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Effects of toe-in angles on knee biomechanics in cycling of patients with medial knee osteoarthritis

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ABSTRACT

Background: Cycling is commonly prescribed for knee osteoarthritis, but previous literature on biomechanics during cycling and the effects of acute intervention on osteoarthritis patients does not exist. Due to their altered knee kinematics, osteoarthritis patients may be at greater risk of osteoarthritis progression or other knee injuries during cycling. This study investigated the effects of reduced foot progression (toe-in) angles on knee joint biomechanics in subjects with medial compartment knee osteoarthritis.

Methods: Thirteen osteoarthritis and 11 healthy subjects participated in this study. A motion analysis system and custom instrumented pedal was used to collect 5 pedal cycles of kinematic and kinetic data in 1 neutral and 2 toe-in conditions (5° and 10°) at 60 RPM and 80 W.

Findings: For peak knee adduction angle, there was a 61% (2.7°) and a 73% (3.2°) decrease in the 5° and 10° toe-in conditions compared to neutral in the osteoarthritis group and a 77% (1.7°) and 109% (2.4°) decrease in the healthy group for the 5° and 10° conditions, respectively. This finding was not accompanied by a decrease in pain or peak knee abduction moment. A simple linear regression showed a positive correlation between Kelgren–Lawrence score and both peak knee adduction angle and abduction moment.

Interpretation: For individuals who cycle with increased knee adduction angles, decreasing the foot progression angle may be beneficial for reducing the risk of overuse knee injuries during cycling by resulting in a frontal plane knee alignment closer to a neutral position.

1. Introduction

It has been estimated that nearly 27 million people in the USA suffer from osteoarthritis (OA) (Lawrence et al., 2008). The medial compartment of the knee is the most common site affected by OA (Lawrence et al., 2008) and has attracted much attention for treatment and symptom alleviation. Aerobic exercise is one of the more effective non-pharmacologic treatment options for OA (Hochberg et al., 2012a, 2012b; Jordan et al., 2003; Wortley et al., 2013; Zhang, 2013; Zhang et al., 2008); however, weight-bearing activities may increase joint loading and pain, which could ultimately prohibit continued participation. To address this issue, exercises such as cycling that are intended to reduce joint loading compared to weight-bearing activities are commonly recommended by prominent health organizations (AAOS, 2014; Westby, 2012; Winters). Interestingly, even though cycling is commonly recommended by these organizations, and loading to the knee joint has shown to be reduced compared to walking in an instrumented joint replacement (D'Lima et al., 2008), only a few studies exist in literature to suggest that cycling is specifically beneficial for knee OA sufferers (Mangione et al., 1999; Salacinski et al., 2012). In contrast, one community-based study performed in Iran showed that the risk of knee OA was actually increased in individuals who cycled more than 30 min per day (Dahaghin et al., 2009). This is important because a general cycling prescription for pain reduction in OA patients may be counterproductive to the patient if cycling kinematics and kinetics are not taken into account. Furthermore, anecdotal evidence from patients in our lab has suggested a lack of desire to participate in cycling because it is painful for the knees. These findings are not unreasonable considering knee injuries are the leading complaint in cycling (Dettori and Norvell, 2006; Kennedy et al., 2007).

Due to the lack of literature regarding cycling with OA, it is unclear if people with knee OA present the same cycling patterns as healthy

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individuals. In gait, it has been well established that people with OA do not present the same kinematics and kinetics as healthy individuals. Specifically, individuals with medial knee OA show increased knee varus alignment and increased peak internal knee abduction moments (KAM) compared to healthy controls (Baliunas et al., 2002; Cerejo et al., 2002; Mundermann et al., 2005). Therefore, it is possible that differences in kinematics and kinetics between healthy and OA individuals may also exist in cycling. Bailey et al. (2003) found that experienced cyclists with a history of overuse knee pain were associated with increased knee abduction angles compared to the healthy controls. Thus, knee joint malalignment during cycling may be a concern for individuals with medial knee OA because it may exacerbate OA symptoms, cause overuse injuries, or lead to other problems. If abnormal cycling kinematics and kinetics are present, corrective measures could potentially encourage normal riding patterns and reduce the chances of increased knee injuries while cycling.

During gait, the internal knee abduction moment (KAM), a surrogate measure for loading to the medial compartment of the knee (Schipplein and Andriacchi, 1991), is an important factor associated with knee OA (Baliunas et al., 2002; Cerejo et al., 2002). Simple gait modification strategies have been shown to reduce KAM (Fregly et al., 2007; Guo et al., 2007; Mundermann et al., 2008; Shull et al., 2013). Guo et al. (2007) attempted to reduce the KAM by requiring their participants to walk in an increased toe-out (foot progression) angle during walking. The results showed that participants were able to reduce their second peak KAM by 40% with a 15° increase of foot progression angle. However, no changes were noted for the first peak KAM, which is more closely related to loading response during gait and severity and progression of medial knee OA. Shull et al. (2013) attempted to reduce the KAM by having their participants walk in a toe-in foot progression angle (0.75° shank angle increase from baseline). They found that this method of walking reduced the first peak knee adduction moment by about 11%, but the second peak KAM remained unchanged. The result provides a promising yet simple method to effectively reduce the KAM during walking and may be a potential solution for reducing the KAM during cycling in the medial knee OA population.

To our knowledge, no studies have explored the effects of limb alignment alterations on the internal knee abduction moment of medial knee OA patients during cycling. Changes in lower extremity alignment using an increased toe-in foot progression angle could alter the frontal plane kinematics by placing the knee in a more medial position (Shull et al., 2013). This alignment change would decrease the length of the frontal plane moment arm of the pedal reaction force to the knee joint center, thus decreasing the KAM. Previous literature has also suggested that the sagittal plane (Walter et al., 2010) and transverse plane (Boyd et al., 1997; Ruby and Hull, 1993) knee moments may be important variables for knee injuries.

Therefore, the primary purpose of this study was to investigate the effects of changes in toe-in foot progression angles on peak knee adduction angle, peak KAM, and pain in subjects with medial compartment knee OA during stationary cycling. It was hypothesized that toe-in foot progression angles would reduce the peak knee adduction angle, the peak KAM, and subjective knee pain in subjects with medial knee OA during stationary cycling compared to a neutral foot position. Additionally, increased toe-in foot progression angle would have greater effects on medial knee OA patients compared to healthy controls.

2. Methods

2.1. Participants

Eleven healthy male and female participants [age: 50.0 (9.7) years, height: 1.75 (0.12) m, weight: 80.17 (23.13) kg, BMI: 25.9 (5.4) kg/m^2] and thirteen participants with knee OA [age: 56.8 (5.2) years, height: 1.80 (0.14) m, weight: 83.2 (22.3) kg, BMI: 26.6 (3.6) kg/m^2] between the ages of 35 and 65 years volunteered for participation in this study. Each participant with OA had medial compartment tibiofemoral OA in either one or both of their knees. To be included in the study, the OA participants must have had at least a grade 1 on the Kellgren–Lawrence (K/L) scale (Kellgren and Lawrence, 1957) (Grade 1: $N = 5$; Grade 2: $N = 3$; Grade 3: $N = 3$; Grade 4: $N = 2$), which was diagnosed and verified with radiographs by a rheumatologist. Participants were excluded from the study if they had OA in the hip or ankle joints, had previously had a lower extremity joint replacement, had knee joint arthroscopic surgery or intra-articular injections within 3 months prior to testing, had systemic inflammatory arthritis such as rheumatoid or psoriatic arthritis, or had lower back pain that referred to the lower limbs. The participants were not excluded from the study if they had additional patellofemoral OA or OA in the lateral compartment of their knee(s). All OA subjects must have been experiencing pain the majority of the days of the week, for at least the previous 6 months. Subjects were asked to cease pain medication use at least 2 days prior to study participation (this only occurred in 1 subject). The healthy participants were pain free in their lower extremities for at least 6 months prior to the study and were not diagnosed with any type of lower extremity OA. All participants must have had a BMI of no more than 35 kg/m^2 and must have been able to walk and ride a stationary bike without aid. Biking experience was not controlled in this study, but only 2 participants (one male and one female) reported riding a bike on a regular basis. Each participant gave informed consent and the study was approved by the Institutional Review Board.

For the X-rays, the OA participants were in a bilateral standing position with a semi-flexed knee while anterior/posterior radiographs of both knees were taken in frontal plane (Buckland-Wright et al., 2004). Additionally, a sagittal plane radiograph of each knee was taken while the participant stood in a semi-flexed knee position to determine the presence of patellofemoral OA.

2.2. Instrumentation

A nine-camera motion analysis system (240 Hz, Vicon Motion Analysis Inc., UK) was used to acquire three-dimensional (3D) kinematics during the cycling test. The participants wore tight fitting spandex shorts and a T-shirt. To identify joint centers, anatomical markers were placed bilaterally on the 1st and 5th metatarsals, medial and lateral malleoli, medial and lateral epicondyles, left and right greater trochanters, left and right iliac crests, and left and right acromion processes. A semi-rigid thermoplastic shell with four noncollinear tracking markers affixed was attached to the trunk, pelvis, thighs, and shanks using hook and loop wraps. Three individual markers were placed on the posterior and lateral side of heel counter of standard lab shoes (Noveto, Addidas).

A cycle ergometer (Excalibur Sport, Lode, Groningen, Netherlands) was used during testing. The ergometer was electro-mechanically braked, which allowed for a precise workload setting that was independent of the pedal cadence. Additionally, the ergometer had removable pedals and had the capability of adjusting the seat and handlebar to fit each rider.

A customized instrumented bike pedal was used on the cycle ergometer, which allowed recordings of 3D pedal reaction forces (PRF) and moments using two 3D force sensors (Type 9027C, Kistler, Switzerland) connected with two charge amplifiers (Type 5073A and 5072A, Kistler, Switzerland). The sensors could be placed in either the left or right pedal, depending on the desired limb to be analyzed. A dummy pedal with the same mass and design was used on the opposite side. The pedal reaction forces and 3D kinematics were recorded through the Vicon Nexus system simultaneously.

2.3. Experimental protocol

Upon arrival to the laboratory, each participant filled out a Knee Osteoarthritis Outcome Score (KOOS) survey for each of their knees to