Clinical Biomechanics 30 (2015) 578–584

Contents lists available at ScienceDirect

Clinical Biomechanics

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

Knee joint motion and muscle activation patterns are altered during gait in individuals with moderate hip osteoarthritis compared to asymptomatic cohort

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ARTICLE INFO

Article history:
Received 27 November 2014
Accepted 2 April 2015

Keywords:
Hip osteoarthritis
Gait analysis
Electromyography
Kinematics
Principal component analysis

ABSTRACT

Background: Knee replacements are common after hip replacement for end stage osteoarthritis. Whether abnormal knee mechanics exist in moderate hip osteoarthritis remains undetermined and has implications for understanding early osteoarthritis joint mechanics. The purpose of this study was to determine whether three-dimensional (3D) knee motion and muscle activation patterns in individuals with moderate hip osteoarthritis differ from an asymptomatic cohort and whether these features differ between contra- and ipsilateral knees.
Methods: 3D motions and medial and lateral quadriceps and hamstring surface electromyography were recorded on 20 asymptomatic individuals and 20 individuals with moderate hip osteoarthritis during treadmill walking, using standardized collection and processing procedures. Principal component analysis was used to derive electromyographic amplitude and temporal waveform features. 3D stance-phase range of motion was calculated. A 2-factor repeated analysis of variance determined significant within-group leg and muscle differences. Student's t-tests identified between group differences, with Bonferroni corrections where applicable ($\alpha = 0.05$).
Findings: Lower sagittal plane motion between early and mid/late stance (5°, $P = 0.004$, effect size: 0.96) and greater mid-stance quadriceps activity was found in the osteoarthritis group ($P = 0.01$). Compared to the ipsilateral knee, a borderline significant increase in mid-stance hamstring activity was found in the contralateral knee of the hip osteoarthritis group ($P = 0.018$).
Interpretation: Bilateral knee mechanics were altered, suggesting potentially increased loads and knee muscle fatigue. There was no indication that one knee is more susceptible to osteoarthritis than the other, thus clinicians should include bilateral knee analysis when treating patients with hip osteoarthritis.

1. Introduction

Lower extremity osteoarthritis (OA) contributes to morbidity in adult populations around the world and significantly impacts mobility and activity (Song et al., 2013; White et al., 2013). As there is currently no cure, many management approaches focus on symptom relief (Escobar et al., 2012; Fernandes et al., 2013; Lane et al., 2011; McAlindon et al., 2014; Zhang et al., 2008), yet little impact has been shown in reducing disease progression (Lane et al., 2011). Surgical interventions are increasingly required to reduce the burden of OA, with rates projected to increase over 400% in coming decades (Kurtz et al., 2007). Many individuals receiving a knee or hip replacement will go on to require subsequent replacement of another lower extremity joint (Gillam et al., 2013), contributing to the escalating long-term burden of OA that is seldom captured by current projections.

In a recent study, Gillam et al., 2013 found significant hazard ratios of 1.83–2.97 for a contralateral knee replacement when participants' first joint replacement was a total hip. Hazard ratios were lower if the subsequent knee replacement was ipsilateral (0.51–0.52) (Gillam et al., 2013). This supports previous work indicating increased likelihood of contralateral knee OA progression, rather than ipsilateral, following a hip replacement (Shakoor et al., 2002). Given the influence of mechanics in lower limb OA (Felson, 2013) the question arises as to whether the progression of knee OA in this population is a result of abnormal knee mechanics secondary to hip OA.

Gait analysis has been used as a method to study joint mechanics in OA, because of the mechanical demands (Andriacchi and Mundermann,

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http://dx.doi.org/10.1016/j.clinbiomech.2015.04.002
0268-0033/

2006; Andriacchi et al., 2004; Felson, 2013; Wilson et al., 2009) and importance as a daily functional activity. Biomechanics and muscle activation measures provide a non-invasive approach to understanding joint function during walking. While sagittal plane hip movement is typically reduced in individuals with hip OA (Hurwitz et al., 1997; Kubota et al., 2007; Ornetti et al., 2011) during stance, understanding of knee mechanics in this population is lacking. Moreover, studies that have looked at stance phase knee mechanics tend to focus on late stage disease or post total hip replacement populations (Foucher and Wimmer, 2012; Ornetti et al., 2011; Shakoor et al., 2003). Knee mechanics, including a muscular system assessment are poorly understood in individuals with hip OA, who are not candidates for hip replacement.

The passive osteoligamentous, muscular, and the neurological subsystems are thought to be fundamental to supporting joint function (Panjabi, 1992; Sims, 1999; Solomonow and Krogsgaard, 2001) yet how lower extremity muscles activate during walking and the relationships with joint mechanics in individuals with hip OA is not clear. A greater understanding of knee joint muscle activation patterns in individuals with knee OA is emerging, linked to OA severity (Rutherford et al., 2013), progression (Hubley-Kozey et al., 2013) and joint mechanics (Heiden et al., 2009). Quadriceps activation is greater and more prolonged and greater levels of lateral hamstring activation and prolonged stance phase activity are found in individuals with medial compartment OA (Lynn and Costigan, 2008; Rutherford et al., 2013). Compensations by the neuromuscular system may occur to preserve knee joint function as previously described in the context of knee OA, but whether such changes to the knee exist with hip OA is unclear. Understanding alterations to knee mechanics and muscle activation patterns in individuals with hip OA may provide insight into the evolution of lower extremity OA and relationships between knee and hip OA pathomechanics.

The purpose of this investigation was to determine whether three-dimensional (3D) knee joint movements and quadriceps and hamstring activation patterns in individuals with unilateral symptomatic moderate hip OA are different from an asymptomatic cohort and whether these mechanics and muscle activation patterns differ between contra- and ipsilateral knee joints.

Given previous findings of reduced sagittal plane hip joint motion, it is hypothesized that sagittal plane knee motion in the ipsilateral knee of individuals with hip OA will be reduced compared to the contralateral knee and healthy group, and that no differences in transverse or frontal plane motions will exist within or between groups. Given the hypothesized alterations in knee motion, it is hypothesized that both ipsilateral and contralateral quadriceps and hamstrings will activate for longer durations during stance compared to the asymptomatic cohort, and that no activation differences between the medial and lateral sites of these muscles will be found, contrary to that previously described in individuals with knee OA.

2. Methods

2.1. Participants

Participants with unilateral symptomatic hip OA were recruited over 1 year (2013–14) from local orthopedic clinics after consultation with an orthopedic surgeon regarding hip arthroscopy for early OA management. Participants were excluded if they were candidates for total hip replacement. A functional classification was also used to determine moderate severity as has been used in knee OA gait studies whereby individuals with hip OA self-reported no limitations with walking a city block, climbing stairs and jogging approximately 5 meters (Hubley-Kozey et al., 2006). Hip OA was determined using the American College of Rheumatology criteria (Altman, 1991). Asymptomatic participants were recruited from the general community using website and email based advertisements and considered a sample of convenience. These individuals had reported no pain or known functional limitations in the ankles, knees, hips or low back. All participants were required to be ≥50 years of age, have no fracture or injury other than a sprain or strain (within one year) or no previous knee/hip joint surgery. All participants had to be able to walk independently with no neurological or cardiovascular disorder that would impair walking ability. The protocol was approved by the local institutional ethics review committee and participants provided written informed consent.

Standard A/P pelvis and lateral radiographs were available in the hip OA group. Radiographs were graded using the Kellgren–Lawrence (KL) ordinal radiographic scale (Kellgren and Lawrence, 1957) by a single, experienced reader (IW), who was blinded to participant identification and gait analysis outcomes (Vignon et al., 1999) at the time of scoring.

2.2. Procedures

Once informed consent was obtained, participants changed into a T-shirt and fitted shorts, removed their footwear and completed at least five self-paced walking trials across the GaitRITE™ portable pressure sensitive walkway (CIR Systems, Clifton, NJ, USA) to determine average self-selected gait speed. This 5.4 m × 0.6 m walkway is a valid tool for measuring spatial and temporal gait characteristics (Bilney et al., 2003; McDonough et al., 2001). All participants completed the Hip Outcome Osteoarthritis Score (HOOS), the International Hip Outcome Tool (iHOT-33) and Oxford 12 self-report questionnaires.

Following these trials, participants were prepared for surface electromyography (EMG); skin was lightly shaved and cleaned with 70% alcohol wipes. Consistent with guidelines (Hermens et al., 2000) and standard procedures, Ag/AgCl surface electrodes (10 mm diameter, 30 mm inter-electrode distance, Red Dot, 3M Health Care, St. Paul MN, USA) were placed bilaterally in a bipolar configuration over vastus lateralis (VL) and medialis (VM) and both medial (MH) and lateral (LH) hamstrings. Muscle palpation and a series of isometric contractions for specific muscle groups were used for signal validation and gain adjustment. Surface EMG was recorded with two AMT-8™ 8-channel Bortec systems (Bortec Inc., Calgary, Canada) (Input Impedance: ~10 GΩ, CMRR: 115 dB at 60 Hz, Band-pass (10–1000 Hz)) using a custom LabVIEW™ 2013 program (National Instruments Corporation, Austin, TX, USA) at 2000 Hz.

Using a standard lower extremity motion capture marker set, rigid sets of four retro-reflective markers were affixed to the trunk (at the level of the inferior scapular angles), over the sacrum, and bilateral posterior femur and tibia using Velcro straps and secured with adhesive tape. Single retro-reflective markers were placed over the lateral aspect of the shoulders (below acromion), 7th cervical vertebra, greater trochanters, medial and lateral femoral and tibial epicondyles, medial and lateral malleoli, 5th metatarsal head, and posterior heels.

Prior to gait analysis, a kinematic model calibration was completed, including a standing calibration trial, a virtual sternum, 2 virtual anterior superior iliac spine location trials and 2 standing hip joint center calculation trials that required the subject to move each leg through hip flexion, extension and abduction (Camomilla et al., 2006). Retro-reflective skin marker motion was captured at 50 Hz using four Qualisys® Pro-reflex motion analysis sensors (Qualisys, Gothenburg, Sweden).

Participants began walking on the treadmill with at least 4 min of accommodation/warm-up. Speed was set to that self-selected on the GaitRITE™ walkway. Following this, three 20-second data collections were completed, with approximately 1 min between collections where participants continued to walk on the treadmill. Participants were blinded to collection intervals. After completion, all retro-reflective skin surface markers were removed and a resting muscle activity trial (EMG subject bias) was recorded with the participant lying supine. Electrodes were subsequently removed.