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Increased hip internal abduction moment and reduced speed are the gait strategies used by women with knee osteoarthritis

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ABSTRACT

The purpose of this study was to identify the gait strategies in women with mild and moderate knee osteoarthritis (OA). Forty women diagnosed with OA of the knee and 40 healthy women participated in the study. Toe-out progression angle, trunk lateral lean, hip internal abduction moment and gait speed were measured using Qualisys ProReflex System and two force plates. Principal component analysis was applied to extract features from the gait waveforms data that characterized the waveforms main modes of temporal variation. Discriminant analysis with a stepwise model was conducted to determine which strategies could best discriminate groups. According to the discriminant model, the PC2 of the internal abduction moment of the hip and the gait speed were the most discriminatory variables between the groups. The OA group showed decreased gait speed, decreased hip internal abduction moment during the loading response phase, and increased hip internal abduction moment during the mid and terminal stance phases. Interventions that may increase hip internal abduction moment, such as the strengthening of the hip abductors muscles, may benefit women with knee OA. Training slower than normal gait speeds must be considered in light of potential adverse implications on overall physical function, daily tasks, and safety.

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1. Introduction

Knee osteoarthritis (OA) is a common chronic joint disease in elderly people that mainly affects the medial tibiofemoral compartment (Woolf and Pfleger, 2003). Excessive knee adduction moment accelerates the progression of knee OA (Baliunas et al., 2002; Nasim et al., 2009; Lynn et al., 2007; Miyazaki et al., 2002) and is positively correlated with the pain level in individuals with knee OA (Robbins et al., 2011). Therefore, individuals with knee OA frequently adopt mechanical strategies during gait in order to reduce the knee adduction moment (Chang et al., 2005, 2007; Hunt et al., 2008; Rutherford et al., 2008). The most common strategies include: increased toe out progression angle (Chang et al., 2007; Lynn et al., 2007; Rutherford et al., 2008), increased lateral trunk lean (Hunt et al., 2008; Kosuke et al., 2008), increased internal abductor moment at the hip (Chang et al., 2005), and decreased speed (Mündermann et al., 2004). Independent of the strategy, reduction of the knee adduction moment is either achieved by decreasing the moment arm of the ground reaction forces or the center of mass acceleration in the frontal plane.

Two loading peaks define the knee adduction moment during gait: the first peak occurs at the loading response phase, when weight is transferred to the support leg, and the second occurs at the push-off phase, when body mass acceleration increases (Landry et al., 2007). Both increased toe out angle (Chang et al., 2007) and lateral trunk lean angles (Mündermann et al., 2008) explain part of the variability in the knee adduction moment; however, lateral trunk lean has shown more consistency in reducing the knee adduction moment during late stance (Hunt et al., 2008). Although reduced gait speed may decrease the knee adduction moment during late stance, most studies failed to support this hypothesis (Robbins and Maly, 2009; Milena et al., 2011). While the mechanical strategies adopted by individuals with knee OA may reduce loading of the knee joint, the benefits of these strategies are still unclear.

It is likely that different individuals with knee OA adopt different strategies depending on the availability of structural and dynamical musculoskeletal resources. In addition, simultaneous understanding of the strategies adopted by individuals with knee OA may help to identify clinical targets for rehabilitation programs intervention. Therefore, the purposes of the present study were to investigate the mechanical strategies adopted by elderly females with knee OA and also to identify the strategies that most differentiate the OA group from an age-pared asymptomatic group. Our hypothesis is that gait speed, trunk lateral lean and increased hip

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abductor moment are the gait strategies adopted by individuals with knee OA.

2. Methods

2.1. Participants

The OA group was composed of 40 women, diagnosed with OA at the medial compartment of one or both knees by an orthopedic surgeon. In subjects with bilateral knee OA, the lower limb with the highest score in the WOMAC pain subscale (i.e. worse pain) was analyzed. Only women with medial knee OA classified as mild or moderate (grades 2 and 3), without any indication for surgery according to the American College of Rheumatology (Altman et al., 1986), were included in the study. The radiographic classification was based on the Kellgren and Lawrence criteria (Kellgren and Lawrence, 1957). An asymptomatic group was selected for comparison. This group was composed of 40 age-matched healthy women, with no diagnosis of knee OA and no significant symptoms (e.g., pain, stiffness or palpable effusion) that are consistent with the diagnosis of knee OA (Altman et al., 1986). In the control group, the dominant side limb was chosen for analyses. Participants were excluded if they were involved in physical therapy treatment for knee OA in the 3 months prior to the study; reported history of falls in the 6 months prior to the study; reported any history of trauma, surgery or other diseases affecting the lower limb joints; needed assistive devices for walking; and/or presented cognitive impairment as defined by the Mini-Mental State Examination (cutoff of 18) (Brucki et al., 2003). Subjects were recruited from the local community. The present study received approval from the University's Ethics Committee under process number ETIC 0599/08. All of the participants signed terms of informed consent.

2.2. Procedures and instrumentation

Initially, the participants' height and mass were obtained to compute their body mass index (BMI). Subsequently, participants responded to the Western Ontario and McMaster Universities Arthritis Index (WOMAC) questionnaire, specifically designed to evaluate pain and stiffness of patients with hip and knee OA (Bellamy et al., 1988). The scores of the WOMAC subscales were calculated using a 5-point Likert scale (0, 25, 50, 75, 100), where lower scores indicate better condition in that domain (Kirkwood et al., 2011; Resende et al., 2013).

Gait analysis was performed using an eight-camera motion analysis system (Qualisys ProReflex Medical AB, Gothenburg, Sweden) synchronized with two force plates (AMTI—Advanced Mechanical Technology, OR6-6 model, Watertown, MA, USA). The motion analysis system has an accuracy of 0.6 mm as specified by the manufacturer, and registered the position of selected markers at a frequency of 120 Hz. The force plate registered ground reaction force (GRF) data at a frequency of 1000 Hz, which was subsequently resampled to 120 Hz.

Anatomical markers and clusters of tracking markers were used to determine the coordinate of the trunk, pelvis and lower limb segments using data obtained during the static trials. Clusters of tracking markers were used to capture the motion of the trunk, pelvis, thigh, shank and foot using data obtained during walking (i.e., dynamic trials). The location of the markers was chosen according to current recommendations for minimizing soft tissue artifacts (Chiari et al., 2005; Manal et al., 2000; Schache et al., 2008).

For the static trial, anatomical markers were placed on the following locations: the acromioclavicular joint bilaterally; spinous process of the seventh cervical vertebrae; sternal manubrium; highest point of the left and right iliac crest; bilateral greater trochanters; medial and lateral epicondyles of the femur; lateral and medial malleoli; calcaneus and on the heads of the first and fifth metatarsals. For the dynamic trials, markers were placed over the left and right sternoclavicular joints; in addition, the markers placed over the spinous process of the seventh cervical vertebrae and over the sternal manubrium were used as tracking markers of the trunk. Clusters of tracking markers were attached to the participant's pelvis, thigh and shank. The pelvis cluster consisted of a rigid plate containing 4 non-collinear tracking markers. The cluster was attached on the posterior surface of the sacrum with elastic fastenings involving the entire segment. The cluster of the thigh was a non-rigid neoprene girdle with 3 tracking markers attached (Schache et al., 2008). The shank cluster consisted of a rigid plate attached to a neoprene girdle with 3 tracking markers (Manal et al., 2000). For the foot, the anatomical markers, which were also used as tracking markers, were attached directly over the calcaneus, lateral malleoli and head of the fifth metatarsal. After positioning of the markers, participants were asked to stand still using a comfortable stance for 5 s in order to perform the static trial.

Following the static trial, the anatomical markers were removed and kinematic and kinetic data were collected while participants walked on a 10-m walkway at their self-selected speed. The force plates provided the GRF, thus allowing the determination of the gait cycle (foot contact on the first force plate, toe off, next contact of the same foot on the second force plate). Participants performed 10 trials. We only analyzed trials in which the correct foot was in contact with the force plate and all of the dynamic markers were visible. A pilot test was conducted with 10 subjects to define the test–retest reliability of the procedure used to obtain the study measures.

2.3. Data reduction

The following displacement time-series were obtained: (1) trunk lateral lean (y-axis) represented by the motion of the trunk relative to the lab coordinate system – positive values for trunk lean towards the lower limb defined for analysis; (2) toe-out progression angle was computed as the angle formed by the intersection of the long axis of the foot and the direction of the body forward progression following the methods of Chang et al. (2007).

Inverse dynamic procedures were employed to compute hip internal abduction moment using the GRF and kinematic data – positive values for abduction moment. Hip moments were normalized by body mass and reported in Nm/kg.

All kinematic and kinetic waveforms were (a) filtered with a Butterworth low-pass filter of fourth order with a cut-off frequency set at 6 Hz, and (b) time normalized and sampled at each 1% of the gait cycle, yielding a total of 101 time samples for each participant. For each gait measure, we analyzed the mean waveform of the ten trials of each participant. Gait speed (m/s) was also processed. All data processing was performed using the software Visual 3D (C-Motion, Inc., Rockville, USA).

2.4. Data analysis

2.4.1. Participant's characteristics and gait speed

Anthropometrics and gait speed were analyzed for normality and homogeneity of variance using the Shapiro–Wilk and Levine tests, respectively. In the presence of normality the Student t-test was applied, otherwise the Mann–Whitney exact test was used. The WOMAC scores were presented to describe the characteristics of the OA and asymptomatic groups.

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