Journal of Electromyography and Kinesiology 24 (2014) 497–501

Contents lists available at ScienceDirect

Journal of Electromyography and Kinesiology

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

Interlimb symmetry of dynamic knee joint stiffness and co-contraction is maintained in early stage knee osteoarthritis

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ARTICLE INFO

Article history:
Received 29 October 2013
Received in revised form 21 February 2014
Accepted 19 March 2014

Keywords:
Stiffness
Co-contraction
Knee
Osteoarthritis
Symmetry

ABSTRACT

Individuals with knee OA often exhibit greater co-contraction of antagonistic muscle groups surrounding the affected joint which may lead to increases in dynamic joint stiffness. These detrimental changes in the symptomatic limb may also exist in the contralateral limb, thus contributing to its risk of developing knee osteoarthritis. The purpose of this study is to investigate the interlimb symmetry of dynamic knee joint stiffness and muscular co-contraction in knee osteoarthritis.

Muscular co-contraction and dynamic knee joint stiffness were assessed in 17 subjects with mild to moderate unilateral medial compartment knee osteoarthritis and 17 healthy control subjects while walking at a controlled speed (1.0 m/s). Paired and independent *t*-tests determined whether significant differences exist between groups ($p < 0.05$).

There were no significant differences in dynamic joint stiffness or co-contraction between the OA symptomatic and OA contralateral group ($p = 0.247$, $p = 0.874$, respectively) or between the OA contralateral and healthy group ($p = 0.635$, $p = 0.078$, respectively). There was no significant difference in stiffness between the OA symptomatic and healthy group ($p = 0.600$); however, there was a slight trend toward enhanced co-contraction in the symptomatic knees compared to the healthy group ($p = 0.051$).

Subjects with mild to moderate knee osteoarthritis maintain symmetric control strategies during gait.

1. Introduction

Osteoarthritis (OA) is an increasingly prevalent condition affecting approximately 27 million people in the US alone (Helmick et al., 2007), with osteoarthritis of the knee being especially common and debilitating (Felson et al., 1987). Knee OA is characterized by pain, stiffness, and often results in abnormal gait mechanics (Kaufman et al., 2001; Mundermann et al., 2005; Al-Zahrani and Bakheit, 2002) which have been shown to relate to disease severity (Hunt et al., 2010; Astephen et al., 2008). Current studies investigating these measures in knee OA commonly focus on the symptomatic or more painful limb; however, the assessment of gait mechanics in the contralateral limb is also important as those with asymmetric knee loading have been shown to have an increased risk of developing OA in the unaffected or less severe knee (Shakoor et al., 2002, 2003).

Alterations to gait mechanics have been shown in those with knee OA and include increased loading rates (Mundermann et al., 2005) and reduced internal knee extensor moment (Kaufman et al., 2001). One such gait alteration of importance to the current study is co-contraction of the quadriceps and hamstrings muscles (Zeni et al., 2010). Muscular co-contraction is thought to be an important component of increased knee joint stiffness in those with knee OA. More specifically, those with OA of the knee utilize a strategy of antagonistic muscle activity which may lead to increases in dynamic joint stiffness during gait (Zeni and Higginson, 2009b).

The observed gait alterations on the symptomatic limb mentioned previously may, in turn, necessitate stiffening of the contralateral knee through co-contraction of the quadriceps and hamstrings muscles in order to accept loads resulting from weight shifting off the symptomatic limb. However, the degree and role of co-contraction on the contralateral limb and its relationship to dynamic knee joint stiffness in knee OA remains unclear.

Dynamic knee joint stiffness is a measure which considers both the external knee flexion moment and knee flexion angle and has been used to assess joint stability during dynamic tasks such as walking (Dixon et al., 2010; Zeni and Higginson, 2009b). This

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http://dx.doi.org/10.1016/j.jelekin.2014.03.010
1050-6411/

stiffness arises in the presence of joint laxity, instability (Rudolph et al., 2007), and increased co-contraction (Schmitt and Rudolph, 2007) and is commonly utilized as a means of stabilizing the joint (Petterson et al., 2008). Dynamic knee joint stiffness has not been extensively studied in those with knee OA with the few studies that have looked at this measure solely investigating the symptomatic knee with mixed results (Zeni and Higginson, 2009b; Dixon et al., 2010). Dixon et al. reported higher knee joint stiffness in individuals with varying severities of knee OA compared to asymptomatic controls when walking at a controlled speed of 1.0 m/s (Dixon et al., 2010). The results of their study conflicted with those of Zeni et al. who demonstrated no significant difference in dynamic knee joint stiffness between healthy control subjects and those with moderate knee OA while also walking at the same controlled speed (1.0 m/s) (Zeni and Higginson, 2009b). Despite utilizing the same walking speed, differences in the results of these studies may be attributed to their varying methods for calculating dynamic joint stiffness. While these studies investigated joint stiffness between healthy subjects and those with knee OA, no previous work has determined whether this measure is symmetric between the symptomatic and contralateral limbs in knee OA.

Investigating the relationship between interlimb dynamic joint stiffness and muscular co-contraction in knee OA may elucidate whether the detrimental changes seen in the symptomatic limb demand excessive loading on the asymptomatic limb, thus contributing to its risk of initiating or furthering disease progression (Shakoor et al., 2002). A better understanding of the presence and severity of between-limb asymmetries in knee OA is essential when considering the design of early disease intervention strategies, such as strength training. Therefore, the purpose of this study was to investigate interlimb symmetry of muscular co-contraction and its relation to dynamic knee joint stiffness in a population with osteoarthritis of the knee. We hypothesized there would be a significant difference in both dynamic knee joint stiffness and muscle co-contraction between the OA symptomatic limb and the healthy control group as well as between the OA contralateral limb and the healthy control group. Additionally, we hypothesized the OA subjects would demonstrate interlimb symmetry, with no significant difference between limbs with regard to either dynamic knee joint stiffness and muscle co-contraction.

2. Methods

2.1. Subjects

After receiving Institutional Review Board approval, 17 subjects with mild to moderate (Kellgren Lawrence grade 2–3), unilateral, medial compartment knee OA and 17 healthy control subjects were recruited and participated in this study (Table 1). Subjects' knee OA grade was assessed using the Kellgren Lawrence (KL) grading system (Kellgren and Lawrence, 1957) by inspection of bilateral, anterior–posterior, 30° flexed knee radiographs. Subjects were included in the study if they had a diagnosis of knee OA confirmed by a physician through radiographs. Subjects were excluded from participation if they had severe knee OA (KL grade = 4), any neurologic or cardiopulmonary conditions, musculoskeletal disease or joint replacement, gout, rheumatoid or other systemic inflammatory arthritis, or had intra-articular injections within 6 months prior to testing. Additionally, subjects were excluded if they were unable to walk on a treadmill without an assistive device such as a cane or walker, or without the use of handrails.

2.2. Data collection

Electromyographic data were obtained from dual Ag/AgCl surface electrodes (Noraxon U.S.A. Inc., Scottsdale, AZ) positioned parallel to the muscle fibers over the muscle belly center of the vastus lateralis (VL) and semimembranosus (SM) bilaterally. Proper placement of the electrodes was verified by isolation of each muscle's movements against resistance.

Subject's maximal voluntary isometric contraction (MVIC) was measured using manual resistance and used for normalizing data during the walking trials. Subjects were seated and asked to maximally extend their leg against an external load while the VL MVIC was measured. In order to measure the SM MVIC, subjects stood supported and were asked to maximally flex their knee while motion of the tibia was resisted. During all MVIC trials, subjects were provided visual feedback of the EMG signal as well as verbal encouragement.

For the walking trials, subjects were asked to walk on an instrumented split-belt treadmill (Bertec Corp., Columbus, OH) at a controlled speed of 1.0 m/s. A speed of 1.0 m/s was used in order to reduce the effect of differences in gait variables that may be directly affected by walking speed (Bejek et al., 2005). Subjects were allowed a familiarization period with treadmill walking in order to collect accurate data for gait analysis (Zeni and Higginson, 2010). Data was then collected for a period of 30 seconds while subjects continued walking. Subjects were also connected to an overhead safety harness which safeguarded against falling. Raw analog EMG signals were digitally sampled at 1080 Hz. Center of pressure and ground reaction force data from both the left and right force plates were also collected at 1080 Hz. Three-dimensional kinematics were obtained via 23 retroreflective markers placed bilaterally (Zeni and Higginson, 2009b). An eight camera motion capture system (Motion Analysis, Santa Rosa, CA) collected kinematic data at 60 Hz. Joint moments were determined by inverse dynamics using Orthotrak 6.3.4 (Motion Analysis) and normalized to subject's body mass. In the healthy control subjects, the limb chosen for analysis alternated between right and left for each consecutive subject.

2.3. Data processing

All marker coordinate data was smoothed with a 4th order Butterworth filter with a cutoff frequency of 6 Hz.

Raw EMG data collected during all walking and MVIC trials were bandpass filtered at 20–400 Hz with a 4th order Butterworth filter. The data were then rectified and passed through a low pass 8th order filter with a cutoff frequency of 20 Hz in order to create a linear envelope. The data was then normalized to peak values obtained during MVICs.

Table 1
Mean (sd) demographic information for all male (M) and female (F) test subjects.

	OA			Healthy		
	F ($n = 10$)	M ($n = 7$)	$n = 17$	F ($n = 9$)	M ($n = 8$)	$n = 17$
Age (years)	60 (9.0)	66.4 (8.4)	62.6 (9.1)	57.2 (7.2)	66.1 (11.5)	61.4 (10.2)
Weight (kg)	84.6 (13.4)	89.5 (11.1)	86.6 (12.4)	65.6 (10.7)	81.1 (10.2)	72.9 (12.9)
BMI (kg/m^2)	31.1 (5.9)	29.0 (2.0)	30.3 (4.7)	24.0 (3.0)	25.9 (2.0)	24.9 (2.7)
KL grade	2.6 (0.52)	2.3 (0.49)	2.47 (0.51)	0.97 (0.08)	0.94 (0.18)	0.95 (0.02)