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Kinematic gait patterns and their relationship to pain in mild-to-moderate hip osteoarthritis

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ABSTRACT

Background: Mild-to-moderate hip osteoarthritis is often managed clinically in a non-surgical manner. Effective non-surgical management of this population requires characterizing the specific impairments within this group. To date, a complete description of all lower extremity kinematics in mild-to-moderate hip osteoarthritis patients has not been presented. The aim of the present study is to describe the lower extremity gait kinematics in mild-to-moderate hip osteoarthritis patients and explore the relationship between kinematics and pain.
Methods: 22 subjects with mild-to-moderate radiographic hip osteoarthritis (Kellgren–Lawrence grade 2–3) and 22 healthy age and BMI matched control subjects participated. Kinematic treadmill walking data were collected across all lower extremity joints. A two-way repeated measures analysis of variance estimated mean differences in gait kinematics between groups. Correlations between gait kinematics and pain were assessed using a Spearman correlation coefficient.
Findings: Hip osteoarthritis subjects hiked their unsupported hemi-pelvis 1.40° ($P < 0.001$) more than controls and tilted their pelvis 4.65° more anteriorly ($P = 0.01$). Osteoarthritis subjects walked with 4.30° more peak hip abduction ($P < 0.001$), 8.57° less peak hip extension ($P < 0.001$), and 10.54° more peak hip external rotation ($P < 0.001$). Kinematics were related to pain in the ankle frontal plane only ($r = -0.43$, $P < 0.05$).
Interpretation: Individuals with mild-to-moderate hip osteoarthritis demonstrate altered gait biomechanics not related to pain. These altered biomechanics may represent effective therapeutic targets by clinicians working with this population. Understanding the underlying patho-anatomic changes that lead to these biomechanical changes requires further investigation.

1. Introduction

Hip osteoarthritis (hip OA) can be a leading cause of pain, loss of function, and long-term disability and is managed either surgically or with conservative therapies depending on the severity of the disease and/or the level of patient disability (Badley, 1995; Nelson et al., 2014). While surgical interventions are effective management strategies in those with end-stage hip OA (Ewen et al., 2012), the majority of individuals with hip OA are non-surgical candidates for whom conservative management therapies are the first treatment option (Dieppe and Lohmander, 2005). Given the current and expected increase in prevalence of individuals with non-surgical hip OA, an increased understanding of how milder forms of hip OA can be best managed conservatively has been identified as a priority (Fernandes et al., 2013).

Effective management of chronic conditions such as hip OA necessitates a detailed description of the impairments and functional limitations within that population in order to help guide the treating clinician (Mills et al., 2013a, 2013b). To date, an increasing body of literature is beginning to emerge that describes the limitations found in individuals with both mild-to-moderate and severe hip OA. It has been demonstrated that individuals with severe hip OA awaiting hip surgery report decreased functional ability and demonstrate functional impairments on objective function testing that appears related to pain and strength changes (Zeni et al., 2014). In addition, movement pattern changes, as measured by 3D gait analysis, have also been widely demonstrated in end-stage hip OA individuals, particularly in the sagittal plane of the hip, knee, and ankle (Meyer et al., 2015; Schmitt et al., 2015; Zeni et al., 2015). Of particular interest are the ambulation patterns in individuals with mild-to-moderate hip OA given the important role that biomechanics are thought to play in the OA disease process (Brandt et al., 2008), and since detection of early disease changes increases the likelihood of halting or reversing the disease trajectory (Hunter, 2011). Studies examining the kinematic gait patterns of individuals with mild-to-moderate hip OA demonstrate that this population walks with decreased sagittal plane hip movement, compensatory changes in sagittal plane knee and ankle movements (Eitzen et al., 2012; Watelain et al., 2001), and altered frontal plane center of mass

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movements that may predispose them to an increased risk of falls (Lin et al., 2015). In addition, the best kinematic discriminator between healthy control subjects and individuals with early hip OA also appears to lie in the sagittal plane (Laroche et al., 2014). While the gait kinematics of individuals with mild-to-moderate hip OA is becoming more completely described (Kumar et al., 2015), there has not, to our knowledge, been a description of joint kinematics across all lower extremity segments (pelvis, hip, knee, and ankle) in all three anatomical planes (sagittal, transverse, frontal). In addition, an exploration of how gait kinematics are influenced by pain in individuals with mild-to-moderate hip OA is also needed given the potential role pain may have on gait variable outcomes. While the relationship between pain and gait kinematics has been explored in end-stage hip OA (Zeni et al., 2014) and in the sagittal plane in mild-to-moderate hip OA (Hurwitz et al., 1997), a complete description of this relationship in mild-to-moderate hip OA is still needed.

Therefore, the purpose of the present study was to provide a comprehensive description of the gait kinematics in individuals with radiographic evidence of mild-to-moderate hip OA and compare these findings with healthy age-matched controls. In addition, an understanding of how this kinematics relate to pain was sought. We hypothesized that hip OA patients would walk with decreased range of motion (RoM) in the sagittal plane and that decreases in RoM across the transverse and frontal planes would also be observed as early-stage changes. It was further hypothesized that the increased frontal and transverse plane motions would be related to pain as hip OA patients attempted to offload their affected hip.

2. Methods

2.1. Recruitment and sample

In this cross-sectional study, and based on an a priori power analyses ($\beta = 0.20$; $P = 0.05$), 22 individuals with mild-to-moderate radiographic hip OA and 22 healthy age and BMI matched subjects participated in the present study. Hip OA subjects were recruited by convenience between June 2013 and May 2014 and subject inclusion criteria were: 1) fulfillment of the American College of Rheumatology (ACR) criteria for hip OA which includes pain and radiographic changes (Altman et al., 1991); 2) standing AP radiograph of the pelvis taken within the past 2 years that demonstrates Kellgren and Lawrence (KL) grade 2–3 changes (Kellgren and Lawrence, 1957); 3) aged 35–70 years old; and 4) pain of at least 1 of 10 on a Visual Analogue Scale (VAS) in either hip or groin. Exclusion criteria included: 1) prior ipsilateral and/or contralateral surgery or clinically diagnosed musculoskeletal, neurological, or joint pathology causing pain or affecting function of the low back, pelvis, or lower extremities; 2) current or past (within 3 months) intra-articular corticosteroid use; 3) participation in a strengthening, stretching, or rehabilitation program currently or in the past 3 months; 4) any other systemic arthritic conditions (e.g. rheumatoid arthritis, spondyloarthropathies); 5) inability to abstain from medication for 24 h; and 6) previous medical conditions (e.g. stroke) that affect gait patterns. Use of analgesics and other prescribed medications were permitted during the study but not 24 h before testing. In those subjects with bilateral hip OA involvement, the most painful hip was used as the joint of interest. The control group was made up of healthy individuals, matched on age and body mass index (BMI), who had previously been recruited by convenience and had completed a 3D gait analysis in our lab. The present study was approved by the University of Calgary Conjoint Health and Research Ethics Board and written informed consent was obtained from each subject prior to study commencement.

2.2. Pain and self-report questionnaires

Pain (independent variable) was assessed for each subject using a 10 cm VAS with extremes anchored at 0 cm = "no pain" and 10 cm = "worst imaginable pain" (Hawker et al., 2011). The subjects were asked to rate their pain on average over the past 1 week with all life activities considered. Subject function was assessed using the 17 question function sub-scale of the Western Ontario McMaster Universities Osteoarthritis Index (WOMAC) questionnaire (McConnell et al., 2001), while quality of life was assessed using the Assessment of Quality of Life Questionnaire (V2) (AQOL-V2) (Whitfield et al., 2006).

2.3. Radiographs and OA definition

Standing anterior–posterior (A–P) radiographs of the pelvis (taken within the past 2 years) were obtained from each participant. A–P radiographs for each subject were read and graded by different radiologists owing to the 2 year rolling recruitment. Only those subjects whose radiographs demonstrated Kellgren and Lawrence (KL) grade 2–3 changes (mild-to-moderate) (Kellgren and Lawrence, 1957) were considered eligible for the present study.

2.4. Gait analysis

Kinematic data were collected using an 8-camera 3D motion capture system (Vicon MX-3 +, Vicon, Oxford, UK) at a frequency of 200 Hz. Prior to the collection of gait data, 9 mm spherical retro-reflective markers were placed on the pelvis and lower extremities bilaterally according to the marker set used by Osis et al. (2014). Specifically, anatomical markers were specifically placed on the following bilateral anatomical landmarks: iliac crest; greater trochanter; anterior superior iliac spine; medial and lateral femoral condyles; fibular head; tibial tuberosity; medial and lateral malleoli; and 1st and 5th metatarsal heads.

In order to track segment positions during gait, marker clusters comprised of rigid shells ("technical clusters") were placed over the pelvis, thighs, and shanks. A technical cluster with 3 affixed markers was placed over the pelvis, and clusters with 4 affixed markers were placed over the thighs and shanks bilaterally. A technical marker cluster was established for the foot by aligning two markers vertically along the posterior heel counter of the shoe and placing one marker laterally (Pohl et al., 2010). Following the placement of anatomical and technical markers, a static standing trial was collected with each subject's feet placed 0.3 m apart, aligned with a graphic template underfoot. This standing static trial permits a determination of the position of anatomical landmarks with respect to the technical clusters (Cappozzo et al., 1995) as well as the construction of joint coordinate systems (Cole et al., 1993).

Following completion of the static trial, anatomical markers were removed and subjects walked on a treadmill at a speed of 1.1 m/s for 5 min. Before the collection of dynamic walking data, subjects walked on the treadmill for 3–5 min to allow an accommodation to the speed of the treadmill and to facilitate a natural walking pattern (Pohl et al., 2010). Kinematic data from at least 10 consecutive footfalls of the target limb during stance were collected, following the accommodation period (Pohl et al., 2010). The subjects wore standardized shoes provided by the laboratory (Nike Air Pegasus, Nike Inc, Beaverton, Oregon, USA).

Using a custom MATLAB software (R2010a), technical and anatomical coordinate systems were established for each of the pelvis, thigh, shank, and foot using technical and anatomical markers respectively (Cole et al., 1993). Technical coordinate systems were defined for each segment using the technical clusters affixed to a given segment while anatomical coordinate systems were defined for each segment using anatomical markers. Hip joint centers were calculated using the greater trochanter method, whereby the hip joint center is located 25% of the inter-trochanteric distance along the three-dimensional line connecting the ipsilateral with the contralateral trochanter marker (Weinhandl and O'Connor, 2010). Knee and ankle joint centers were calculated as the three-dimensional mid-point of the distance between the medial and the lateral femoral condyles and medial and lateral malleoli, respectively. Joint angles were calculated using the singular value decomposition