Clinical Biomechanics 30 (2015) 820–826

Contents lists available at ScienceDirect

Clinical Biomechanics

journal homepage: www.elsevier.com/locate/clinbiomech

Identifying yoga-based knee strengthening exercises using the knee adduction moment

Heather S. Longpré, Elora C. Brenneman, Ayesha L.M. Johnson, Monica R. Maly *

School of Rehabilitation Sciences, McMaster University, Hamilton, ON Canada

ARTICLE INFO

Article history:
Received 30 July 2014
Accepted 8 June 2015

Keywords:
Muscle strength
Yoga
Arthritis
Knee
Biomechanics
Electromyography

ABSTRACT

Background: This study aimed to compare muscle activations, co-contraction indices, and the knee adduction moment between static standing yoga postures to identify appropriate exercises for knee osteoarthritis.

Methods: Healthy young women (24.4 (5.4) years, 23.1 (3.7) kg/m^2) participated. Primary outcome variables were electromyographic activations of the vastus lateralis, rectus femoris, vastus medialis, biceps femoris, and semitendinosus; co-contraction between the biceps femoris and rectus femoris, and vastus lateralis and vastus medialis; and knee adduction moments of both legs during six static, standing yoga postures (two squatting postures, two lunging postures, a hamstring stretch, and a single-leg balance posture). A two-factor repeated measures analysis of variance was used to identify differences in muscle amplitudes, co-contractions, and knee adduction moment between postures and legs.

Findings: Quadriceps activations were highest during squat and lunge postures ($p \leq 0.001$). Hamstring activations were highest during the hamstring stretch ($p \leq 0.003$). Squat and lunge postures produced higher co-contraction indices than other postures ($p \leq 0.011$). The wide legged squat (Goddess) and lunge with trunk upright (Warrior) produced the lowest knee adduction moments ($p \leq 0.006$), while the single-leg balance posture elicited a higher knee adduction moment than all other postures ($p < 0.05$).

Interpretation: Squatting and lunging postures could improve leg strength while potentially minimizing exposure to high knee adduction moments. Future work should evaluate whether these exercises are useful in people with knee osteoarthritis.

1. Introduction

Quadriceps strengthening is recommended for managing knee pathologies such as osteoarthritis (OA) (Bennell et al., 2013). Increased strength, or the capacity for muscles to generate torque, reduces pain and improves function in knee OA (Bennell et al., 2013). Yoga programs, consisting of a series of physical postures, are modifiable for a variety of physical capabilities. Evidence supports low impact muscle training such as yoga to reduce knee pain and improve physical function in knee OA (Fransen and McConnell, 2008). Yoga improves strength and flexibility (Bukowski et al., 2006; Cheung et al., 2012; Ebnezar et al., 2012; Kolasinski et al., 2005), reduces the risk of cardiovascular disease (Ross and Thomas, 2010), and improves quality of life (Ross and Thomas, 2010). However, there remains a need to identify yoga postures that strengthen muscles surrounding the knee while minimizing potentially damaging knee loads. While some work has assessed the physical demands of yoga for healthy seniors, the biomechanics specific to knee OA pathology have not been explored (Wang et al., 2013).

The external knee adduction moment (KAM) represents the net medial-to-total joint distribution of load at the knee. KAM magnitude increases with knee OA severity (Foroughi et al., 2009). Large KAM at baseline was associated with greater cartilage loss after 12-months in 144 participants with radiographic knee OA (Bennell et al., 2011). Several studies recommend strategies to minimize KAM exposure during gait to avoid pain and minimize OA progression at the knee. Examples include reducing gait speed (Mündermann et al., 2004), walking barefoot (Shakoor and Block, 2006), aligning the center of mass of the body over the weight-bearing foot during single-leg stance, and externally rotating the foot (Rutherford et al., 2008). An exercise program for knee pathologies could utilize these strategies to minimize KAM exposure in an effort to limit pain and disease progression.

Loss of quadriceps strength is also implicated in the initiation and progression of symptomatic knee OA (Segal et al., 2012; Slemenda et al., 1998). Quadriceps weakness is associated with knee pain and disability (Lewek et al., 2004; O'Reilly et al., 1998; Rice et al., 2011; Slemenda et al., 1997, 1998; Zeni et al., 2010). In women, higher quadriceps and hamstring strength protected against the onset of knee OA symptoms (Segal et al., 2009). Furthermore, participation in resistance

* Corresponding author at: School of Rehabilitation Science, Institute for Applied Health Sciences, Rm 435, McMaster University, 1400 Main Street W, Hamilton, ON L8S 1C7, Canada.
E-mail address: mmaly@mcmaster.ca (M.R. Maly).

http://dx.doi.org/10.1016/j.clinbiomech.2015.06.007
0268-0033/

and aerobic exercises improved mobility in knee OA (Fransen and McConnell, 2008; Jenkinson et al., 2009; Messier et al., 2004; Roddy, 2005; Topp et al., 2002). Isometric strengthening program guidelines for people with OA suggest low to moderate intensity submaximal contractions, achieving 40%–60% of maximum voluntary contraction (MVC) of quadriceps and hamstrings (Bennell et al., 2013; Katz et al., 2001; Ratamess et al., 2009). Yoga could be an effective way to strengthen these muscle groups in knee OA.

Co-contraction of muscles crossing the knee has implications for joint stability and load. While co-activation balances pressure distribution across joint surfaces (Ebenbichler et al., 1998) and increases joint stability (Hortobágyi and DeVita, 2000; Kamen and De Luca, 1989), it can also increase joint contact forces which, in excess, are thought to contribute to degradation of the articular surfaces (Lewek et al., 2005). Increased co-contraction of agonists and antagonists is evident in knee OA (Hubley-Kozey et al., 2006; Lewek et al., 2005; Schmitt and Rudolph, 2007). Exploring the co-contraction index (CCI) is important in identifying yoga postures that limit abnormal joint loading while eliciting an adequate muscle stimulus to promote strengthening.

This study aimed to compare thigh muscle activations, co-contraction, and KAM between static yoga postures in healthy, young women. Our goal was to identify which standing yoga postures maximized quadriceps and hamstring activations while minimizing the KAM. We also calculated two co-contraction indices (agonist to antagonist, lateral to medial) to monitor whether co-contraction could contribute to larger loads on the medial knee. We hypothesized that the lunging postures would produce the highest quadriceps and hamstring activations, and minimal KAMs compared to other postures. Lunging challenges balance and strength, thus demanding muscle activation. Lunging also enables ideal alignment of the body center of mass over the flexed knee in the frontal plane, therefore minimizing KAM. Findings will guide the development of a yoga-based strengthening program that limits exposure to excessive KAMs for knee OA.

2. Methods

2.1. Participants

Thirty healthy women (age 18 to 40 years) were recruited from a university population. Similar to previous studies exploring new interventions for knee OA (Clark et al., 2013; Van den Noort et al., 2014), women with knee OA were not selected for this lengthy protocol. This study focused on women because knee OA affects women more frequently than men (Felson et al., 2000). Participants were physically active and had no contraindications to exercise on the Physical Activity Readiness Questionnaire (Thomas et al., 1992). Exclusion criteria included pregnancy and a history of knee pain, injury, or surgery. For descriptive purposes, the participants were interviewed about their yoga experience. This study was approved by the McMaster University Human Integrated Research Ethics Board. Written, informed consent was obtained from all participants.

2.2. Protocol

Participants were instrumented for motion capture and electromyography (EMG) before performing trials of maximum muscle activations, walking, and six standing yoga postures (Fig. 1). The yoga postures included two squats, two lunges, a standing hamstring stretch, and a single-leg balance posture. Participants were barefoot and given ample opportunity to learn and practice each posture, with instructions from the lead researcher. Each posture was held static for 10 s and repeated three times. Posture order was randomized. During a posture, each foot was in full contact with a separate force platform, except for the single-leg balance posture. The primary leg was the forward leg during lunges (Extended Lateral Angle, Warrior) and the standing hamstring stretch (Triangle); the straight leg during the single-leg balance posture (Tree); and the left leg during squats (Chair, Goddess).

2.2.1. Squatting postures

"Chair" posture was performed with the feet in neutral rotation (toes pointed forward), slightly less than hip width apart. Participants kept their torso upright and flexed their shoulders to 180°. "Goddess" posture was performed with the feet externally rotated approximately 45°, slightly greater than shoulder width apart. Participants kept their torso upright, abducted their shoulders to 90°, externally rotated their shoulders to 90°, and flexed their elbows to 90°. For both squats, participants were encouraged to squat without allowing their knees to travel anterior to their toes, until their thighs were approximately parallel to the floor, keeping their body mass distributed evenly through both feet.

2.2.2. Lunging postures

The two lunges used the same leg position but different trunk and arm positions. "Extended Lateral Angle" posture was performed by stepping forward with the left foot. The left foot was in neutral rotation. The left knee was flexed until the thigh was parallel to the floor such that the thigh and shank were perpendicular to one another. The right foot was externally rotated approximately 45°, and the heel of the left foot was in line with the inner arch of the right foot. The right knee was in full extension. Participants placed their left hand beside the medial aspect of the left ankle, without grasping the ankle or touching the force platform. This position required the torso to be flexed and rotated to the right such that the torso was oriented as close to parallel to the sagittal plane as possible. Finally, participants abducted the right shoulder 90° such that the right arm was vertical. During "Warrior" posture, participants kept the pelvis and torso in the coronal plane and flexed both shoulders to 180° with the arms positioned overhead.

2.2.3. Standing hamstring stretch posture

"Triangle" posture was performed by stepping forward with the left foot less than 1 m, with the left foot oriented in neutral rotation, and the right foot externally rotated approximately 45°. The heel of the left foot was aligned with the inner arch of the right foot. Both knees were in extension. Participants placed the left hand on the medial aspect of the left ankle, without grasping the ankle or touching the force platform. The torso was flexed and rotated to the right, parallel to the sagittal plane as much as possible. Finally, the right shoulder was externally rotated 180° with the right arm in full extension.

2.2.4. Single-leg balance posture

"Tree" posture was performed by standing with the feet in neutral rotation, hip width apart, with the hands in front of the chest and the palms pressed together. Participants slowly transferred their body mass onto the right leg, raised their left leg, and externally rotated the hip placing the plantar surface of the left foot on the medial right shank.

2.3. Measures

2.3.1. Muscle activation

The mean EMG amplitude of the left and right rectus femoris, vastus lateralis, vastus medialis, biceps femoris, and semitendinosus relative to their activations during a maximum voluntary isometric contraction (MVIC) were collected during each static yoga posture. Muscle activation was monitored using ten silver/silver chloride surface electrodes with a 20 mm inter-electrode distance affixed to the prepared skin along the orientation of the muscle fibers (www.seniam.org, Enschede, Netherlands). The EMG was pre-amplified through participant-mounted dual differential amplifiers (input impedance > 100 MΩ, CMRR > 100 dB, SNR < 1 μV Root Mean Square of baseline noise, base gain of 200, and a final gain of 500) (Desktop DTS, Noraxon USA, Scottsdale, AZ, USA). The EMG data were bandpass filtered between 10 500 Hz, time synchronized with motion capture