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Knee motion and muscle activation patterns are altered in hip osteoarthritis: The effect of severity on walking mechanics

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ABSTRACT

Background: Knee function is impaired in individuals with moderate hip osteoarthritis. How this extends to those undergoing total hip arthroplasty is unknown despite the common requirement for knee arthroplasty in this population. The study purpose was to determine whether sagittal plane knee joint movements and quadriceps and hamstring activation patterns differ between individuals with either moderate or severe unilateral hip osteoarthritis, and between ipsilateral and contralateral knees.
Methods: 20 individuals with moderate osteoarthritis and 20 with severe osteoarthritis were recruited. Sagittal knee motion and surface electromyograms from the hamstrings and quadriceps were collected during treadmill walking at a self-selected speed. Principal component analysis captured amplitude and temporal sagittal plane motion and EMG waveform features. Student's *t*-tests and Analysis of Variance determined between group differences and within/between group leg differences.
Findings: The severe groups' contralateral knee was in greater flexion at initial contact and demonstrated a movement profile of a longer stance phase ($p < 0.001$). The severe group had reduced sagittal plane knee motion ($p < 0.0001$); more so in the ipsilateral knee ($p < 0.0001$). The severe group had greater hamstring ($p = 0.009$) and quadriceps activation ($p < 0.001$) overall, specifically mid-stance quadriceps bilaterally ($p = 0.002$). Ipsilateral sagittal plane knee motion was reduced in both groups. Compared with those with moderate osteoarthritis, individuals with severe osteoarthritis walk with reduced sagittal plane knee motion bilaterally, suggesting prolonged contralateral stance, and elevated mid-stance hamstring and quadriceps activation.
Interpretation: Altered kinematics and muscle activity could contribute to a greater mechanical demand on the contralateral knee in those with more severe hip osteoarthritis.

1. Introduction

Osteoarthritis (OA) is a common, debilitating disease and is the most prevalent, chronic musculoskeletal disease and cause of disability in the elderly (Egloff et al., 2012). Hip and knee joint arthroplasty is increasingly required to ensure continued mobility and quality of life (Litwic et al., 2013) in individuals with severe OA. These treatment options are considered for end-stage disease, however OA often develops years before these treatments are necessary.

In hip OA, ambulatory mobility is impaired and characteristic hip joint impairments exist. The most common gait impairment is found to be reduced sagittal plane hip movement, focused primarily on reduced extension found in those with moderate OA (Eitzen et al., 2012; Ornetti et al., 2011) and even more limited in individuals with severe OA (Rutherford et al., 2015a). Concurrent with altered kinematics, in individuals with severe OA, greater gluteus maximus and medius activity is found in mid-stance of gait (Rutherford et al., 2015a), and increased gluteus medius activity during functional activities (e.g. Stair ascent/descent), compared with healthy individuals (Dwyer et al., 2013). Collected, a clearer understanding of hip mechanics associated with the hip OA process is emerging; however, less certain are the implications of these alterations on other lower extremity joints.

Contralateral knee loads, as measured indirectly using the knee adduction moment during gait, are found to be greater when compared to ipsilateral knee loads in individuals with unilateral hip OA (Schmidt et al., 2017; Shakoor et al., 2003). Using a statically determinate muscle

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model to predict peak medial compartment forces in the knee during gait, Shakoor et al. (2003) found significantly higher contralateral knee forces compared to ipsilateral. These data support the mechanical rationale for greater chances of requiring a contralateral over an ipsilateral knee replacement, following a primary unilateral hip arthroplasty (Gillam et al., 2013; Sayeed et al., 2009). In earlier disease, the story is less clear. Sagittal plane knee motion and moments are reduced ipsilaterally (Eitzen et al., 2012) and bilaterally (Rutherford et al., 2015b) with concomitant patterns of elevated quadriceps activity during mid-stance. Together, these data support that contralateral knee mechanics are altered in individuals with hip OA, yet the integration of muscle activation is less known; an important component given the role of muscle forces for knee cartilage health (Abusara et al., 2016). Previous work has investigated knee motion and muscle activation in individuals with moderate hip OA compared to an asymptomatic group (Rutherford et al., 2015b). Further work is required to ascertain whether knee mechanics and muscle activation differences exist in those with severe hip OA awaiting total hip replacement.

The study objective was to determine whether sagittal plane knee joint movements and quadriceps and hamstring activation patterns differ between individuals with unilateral symptomatic hip OA considered for conservative treatment (Symptomatic Moderate OA (MOA)) and individuals awaiting total hip arthroplasty (Symptomatic Severe OA (SOA)), and whether there is a difference between the ipsilateral and contralateral knees. It was hypothesized that individuals with SOA will present with less knee range of motion throughout the gait cycle compared to MOA group and on the ipsilateral leg compared to contralateral. No differences will be found between limbs in the MOA group. Given altered knee movement strategies during mid to late stance, greater and more prolonged quadriceps and hamstring activation will be found during mid-stance on the ipsilateral side compared to contralateral in the SOA group, while no changes between limbs will be found in the MOA group.

2. Methods

2.1. Participants

For this cross-sectional research study, participants with unilateral symptomatic hip OA were recruited from orthopedic clinics after consultation with an orthopedic surgeon. Participants were either: 1) under conservative OA management (MOA group) and not candidates for surgery; or 2) were awaiting hip arthroplasty for OA (SOA group). Individuals in the MOA group also self-reported their ability to walk more than a city block, climb stairs and jog 5 m as per previous classification of hip MOA (Rutherford et al., 2015a,b) where as individuals with SOA reported inability with one or more of these tasks. Hip OA was categorized using the American College of Rheumatology (ACR) criteria (Altman, 1991). Standard A/P pelvis and lateral radiographs were used to identify radiographic severity. An experienced reader (IW) graded hip radiographs, using the Kellgren–Lawrence (KL) ordinal radiographic scale (Kellgren and Lawrence, 1957). IW was blinded to subject identification and gait analysis outcomes at the time of scoring. Radiographs were not used to classify OA severity. All participants were required to be ≥ 50 years of age, have no previous injury other than a sprain or strain within the last year, and have no previous knee or hip joint surgery. Participants had to be able to walk independently, with no medical disorders other than hip OA that could impair walking ability. Participants were excluded if knee symptoms were present that indicated knee OA based on ACR criteria. The local institutional ethics review committee approved the protocol (Romeo # 1014555) and all subjects provided written informed consent.

2.2. Procedures

Participants completed the Hip Outcome Osteoarthritis Score (HOOS) (Scored based on instructions provided at www.koos.nu on sections of Pain, Symptoms, Activities of Daily Living and Quality of Life were 0 indicates extreme problems and 100 indicates no problems). Height and mass were recorded. All participants completed at least five self-paced walking trials across the GaitRITE™ portable pressure sensitive walkway (CIR Systems, Clifton, USA) to determine average self-selected gait speed. This 0.6 m × 5.4 m walkway is a valid tool for measuring temporal and spatial gait characteristics (Bilney et al., 2003).

Participants were prepared for surface electromyography (EMG). Consistent with SENIAM guidelines (Hermens et al., 2000), vastus medialis (VM), vastus lateralis (VL), medial (MH) and lateral (LH) hamstring electrode locations were marked with ink. Skin was shaved and cleaned with 70% alcohol wipes and Ag/AgCl surface electrodes (10 mm diameter, 30 mm inter-electrode distance, Red Dot, 3 M Health Care, St. Paul, USA) were placed in a bipolar configuration. Muscle palpation and isometric contractions for specific muscle groups were used for signal validation and gain adjustment. Surface EMG was recorded at 2000 Hz using an AMT-8™ Bortec system (Bortec Inc. Calgary, Canada) (Input Impedance: 10 GΩ, CMRR: 115 dB at 60 Hz, Band-pass (10–1000 Hz), Gain Range 500–5000) and custom LabVIEW™ 2013 programs (National Instruments Corporation, Austin, USA).

Rigid sets of four retro-reflective markers were affixed to the pelvis (atop the sacrum), and bilateral lateral femur and tibia using Velcro straps, secured with tape. Single retro-reflective markers were placed laterally over the shoulders (below acromion), 7th cervical vertebra, greater trochanters, medial and lateral femoral and tibial epicondyles, medial and lateral malleoli, head of the 5th metatarsals, and posterior heels. Prior to gait analysis, a kinematic model calibration was completed, including a standing calibration trial, a virtual sternum and two virtual Anterior Superior Iliac Spine location trials. Retro-reflective skin marker motion was captured at 50 Hz using four Qualisys® Pro-reflex motion analysis sensors (Gothenburg, Sweden). Markers over the greater trochanters, medial tibial and femoral epicondyles, lateral tibial epicondyles and medial malleoli were then removed. Motion capture methods have been described previously (Rutherford et al., 2015a,b).

Participants walked barefoot on the treadmill at the self-selected GaitRITE™ walkway speed for at least 5 min, followed by a 20-second data collection. Participants walked continually and were blinded to collection time. After completion, markers were removed and a resting muscle activity trial (EMG subject bias) was recorded with the participant supine. Electrodes were subsequently removed.

2.3. Data analysis

Raw EMG signals were processed to minimize the effects of treadmill noise contamination. Signals were band pass filtered (4th order Butterworth) with a pass band from 20 to 500 Hz (De Luca et al., 2010) and (ii) band-stop filtering at 60 Hz (and harmonics) in the frequency domain (using Fast Fournier Transformation, FFT and following inverse FFT) as previous (Rutherford et al., 2015a,b). All EMG signals were corrected for resting bias, converted to micro-volts, full-wave rectified and filtered using a Butterworth, 6 Hz recursive, 4th order, low-pass filter to create a linear enveloped signal (Rutherford et al., 2015a,b). All EMG waveforms were amplitude normalized to the maximum EMG amplitude obtained for each muscle during the gait cycle (Burden, 2010).

Technical and local anatomical bone embedded coordinate systems for the pelvis, thigh, and shank were derived from virtual points and skin markers. The rigid plates were tracked during the walking trials. Joint angles were calculated using a 6-degree of freedom model through Cardan/Euler rotations (z–y–x sequence), where knee joint flexion occurred about the z-axis (Rutherford et al., 2015b). For heel strike detection, a kinematic method was used (Zeni et al., 2008). Knee joint angles and EMG were time normalized to 100% of the gait cycle (i.e. 101 data points representing heel strike to ipsilateral heel strike) using a cubic spline interpolation technique. All signal processing and