motion capture cameras (Motion Analysis Corporation, Santa Rosa, USA) sampling at 120 Hz. Participants first performed a trial of natural walking on a treadmill at a self-selected speed lasting five minutes, and data were collected during the final 15 s of walking. Data were immediately processed using commercially-available software to determine each individual's self-selected toe-out angle during walking — defined as the mean value during foot-flat from ten consecutive gait cycles. Foot-flat was determined as the period between cessation of vertical displacement of the toe marker and initiation of movement of the heel marker. Participants then stood on a protractor device (Fig. 1) to calibrate the calculated real-time toe-out angle with a known amount of toe-out, and were instructed to increase their toe-out angle (most symptomatic limb for KOA group; randomly chosen for young group) to a target angle equal to ten degrees greater than that observed during natural gait. A green line depicting this target toe-out angle was then placed on the biofeedback video screen positioned directly in front of the participant (Fig. 2). Participants then performed a second treadmill walking trial at their self-selected walking speed where they were instructed to match their real-time toe-out angle – depicted as a vertically scrolling black line – to the target angle during each foot-flat phase of the study limb. This trial also lasted five minutes and kinematic data from the last 15 s were collected.

Using commercially-available software (Orthotrak; Motion Analysis Corporation, Santa Rosa, USA) kinematics were calculated by using a series of ordered rotations whereby the local coordinate system of the distal segment was rotated about the local coordinate system of the proximal segment. External rotation at the thigh, shank and foot was calculated during foot-flat of the study limb over the first ten consecutive gait cycles of each data sample, and mean peak values were calculated for each segment and walking condition. Transverse rotation of lower limb segments has been previously validated in the adult population, demonstrating coefficients of multiple correlation for the hip, knee and foot between 0.4 and 0.6 (Kadaba et al., 1989), with more recent studies reporting values ranging from 0.6 to 0.9 (Mcginley et al., 2009).

2.3. Statistical analysis

Performance of toe-out gait was examined using paired t-tests by comparing differences in peak external rotation angle at the thigh, shank, and foot for all individuals between walking conditions and between segments (thigh, shank, foot). To examine between-group differences, changes in peak external rotation at each lower limb segment with toe-out walking were examined using independent samples t-tests. All statistical analyses were conducted using the Statistical Package for the Social Sciences (SPSS; ver. 20; IBM Corporation, Armonk, USA).

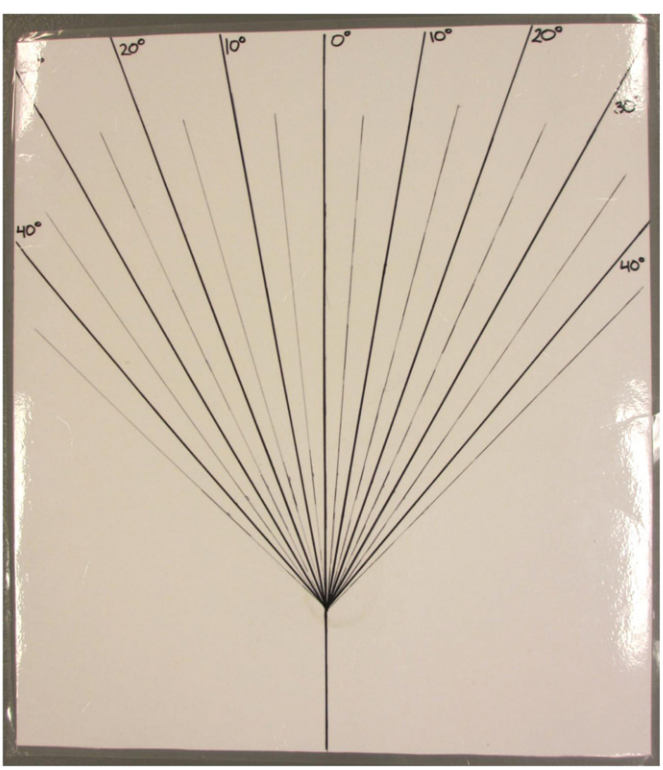

Fig. 1. Protractor device used to accurately guide participants' foot to the target angle ten degrees beyond that observed during natural gait.

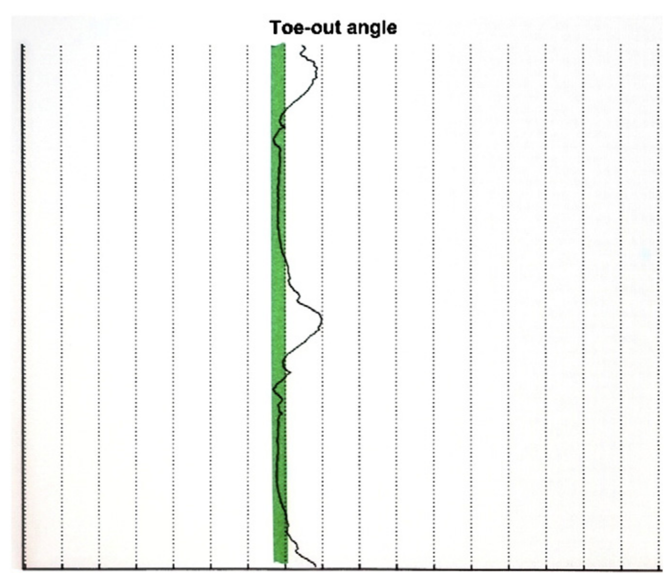

Fig. 2. Biofeedback provided during toe-out gait trial depicting real-time study limb toe-out angle (black scrolling line) and target toe-out angle (green static line). Feedback was provided on-screen directly in front of the participant and calibrated so that the target angle calculated using the software matched the angle obtained during the standing trial on the protractor device.