Clinical Biomechanics 34 (2016) 30–37

Contents lists available at ScienceDirect

Clinical Biomechanics

journal homepage: www.elsevier.com/locate/clinbiomech

Lecture

# Ipsilateral and contralateral foot pronation affect lower limb and trunk biomechanics of individuals with knee osteoarthritis during gait

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## ARTICLE INFO

*Article history:*
Received 4 December 2015
Accepted 15 March 2016

*Keywords:*
Knee osteoarthritis
Gait
Foot pronation
Lateral wedges
Biomechanics

## ABSTRACT

*Background:* Lateral wedges have been suggested for the treatment of individuals with knee osteoarthritis, but it may have undesirable effects on the biomechanics of gait through increased foot pronation. This study investigated the effects of increased unilateral foot pronation on the biomechanics of individuals with knee osteoarthritis during gait.

*Methods:* Biomechanical data of twenty individuals with knee osteoarthritis were collected while they walked in three conditions: i) flat sandals; ii) wedged sandal on the knee osteoarthritis limb and flat sandal on the healthy limb; and iii) flat sandal on the osteoarthritis and wedged sandal on the healthy limb. Knee pain and comfort were evaluated. Principal Component Analysis followed by ANOVA was implemented to identify differences between conditions.

*Findings:* The wedged sandal on the osteoarthritis limb increased rearfoot eversion ($P < 0.001$; ES $= 0.79$); increased shank rotation range of motion ($P < 0.001$; ES $= 0.70$); reduced knee internal rotation moment ($P < 0.001$; ES $= 0.83$); reduced hip internal rotation moment ($P = 0.001$; ES $= 0.66$); increased ipsilateral trunk lean ($P = 0.031$; ES $= 0.47$); and increased trunk rotation range of motion ($P = 0.001$; ES $= 0.69$). Walking with the wedged sandal on the healthy limb increased hip ($P = 0.003$; ES $= 0.61$) and knee ($P = 0.002$; ES $= 0.63$) adduction moments. Individuals reported greater comfort walking with the flat sandals ($P = 0.004$; ES $= 0.55$).

*Interpretation:* Increased unilateral foot pronation of the knee osteoarthritis and healthy limbs causes lower limb and trunk mechanical changes that may overload the knee and the lower back, such as increased knee adduction moment, shank rotation and trunk lateral lean. Foot motion of both lower limbs should be evaluated and care must be taken when suggesting lateral wedges for individuals with knee osteoarthritis.

## 1. Introduction

Osteoarthritis (OA) is a progressive disease that causes significant disability and loss of function (McKean et al., 2007), with the lifetime risk of developing knee OA estimated to be 45% (Murphy et al., 2008). The knee external adduction moment during gait predicts knee OA progression (Miyazaki et al., 2002), which led researchers to investigate the effects of different interventions to reduce the knee adduction moment and hopefully slow down knee OA progression (Radzimski et al., 2012). In this context, although walking with lateral wedges reduces the knee adduction moment (Kerrigan et al., 2002) and pain (Keating et al., 1993; Wolfe and Brueckmann, 1991), longitudinal studies failed to demonstrate its effects on knee OA progression (Baker et al., 2007; Barrios et al., 2009; Bennell et al., 2011; Pham et al., 2004), and a recent Cochrane review concluded that evidence is lacking to suggest that a lateral wedge is more effective than no treatment (Duivenvoorden et al., 2015). In addition, Jones et al. (2014) demonstrated that the change in the knee adduction moment using lateral wedges was not associated with the direction of knee pain change, which might be related to the limitations of the knee adduction moment as a measure of knee loading (Winby et al., 2013). Alternatively, it is possible that, as described in healthy young individuals (Resende et al., 2015), lateral wedges could also increase foot pronation and shank internal rotation in knee OA individuals, which would contribute to the knee cartilage thinning (Andriacchi et al., 2006) and consequently counterbalance the positive effects of lateral wedges in reducing knee adduction moment.

Independently of using lateral wedges, individuals with knee OA have increased foot pronation (Levinger et al., 2012), which may be a compensatory response to allow the medial part of the foot to contact

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http://dx.doi.org/10.1016/j.clinbiomech.2016.03.005
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the ground in the presence of knee (Riegger-Krugh and Keysor, 1996) or forefoot (Lufler et al., 2012) varus malalignment. Therefore, increased foot pronation may not be symmetric between the knee OA limb and the contralateral limb. In healthy young individuals, unilateral foot pronation increases the knee adduction moment of the contralateral side (Resende et al., 2015), probably through increases in pelvic ipsilateral drop and/or ipsilateral trunk lean (Takacs and Hunt, 2012). If this relationship holds true for knee OA individuals, it should be taken in account when implementing interventions such as lateral wedges.

This study investigated the effects of increased ipsilateral and contralateral foot pronation on the knee OA limb and trunk biomechanics of individuals with knee OA during the stance phase of gait. We hypothesized that increased foot pronation of the knee OA limb will increase ipsilateral lower limb internal rotation angles and ipsilateral pelvic drop and trunk lean and reduce internal rotation moments during the stance phase of gait. In addition, increased foot pronation of the healthy limb will increase knee and hip adduction angles and moments of the knee OA limb.

## 2. Methods

### 2.1. Participants

Sample size was determined as the number of participants necessary to reach a statistical power of 80% with a significance level of 0.05, considering an expected moderate effect size ($d = 0.5$). Twenty participants (13 females) diagnosed with medial compartment knee OA of one ($N = 9$) or both ($N = 11$) knees by an orthopedic surgeon, with an average age, mass and height of 67 years (SD 8.3), 87.9 kg (SD 18) and 170 cm (SD 8), respectively, participated in the study. In order to prevent the effects of different severity levels of OA on the results, only participants with knee OA classified as moderate (grade 3) were included in the study. The radiographic classification was based on the Kellgren and Lawrence criteria (Kellgren and Lawrence, 1957). The inclusion criteria were no history of falls, no surgery or injury to either lower limb in the past six months, no history of stroke or any other form of arthritis, neuromuscular or cardiovascular disorders, being able to ambulate without assistive device and being able to walk a city block and being able to climb stairs in a reciprocal fashion. The exclusion criterion was the report of pain over 80 mm on a 100 mm visual analog scale (VAS) or walking unsteadily during data collection. Each participant signed a consent form approved by the university's Ethical Research Committee.

### 2.2. Procedures

The participants answered the Western Ontario and McMaster Universities Arthritis Index (WOMAC) (Bellamy et al., 1988) and the Lower Extremity Activity Scale (LEAS) (Saleh et al., 2005). The scores of the WOMAC subscales were calculated by a 5-point Likert scale, where lower scores indicate better condition in the domain. Then, the heights and masses of the participants were measured. Subsequently, gait data were recorded at 200 Hz using a 12-camera motion capture system (Oqus 4, Qualisys, Gothenburg, Sweden) and six force platforms (Custom BP model, AMTI, Massachusetts, USA). The force platforms registered ground reaction force data at a frequency of 1000 Hz, which was subsequently resampled at 200 Hz.

Anatomical and clusters of tracking markers were used to determine the coordinates of the trunk, pelvis, thigh, shank and feet (Cappozzo et al., 1995) using data obtained with the participant in a relaxed standing position (static trials) (Fig. 1a and b). Specifically for the rearfoot kinematics, it was used a segmented foot model (Wright et al., 2011). Gait data were collected in three different conditions: 1) control condition: the participant walked wearing flat sandals on both limbs (Fig. 1c); 2) ipsilateral side inclined condition: the participant walked wearing a sandal with a 10° lateral wedge on the knee OA limb and a flat sandal on the contralateral limb (hereafter healthy limb) (Fig. 1d); and 3) contralateral side inclined condition: the participant walked wearing a flat sandal on the knee OA limb and a sandal with a 10° lateral wedge on the healthy limb (Fig. 1e). The magnitude of 10° was chosen based on the findings of a previous study demonstrating that elderly people have mean forefoot varus of 9.9° (Gross et al., 2007). Only the knee OA limb data were analyzed for the three conditions. In individuals with bilateral knee OA, the limb with the highest score in the WOMAC pain subscale (i.e., worse pain) was analyzed and the contralateral limb was assigned “healthy” and referred as the healthy limb. The wedged sandals were flat at the rearfoot and 10° laterally wedged (medially depressed) under the forefoot, which has been shown to affect the duration and amplitude of subtalar pronation during walking (Monaghan et al., 2013). Two sizes of sandals for each condition, with the specific dimensions described in a previous study (Resende et al., 2015), were used in this study. The sandals' bases were made of high-density ethylene vinyl acetate and were attached to the participants' feet with Velcro. The participants walked at their self-selected speed, performing five trials per condition along a 15-m distance. The order of data collection was randomized. Before data collection the participants walked for approximately 1 min to familiarize with each set of sandals.

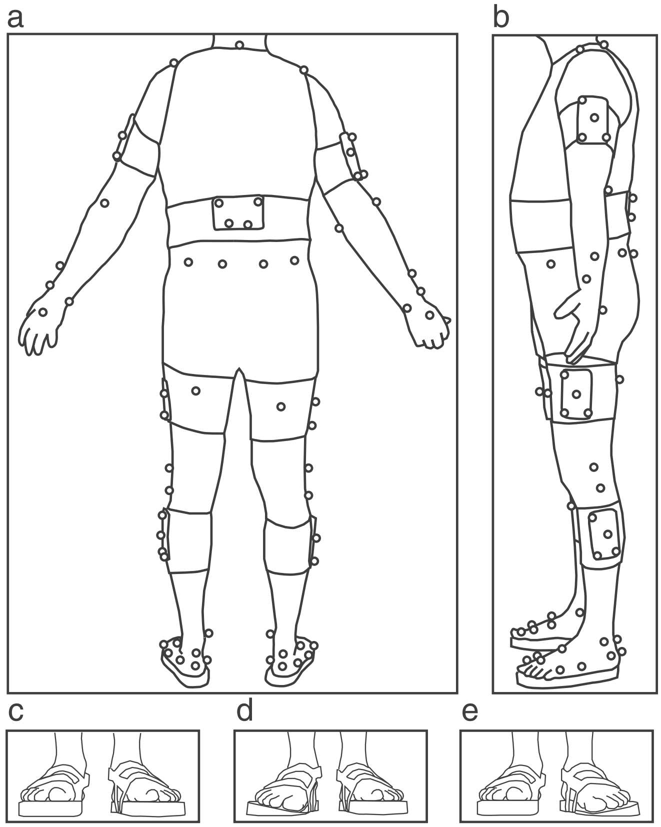

**Fig. 1.** Marker placement, posterior (a) and lateral (b) view, and the 3 different conditions considering a participant with knee osteoarthritis on the right limb: control (c), ipsilateral side inclined (d) and contralateral side inclined (e).

Between data collections in each condition, the participants rested for 2 min. At this point, the participants completed the VAS to rate the knee pain and the comfort level of walking with the previous pair of sandals. The pain VAS ranged from “no pain” at one end to “worst pain imaginable” at the other end (Wessel, 1995). The comfort VAS was also represented by a 100 mm horizontal line but anchored with the terms “not comfortable at all” to “most comfortable imaginable” (Wessel, 1995). The outcome measure for both VAS was the distance in mm of the participant's mark on the line.