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# Lower leg compensatory strategies during performance of a step up and over task in patient six-months after total knee arthroplasty

Federico Pozzi[a,*], Adam R. Marmon[b,c], Lynn Snyder-Mackler[b], Joseph Zeni Jr.[b]

[a] Division of Biokinesiology and Physical Therapy, University of Southern California, 1540 Alcazar St., CPH 155, Los Angeles, CA 90266, United States
[b] Department of Physical Therapy, University of Delaware, United States
[c] Department of Orthopaedics and Rehabilitation Services, Christiana Health Care System, United States

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ABSTRACT

The purpose of this study was to assess the ankle, knee, and hip joint contributions to the total support moment (TSM) and the activation patterns of muscles in the lower leg in patients after total knee arthroplasty (TKA) and healthy older adults during the step up and over task. Moreover, the relationship between quadriceps strength and knee contribution to TSM was measured. Twenty patients six-months after TKA and twenty healthy controls were recruited for this study. Motion and surface electromyographic (EMG) analyses were performed during a step up and over task. Biomechanics and EMG variables were compared between groups using ANCOVA models with movement speed as covariate. Patients after TKA had reduced contribution to the TSM from the knee joint, and greater contribution from the hip and ankle joints, possibly to compensate for the reduced contribution at the knee. No consistent differences of EMG activation or co-contraction were found between groups. Patients with stronger quadriceps had significantly higher knee contribution to TSM during the lowering phase of the task. The results of this study suggest that patients after TKA may use compensatory strategies at the hip and ankle joints to safely perform the step up and over task. Patients may rely on the force generating ability of the quadriceps during the lowering phase as they are not able to compensate with other joints of the lower extremity during this phase of the task.



## 1. Introduction

After total knee arthroplasty (TKA), patients demonstrate reduced knee flexion angles and excursions during gait [1], stair ascent and descent [2,3], and step up and over tasks [4] compared to their non-operated leg or control subjects. These kinematic changes result in lower internal knee extension moments, knee power absorption and knee power generation [1–4]. Although most previous studies have focused on kinetic differences between individual joints [1,2,4,5], few have evaluated the underlying coordination strategy of the whole lower extremity kinetic chain [3,6].

During weight bearing activities, internal extensor moments at the hip, knee, and ankle prevent the collapse of the body during closed-chain movements [7]. The summation of these individual joint moments is referred to as the total support moment (TSM), and is considered a surrogate measure of the overall moment required to support the center of mass [7,8]. Individual joint contributions to the TSM reflect the global coordination strategy and within-segment compensations that occur in the presence of pathology or impairments of the lower extremity [7]. Compared to healthy control subjects, individuals after TKA have altered contribution of the lower extremity joints to TSM during gait [6] and stair climbing [3]. In patients after TKA, there was higher contribution to TSM from the hip and lower contribution from the knee compared to a control group during both activities.

Coordination of the lower extremity chain can also be inferred from the muscle activation patterns that drive joint moments in the sagittal plane. For example, low knee joint moments may arise as a result of altered joint position and reduced external forces [1], or from excessive muscle activation and co-contraction of antagonistic muscles [9]. Evaluation of muscle activation patterns is critical because while kinetic coordination patterns may be equivocal between those with high and low muscle activation, the resultant joint forces are not. Individuals with greater co-contraction have greater internal compressive forces [10,11]. Additionally, interventions addressing abnormal kinetics should address the underlying cause to either reduce co-contraction of

* Corresponding author.
*E-mail address:* pozzi@usc.edu (F. Pozzi).

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agonist muscles, increase joint excursion angle, or correct for movement asymmetries.

While knee specific biomechanical impairments have been previously measured during the step up and over task [4], neither the potential compensatory strategy at the hip and ankle joints nor the underlying muscle activation patterns have been evaluated. Therefore, the purpose of this study was to (1) assess ankle, knee, and hip joint contributions to TSM during the step up and over task; (2) measure the activation pattern of the lower leg muscles during the task; and (3) assess the relationship between knee contribution to TSM during the step up and over task and quadriceps strength. We hypothesized that patients 6 months following TKA would shift the contribution to proximal joints to compensate for reduced contribution at the knee joint and that the magnitude of compensation would be related to quadriceps strength. We also anticipated that subjects after TKA would have greater EMG activation of knee musculature compared to the control group to increase stability when normalized to each subject's maximal voluntary contraction.

## 2. Methods

### 2.1. Participants

A secondary analysis of data from twenty patients 6 months following unilateral TKA and twenty older adults without lower extremity joint pathology was performed. Participants between 50 and 85 years of age were recruited, but individuals were excluded if they had: (1) surgery on the lower extremities (other than the unilateral TKA for the TKA group); (2) knee pain greater than 4 out of 10 on an analog scale in the non-operated knee (TKA group) or either knee (control group); (3) neuromuscular, cardiovascular, and/or musculoskeletal impairments that limited physical function; (4) uncontrolled hypertension; (5) reported altered sensation (tingling or numbness) in their feet; (6) body mass index (BMI) > 50; or (7) if they were unable to perform the step up and over task without supervision. The study was approved by the Human Subjects Review Board and each participant gave informed consent prior to starting any study component.

### 2.2. Procedure

#### 2.2.1. Strength measurement

Quadriceps maximal voluntary isometric strength was measured using an electromechanical dynamometer (Kin-Com, Chattex Inc., Chattanoga, TN, USA). Participants were positioned according to manufacturer recommendation with the knee flexed to 75°. Three maximal voluntary isometric contractions (MVIC) were performed with one minute of rest between contractions [4]. Data were acquired at 200 Hz using a custom made software. Data were collected in Newtons and normalized to body mass (Kg), with the best of the three trials used for further analysis.

#### 2.2.2. Biomechanical testing

The motion analysis system included 8 cameras (Vicon, Oxford Metrics Ltd., London, UK) synchronized with two force plates (Bertec Corporation, Worthington, OH, USA). Kinematic and kinetic data were collected at 120 and 1080 Hz, respectively. Subjects were equipped with retroreflective markers: 18 single markers were placed bilaterally over specific anatomical locations (acromion, iliac crest, greater trochanter, lateral femoral condyle, head of the 5th metatarsal, and two markers on the heel). Five rigid thermoplastic shells with four markers were used to track the movement of the trunk, thigh and shank; one thermoplastic shell with three markers was used to track the pelvis. Motion analysis was performed as participants stepped up and over a wooden step (length 31.5 cm, width 43.5 cm, height 20.5 cm) screwed into one force plate via a flat metal footing positioned on either side [4,12–14]. Participants were instructed to stand 5 cm behind the box and then step onto it with one limb (stepping limb), traverse over the step to clear the swinging limb, land on the force plate in front of the wooden step with the contralateral limb (landing limb), and continue walking (Fig. 1) [4].

After a description and demonstration of the task, participants performed two practice trials. If subjects were able to perform the task without supervision, participants completed 5 trials using each limb as the stepping and landing limb. Only data from the surgical limb were used for this analysis.

#### 2.2.3. Electromyography

Surface electromyography (EMG) was collected using active surface electrodes (Motion Lab Systems, Baton Rouge, LA, USA). Double differential, preamplified electrodes were placed bilaterally over the belly of six muscles of the lower extremity: vastus medialis and lateralis, lateral hamstring, medial and lateral gastrocnemius, and tibialis anterior. Prior to applying the electrodes, the skin was shaved and cleaned with alcohol [15]. MVIC trials were then performed; signal quality was evaluated and channels gains adjusted then the maximal volitional activation was recorded, including 1–2 s in which the muscle was quiet. Separate trials were performed for each muscle group. During the step up

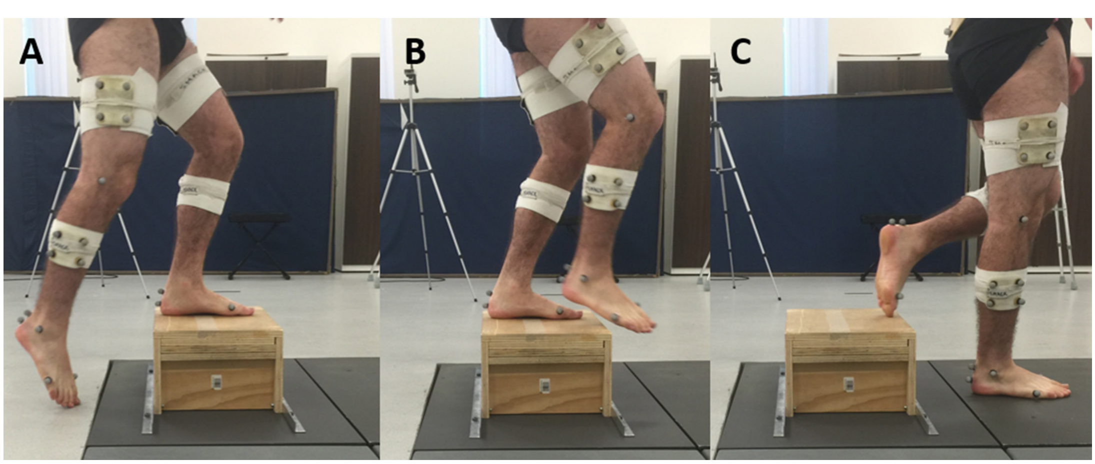


**Fig. 1.** Representative participant performing the step up and over task. Participant is completing the propulsive (A), lowering (B), and weight acceptance (C) phases of the task. Participants wore shoes during the data collection.