The Knee xxx (2017) xxx–xxx

Contents lists available at ScienceDirect

The Knee

Neuromuscular adaptations in older males and females with knee osteoarthritis during weight-bearing force control

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ARTICLE INFO

Article history:
Received 22 November 2016
Received in revised form 7 April 2017
Accepted 6 June 2017
Available online xxxx

Keywords:
Osteoarthritis
Sex differences
Knee stability
Neuromuscular control
Older adults
Electromyography

ABSTRACT

Background: Females exhibit significantly greater incidence, prevalence, and severity of osteoarthritis (OA) compared to males. Despite known biological, morphological, and functional differences between males and females, there has been little sex-related investigation into sex-specific biomechanical and neuromuscular responses to OA.

Objective: To identify sex-related differences in OA-affected adults and within-sex differences between healthy and OA-affected adults' muscular activation patterns during lower limb loading.

Methods: Thirty adults with OA and 36 controls completed a standing ground reaction force (GRF) matching protocol requiring participants to expose equal body weight to each leg and modulate horizontal GRFs while maintaining constant joint positions. Electromyography was plotted as a function of GRF direction to depict muscle activation patterns. Muscles were classified as a general joint stabilizer, specific joint stabilizer or moment actuator by quantifying activation patterns with a test of asymmetry, specificity index and mean direction of activity. Lower limb kinematics and kinetics were also recorded.

Results: In general, muscle roles as it relates to joint stability did not differ between groups. Compared to controls, both males and females with OA demonstrated greater rectus femoris activity and reduced knee rotation moments. Females with OA had significantly greater biceps femoris and gastrocnemius activity during respective lateral, and anterior–medial loading directions compared to males with OA.

Conclusions: We identified fundamental differences in muscular stabilization strategies in older adults with OA as well as sex-related changes in neuromuscular function that may influence joint loading conditions and provide insight into the greater incidence of knee OA in females.

1. Introduction

Many factors have been postulated to increase one's risk for developing knee osteoarthritis (OA) including previous joint injury, excessive joint loading through highly repetitive tasks, obesity [1] and genetics [2]. Recently, studies suggest that

Abbreviations: ϕ, mean direction of muscle activation; ANOVA, analysis of variance; BF, biceps femoris; EMG, Electromyography; FOA, females with osteoarthritis; FOC, female controls; GRF, ground reaction force; KOOS, Knee Osteoarthritis and injury Outcome Score; LG, lateral gastrocnemius; MANOVA, multivariate analysis of variance; MG, medial gastrocnemius; MOA, males with osteoarthritis; MOC, male controls; MVIC, maximum voluntary isometric contraction; OA, osteoarthritis; RF, rectus femoris; SEM, standard error of measurement; SI, specificity index; ST, semitendinosus; TFL, tensor fascia lata; VL, vastus lateralis; VM, vastus medialis; X_{EMG}, mean magnitude of muscle activation.

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https://doi.org/10.1016/j.knee.2017.06.004
0968-0160/

neuromuscular adaptations associated with aging, such as muscle weakness and reduced capacity for muscular control, may be a primary contributor to OA since it is further exaggerated in older adults with knee OA [3–5] and has been experimentally [6,7] and clinically [8,9] linked to the onset and progression of joint degeneration. Altered neuromuscular function, especially muscle weakness, is thought to result in more variable internal contact loads at the articulating surfaces, thus eliciting metabolic changes of the chondrocytes and compromising the mechanical properties of cartilage [6,10,11].

Rudolph et al. [4] examined knee laxity, muscular strength and walking kinematics in young, middle aged and older healthy adults and compared these results to individuals with OA. Both healthy older adults and those with OA had a loss of voluntary muscle force production, reduced knee motion and increased co-activation of the hamstring and quadriceps muscles compared to healthy young and middle aged adults. Reduced knee motion and increased hamstring–quadriceps co-activation has been reported elsewhere [3,5,12,13] and is believed to be a "knee stiffening strategy" adapted by individuals with joint instability, as measured by anterior tibial laxity, and reduced voluntary muscle control. Rudolph et al. [4] also showed that individuals with OA demonstrated further reductions in muscle strength, knee motion and increased co-activation compared to their healthy age-matched counterparts. Rudolph et al. [4] imply that individuals with OA adapt the "knee stiffening strategy" to a degree that no longer efficiently stabilizes the knee joint but rather introduces adverse loads, thus contributing to the development and progression of joint degeneration [4,14,15].

Furthermore, females exhibit significantly greater incidence, prevalence and severity of OA compared to males [16]. There are established functional differences between males and females, such as knee joint laxity [17–19], lower extremity alignment [20], as well as muscle activation and movement patterns during exercises [21,22]. The most obvious variation is that of muscular strength [8,17,23]. The presence of muscle weakness seems to increase the rate of cartilage loss in females compared to males [24]. Recently, Astephen-Wilson et al. [21] demonstrated that females with end-stage OA activated their quadriceps and gastrocnemius muscles to a greater level than males throughout the stance phase of gait. Greater activation was accompanied by reduced knee adduction and rotational moments and increased knee flexion moments in females compared to males. These results suggest that females adapt the "knee stiffening strategy" proposed by Rudolph et al. [4] to a greater degree than males. However, how these sexual dimorphisms contribute to the increased rates and severity of OA in females still remains unknown. We therefore believe that the examination of neuromuscular control as it relates to OA must be investigated across sexes since these findings may have the potential to increase our understanding of the mechanisms of OA.

We have developed and validated a test that allows us to describe the roles of lower limb muscles as it relates to knee joint stability [25,26] and have since identified differences in neuromuscular function and muscle roles between healthy younger males and females [27], healthy older males and females [28], and individuals with and without anterior cruciate ligament injury [29]. However, the functional roles of muscles have yet to be fully explored in older adults with OA. The objective of this study was to identify sex-related differences in muscle activation patterns between individuals with OA and matched controls. This was investigated through three planned comparisons: (1) males and females with OA, (2) females with OA (FOA) and female controls (FOC), and (3) males with OA (MOA) and male controls (MOC). We hypothesized that OA-affected adults would have greater muscle activity (specifically of the quadriceps) and reduced knee joint moments than healthy older adults regardless of sex. These differences will be further exaggerated in FOA compared to MOA. By identifying differences in activation strategies in response to OA and sex, we hope to provide insight into which muscles can be targeted to improve joint stability, potentially as a prophylactic means of slowing the degenerative process.

2. Methods

2.1. Participants

Thirty-six healthy controls and 30 adults with knee OA completed the protocol for this study (Table 1). Participants were included if they were at least 50 years of age and physically active two days a week. Participants were excluded if they reported a history of a significant lower limb injury (i.e. ligament rupture); a lower limb fracture, a lower extremity motor nerve lesion, corticosteroid injection, and/or the presence of a knee joint effusion, within six months prior to participation; diabetes. Potential

Table 1
Group mean (standard deviation) of subject demographics and subjective functional scores.

	Controls		OA	
	Males	Females	Males	Females
n	19	17	16	14
Age (years)	63.5 (7.5)	60.7 (5.4)	66.7 (7.5)	64.3 (6.4)
BMI (kg/m^2)	26.0 (4.1)	23.0 (2.6)	25.6 (3.7)	26.6 (2.5)
KOOS				
Symptoms	94.2 (6.5)	93.3 (6.8)	71.9 (15.4)	65.0 (14.9)
Pain	97.5 (3.1)	96.7 (3.6)	73.8 (16.0)	72.5 (16.6)
ADL	98.4 (2.9)	98.3 (3.2)	83.1 (14.2)	80.7 (12.8)
Sports & rec	95.8 (8.6)	94.2 (8.2)	59.6 (25.8)	55.3 (13.4)
QOL	95.1 (7.7)	93.0 (12.6)	52.7 (20.0)	45.5 (17.9)

BMI = body mass index; KOOS = Knee injury and Osteoarthritis Outcome Score; ADL = activities of daily living; rec = recreation; QOL = quality of life.

Please cite this article as: Bigham HJ, et al, Neuromuscular adaptations in older males and females with knee osteoarthritis during weight-bearing force control, Knee (2017), https://doi.org/10.1016/j.knee.2017.06.004