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The role of knee joint moments and knee impairments on self-reported knee pain during gait in patients with knee osteoarthritis

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ABSTRACT

Background: The association between high mechanical knee joint loading during gait with onset and progression of knee osteoarthritis has been extensively studied. However, less attention has been given to risk factors related to increased pain during gait. The purpose of this study was to evaluate knee joint moments and clinical characteristics that may be associated with gait-related knee pain in patients with knee osteoarthritis.
Methods: Sixty-seven participants with knee osteoarthritis were stratified into three groups of no pain (n = 18), mild pain (n = 27), or moderate/severe pain (n = 22) based on their self-reported symptoms during gait. All participants underwent three-dimensional gait analysis. Quadriceps strength, knee extension range of motion, radiographic knee alignment and self-reported measures of global pain and function were also quantified.
Findings: The moderate/severe pain group demonstrated worse global pain ($P < 0.01$) and physical function scores ($P < 0.01$) compared to the no pain and the mild pain groups. The moderate/severe pain group also walked with greater knee flexion moments during the midstance phase of gait compared to the no pain group ($P = 0.02$). Additionally, the moderate/severe pain group demonstrated greater varus knee malalignment ($P = 0.009$), which was associated with higher weight acceptance peak knee adduction moments ($P = 0.003$) and worse global pain ($P = 0.003$) and physical function scores ($P = 0.006$).
Interpretation: Greater knee flexion moment is present during the midstance phase of gait in patients with knee osteoarthritis and moderate/severe pain during gait. Additionally, greater varus malalignment may be a sign of increased global knee joint dysfunction that can influence many activities of daily living beyond gait.

1. Introduction

Knee osteoarthritis (OA) is a prevalent musculoskeletal condition in older adults, with a reported 13.3 million cases of radiographic disease in at least one knee in the United States alone (Dillon et al., 2006). Chronic knee pain is a common complaint in patients with knee OA and has been indicated as a major cause of limitations in daily activities and an important reason for seeking medical care (Bedson et al., 2007; Jinks et al., 2007). One common functional task that is adversely affected by knee OA is the ability to walk, which reflects the capacity to undertake day-to-day activities of daily living. It has been reported that older adults with knee OA are more likely than their age- and gender-matched counterparts without knee OA to report difficulty with walking long distances, due in part to having knee pain. Additionally, walking has been suggested as an effective form of exercise to help reduce functional limitations and disability in individuals with knee OA (Roddy et al., 2005). However, it is plausible that individuals with knee OA may experience increased pain when walking for exercise. To date, research on gait mechanics in individuals with knee OA has primarily focused on gait differences between individuals with and without knee OA or varying levels of knee OA severity (Astephen et al., 2008; Baliunas et al., 2002; Chen et al., 2003). Conversely, little attention has been given to gait deviations that may be associated with increased pain during gait in this patient population.

Increased ambulatory knee joint compressive loads have been previously indicated as an important contributing factor to the pathomechanics and symptomology in knee OA (Felson, 2013). Current literature on gait biomechanics in individuals with knee OA has focused primarily on the variations in the external knee adduction moment (KAM) as a surrogate measure of the medial compartment knee joint compressive loading. Higher KAM has been previously associated with presence of medial compartment knee OA (Hurwitz et al., 2002; Mundermann et al., 2005), greater radiographic disease severity (Baliunas et al., 2002; Sharma et al., 1998) and higher rates

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of disease progression (Creaby et al., 2010; Chehab et al., 2014). Previous reports also indicate that presence of higher KAM during gait may be a risk factor for developing knee pain in the future (Amin et al., 2004). Additionally, increased KAM has been indicated as the cause of gait-related pain in patients with mild symptomatic knee OA (Thorp et al., 2007). As such, gait modification strategies aimed at minimizing KAM such as reduced gait speed, increased ipsilateral trunk lean, toe-out gait, and medial knee thrust have been advocated as potential treatment strategies for patients with knee OA (Farrokhi et al., 2013; Simic et al., 2011). However, a number of studies have also reported that gait-related knee pain is inversely correlated with KAM, suggesting that pain is a protective mechanism that leads to a self-selected reduction in KAM during gait (Henriksen et al., 2010; Schnitzer et al., 1993; Teichtahl et al., 2006; Heiden et al., 2009).

Given that patients who experience knee pain during gait walk with smaller KAM, it is plausible that their knee pain may be associated with other mechanical factors that lead to increased compressive knee joint loads. For example, an increase in the knee flexion moment (KFM) has been suggested to substantially contribute to greater knee joint contact forces despite reductions in KAM (Walter et al., 2010; Manal & Buchanan, 2013). To counterbalance the externally generated KFM, an equal and opposite internal knee extension moment is needed which is primarily produced by increases in the quadriceps muscle force that can lead to higher axial knee joint compression and elevated knee joint contact forces (Manal & Buchanan, 2013; Sasaki & Neptune, 2010). Higher KFM during gait has been previously reported in individuals with knee OA compared to OA-free individuals (Heiden et al., 2009; Gok et al., 2002; Al-Zahrani & Bakheit, 2002), with higher KFM contributing to a faster rate of disease progression (Chehab et al., 2014). To date, little information is available on the concurrent influence of KAM and KFM on gait-related knee pain in patients with knee OA.

Considerations for the potential role of common OA-related knee impairments such as quadriceps muscle weakness, limited knee extension range of motion and varus malalignment on gait-related knee pain may also be important, given the influence of these impairments on knee joint loading during gait. Quadriceps muscle weakness has been previously associated with reduced knee flexion excursions, a more rapid increase in the ground reaction forces and greater rates of lower limb loading (Mundermann et al., 2005; Cook et al., 1997; Radin et al., 1991). Limited knee extension range of motion in patients with knee OA has also been suggested to lead to greater knee flexion angles during lower extremity weightbearing, larger KFMs, and smaller excursion of knee joint contact surfaces during gait, leading to increased focal areas of knee joint contact loading (Childs et al., 2004; Farrokhi et al., 2015). Additionally, varus malalignment has been associated with increased KAM and knee pain (Hurwitz et al., 2002; Zifchock, 2011), while a reduction of varus malalignment through corrective bracing of the knee joint has shown to decrease KAM and reduce pain in patients with knee OA (Draganich et al., 2006; Gaasbeek et al., 2007).

Current literature is particularly unclear on the potential associations between presence of gait-related knee pain with ambulatory knee joint moments and the commonly observed OA-associated knee impairments in patients with knee OA. Therefore, the aims of this study were; (1) to determine if KAM and KFM are different between patients with knee OA with different levels of self-reported knee pain during gait, (2) to determine if group differences exist in the commonly observed OA-associated impairments of quadriceps muscle weakness, limited knee extension range of motion, and knee varus malalignment between patients with knee OA with different levels of self-reported knee pain during gait, and (3) to examine the strength of relationship between OA-associated impairments of the knee joint with KAM, KFM, and global measures of pain and function in patients with knee OA.

2. Methods

2.1. Participants

Biomechanical data from a subsample of 65 participants recruited as part of a randomized clinical trial of exercise therapy for knee OA (Fitzgerald et al., 2011) were utilized in this study. Participants were included if they had primary radiographic medial compartment knee OA (grades 2–4) that was more severe by at least one grade compared to the lateral compartment according to the Kellgren and Lawrence (KL) radiographic severity rating scale (Kellgren & Lawrence, 1957). For all participants, the knee in which they reported symptoms was designated as the test knee. In cases where both knees experienced symptoms, the more problematic knee, as chosen by the participant, was designated as the test knee. Participants were then stratified into three groups of patients with no pain ($n = 18$), mild pain ($n = 26$) or moderate/severe pain ($n = 21$) during gait. Self-reported knee pain during gait was evaluated from the 5 possible responses (none, mild, moderate, severe, and extreme) to the following question on the Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC) pain subscale: "How much pain have you experienced over the last week while walking on flat surfaces?" Given that no patient in our study reported "extreme" pain during gait, the highest pain category was regarded as severe pain. Additionally, the moderate and severe pain categories were combined due to the fact that only 3 patients reported having severe pain during gait. To justify combining the two groups, a sensitivity analysis was performed which demonstrated that including or excluding the data from the three participants with severe pain to those with moderate pain did not change the findings of the study.

2.2. Gait analysis

Participants walked along an 8.5 m long vinyl-tiled walkway at a self-selected pace while wearing their own walking shoes. An eight camera Vicon® (Vicon Peak—UK) 612 motion measurement system was used to capture three-dimensional motion data at a sampling rate of 120 Hz using a Plug-In-Gait marker set. Two Bertec® (Bertec Corporation, OH, USA) force platforms were used to obtain ground reaction forces at a rate of 1080 Hz which were then synchronized with the motion data. An average of five trials at each subject's self-selected gait velocity were collected and averaged with the subjects not targeting the force platforms.

2.3. Biomechanics data management

Gait analysis was performed using a custom-written code (MatLab TM version7.0, The Mathworks, Inc., Natick, MA, USA). Joint angle trajectories from the Plug-In-Gait model and ground reaction force data were low-pass filtered (Butterworth fourth order, zero phase lag) at 6 and 40 Hz, respectively. The trajectory data from the reflective markers combined with the ground reaction forces were used to calculate the external knee joint moments using inverse dynamics equations and were normalized by body mass. Lower extremity moments were then quantified for two distinct phases of the gait cycle: 1) weight acceptance as the time period between initial contact to the peak knee flexion angle during early stance, and 2) midstance as the time period starting with maximum knee flexion angle to the peak knee extension angle during the late stance phase of gait.

2.4. Knee extension strength and range of motion

The maximum voluntary isometric torque output for knee extension was measured using a Biodex System 3 dynamometer. All tests were performed with the subject seated and the knee at 60° of flexion. A minimum of 3 trials and a maximum of 6 trials were performed. After 3 trials, when a trial had a maximum torque output less than the