The Knee 21 (2014) 1115–1119

Contents lists available at ScienceDirect

The Knee

Quadriceps/hamstrings co-activation increases early after total knee arthroplasty

Abbey C. Thomas [a,1], Dana L. Judd [a], Bradley S. Davidson [b], Donald G. Eckhoff [c], Jennifer E. Stevens-Lapsley [a,*]

[a] University of Colorado, Physical Therapy Program, Department of Physical Medicine and Rehabilitation, Aurora, CO 80045, United States
[b] Department of Mechanical and Materials Engineering, University of Denver, Denver, CO 80208, United States
[c] Department of Orthopaedics, University of Colorado Anschutz Medical Campus, Aurora, CO 80045, United States

ARTICLE INFO

Article history:
Received 9 April 2014
Received in revised form 4 June 2014
Accepted 8 August 2014

Keywords:
Strength
Walking
Muscle activity
Total knee replacement

ABSTRACT

Quadriceps and hamstrings weakness and co-activation are present following total knee arthroplasty (TKA) and may impair functional performance. How surgery and post-operative rehabilitation influence muscle activation during walking early after surgery is unclear.
Purpose: Examine muscle strength and activation during walking before and one and 6-months post-TKA.
Methods: Ten patients (n = 6 female; age: 64.7 ± 7.9 years; body mass index[BMI]:29.2 ± 2.5 kg/m^2) and 10 healthy adults (n = 6 female; age: 60.6 ± 7.4 years; BMI: 25.5 ± 4.0 kg/m^2) participated. The patients underwent bilateral quadriceps and hamstrings strength testing and assessment of quadriceps/hamstrings co-activation and on/off timing using surface electromyography during a six-minute walk test (6MW). Groups, limbs, and changes with TKA surgery were compared.
Results: Patients reported greater 6MW knee pain pre- versus post-TKA and compared to controls ($P < 0.05$). Patients had weaker surgical limb hamstrings ($P < 0.05$) and bilateral quadriceps ($P < 0.05$) strength than controls pre- and post-TKA. Before and 1-month post-TKA, patients had side-to-side differences in quadriceps and hamstrings strength ($P < 0.05$). Controls walked farther than patients ($P < 0.01$). Patients demonstrated greater surgical limb co-activation pre-operatively than controls ($P < 0.05$). Co-activation was higher bilaterally one-month post-TKA compared to controls ($P < 0.05$). Patients turned off their quadriceps later during stance than controls before and 1-month post-TKA ($P < 0.05$).
Conclusions: Muscle strength, co-activation, and timing differed between patients and controls before and early after surgery. Rehabilitation to improve strength and muscle activation seems imperative to restore proper muscle firing patterns early after surgery.

1. Introduction

Total knee arthroplasty (TKA) is commonly performed to relieve pain and disability associated with knee osteoarthritis (OA). Despite pain relief and high patient satisfaction following surgery [1], deficits in lower extremity muscle strength and functional performance persist post-operatively [2]. Previous research suggests that quadriceps and hamstrings weakness and impaired gait biomechanics may persist for years following surgery [2,3].

Recovery of muscle strength is often difficult after TKA. In the first post-operative month, quadriceps strength declines by up to 60% [4]. While strength improves over time, quadriceps strength deficits of approximately 30% have been reported upwards of two years post-operatively compared to healthy adults [5]. Similarly, hamstrings strength reductions up to 50% have been reported in the immediate post-operative period [6,7] compared to pre-operative levels. Hamstrings strength deficits of nearly 30% may persist years after surgery compared to healthy adults [5].

Muscle weakness, particularly in the quadriceps, is related to impaired functional performance. Patients with quadriceps weakness following TKA walk slower and with aberrant biomechanics compared to healthy adults [8,9]. Patients frequently adopt a knee stiffening strategy during level walking following TKA, which is characterized by limited knee flexion range of motion and reduced demand placed on the quadriceps musculature [10]. Abnormal phasing of quadriceps and hamstring muscle activity may also occur with a knee stiffening strategy during walking, possibly altering kinematics and joint loading, hastening disease progression [10].

During daily activities, muscle groups surrounding the knee joint may fire individually to flex or extend the joint as necessary. Muscle co-activation is also common during daily activities, including walking, and occurs when multiple muscle groups are active at the same time. Increased levels of quadriceps/hamstrings co-activation have been

* Corresponding author. Tel.: +1 303 724 9170.
E-mail address: jennifer.stevens-lapsley@ucdenver.edu (J.E. Stevens-Lapsley).
[1] Present address: Biodynamics Research Laboratory, Department of Kinesiology, University of North Carolina at Charlotte, Charlotte, NC 28233.

http://dx.doi.org/10.1016/j.knee.2014.08.001
0968-0160/

reported frequently in patients with knee OA when compared with healthy adults, and may be related to dysfunction in these muscle groups [11,12]. In a comparison of patients measured two years following TKA to healthy adults, increased quadriceps/hamstrings co-activation occurred as a result of prolonged activity of the quadriceps during stance [13]. While this increased co-activation purportedly occurs to improve knee joint stability [12,14], it may also increase compressive forces through the joint and precipitate degeneration. Further, increased co-activation suggests that patients have difficulty isolating their quadriceps and hamstrings muscles during functional tasks, which may relate to muscle weakness after TKA [15].

While the presence of co-activation has been reported in patients with knee OA and long term following TKA, quadriceps and hamstrings muscle activation patterns in the acute post-operative period remain unclear. Understanding activation patterns, including timing and co-activation, is necessary to successfully counter abnormal muscle activity during post-operative rehabilitation with targeted intervention strategies. This study, therefore, examined bilateral quadriceps and hamstrings strength and muscle activity during walking in patients before, one month after, and six months after TKA. Additionally, we compared the results to those obtained in healthy older adults. We hypothesized patients would demonstrate muscle weakness and higher levels of quadriceps/hamstrings co-activation at all time points compared to healthy adults.

2. Methods

2.1. Participants

Ten patients and 10 healthy, older adults (controls) participated (Table 1). Patients were eligible if they were undergoing a unilateral, primary TKA for knee OA using a medial parapatellar approach [7]. Individuals were excluded from participation if they had: 1) current lower extremity orthopedic conditions besides knee OA in the patient cohort; 2) uncontrolled diabetes; 3) cardiovascular or neurological disease; 4) body mass index $\geq$35 kg/m^2; or 5) any other medical conditions that severely limited function. Patients completed three testing sessions: pre-operative and one and six months post-operative. The control group completed only one testing session. Participants received rehabilitation as recommended by their surgeon, which typically consisted of five to six home physical therapy sessions over the first one to two weeks post-operatively, followed by four to six weeks of outpatient physical therapy (one to two days/week). This study was approved by the Colorado Multiple Institutional Review Board. All participants provided written, informed consent prior to participation.

2.2. Procedures

2.2.1. Pain assessment

Participants completed a numerical rating of pain scale during testing. Pain was rated on a scale of 0–10 (0: no pain present; 10: worst pain possible) after participants completed the six-minute walk test.

2.2.2. Electromyography and step data

After cleaning the skin with isopropyl alcohol, surface electromyography (EMG) electrodes (DE2.3, Delsys Inc, Boston, MA, USA) were placed bilaterally over the vastus lateralis and biceps femoris [16]. A ground electrode was placed over the lateral humeral epicondyle. Data were amplified by 1000 and stored using the Myomonitor IV datalogger (Delsys Inc., Boston, MA). Heel strike timing for each step was determined by use of heel switches collecting synchronously with the EMG data.

Table 1
Participant baseline demographics. Data are mean ± standard deviation.

	Patient (n = 10)	Healthy (n = 10)
Sex (% female)	60	60
Age (years)	64.70 ± 7.90	60.60 ± 7.44
Body mass index (kg/m^2)*	29.15 ± 2.50	25.47 ± 4.00

* indicates significant difference between groups ($P < 0.05$).

2.2.3. Strength

Participants performed isometric quadriceps and hamstrings strength assessment using an electromechanical dynamometer (Humac Norm, CSMI Solutions, Stoughton, MA, USA). Strength data were collected in real-time using a computer running AcqKnowledege v3.8.3 (Biopac, Inc., Goleta, CA, USA) [7,17]. All strength assessments were performed bilaterally, beginning with the nonsurgical limb in patients and the left limb in the control group.

For all muscle strength testing, participants were seated with the hip and knee flexed to 85° and 60°, respectively [7,17]. Following two submaximal warm-up repetitions, participants performed a series of maximal voluntary isometric contractions (MVICs) until the torque values generated during two trials were within 5% of each other. A maximum of four trials were performed. Participants were given verbal and visual feedback during testing to elicit maximal effort. The highest torque value across all MVICs was normalized to participant body mass (Nm/kg) and used for analysis. The hamstrings were tested before the quadriceps.

2.2.4. Functional performance

Physical function was assessed using the six-minute walk test (6MW). The 6MW assesses the distance a person can walk in six minutes [18]. To perform the 6MW, participants walked laps in a 30.5 m hallway and the distance covered, in meters, was recorded [19].

2.2.5. EMG data analysis

The EMG data were bandpass filtered using a fourth order, zero lag, Butterworth filter with 20–350Hz cutoff frequencies [20]. The Teager-Kaiser Energy Operator (TKEO) was applied to the filtered EMG signal. The TKEO combines the amplitude and instantaneous frequency [21] of the EMG signal and is recommended for use when determining timing in data with a low signal-to-noise ratio [22]. Linear envelopes were created with full-wave rectification and a fourth-order, zero phase lag, low-pass filter (6Hz cutoff). Linear envelope data were normalized by dividing by the mean amplitude of the signal during the 6MW [23,24]. EMG data were time normalized to 100% of the complete gait cycle (*i.e.*, heel strike to heel strike). Ensemble averages were calculated from 10 strides of the 6MW test and used to calculate the dependent variables.

The quadriceps/hamstrings co-activation index (CAI) was calculated based on the integrated EMG signal [25]. Quadriceps and hamstrings on and off times (Q_{on}, Q_{off}, H_{on}, H_{off}) were calculated as the instances (in % gait cycle) when the linear envelope crossed 20% of the mean normalized linear envelope.

2.3. Statistical analysis

The independent variables for analysis were group (patient and control), limb (surgical and nonsurgical), and time (pre-op, one month post-op, and six months post-op). Dependent variables were pain, quadriceps strength, hamstrings strength, 6MW distance, CAI, and quadriceps on/off times (Q_{on}, Q_{off}), and hamstrings on/off times (H_{on}, H_{off}). Independent samples t-tests compared the dependent variables between the control group and the patient group (at each time). Paired samples t-tests were used to compare dependent variables between limbs at each time. The *a priori* alpha level was 0.05. All statistical analyses were performed in IBM SPSS Statistics (version 19, Armonk, NY, USA).