Journal of Electromyography and Kinesiology 23 (2013) 1485–1493

Contents lists available at ScienceDirect

Journal of Electromyography and Kinesiology

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

Muscle activation and coactivation during five-time-sit-to-stand movement in patients undergoing total knee arthroplasty

Bradley S. Davidson [a,b,*], Dana L. Judd [b], Abbey C. Thomas [b], Ryan L. Mizner [c], Donald G. Eckhoff [d], Jennifer E. Stevens-Lapsley [b]

[a] Department of Mechanical and Materials Engineering, University of Denver, United States
[b] Department of Physical Medicine and Rehabilitation, University of Colorado Anschutz Medical Campus, United States
[c] School of Physical Therapy and Rehabilitation Science, The University of Montana, United States
[d] Department of Orthopedic Surgery, University of Colorado Hospital, Anschutz Medical Campus, United States

ARTICLE INFO

Article history:
Received 20 November 2012
Received in revised form 24 April 2013
Accepted 7 June 2013

Keywords:
TKA
Coactivation
Sit to stand
Quadriceps strength
Osteoarthritis
Electromyography

ABSTRACT

Quadriceps weakness is prevalent with knee osteoarthritis (OA) and after total knee arthroplasty (TKA). To compensate for quadriceps dysfunction, patients often alter movement strategies. Little is known about muscle coordination during sit-to-stand (concentric) and stand-to-sit (eccentric) movements in the acute postoperative period. This investigation characterized the distribution of muscle activation between the concentric and eccentric phases during a five-time-sit-to-stand (FTSTS) movement in late stage OA and one month after TKA. Patients and healthy participants performed a FTSTS while recording bilateral ground reaction forces (GRFs) and electromyography (EMG). Concentric and eccentric ensemble averages of the GRF and EMG were calculated for the concentric and eccentric phases. Coactivation indices, integrated EMG, and GRF were calculated for each limb and phase. Patients demonstrated higher eccentric coactivation than the healthy group. Postoperative loading was higher in the nonsurgical limb. Postoperative quadriceps activity was lower in the concentric phase and higher in the eccentric phase than the healthy group. Higher coactivation in the patients resulted from sustained distribution of quadriceps activity throughout the eccentric phase. This indicated an inability to coordinate muscle firing when rapidly lowering to a chair and occurred despite unloading of the surgical limb. Although these patterns may serve as a protective strategy, they may also impede recovery of muscle function after TKA.

1. Introduction

Symptomatic knee osteoarthritis (OA) affects over 12% of adults ages 60 and over in the United States (Dillon et al., 2006). Total knee arthroplasty (TKA) is frequently performed to relieve pain and disability in patients suffering from end-stage knee OA. Although TKA reliably reduces pain, a combination of strength and functional performance deficits may persist several years after surgery (Ritter et al., 2004; Silva et al., 2003).

Compared with their healthy counterparts, patients with knee OA demonstrate lower extremity muscle weakness that is exacerbated one month after surgery (Bade et al., 2010). In particular, quadriceps strength deficits of 50–60% exist one month postoperatively (Mizner et al., 2005; Stevens-Lapsley et al., 2010) and strength deficits persist years after surgery (Silva et al., 2003). Quadriceps weakness and central activation deficits are associated with declines in functional performance in patients following neurologic injury (Horstman et al., 2008) as well as frail, older adults (Brown et al., 1995). To accommodate for this muscle weakness, patients frequently alter muscle activation and movement strategies during functional tasks both before and after TKA. For example, patients often employ a “knee stiffening strategy” during walking in which they limit their sagittal plane knee range of motion and concurrently reduce the knee extension moment while increasing quadriceps/hamstrings muscle coactivation (Benedetti et al., 2003).

Movement strategies by which patients limit quadriceps work have also been measured in other activities of daily living. For example, Mizner and Snyder-Mackler (2005a) linked quadriceps weakness to difficulties in performing a sit-to-stand task. Three months after TKA, patients performed a sit-to-stand task with symmetrical sagittal plane joint kinematics, but with smaller peak vertical ground reaction forces and lower quadriceps muscle recruitment in the surgical limb compared to the nonsurgical limb. These asymmetric knee joint kinetics were associated with asymmetric quadriceps strength between limbs (Mizner and Snyder-Mackler, 2005b). Further, when compared to healthy

* Corresponding author. Address: University of Denver, 2390 S Gaylord Street, Denver, CO 80210, United States. Tel.: +1 303 871 2133.
E-mail address: bradley.davidson@du.edu (B.S. Davidson).

1050-6411/$ - see front matter © 2013 Published by Elsevier Ltd.
http://dx.doi.org/10.1016/j.jelekin.2013.06.008

adults, patients after TKA performed the sit-to-stand movement with larger hip flexion angles (Farquhar et al., 2008), which reduces the required knee extension moment during a sit to stand activity by positioning the center of mass of the trunk closer to the knee joint center (Doorenbosch et al., 1994). Similar to a stiff knee gait, this strategy reduces the mechanical work performed by the quadriceps, perhaps as a response to the existing quadriceps muscle weakness. Although this strategy successfully reduces the demand on the quadriceps, it also increases the work performed by the hip extensor muscles (Farquhar et al., 2008), which includes the hamstrings and may contribute to altered muscle coactivation strategies about the knee joint. The combination of increasing hip flexion and muscle coactivation about the knee results in difficulty isolating the quadriceps muscle during what is normally a quadriceps-dominated task. This lack of isolated force production by the quadriceps during daily activity may prove detrimental to recovery of normal quadriceps muscle function (Rossi et al., 2006; Silva et al., 2003; Walsh et al., 1998).

Although altered movement strategies during sit-to-stand tasks after TKA have been examined in previous work, less is known about the muscle activation patterns during this task, especially in the acute postoperative period. In addition, muscle activation patterns while lowering to a chair before and after TKA are unknown. Like the sit-to-stand task, lowering to a chair demands larger joint moments at the hip and knee than other activities of daily living (Doorenbosch et al., 1994). However, lowering the body requires a controlled deceleration of the center of mass against gravity. This deceleration is accomplished through eccentric activation of the lower extremity extensors, which may be impaired in the presence of quadriceps dysfunction. Because lowering to a chair places different demands on the knee joint and the surrounding musculature than the sit-to-stand task, examining muscle activity patterns during each task may provide unique insights into coordination, coactivation, and compensatory strategies in patients before and after TKA.

The primary objective of this study was to characterize muscle activations during a sit-to-stand task and during lowering to a chair in patients with unilateral TKA and healthy adults of similar age. We examined bilateral muscle activity in the quadriceps and hamstrings using electromyography (EMG), the ground reaction force under each limb during the task, the time to complete the five-time-sit-to-stand task, and muscle strength. We hypothesized that patients would demonstrate asymmetric limb loading and slower performance of a five-time-sit-to-stand task before and after TKA compared with healthy adults. We also hypothesized that patients would demonstrate greater levels of surgical limb quadriceps/hamstring coactivation during the lowering (eccentric) phase of the task both before and after TKA when compared to the healthy group. Finally, we hypothesized that patients would perform a five-time-sit-to-stand task more slowly, with more asymmetry, and with higher levels of quadriceps/hamstrings coactivation one month after surgery compared with before surgery.

2. Methods

2.1. Participants

This investigation included two groups: (1) patients with end-stage OA scheduled to receive a unilateral TKA and (2) healthy participants (Table 1), and consisted of a sample of convenience. Patients with end-stage OA ($n = 10$) performed maximum isometric knee extensor and flexor strength testing and a five-time-sit-to-stand (FTSTS) task before receiving a primary, unilateral quadriceps splitting TKA (preoperative). Patients were excluded from the study if pain in the contralateral knee was greater than 4/10 during activity or if any other unstable lower-extremity orthopedic conditions were present. One month after TKA (postoperative), patients visited the laboratory again for the same testing. Healthy participants ($n = 13$) performed the FTSTS task on one occasion in an identical session as the patient group. This protocol was approved by the Colorado Multiple Institutional Review Board (COMIRB), and each participant provided written informed consent.

Table 1
Mean (SD) of baseline anthropometry. Age, height, mass, and BMI were tested with two-tailed paired *t*-tests and distribution of sex was tested with a two-tailed Chi-squared test.

	Patient	Healthy	*P*-value
Age (years)	59.7 (9.1)	63.9 (6.8)	0.22
Height (m)	1.70 (0.12)	1.73 (0.09)	0.50
Mass (kg)	84.4 (17.0)	79.8 (15.0)	0.28
BMI (kg/m^2)	28.0 (4.1)	26.4 (3.8)	0.39
% Female	70.0	38.4	0.13
% Male	30.0	61.6	

2.2. Strength testing

Maximum voluntary isometric (MVIC) quadriceps and hamstrings muscle strength measurements were performed while participants were seated and stabilized on an electromechanical dynamometer (HUMAC NORM CSMI, Stoughton, MA). Participants were positioned in 85° of hip flexion and 60° of knee flexion as previously described (Mintken et al., 2007; Stevens-Lapsley et al., 2010). Data were sampled using a Biopac Data Acquisition System at a sampling frequency of 2000 Hz (Biodex Medical Systems, Inc., Shirley, NY) and analyzed using AcqKnowledge software, Version 3.8.2 (Biodex Medical Systems). Strength measurements were expressed in units of normalized torque (N m/kg), which was calculated by multiplying the force (N) collected by the dynamometer by the lever arm length (m; medial joint line to one inch superior to the medial malleolus) and normalizing by mass (kg). All participants were given visual targets and strong verbal encouragement during each MVIC to achieve an accurate maximum effort. MVICs for each muscle group were performed twice; however, if maximum torque during the first two trials differed by more than 5%, a third trial was performed. The trial with the highest torque was used for analysis.

2.3. Five-time-sit-to-stand task

During the FTSTS task, participants were seated in a chair of standardized seat height (46 cm) with their feet placed on the center of each force platform (Whitney et al., 2005). They were instructed to perform the FTSTS task "as quickly and safely as possible". Time taken to transfer five times between the sitting and standing positions was recorded. Participants were encouraged to avoid using their hands during the test, both on the chair armrests and their legs. However, nine patients used the armrests for assistance during preoperative collection and eight patients used the armrests for assistance during postoperative collection. To preserve natural movement, no additional instructions were given.

Ground reaction forces (GRFs) and electromyography (EMG) data were recorded during the FTSTS task. Vertical GRFs under each limb were recorded using individual force platforms (PASCO scientific, Roseville, CA) placed under each foot. After cleaning the skin surface with isopropyl alcohol, differential bilateral surface EMG electrodes were placed on quadriceps (*vastus lateralis*) and hamstrings (*biceps femoris*) according to SENIAM guidelines (Merletti and Hermens, 2000). These active electrodes were Delsys