Clinical Biomechanics 30 (2015) 1140–1145

Contents lists available at ScienceDirect

Clinical Biomechanics

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

The associations between quadriceps muscle strength, power, and knee joint mechanics in knee osteoarthritis: A cross-sectional study☆,☆☆

Amanda M. Murray [a,*], Abbey C. Thomas [b], Charles W. Armstrong [c], Brian G. Pietrosimone [d], Michael A. Tevald [e]

[a] *Department of Physical Medicine and Rehabilitation, University of Colorado Denver, Aurora, CO, United States*
[b] *Department of Kinesiology, University of North Carolina at Charlotte, Charlotte, NC, United States*
[c] *Department of Kinesiology, University of Toledo, Toledo, OH, United States*
[d] *Department of Exercise and Sport Science, University of North Carolina at Chapel Hill, Chapel Hill, NC, United States*
[e] *Department of Rehabilitation Sciences, University of Toledo, Toledo, OH, United States*

ARTICLE INFO

Article history:
Received 14 January 2015
Accepted 18 August 2015

Keywords:
Osteoarthritis
Muscle power
Biomechanics
Gait

ABSTRACT

Background: Abnormal knee joint mechanics have been implicated in the pathogenesis and progression of knee osteoarthritis. Deficits in muscle function (i.e., strength and power) may contribute to abnormal knee joint loading. The associations between quadriceps strength, power and knee joint mechanics remain unclear in knee osteoarthritis.
Methods: Three-dimensional motion analysis was used to collect peak knee joint angles and moments during the first 50% of stance phase of gait in 33 participants with knee osteoarthritis. Quadriceps strength and power were assessed using a knee extension machine. Strength was quantified as the one repetition maximum. Power was quantified as the peak power produced at 40–90% of the one repetition maximum.
Findings: Quadriceps strength accounted for 15% of the variance in peak knee flexion angle ($P = 0.016$). Quadriceps power accounted for 20–29% of the variance in peak knee flexion angle ($P < 0.05$). Quadriceps power at 90% of one repetition maximum accounted for 9% of the variance in peak knee adduction moment ($P = 0.05$).
Interpretation: These data suggest that quadriceps power explains more variance in knee flexion angle and knee adduction moment during gait in knee osteoarthritis than quadriceps strength. Additionally, quadriceps power at multiple loads is associated with knee joint mechanics and therefore should be assessed at a variety of loads. Taken together, these results indicate that quadriceps power may be a potential target for interventions aimed at changing knee joint mechanics in knee osteoarthritis.

1. Introduction

Knee osteoarthritis (OA), a leading cause of disability amongst older adults in the United States (Guccione et al., 1994), is associated with altered knee joint mechanics. In the sagittal plane, individuals with knee OA often exhibit a stiffened knee gait, consisting of reduced knee flexion angles (KFA) and external knee flexion moment (KFM) during the stance phase (Rudolph et al., 2007). In the frontal plane, an elevated external knee adduction moment (KAM), which is a surrogate for medial compartment loading, has been reported (Rudolph et al., 2007). These mechanical gait adaptations may reduce force attenuation at the knee, increase the rate of joint loading (Lafortune et al., 1996), and contribute to articular cartilage damage and, ultimately, the initiation and progression of the disease (Andriacchi et al., 2004; Mills et al., 2013).

Because the musculature around the knee, particularly the quadriceps, can influence joint mechanics and loading (Pandy and Andriacchi, 2010), deficits in muscle function may contribute to abnormal joint loading in individuals with knee OA. In the sagittal plane, adequate quadriceps strength is required to control knee flexion during stance and attenuate forces acting on the knee (Perry and Burnfield, 2010). Quadriceps strength, which is compromised in individuals with knee OA (Slemenda et al., 1997), has been reported to be positively associated with KFA during stance in individuals with knee OA (Bennell et al., 2004; Schmitt and Rudolph, 2007). A positive association between quadriceps strength and KFM has been observed in individuals with other knee problems, such as ACL deficiency (Lewek et al., 2002), as well as healthy older adults (Samuel et al., 2012). However, this association has not been reported in individuals with knee OA. In the frontal plane, several modeling studies have suggested an important role for the quadriceps in offsetting the KAM (Schipplein and Andriacchi, 1991; Shelburne et al., 2006), although no significant association between quadriceps strength and KAM has been found in individuals with knee OA (Calder

---

☆ All authors were involved in this study and the preparation of this manuscript. The material in this manuscript has not been submitted for publication elsewhere.

☆☆ The study protocol was approved by the University of Toledo Biomedical Institutional Review Board (#107856).

* Corresponding author at: University of Colorado Denver, Physical Therapy Program, MS C244, 13121 E. 17th Ave., Room 3106, Aurora, CO 80045, United States.
E-mail address: Amanda.Murray@ucdenver.edu (A.M. Murray).

http://dx.doi.org/10.1016/j.clinbiomech.2015.08.012
0268-0033/© 2015 Elsevier Ltd. All rights reserved.

et al., 2014; Lim et al., 2009). Furthermore, improving quadriceps strength has had little to no effect on KFA, KFM, or KAM in this population (Lim et al., 2008; Pietrosimone et al., 2010). Therefore, it is possible that muscle strength may not be the best target for influencing knee joint loading in patients with knee OA.

Muscle power is the product of force and contraction velocity, and the velocity component may make power a better indicator of the ability of a muscle to influence joint mechanics and loading during dynamic tasks. Muscle power is a more critical determinant of physical function than muscle strength in older adults (Reid and Fielding, 2012), and interventions specifically designed to improve muscle power, such as high-velocity power training, are associated with greater improvements in physical function than traditional strength training (Tschopp et al., 2011). In people with knee OA, impaired quadriceps power is associated with poor functional performance and self-reported function (Accettura et al., 2015; Berger et al., 2012). However, the influence of quadriceps muscle power on knee joint mechanics in knee OA has not been adequately studied, as we are only aware of one study on this topic (Calder et al., 2014). Calder and colleagues (2014) reported that quadriceps power, assessed at 25% of maximal voluntary isometric contraction (MVIC), was more closely associated with peak KAM than quadriceps strength. However, there were several limitations to this investigation. First, sagittal plane mechanics, such as KFA and KFM, were not investigated. Second, while many studies examining the role of muscle power in function (Berger et al., 2012; Foldvari et al., 2000) assess power at multiple loads, Calder and colleagues (2014) assessed power at a single load (25% MVIC). The rationale for this approach was not described in the study, but prior studies suggest that this may influence the nature of the associations between muscle power and knee joint mechanics. For example, Puthoff and Nielsen (2007) reported that the load at which power is assessed influences the strength of the association between power and the performance of functional tasks, suggesting the possibility of a load dependence in the relationship between power and joint mechanics. The presence of such a load dependence could influence the design of future studies and interventions for people with knee OA. Therefore, the purposes of this study were twofold: 1) to examine the contributions of quadriceps muscle strength and power to knee joint mechanics (peak KFA, peak KFM, and peak KAM) during stance phase of gait, and 2) to explore the association between muscle power at low, moderate, and high loads and knee joint mechanics in individuals with knee OA. With respect to the first purpose, we hypothesized that quadriceps muscle strength would be associated with peak KFA, but not with either of the joint moments, and that quadriceps muscle power would be associated with all measures of knee joint mechanics. With respect to the second purpose, we hypothesized that the association between quadriceps muscle power and knee joint mechanics would exhibit load dependence, with power assessed at a low load being more closely associated with mechanical variables than power assessed at a high load or overall peak power.

2. Methods

A cross-sectional study design was employed and data were collected in a university research laboratory over two testing sessions that were separated by approximately one week. Quadriceps power and strength were collected in the first session and knee joint mechanics during level-ground gait were collected during the second session.

2.1. Participants

Forty-six participants with knee OA were referred from local orthopedic surgeons or recruited from the local community as part of an ongoing intervention study. All measurements reported here were taken at baseline before any intervention was employed.

Participants were eligible for the study if they were 40 years of age or older with a physician diagnosis of knee OA that resulted in moderate impairments in physical function (WOMAC Function subscale ≥21) (Tubach et al., 2005). Participants with bilateral knee OA indicated which knee was more painful, and that limb was utilized for all analysis. Individuals were excluded if they had a history of any of the following: 1) a neurological or neuromuscular disease that would impair lower extremity function, 2) a significant cardiac or vascular event in the past year, 3) a medical condition that would make exercise unsafe (such as unstable angina) (Pescatello et al., 2014), 4) a total knee replacement on the involved leg, and 5) orthopedic surgery to either leg in the past six months. Additionally, individuals who weighed ≥160 kg were excluded due to weight limitations of equipment. Prior to participation in this study, participants signed a written informed consent approved by the Institutional Review Board at the University of Toledo.

2.2. Quadriceps muscle strength and power measurements

Muscle strength and power were assessed with a pneumatic knee extension machine (model A400, Keiser Corporation, Fresno, CA, USA) (Fielding et al., 2002). Prior to beginning the muscle function assessment, participants performed a five minute warm-up consisting of cyclic leg extension with minimal resistance (approximately 18 kg) on a leg press machine. Quadriceps strength was quantified as the one repetition maximum (1 RM) (Fielding et al., 2002). Participants sat in the machine with their knee in 90° of flexion and their arms crossed over their chest. They extended their knee over 2 sec, paused at end range, and then returned to the starting position over 2 sec. Initially, a load that the subject could easily move was selected, and the position of the lever arm on the device when the participant's knee was fully extended was considered end range. The investigator gradually increased resistance until the participant could no longer complete one repetition through the full knee extension range of motion, as determined by visual comparison of the end position to the end range determined with a low load. To minimize the effects of fatigue, 45–60 s of rest were provided between repetitions. The last full repetition was recorded as the 1 RM (kg) and normalized to body mass (kg).

Quadriceps power was assessed at 40%, 50%, 60%, 70%, 80%, and 90% of 1 RM, in a random order, following a procedure that is widely used in the literature (Fielding et al., 2002; Foldvari et al., 2000; Puthoff and Nielsen, 2007; Sayers et al., 2012). Because the load at which peak power occurs can vary substantially (Puthoff and Nielsen, 2007), an accurate measure of power requires the assessment of power at multiple loads. During the assessments, participants were instructed to extend their knee as hard and fast as possible, pause at the end range, and then return to the starting position over 2 sec. Three trials were performed at each load. Because previous studies in older adults have suggested the load at which muscle power is assessed may influence the relationship with mobility tasks, peak power produced at 40% of 1 RM (low load), 70% of 1 RM (moderate load) and 90% of 1 RM (high load), as well as the greatest power (W) produced from the six loads (peak power), were recorded, normalized to body mass, and used for analysis (Puthoff and Nielsen, 2007).

2.3. Gait analysis

Knee joint kinematics and kinetics were collected using a three-dimensional, 12-camera passive marker motion capture system (Eagle System, Motion Analysis Corporation, Santa Rosa, CA, USA) sampling at 200 Hz synchronized with a force platform (AMTI OR6-5, Advanced Motion Technology, Inc., Watertown, MA, USA) sampling at 1000 Hz. Participants were outfitted with thirty-five retroreflective markers attached to skin or tight fitting clothing by adhesive tape. Markers were placed on the C7 spinous process and bilateral acromioclavicular joints, iliac crests, anterior superior iliac spines, posterior superior iliac spines, greater trochanters, anterior thighs, medial and lateral femoral epicondyles, tibial tuberosities, lateral shanks, distal shanks, medial and lateral malleoli,