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Acetabular cartilage defects cause altered hip and knee joint coordination variability during gait

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ABSTRACT

Background: Patients with acetabular cartilage defects reported increased pain and disability compared to those without acetabular cartilage defects. The specific effects of acetabular cartilage defects on lower extremity coordination patterns are unclear. The purpose of this study was to determine hip and knee joint coordination variability during gait in those with and without acetabular cartilage defects.

Methods: A combined approach, consisting of a semi-quantitative MRI-based quantification method and vector coding, was used to assess hip and knee joint coordination variability during gait in those with and without acetabular cartilage lesions.

Findings: The coordination variability of the hip flexion–extension/knee rotation, hip abduction–adduction/knee rotation, and hip rotation/knee rotation joint couplings were reduced in the acetabular lesion group compared to the control group during loading response of the gait cycle. The lesion group demonstrated increased variability in the hip flexion–extension/knee rotation and hip abduction–adduction/knee rotation joint couplings, compared to the control group, during the terminal stance/pre-swing phase of gait.

Interpretation: Reduced variability during loading response in the lesion group may suggest reduced movement strategies and a possible compensation mechanism for lower extremity instability during this phase of the gait cycle. During terminal stance/pre-swing, a larger variability in the lesion group may suggest increased movement strategies and represent a compensation or pain avoidance mechanism caused by the load applied to the hip joint.

1. Introduction

Altered gait patterns have been observed in individuals with hip osteoarthritis (OA) (Eitzen et al., 2012; Foucher et al., 2012; Hurwitz et al., 1997, 1998; Watelain et al., 2001). Traditional methods of analyzing kinematics (i.e., Euler angles, inverse kinematics, etc.) are widely used in understanding the effects of hip joint OA on gait patterns (Eitzen et al., 2012; Foucher et al., 2012; Hurwitz et al., 1997, 1998; Watelain et al., 2001). Specifically, hip joint sagittal plane range of motion was reduced in those with hip OA when compared to healthy controls (Eitzen et al., 2012; Hurwitz et al., 1997, 1998; Kumar et al., 2015; Zeni et al., 2014). Those with hip OA also demonstrated reduced hip extension in late stance (Eitzen et al., 2012; Watelain et al., 2001; Zeni et al., 2014). The average standard deviation, used to quantify variability during the entire gait cycle, was reduced for hip and knee sagittal plane angles in those with severe hip OA (Kiss, 2010) and may indicate less flexibility (mobility) in movement strategies between hip and knee joints (Newel and Corcos, 1993). In addition, those with hip OA demonstrated significantly greater hip internal rotation and adduction compared to healthy controls during gait (Watelain et al., 2001).

Although valuable, these traditional kinematic analyses in isolation do not allow for an understanding of the joint coupling mechanisms that are involved in healthy or pathological gait. Vector coding is a simple method of assessing position data and quantifies the variability in the coordinative structures within or between joints or segments during performance of a dynamic task (Sparrow et al., 1987). Modified versions of the vector coding method have been used to study coordination patterns in walking (Chang et al., 2008) and running (Heiderscheit et al., 2002). Vector coding was suggested to be a clinically useful tool that is able to analyze and draw conclusions on joint position data (Miller et al., 2010). In addition, analysis of joint coordination patterns may be

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more sensitive to subtle changes in motion patterns compared to traditional joint kinematic analyses (Armour Smith et al., 2014). Joint coordination variability has been studied in gait of healthy individuals (Armour Smith et al., 2014; Barrett et al., 2008; Chang et al., 2008), yet this type of analysis has not been used to understand the gait patterns of those with hip joint OA.

Assessment of hip joint OA using magnetic resonance imaging (MRI) provides significant additional information beyond that provided by standard radiographs, particularly in the early phases of the disease. MRI allows for direct visualization of cartilage and other joint structures that are critical in understanding the OA disease process (Kumar et al., 2013; Morgenroth et al., 2014). Using a semi-quantitative MRI-based quantification method (Lee et al., 2014), it was shown that acetabular cartilage lesions in those with hip OA were associated with greater pain and disability compared to those with other types of hip joint abnormalities (Kumar et al., 2013). This suggests that acetabular cartilage lesions hold greater clinical significance than other hip joint abnormalities such as femoral cartilage lesions, bone marrow edema, and labral tears (Kumar et al., 2013). Despite a greater amount of pain and disability, measures of physical performance did not demonstrate any significant relationships with MRI-based findings and suggest that further analysis is needed to evaluate the relationships between hip MRI abnormalities and hip joint movement patterns (Kumar et al., 2013). Also, weak associations between acetabular cartilage lesions and gait parameters were observed and suggest that a study with a larger sample size is needed to confirm these findings (Kumar et al., 2015). Therefore, it may be possible that traditional planar kinematic analyses may not be sensitive enough to detect changes that may occur with pathologies such as acetabular cartilage lesions.

An analysis combining MRI-based determination of acetabular cartilage lesions and coordination variability may help researchers and clinicians to better understand the pathophysiology of hip OA and potentially how this could be modified. Therefore, the purpose of this study was to use vector coding to examine lower extremity hip and knee joint coordination variability during gait between individuals with and without acetabular cartilage lesions. It was hypothesized that individuals with acetabular cartilage lesions would demonstrate decreased joint coordination variability during the stance phase of gait compared to those without acetabular cartilage lesions.

2. Methods

2.1. Participants

These are retrospective analyses from the baseline data of an ongoing longitudinal observational study on hip OA. Participants in this study were recruited from the community using flyers and advertisements. Weight-bearing anterior–posterior radiographs of each participant were analyzed using the Kellgren–Lawrence (KL) score (Kellgren and Lawrence, 1957), and a KL score was determined for each hip joint. The hip joint with the higher KL score was selected as the “index” hip and was used for testing in this study. Participants were classified as those with mild-moderate radiographic hip OA (KL grade 2 or 3) and without radiographic hip OA (KL grade 0 or 1). A total of 93 participants were recruited for this study. Since previous studies using vector coding to analyze the effects of radiographic hip OA have not been performed, previously published data on hip sagittal plane excursion in those with (KL grade 2 or 3) and without (KL grade 0 or 1) radiographic hip OA (Kumar et al., 2015) was used as inputs into a power analysis. The power analysis performed in the current study used an alpha and a power of 0.05% and 95%, respectively. The power analysis indicated a minimum of 38 participants per group were needed. Participants were excluded if they presented with any of the following: contraindication to MRI imaging, hip KL grade greater than 3, total joint replacement of any lower extremity joint, previous hip joint trauma, pain at any other lower extremity joint, any spine or lower extremity conditions that would limit or affect their ability to perform the dynamic tasks of the data collection, and any radiographic indications of knee or ankle joint OA. All participants provided informed consent prior to participation in the study. This study was approved by the university committee on human research.

In addition, each participant's self-reported measure of pain and activities of daily living (ADL) were assessed using the Hip Disability and Osteoarthritis Outcome Score (HOOS) (Nilsdotter et al., 2003). The HOOS was demonstrated to be a reliable and valid measure of overall hip joint function in people with OA (Nilsdotter et al., 2003). These scores were based on a scale of 0 to 100, with 0 representing worse hip pain or function and 100 representing no hip pain or function issues.

2.2. MRI acquisition and analysis

MRI acquisition was performed using a 3-T MRI scanner (GE MR750, GE Healthcare, Waukesha, WI, USA) and an eight-channel cardiac coil (GE Healthcare, Waukesha, WI, USA). Participants were positioned supine and immobilized using straps in order to ensure a consistent and comfortable position (Supplementary Fig. 1). The participants' feet were stabilized in order to prevent any type of movement during the scan. The imaging parameters and protocol used in this study to obtain MR images of the hip joint have been previously described (Kumar et al., 2013; Lee et al., 2014) and are explained here briefly. Sagittal, oblique coronal, and oblique axial orientated images using an intermediate-weighted, fat-suppressed, fast spin-echo (FSE) sequence were obtained with a repetition time (TR) of 2400–3700 ms, echo time (TE) of 60 ms, field of view of 14–20 cm, matrix size of 288x224, and slice thickness of 3–4 mm.

Using the semi-quantitative MRI-based SHOMRI quantification method (Lee et al., 2014), the acetabular cartilage layer was divided into 4 subregions and scored using a 3-point scale, where a score of 0, 1, and 2 indicate no loss, partial thickness loss, and full thickness loss, respectively. The four subregions of the acetabulum included the anterior, posterior, superomedial, and superolateral portions of the acetabulum cartilage layer (Supplementary Fig. 2). The anterior and posterior regions of the acetabulum were defined as the anterior and posterior 1 cm of the femoral head using the sagittal plane images. The mid-portion of the acetabular region was defined using the sagittal plane image and divided into a superolateral and superomedial region, moving from the lateral to medial direction, using the coronal plane images. The anterior and posterior acetabulum regions were scored on the sagittal plane images, while the superolateral and superomedial regions were scored using the coronal plane images. Participants with an acetabular cartilage score greater than 0 in any of the 4 acetabular subregions were considered to have an acetabular cartilage lesion and were included into the acetabular lesion group (LG), while participants with no acetabular cartilage lesions were included into the non-acetabular lesion group (NG).

2.3. Gait data acquisition and processing

Three-dimensional position data were collected at 250 Hz using a 10-camera motion capture system (VICON, Oxford, UK), and kinetic data were collected synchronously at 1000 Hz using force platforms (AMTI, Watertown, MA, USA). A marker set consisting of 41 retro-reflective markers was used to collect three-dimensional position data (Kumar et al., 2014, 2015). Specifically, fifteen retro-reflective markers placed at anatomical landmarks on both lower extremities were used to define joint centers. Ten of the fifteen markers were used for identification of joint centers and were placed at the greater trochanters, medial and lateral femoral epicondyles, medial and lateral malleoli, and the first and fifth metatarsal heads. The remaining five markers were used to track pelvis motion and were placed at the anterior superior iliac spines, iliac crests, and at the L5/S1 joint. Additional segment tracking was performed using marker clusters, each consisting of four