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Analysis of muscle activation patterns during transitions into and out of high knee flexion postures

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ABSTRACT

Increased risk of medial tibiofemoral osteoarthritis (OA) is linked to occupations that require frequent transitions into and out of postures which require high knee flexion (>90°). Muscle forces are major contributors to joint loading, and an association between compressive forces due to muscle activations and the degeneration of joint cartilage has been suggested. The purpose of this study was to evaluate muscle activation patterns of muscles crossing the knee during transitions into and out of full-flexion kneeling and squatting, sitting in a low chair, and gait. Both net and co-activation were greater when transitioning out of high flexion postures, with maximum activation occurring at knee angles greater than 100°. Compared to gait, co-activation levels during high flexion transitions were up to approximately 3 times greater. Co-activation was significantly greater in the lateral muscle group compared to the medial group during transitions into and out of high flexion postures. These results suggest that compression due to activation of the medial musculature of the knee may not be the link between high knee flexion postures and increased medial knee OA observed in occupational settings. Further research on a larger subject group and workers with varying degrees of knee OA is necessary.

1. Introduction

Osteoarthritis of the knee is a debilitating and costly disease that is becoming increasingly more prevalent (Hunter, 2011). Knee osteoarthritis occurs as the result of both biochemical and mechanical factors (Griffin and Guilak, 2005). There is strong evidence to suggest that occupations involving high knee flexion activities – movements that require greater than 90° of knee flexion – pose an increased risk for the development of both tibiofemoral and patellofemoral knee osteoarthritis (Anderson and Felson, 1988; Coggon et al., 2000; Cooper et al., 1994; Teichtahl et al., 2010). The relationship has been shown for both men and women and across different occupations, including miners, carpenters and agricultural workers (Coggon et al., 2000; Cooper et al., 1994; Teichtahl et al., 2010), with additional reports suggesting an association between musculoskeletal pain in the knee and high-flexion postures for child-care workers (Grant et al., 1995; Horng et al., 2008). Although exposures to cyclical loading are necessary for the maintenance of healthy cartilage (Griffin and Guilak, 2005), elevated risk of the development of knee OA has been linked to workers who report prolonged kneeling or squatting (>1 h per day), as well as those who are in and out of these high flexion postures (>30 cycles per day) (Coggon et al., 2000).

Currently, two primary mechanisms have been proposed to explain why repetitive knee use may increase the risk of osteoarthritis: (1) the risk of damage to the knee such as meniscal or ligament injuries may increase with prolonged periods of kneeling or squatting, and these injuries are known risk factors for knee osteoarthritis, or (2) repetitive loading may directly lead to cartilage loss (Cooper et al., 1994). In terms of osteoarthritis development through a repetitive loading mechanism, co-activation and net muscle activation of muscles crossing the knee may be used as surrogate measures of medial, lateral, and total joint compressive loading (Lewek et al., 2004), with applications in evaluating the potential risk of high knee flexion tasks. When co-activation is elevated on one side of the knee, this is termed "directed co-activation" (Sturnieks et al., 2011) and may suggest increased joint surface loading in either the lateral or medial joint compartment. However, the literature regarding the mechanics of the knee in high flexion postures is sparse, limiting our ability to distinguish how transitioning into and out of high flexion postures may promote the development of osteoarthritis.

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Recently, the role of muscle contraction around the knee joint and the effect on the development of knee osteoarthritis has been questioned (Bennell et al., 2008). It is understood that high compressive loads at the knee in obese individuals are a risk factor for knee OA (Vrezas et al., 2010), specifically in the medial compartment where higher knee adduction moments are associated with higher joint surface loading (Teichtahl et al., 2003) and the progression of medial knee OA (Miyazaki et al., 2002; Bennell et al., 2011). In addition, high tibiofemoral joint compressive forces in deep squatting activities have been reported (Steele et al., 2012; Thambyah et al., 2005). Our study focuses on muscle activation of surface musculature at the knee during repetitive, high flexion tasks that are common in occupations that have a demonstrated relationship between frequent transitions and the development of knee OA, such as kneeling, squatting, or sitting in a chair with a low seat-pan, since muscle forces are considered to be the greatest contributor to joint contact force (Herzog et al., 2003).

The objective of this study was to compare muscle activity and co-activation between transitions into and out of high knee flexion postures, including descending to and ascending from, full flexion kneeling, squatting, and sitting in low seating. Particular attention was given to the comparison between lateral and medial co-activation patterns due to the association with medial compartment loading and the onset of knee OA. These findings provided specific ranges of knee flexion angles during high flexion activities that should be the focus of future study and prevention efforts. We hypothesized that getting up from positions of high knee flexion would require greater net activation and co-activation compared to moving down into these postures due to the need to propel the body upwards against gravity from a position in which the knees are maximally flexed and in direct contact with the floor, thus requiring the largest vertical translation of the body center of mass. In addition, this study analyzed muscle activation patterns within each transition phase. We hypothesized that co-activation would be greater in the muscles on the medial side of the knee during the transition into and out of high flexion postures, resulting in increased compression in the medial compartment. This hypothesis is based on previous data that has shown that high-flexion activities contribute to increased risk of medial compartment knee OA more so than lateral compartment knee OA (Cooper et al., 1994; Coggon et al., 2000). Thus, due to the dominant role of muscle activation contribution to joint loading, we might expect that a higher incidence of medial knee OA might be due in part to greater co-activation on the medial side of the knee during high flexion tasks.

2. Methods

2.1. Participants

Twenty-two women (age: 21.4 ± 2.5 years; body mass: 67.3 ± 12.1 kg; height: 166.4 ± 8.5 cm) were recruited to participate in this study. One participant opted out of the study after instrumentation and before data collection. Individuals with known history of lower limb injuries or who were unable to squat, kneel or sit without pain were excluded. All participants were able to perform the squatting and kneeling activities with a minimum of 127° degrees of flexion. Participants provided informed consent prior to participation in accordance with the University of Waterloo Office of Research Ethics requirements.

2.2. Protocol

The study procedure consisted of four activity conditions. Participants were asked to: (1) walk along an 8.5 m walkway with a normal stride and at a self-selected pace; (2) squat with as much knee flexion as possible with heels raised and weight supported on the forefoot (Fig. 1a); (3) kneel onto both knees with maximal knee flexion and ankles dorsiflexed (Fig. 1b); and (4) sit in a chair with a low seat pan (CLASS stacking chair, Alumni Classroom Furniture, Waterloo, ON, CA) (Fig. 1c) to simulate common activities for childcare workers. Participants were required to complete the high flexion tasks with their arms crossed over their chest in order to standardize the activity between participants and to prevent interference with either the EMG or motion tracking markers. Participants were barefoot for all tasks. Prior to collection, participants were given the opportunity to familiarize themselves with the activity. Each condition was repeated 5 times and trials were excluded if markers were missing. Muscle activity and lower body joint kinematics were measured during all activities.

2.2.1. Electromyography

The EMG signals were measured using a wired amplifier system (AMT-8, Bortec, Inc., Calgary, AB, Canada) sampled at 2048 Hz with a band pass filter of 10-1000 Hz. Signal amplification was adjusted to maximize the signal without saturation. Surface electromyography (EMG) data was recorded bilaterally for the lateral gastrocnemius (LG), medial gastrocnemius (MG), vastus lateralis (VL), rectus femoris (RF), vastus medialis (VM), biceps femoris (BF) and medial hamstrings (MH). A reference electrode was placed on the ulnar styloid process bilaterally. The skin surface was prepared by shaving, abrasion (NuPrep Skin Prep Gel, Weaver and Company, Aurora, CO, USA), and cleaning with alcohol. Surface electrodes (Ambu ® Blue Sensor N, Denmark) were applied according to SENIAM guidelines (Hermens et al., 1999), with an inter-electrode distance of 2 cm. Electrode placement was verified through a series of functional tests.

All EMG data were processed through a critically damped dual-pass, high-pass filter with a 20 Hz cut-off, followed by full-wave rectification and a dual-pass, low-pass critically damped filter with a cut-off of 6 Hz. Signals were visually inspected to ensure signal quality. All EMG signals from all tasks were then normalized to the mean muscle activation level of at least three strides of gait at a self-selected pace (Arsenault et al., 1986; Layne et al., 1997; Benoit et al., 2003; Burden et al., 2003). All activities were normalized to the same reference value (mean activation of the muscle during gait) to facilitate comparison of signals between tasks. For gait trials, the task was defined from heel contact to heel contact, and for high flexion transitions, the task was defined from the point of initial kinematic movement to achievement of the final static posture. To calculate co-activation, muscles were classified in terms of knee flexors and extensors such that antagonist muscle groupings could be compared. Thus, the following normalized EMG quantities were calculated for both legs for the lateral side: VL (knee extensor) and (BF + LG) (knee flexors); and the medial side: VM (knee extensor) and (MH + MG) (knee flexors). Flexor and extensor muscles were analyzed at each data point and magnitude of muscle activation was classified as either 'higher EMG' or 'lower EMG.' Co-activation was calculated using the following equation (where n indicates the total number of data frames and i indicates an individual data frame), which takes the average of the co-activation values over the trial to give a single co-contraction index value:

$$\mathrm{CCI} = \frac{1}{n}\sum_{i=1}^{n}\frac{\text{lower EMG}_\mathrm{i}}{\text{higher EMG}_\mathrm{i}}(\text{lower EMG}_\mathrm{i} + \text{higher EMG}_\mathrm{i})$$

modified from Rudolph et al. (2000).

For example, during a simple leg extension task and analyzing the lateral musculature only, the VL would have higher activation in comparison to the knee flexors (LH + LG). Therefore, at a single