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Mild leg length discrepancy affects lower limbs, pelvis and trunk biomechanics of individuals with knee osteoarthritis during gait

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ABSTRACT

Background: Leg length discrepancy greater than 1 cm increases odds of progressive knee osteoarthritis in the shorter limb.
Methods: Biomechanical data of 15 knee osteoarthritis participants were collected while they walked under two conditions: (1) control — wearing thick sandals; (2) short limb — wearing a thin sandal on the osteoarthritic limb and a thick sandal on the contralateral limb. The thick and thin sandals had 1.45 cm of thickness difference. The knee osteoarthritis limb was analyzed for both conditions. Ankle, knee, hip, pelvis and trunk kinematics and moments were measured with a motion and force capture system. Principal component analysis and mean hypothesis' tests were used to compare the conditions.
Findings: The short limb condition reduced rearfoot plantarflexion in loading response and increased plantarflexion in late stance ($p < 0.001$), increased ankle dorsiflexion moment ($p = 0.003$), increased knee flexion angle in loading response and delayed knee flexion in late stance ($p = 0.001$), increased knee extension moment in loading response and increased knee flexion moment in terminal stance ($p = 0.023$), reduced hip extension moment in early stance and reduced hip flexion moment in late stance ($p < 0.001$), reduced knee adduction moment ($p = 0.015$), reduced hip adduction angle ($p = 0.001$) and moment ($p = 0.012$) and increased pelvic ($p = 0.023$) and trunk ($p = 0.001$) external rotation.
Interpretation: Mild leg length discrepancy affects the entire kinetic chain of individuals with knee osteoarthritis during gait, increasing knee sagittal plane loading, which helps to explain why mild leg length discrepancy accelerates knee osteoarthritis progression. Mild leg length discrepancy should not be overlooked in knee osteoarthritis individuals.

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1. Introduction

Knee osteoarthritis (OA) is a progressive disease that affects 16.7% of individuals aged ≥45 years (Jordan et al., 2007) and 37.4% of individuals aged ≥60 (Dillon et al., 2006). It is associated with severe pain and disability (Szebenyi et al., 2006), causing an enormous social and economic burden, with an estimated average lifetime cost of $140,300 per person diagnosed with knee OA (Losina et al., 2015). Since knee OA progression causes loss of articular cartilage, it may contribute to the development of leg length discrepancy (LLD) (Sharma et al., 2008). Harvey et al. (2010) demonstrated that having LLD ≥1 cm was associated with increased odds of having knee radiographic OA in the shorter limb (53% vs. 36%, odds ratio 1.9). In addition, because LLD occurs in up to 70% of the general population (Woerman and Binder-Macleod, 1984), and causes biomechanical changes during gait that may overload the knee of the shorter limb (Resende et al., 2016a), it is possible that healthy individuals with LLD would develop knee OA, most likely in the shorter limb (Harvey et al., 2010).

LLD may increase the step down distance during the transition from stance phase of gait on the longer limb to the stance phase on the shorter limb. This increased step down distance along with concomitant changes in joint kinematics results in a shorter time to peak force (Resende et al., 2016a; Walsh et al., 2000), which may increase loading in the shorter limb (Brand and Yack, 1996; White et al., 2004). If

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increased loading in the shorter limb holds true for knee OA individuals, LLD discrepancy might increase joint moments in the osteoarthritic-limb during stance. In addition, it is possible that during the stance phase of gait, the knee OA individuals implement strategies to dynamically lengthen the shorter limb (Resende et al., 2016a) in order to minimize the vertical displacement of the body center of mass and consequently reduce body energy expenditure (Gurney et al., 2001; Kaufman et al., 1996). Some of these strategies, such as increased rearfoot inversion (Levinger et al., 2013; Resende et al., 2016a, 2016b), may also overload the knee, which could explain why LLD is a risk factor for both development and progression of knee OA in the shorter limb (Harvey et al., 2010). Alternatively, it is possible that individuals with knee OA implement strategies to compensate for LLD in other joints, possibly to reduce knee pain, which may also overload these joints.

Most knee OA individuals have LLD <2 cm (Harvey et al., 2010) (hereafter mild LLD). However, there is no consensus in the literature regarding the biomechanical effects of mild LLD during gait (Goel et al., 1997; Kaufman et al., 1996; Resende et al., 2016a). For example, Goel et al. (1997) found no difference in the maximum joint moments at the hip, knee and ankle caused by mild LLD, which led the authors to conclude that mild LLD probably do not contribute to the development of abnormalities. On the other hand, evaluating the pattern of variation of the joints kinematics and kinetics temporal series, Resende et al. (2016a) demonstrated that mild LLD affects the kinematics and moments of the lower limbs joints during walking, suggesting that mild LLD may contribute to the development of injuries. The lack of consensus regarding the biomechanical effects of mild LLD contributes to the clinical settings' assumption that it is reasonable to overlook mild LLD in knee OA individuals, especially because it is expected that these individuals naturally develop mild LLD discrepancy with disease progression. The results of this study might show the opposite. Therefore, this study investigated the effects of mild LLD on the biomechanics of the lower limb with knee OA during gait. It was hypothesized that participants would walk with increased foot plantar flexion and supination, increased knee extension and reduced hip flexion during stance phase in order to dynamically lengthen the shorter limb. In addition, the shorter limb would present increased ankle plantar flexion and knee extension moments.

2. Materials and 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 medium effect size ($d = 0.6$). Fifteen participants (9 females) diagnosed with knee OA of one (N = 8) or both (N = 7) knees by an orthopedic surgeon, with an average age, mass and height of 67 years (SD 8.8), 88.9 kg (SD 20.1) and 169 cm (SD 0.07), 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, being able to walk a city block and being able to climb stairs in a reciprocal fashion. In addition, participants were checked for LLD. LLD was the bilateral difference of the distance from the anterior superior iliac spine and the ipsilateral medial malleolus measured while the subject was lying in a supine position. The mean of two readings was considered as it has been shown to have acceptable validity and reliability when used as a screening tool (Gurney, 2002). 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, Watertown, Massachusetts, USA).

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). Additional forefoot and rearfoot markers were applied to generate and track multi-segment foot kinematics (Wright et al., 2011). Participants then walked under two different conditions as described:

1) control condition: wearing flat thick sandals on both limbs;
2) short limb condition: wearing flat thin sandal on the knee OA limb and a flat thick sandal on the contralateral limb.

Only the osteoarthritic-limb data were analyzed for the two 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" status (Messier et al., 2015; R.A. Resende et al., 2016b). Two sizes of sandals for each condition were used in this study, with the specific dimensions described elsewhere (Resende et al., 2016a). The sandals' bases were made of high-density ethylene vinyl acetate and were attached to the participants' feet with Velcro™ (Cabral et al., 2016). 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

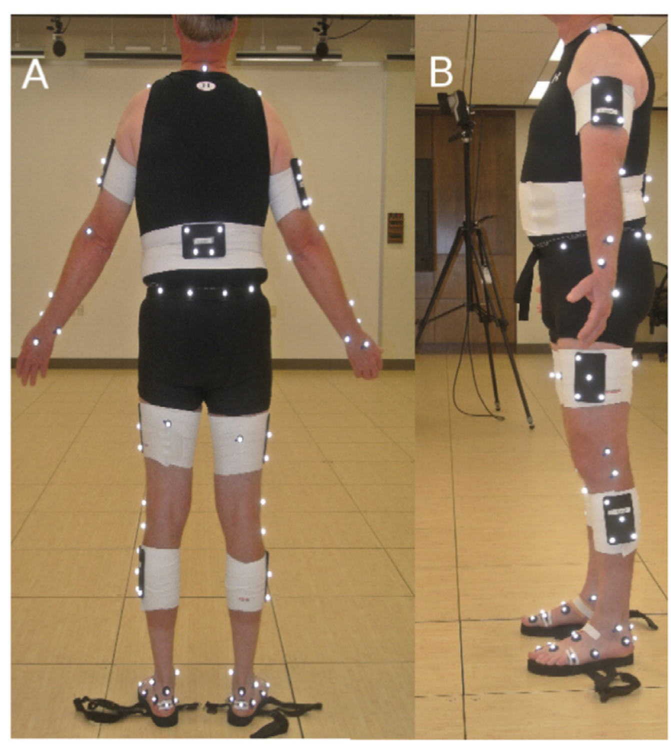

Fig. 1. Marker placement, posterior (A) and lateral (B) view.

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