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Modified walking shoes for knee osteoarthritis: Mechanisms for reductions in the knee adduction moment

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ABSTRACT

The objective of this study was to examine mechanisms underpinning the reduction in knee adduction moment (KAM) and changes in frontal plane knee-ground reaction force (GRF) lever arm with a modified shoe that incorporates both a variable–stiffness sole and lateral wedging. Thirty individuals with symptomatic knee osteoarthritis (OA) and 30 overweight asymptomatic individuals underwent gait analyses wearing modified and standard shoes. In both groups, there was a decrease in the lever arm ($p < 0.001$), and a lateral shift in the center of pressure (COP) offset ($p \le 0.001$). There was no change in frontal plane or medial–lateral GRF magnitudes, lateral trunk lean or stance duration in either group. There was no significant change in the frontal plane hip–knee–ankle angle in the OA group but a significant decrease in the overweight group ($p = 0.003$). In both groups, changes in lever arm and frontal plane GRF magnitude predicted change in peak KAM ($p < 0.01$), but only change in lever arm predicted change in KAM impulse ($p < 0.001$). In the OA group, changes in COP offset and medial–lateral GRF magnitude predicted change in lever arm ($p < 0.05$), whereas changes in trunk lean and hip–knee–ankle angle predicted change in lever arm in the overweight group ($p = 0.01$). In conclusion, the change in lever arm contributed the most to explaining change in KAM parameters with modified shoes. The change in the lever arm was driven by changes evident at the foot in the OA participants (COP and medial–lateral GRF), and by more proximal changes (hip–knee–ankle angle and trunk lean) in the overweight group.

1. Introduction

Dynamic joint loading is implicated in the development of knee pain and structural progression of knee osteoarthritis (OA). The external knee adduction moment (KAM) during walking is a valid and reliable proxy for load distribution across the tibiofemoral joint, such that a greater load is placed medially relative to laterally (Birmingham et al., 2007; Zhao et al., 2007). Peak KAM and KAM impulse are related to radiographic OA and pain severity (Foroughi et al., 2009; Kito et al., 2010), structural OA features (Bennell et al., 2010; Creaby et al., 2010; Foroughi et al., 2009), development of incident knee pain (Amin et al., 2004) and OA structural disease progression (Bennell et al., 2011b; Miyazaki et al., 2002). Since knee OA is a leading cause of pain, disability and healthcare use, developing and evaluating non-surgical interventions which reduce medial knee joint loading may help alleviate symptoms and slow disease onset and progression.

A major risk factor for the development of knee OA is obesity (Cooper et al., 2000; Reijman et al., 2007) and the association maybe mediated by alterations in joint biomechanics (Powell et al., 2005; Wearing et al., 2006). Obese people adjust their movement strategies compared to people of healthy weight (Runhaar et al., 2011). However, evidence is conflicting as to whether obese people have a higher normalized KAM than people of healthy weight. Harding et al. (2012) have reported significant BMI main effects on the pattern of the KAM in people with and without knee OA. Segal et al. (2009) reported an increased absolute peak KAM and KAM impulse in obese people compared to people of healthy weight, and thigh girth significantly predicted the peak KAM. While limited information exists on KAM in overweight individuals without knee OA, there is evidence that increased weight plays a significant role in increasing KAM in those with knee OA (Aaboe et al., 2011; Messier et al., 2005; Moyer et al., 2010). Accordingly, mechanical interventions that reduce the KAM may also be relevant for overweight people who are at risk of developing knee OA.

Lateral wedge insoles have been advocated as a treatment option for medial knee OA given their effectiveness at reducing the KAM (Butler et al., 2007; Hinman et al., 2012; Kerrigan et al., 2002). Unfortunately, they have proven ineffective at improving symptoms or slowing disease progression in clinical trials (Baker et al., 2007; Barrios et al., 2009; Bennell et al., 2011a; Pham et al., 2004). Given that reductions in the KAM with lateral wedge

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insoles inserted into a person's own shoes can be quite variable (Butler et al., 2007; Hinman et al., 2012), it is possible that the actual shoe itself may diminish the load-reducing effect of lateral wedge insoles. In addition, the insertion of a lateral wedge can compromise space within the shoe leading to discomfort (Bennell et al., 2011a). Accordingly, research has begun to focus on designing shoes that reduce mechanical loading at the knee (Erhart et al., 2008; Shakoor et al., 2008). We have developed novel modified shoes that incorporate both a variable stiffness sole and lateral wedging and can reduce the KAM parameters in people with symptomatic knee OA and in overweight asymptomatic people at risk for developing the disease (Bennell et al., 2013). The lateral wedge is incorporated into the shoe sockliner and integrated into the shoe design, serving to complement the variable stiffness sole.

Although our modified shoes successfully lower the peak KAM and KAM impulse, the mechanism by which the shoes reduce these parameters is unknown. The KAM is primarily calculated as the product of the frontal plane ground reaction force (GRF) magnitude and the perpendicular distance from the GRF to the knee joint centre of rotation, (i.e. the knee-GRF lever arm) (Hunt et al., 2006). Thus it is likely that the shoe changes the KAM via one or both of these parameters. Changes in the frontal plane GRF magnitude and the knee-GRF lever arm may occur via distal mechanisms and/or proximal mechanisms (Boyer et al., 2012; Hinman et al., 2012; Jenkyn et al., 2011). Knowledge of factors that influence the KAM and the lever arm is important as it may assist clinicians in choosing a combination of treatments and assist shoe manufacturers to design shoes to maximize changes in these parameters. Therefore, the aims of this study were to (i) examine the contribution of changes in the frontal plane knee-GRF lever arm and frontal plane GRF magnitude to changes in KAM and (ii) examine parameters that contribute to change in knee-GRF lever arm with modified shoes, both in people with symptomatic OA and in asymptomatic overweight people.

2. Methods

2.1. Participants

This is a secondary analysis of data from a study that evaluated the effects of the modified shoes on the KAM (Bennell et al., 2013). Data from the 30 individuals with symptomatic knee OA and 30 overweight asymptomatic individuals (were analyzed. Participants were ≥40 years of age. The OA participants had medial knee OA on x-ray (Altman et al., 1986; Kellgren et al., 1963), an average knee pain during walking $> 3/10$ ($0=$no pain and $10=$worst pain possible) and pain on most days of the previous month. The overweight participants had a body mass index (BMI)≥ 25 kg/m^2 (WHO, 2000), no history of a traumatic knee injury and no knee pain within the previous 12 months. For both groups, people were excluded if they had (i) a BMI > 36 kg/m^2; (ii) a history of lower limb, spinal or hip surgery; (iii) intra-articular corticosteroid injection or knee surgery within previous six months; (iv) used oral corticosteroids within previous four weeks; (v) any other condition affecting walking ability, or inability to walk unaided; or (vi) any systemic arthritic condition or major medical condition. Ethics approval was obtained from the Institutional Ethics Committee and participants provided written informed consent.

2.2. Descriptive measurements

Age, sex, height and body mass were recorded and BMI calculated. OA participants underwent a semiflexed weightbearing posteroanterior knee radiograph to determine OA severity using Kellgren-Lawrence (KL) grade (Kellgren et al., 1963) and knee alignment. Anatomical knee alignment is the medial angle between the anatomical axes of the femur and tibia, determined by drawing a line from the center of the tibial spines to a point 10 cm above/below and bisecting the medial–lateral width of the femur/ tibia (Moreland et al., 1987). An angle $< 180^\circ$ indicates varus alignment. OA participants also completed the Western Ontario and McMaster Universities Arthritis Index (WOMAC), a disease-specific self-reported questionnaire measuring pain, stiffness and physical function (Bellamy et al., 1988).

2.3. Shoes

Participants underwent 3-dimensional gait analyses wearing the (i) modified shoes and (ii) control (non-modified) shoes, in randomized order and blinded to shoe condition. The modified shoes (Gel Melbourne OA, ASICS Oceania Pty. Ltd.) were recreational walking shoes with a specially-designed triple density sole of compression molded ethylene vinyl acetate, where the lateral midsole is stiffer than the medial (Shore A durometer ratings of 62 ± 4 for the lateral sole and 44 ± 4 for the medial sole). The modified shoes also contain a mild full length lateral wedge of $5 \pm 1^\circ$ angulation attached to the underside of the sockliner over the lateral half of the shoe and concealed within the shoe. The control shoes (ASICS Oceania Pty. Ltd.) were standard recreational walking shoes with no modifications.

2.4. Gait analysis

Participants first completed 5 trials, walking at their own self-selected speed in their own shoes over a 10-meter walkway. Time to walk between two sets of photoelectric timing gates was recorded and used to control speed during the subsequent gait analysis.

Kinematic data were collected at 120 Hz using a twelve-camera Vicon motion analysis system (Vicon, Oxford, UK) and kinetic data was synchronously collected at 1200 Hz using three, floor-mounted force plates (Advanced Mechanical Technology Inc., Watertown MA). Passive reflective markers were secured to the skin of the pelvis, lower limbs and the shoes according to the Plug-In-Gait marker set (Vicon, Oxford, UK). Additional markers were placed over the medial knees and malleoli during an initial static standing trial to determine relative positioning of joint centers. The hip joint centres were determined using the methods described by Davis et al. (1991).

Table 1
Biomechanical variables of interest.

Variable	Definition
Peak knee adduction moment (Nm/(BW x HT)%)	Peak external knee adduction moment in first half of stance
Knee adduction angular impulse (Nm.s/(BW x HT)%)	Positive area under the knee adduction moment-time graph. This measure incorporates both the mean magnitude of the (positive) moment and the time for which it is imposed on the knee.
Knee-GRF lever arm (mm)	Perpendicular distance between GRF and knee joint center in laboratory frontal plane. Calculated at time of peak KAM and as an average over stance phase.
Frontal plane GRF magnitude (N)	Resultant magnitude of GRF in laboratory frontal plane. Calculated at time of peak KAM and as an average over stance phase.
Center of pressure (COP) offset (mm)	Distance of the center of pressure from the long axis of the foot (the ankle joint centre to the 2nd metatarsal), where negative values indicate lateral offset. Calculated at time of peak KAM.
Medial–lateral GRF magnitude (N)	Medial–lateral (F_y) component of the GRF. Calculated at time of peak KAM. Positive value is medial force.
Hip–knee–ankle angle (°)	Angle formed from hip–knee–ankle centers, in laboratory frontal plane, where positive values indicate varus. Calculated at time of peak KAM.
Lateral trunk lean (°)	Trunk lean angle in the laboratory frontal plane. A positive value indicates a lean towards the stance limb (in this case the study limb). Calculated at time of peak KAM.
Stance time (s)	Time from heel strike to toe-off of study limb.

GRF=ground reaction force.