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Hip abductor function in individuals with medial knee osteoarthritis: Implications for medial compartment loading during gait

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ABSTRACT

Background: Hip abductor muscles generate moments of force that control lower extremity frontal plane motion. Strengthening these muscles has been a recent trend in therapeutic intervention studies for knee osteoarthritis. The current study investigated the relationship between hip abductor muscle function (strength and activation) and the net external knee adduction moment during gait in those with medial compartment knee osteoarthritis.
Methods: 54 individuals with moderate knee osteoarthritis walked at their self-selected velocity while gluteus medius electromyograms, segment motions and ground reaction forces were recorded. Net external knee adduction moment (KAM) and linear enveloped electromyographic profiles were calculated. Peak KAM was determined and then principal component analyses (PCA) were applied to KAM and electromyographic profiles. Isometric hip abductor strength, anthropometrics and gait velocity were measured. Multiple regression models evaluated the relationship between walking velocity, hip abductor strength, electromyographic variables recorded during gait and KAM waveform characteristics.
Findings: Minimal peak KAM variance was explained by abductor strength ($R^2 = 9\%$, $P = 0.027$). PCA-based KAM waveform characteristics were not explained by abductor strength. Overall gluteus medius amplitude (*PP1-scores*) was related to a reduction in the bi-modal KAM (*PP3-scores*) pattern ($R^2 = 16\%$, $P = 0.003$).
Interpretation: There was no clear relationship between hip abductor muscle strength and specific amplitude and temporal KAM characteristics. Higher overall gluteus medius activation amplitude was related to a sustained KAM during mid-stance. 84 to 90% of the variance in KAM waveform characteristics was not explained by hip abductor muscle function showing hip abductor muscle function has minimal association to KAM characteristics.

1. Introduction

Gait mechanics are central to understanding joint loading in knee osteoarthritis (OA) (Andriacchi et al., 2004). Of particular interest is the net external knee adduction moment (KAM), a surrogate measure of medial compartment loading. This moment is highly correlated ($R^2 = 0.77$) to *in vivo* medial contact loads (Zhao et al., 2007) where greater magnitudes have been related to medial compartment cartilage and bone defects (Creaby et al., 2010), lower cartilage thickness (Andriacchi et al., 2004; Bennell et al., 2011) and poor clinical outcomes (Wang et al., 1990) in individuals with knee OA. Longitudinal studies have found increased odds of medial compartment structural OA progression associated with higher baseline peak KAM (Miyazaki et al., 2002) and KAM impulse (Bennell et al., 2011). While gait related factors, such as reduced walking velocity have been suggested as a way to reduce peak KAM (Mundermann et al., 2004), a recent focus has been on hip abductor muscle-strengthening protocols as a method to alter gait mechanics, specifically the peak KAM (Bennell et al., 2010; Foroughi et al., 2011; Sled et al., 2010; Thorp et al., 2010). Three studies, including randomized control (Bennell et al., 2010; Foroughi et al., 2011) and clinical trials (Sled et al., 2010), found that hip abductor muscle resistance training improved hip abductor strength and reduced symptoms, but no significant differences were found in the peak KAM during gait.

A paper by Chang et al. (2005)) found that greater peak net internal hip abduction moments reduced the odds of medial compartment knee structural progression provided the rationale for the hip abductor strengthening focus. Chang et al. (2005) and Mundermann et al. (2005) theorized that low peak hip abductor moments reflected decreased hip abductor muscle strength and hence an inability to control frontal plane hip motion which in turn could impact the KAM by changing the location of the ground reaction force vector. Neither hip abductor activation nor strength was investigated in either study (Chang et al., 2005; Mundermann et al., 2005). While the hip abductors can produce a moment in the frontal plane (Neumann, 2010) and these muscles are active during gait (Rutherford and Hubley-Kozey, 2009; Winter and Yack, 1987), there was no significant relationships found between hip

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adduction moment features normalized to body mass (Nm/kg) during walking and hip abductor strength or peak activation levels (Rutherford and Hubley-Kozey, 2009). Specifically, 52% of the variance in the initial peak hip adduction moment was explained by walking velocity and no variables in the model explained the mid-stance magnitude. What has not been established however is the link between hip abductor muscle function (strength/activation) and KAM features; two factors considered biomechanical targets for conservative management in individuals with knee OA.

The peak KAM typically occurs during early stance in healthy controls and those with mild to moderate OA, a period of the gait cycle where the gluteus medius (GM) is most active (Rutherford and Hubley-Kozey, 2009; Semciw et al., 2013; Winter and Yack, 1987). These muscles are also activated during mid-stance, a period of gait characterized by single-leg stance. Typically, mid-stance knee adduction moment amplitudes reduce or "unload" (Newell et al., 2008) a feature not evident for those with severe OA (Rutherford et al., 2008) and more recently found to be associated with progression to total knee arthroplasty (Hatfield et al., 2013). Whether hip abductor muscle strength or GM activation features are related to dynamic KAM features during specific phases of the gait cycle has not been established. Despite this equivocal evidence, exercise programs, which include hip abductor strengthening, are recommended in knee OA rehabilitation (Fernandes et al., 2013). Determining whether hip abductor muscle function (strength and/or activation) relate to the KAM dynamic waveform characteristics would shed light on its potential effectiveness as a biomechanical target for conservative management.

The present study investigated the relationship between hip abductor muscle function (strength and activation) and KAM characteristics during gait in individuals with knee OA. The objectives were two fold. To determine the contribution of hip abductor strength, GM activation patterns captured during self-selected gait, and gait velocity to the variance in i) the peak KAM and ii) the KAM waveform features derived from principal component analysis. Based on the current literature, we hypothesize that hip abductor strength will not explain a significant portion of the variance in the peak KAM or magnitude characteristics from PCA. We also hypothesize that GM activation amplitudes and temporal patterns will be associated with KAM amplitudes and temporal patterns.

2. Methods

2.1. Subject selection

Participants with unilateral symptomatic knee OA ($n = 54$) were recruited from the caseload of one orthopedic surgeon (WDS). Knee OA was diagnosed using the American College of Rheumatology guidelines (Altman, 1991). Standard anterior/posterior radiographs confirmed predominant medial compartment radiographic disease presence and were scored using the Kellgren-Lawrence global scoring scale (Kellgren and Lawrence, 1957). All participants met a functional status based on self-report ability to i) reciprocally ascend and descend 10 stairs, ii) safely walk one city block, and iii) jog five meters and were not candidates for total knee arthroplasty (Hubley-Kozey et al., 2006). Participants were over 40 years of age, had no previous injury other than a sprain or strain and were excluded if cardiovascular/respiratory disease or neurological disorders were present that affected their ability to complete the data collection protocol safely. Written informed consent was provided in accordance with the Research Ethics Board.

2.2. Gait analysis

Height and mass were recorded. Circular electrodes (Ag/AgCl, 10 mm diameter, 0.79 cm^2 surface area, 20 mm inter-electrode distance) were placed in a bipolar configuration on the skin in the direction of GM muscle fibers based on SENIAM guidelines (surface electromyography for the non-invasive assessment of muscles), after lightly shaving and cleaning with isopropyl alcohol wipes. A reference electrode was placed on the anterior tibia shaft. Ipsilateral and contralateral isometric hip abduction in single leg stance was performed for validation of electrode placement to evaluate crosstalk (Winter et al., 1994) and to set appropriate gains to maximize signal amplitude. At least 20 minutes elapsed before recordings were made. Electrodes, preamplifiers and lead wires were further secured with adhesive tape and Lycra/spandex shorts.

Infrared emitting diode (IRED) skin surface markers were affixed to the lateral aspect of the lower extremity. This marker cluster and the motion capture procedures have been previously described (Landry et al., 2007). Triangular sets of IRED markers were secured to the foot, tibia, femur and pelvis. Single IRED skin surface markers were placed on the lateral malleolus, lateral epicondyle of the femur, greater trochanter and the lateral aspect of the shoulder. After a standing calibration trial, the digitization of eight virtual points on predefined anatomical landmarks was completed, including right and left anterior superior iliac spines, medial epicondyle of the femur, fibular head, tibial tuberosity, medial malleolus, base of the second metatarsal and center of the posterior calcaneus.

Lower extremity motion during gait was captured in three-dimensions at 100Hz using two optoelectronic motion analysis sensors (Optotrak™, Northern Digital Inc., Waterloo, ON, Canada). Three-dimensional ground reaction forces were recorded from a single force plate (AMTI™, Advanced Mechanical Technology Incorporation, Newton, MA, USA) at 1000Hz that was aligned to the global coordinates of the motion capture system. The electromyogram of GM was recorded using an AMT-8 (Bortec, Inc., Calgary, AB, Canada) eight channel EMG measurement system (Input Impedance: ~10GΩ, CMRR: 115 dB at 60 Hz, Band-pass (10–1000 Hz)). All EMG signals were analog to digitally converted at 1000Hz (16bit, +/- 2 V) using the analogue data capture feature of the Optotrak™ system and stored for processing.

Participants were instructed to walk at their self-selected velocity along a six-meter walkway. After three familiarization trials, at least five walking trials were collected. Velocity was monitored during the data collections with a photo-electric timing component, positioned at known distances on the walkway. Walking trials that differed by greater than 10% of average self-selected speed were re-collected. Velocity was calculated for the analysis using marker positional data at the time of force plate contact and gait cycle completion.

2.3. Hip abductor strength and electromyogram amplitude normalization

Hip abductor strength and maximal GM activity were measured using two maximal voluntary isometric contractions (MVIC). A Cybex™ Isokinetic dynamometer (Lumex, NY, USA) recorded the isometric torque produced by the hip abductor musculature. Participants were positioned in side-lying on a secure, height adjustable exercise table (Rutherford and Hubley-Kozey, 2009). On a small subset ($n = 19$) of the larger sample, which completed testing on two occasions within approximately one month, we found excellent between-day (average five weeks) reliability for this exercise ($ICC_{2,1} = 0.91$ (95% $CI = 0.79, 0.97$)). The lever arm pad was positioned and secured on the distal femur. After one practice trial and gravity correction trial, two maximum isometric hip abduction trials were collected, separated by a 60-second rest period. Participants were instructed to abduct their lower limb into the lever arm pad and hold for three-seconds while minimizing movement in the sagittal and transverse plane. Standardized instructions and verbal encouragement were given to maximize effort.

2.4. Data processing

Data processing was completed using custom programs written in MatLab™ version 7.1 (The Mathworks Inc., Natick, MA, USA). Technical and local anatomical bone embedded coordinate systems for the thigh, tibia and foot were derived from the skin surface markers and digitized