



Muscle Force Steadiness in Older Adults Before and After Total Knee Arthroplasty



Jessica W. Smith, PhD ^{a,b}, Robin L. Marcus, PT, PhD ^b, Christopher L. Peters, MD ^c, Christopher E. Pelt, MD ^c, Brian L. Tracy, PhD ^d, Paul C. LaStayo, PT, PhD ^{a,b,c,e}

^a Department of Bioengineering, University of Utah

^b Department of Physical Therapy, University of Utah

^c Department of Orthopedics and University Orthopedics Center, University of Utah

^d Department of Health and Exercise Science, Colorado State University

^e Department of Exercise Science, University of Utah

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ABSTRACT

The ability to control submaximal muscle forces has been shown to be associated with age-related decreases in physical function, such as increased tendency to fall. This study compared quadriceps muscle force steadiness (MFS) in individuals with knee OA before and after total knee arthroplasty (TKA) to an age-matched group of controls. Lower extremity MFS was measured in 13 subjects with knee OA before and at six months after TKA (TKA-GROUP) and compared to an age-matched control group (CONTROL-GROUP). MFS was significantly more impaired in the TKA-GROUP at the pre-operative, but not post-operative visit, and significantly improved between the pre-operative and post-operative visits. Further research is warranted to evaluate the relation between this MFS measurement and physical functional performance in those at high risk for falling.

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Symptomatic knee osteoarthritis (OA) affects nearly 4.3 million or 12% of adults over the age of 60 in the United States [1,2]. By the year 2030, this number is expected to grow to 25% of adults in the US [3], with a corresponding six-fold increase in the number of total knee arthroplasty (TKA) surgeries from the current annual rate of 500,000 per year [2,4]. TKA has been shown to reduce chronic knee pain associated with OA [5–8], though studies have consistently demonstrated residual mobility deficits linked to reduced quadriceps muscle function [5–12]. Despite the long-term muscle and mobility deficits, the demand for the pain-reducing TKA procedure continues to increase as does the need to identify modifiable factors that may be linked to sub-optimal physical function following surgery [13,14].

Persistent quadriceps weakness in TKA recipients is clinically important as it is coupled to physical function that requires adequate maximal strength and control of submaximal muscle force variability [15,16]. Specifically, muscle atrophy, muscle weakness, and neuromuscular activation deficits are all factors that have been implicated in residual post-operative strength impairments [9,17]. Additionally, declines in proprioception [18], kinesthetic awareness, and other sensory feedback mechanisms, have been linked to slower movement patterns [17,19], decreased power output, and reduced force steady-

ness [20–22]. The consequences of these adaptations include a reduced ability to exert a steady force output during submaximal contractions, as well as greater variability in movement patterns [21,23]. Indeed, most activities of daily living require submaximal effort, and therefore, the ability to execute these tasks steadily, accurately, and without impairment is important to long-term physical function.

Quadriceps muscle force steadiness (MFS), which represents the ability to maintain constant submaximal muscle forces, has been positively correlated with performance during stair stepping in patients with hip OA [24], and with functional performance in elderly women [16], elderly fallers compared to non-fallers [25], and in individuals with knee OA compared to healthy controls [26]. These studies emphasize the importance of submaximal force control, with greater unsteadiness correlating with greater impairment in the ability to move smoothly and accurately, and potentially adapt to changing environments [27]. Indeed, these findings are important because most activities of daily living (ADLs) do not require maximal force output, and therefore, the quality rather than the quantity, of force production is critical to effectively performing a specific task.

By necessity, TKA surgery disrupts the knee joint capsule and associated mechanoreceptors that contribute to proprioceptive feedback and control of muscle force output. While the removal of intra-articular pathology has a predictable pain reduction effect, the effects on MFS and the ability to perform functional activities highly dependent on sensorimotor feedback remain unclear. The impact of TKA surgery on quadriceps MFS has not, to our knowledge, been described. Muscle force steadiness is a novel

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Reprint requests: Jessica W. Smith, PhD, Department of Physical Therapy, Department of Bioengineering, University of Utah, Salt Lake City, UT 84108.

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measurement in this patient population and may have implications as a rehabilitation target for improving physical function and long-term post-operative outcomes.

Thus, the purpose of this study was to compare MFS of submaximal quadriceps force output in individuals with knee OA before and after TKA, to a group of age-matched controls with native knees. We hypothesized that pre-operatively, the surgical leg would exhibit impaired MFS compared to the control group. Because the effects of TKA surgery on MFS are unknown, we propose the null hypothesis that at six months following surgery, MFS would not significantly improve on the surgical leg compared to their pre-operative study visit, or the control group.

Methods

This prospective, controlled study was approved by an Institutional Review Board (IRB) and all subjects consented to participation prior to enrollment. A total of 16 TKA subjects (TKA-GROUP) were recruited from a local orthopedic center and 11 healthy controls (CONTROL-GROUP) with native knees were recruited from local advertisements and institutional subject databases. Subjects included men and women between the ages of 50 and 75 years.

All TKA-GROUP subjects were diagnosed with knee OA, and were scheduled for TKA surgery prior to enrollment. All TKA-GROUP subjects underwent primary TKA by one of two surgeons at a tertiary academic medical center under either a general or spinal anesthetic with a 0.125%–0.25% bupivacaine femoral nerve catheter for 48 h and single shot popliteal fossa block. Procedures were performed using a medial parapatellar arthrotomy. Cemented or cementless cruciate retaining femoral components, cemented modular titanium tibial components and either a cruciate retaining (CR) or anterior stabilized (AS) bearing (Vanguard, BIOMET, Inc., Warsaw, Indiana, USA) were implanted. For the TKA-GROUP, exclusion criteria included rheumatoid arthritis; a body mass index (BMI) > 40; comorbidities that would have influenced the ability of the subject to perform the study assessments; inability to complete questionnaires secondary to cognitive/language difficulties; history of smoking, or alcohol or drug abuse within the past one year; current diagnosis or treatment for cancer, Parkinson's Disease, Multiple Sclerosis, or other neurological conditions; current diagnosis of a chronic inflammatory condition including, but not limited to, lupus or inflammatory bowel disease; and participation in another investigational study involving an exercise protocol <30 days before enrollment in the current study. In the TKA-GROUP subjects, the diagnosis of OA was confirmed pre-operatively with radiographs and careful review of past medical conditions. Table 1 includes a summary of baseline subject characteristics.

The CONTROL-GROUP, comprised of healthy control subjects with native knees, had little to no knee pain with pain levels < 3 out of

10 on a visual analog scale for walking or stair climbing in either knee. The CONTROL-GROUP also had no history of joint arthroplasty or other joint surgery that would interfere with their normal gait patterns.

Study assessments included quadriceps MFS, as measured by the coefficient of variation (CV) of force during MFS tasks, in an open-chain fashion on a KinCom 500H dynamometer (Isokinetic International, Harrison, TN). Self-report outcome measures of physical activity levels were assessed using the Rapid Assessment of Physical Activity (RAPA) survey at the pre-operative and post-operative study visits by the TKA-GROUP and by the CONTROL-GROUP at their one study visit.

Quadriceps Muscle Force Steadiness (MFS)

MFS was quantified by determining the ability to exert a steady submaximal muscle force using a KinCom dynamometer (Isokinetic International, Harrison, TN). The surgical leg for the TKA-GROUP was assessed at two time points: within two months prior to surgery and at six months post-operatively. For the CONTROL-GROUP, MFS measurements were performed at one time point on the dominant leg only, which was the same as the hand they wrote with. The target force for MFS testing was established first by testing the quadriceps maximal voluntary isometric contraction (MVIC) peak force (N), with the hip flexed to 90° and the knee flexed 45°. Prior to the MVIC test, subjects completed three submaximal practice trials to become familiar with the testing procedure. Each practice trial included a self-reported successive increase in force from between 50% and 75% of their MVIC. Each MVIC test consisted of a three-second maximal contraction with 1 to 2 min of rest between each test. The peak force from the three trials was used to calculate the 50% MVIC target force for MFS testing. Concentric and eccentric MFS was tested across a knee range of motion of 75° to 15° of knee flexion. MFS testing was performed isokinetically at a fixed speed of 15°/s, and data were sampled at 1000 Hz. Thus, a total of four seconds of data was collected for each of the concentric and eccentric contractions. The middle two seconds (60° to 30° ROM) was used for data analysis as a conservative strategy to eliminate transition effects in the first and last 1 s of movement.

For MFS testing, the computer monitor was placed approximately three feet in front of the subject and the main lights in the room were dimmed to enhance the visibility of the screen. A bold horizontal target force line representing 50% of MVIC was visible on the screen. The subject was instructed to exert force against the lever arm attached to his or her lower leg and match the target force line on the computer monitor as steadily as possible over the entire range of motion. The subject's force was represented by a bold signal that scrolled horizontally from left to right across the screen. Fifty newtons of force was required to initiate the movement of the lever arm in either concentric or eccentric mode. The same procedure was used for concentric and eccentric MFS testing.

Muscle force steadiness testing included 1) one familiarization trial to become familiar with the testing procedure (not recorded), 2) nine warm-up trials, and 3) up to 15 additional recorded trials that were used for data analysis. The nine warm-up trials were performed to minimize any effects of short-term learning. Criteria for stopping included knee pain greater than or equal to 3 on a 1 to 10 visual analog scale (VAS) scale, with 10 being the highest pain; or if the subject reported fatigue that was significant enough to prevent completion of more trials, even with greater than 5 min of rest. Otherwise, subjects completed all 15 trials.

Following data collection, the concentric and eccentric force–time curves of all the trials were low-pass filtered at 100 Hz (Butterworth). The middle two seconds (60° to 30° of knee flexion) of data were detrended by removing the slope from the data and the standard

Table 1
Baseline Subject Demographics; Pre-Operative TKA-GROUP vs. CONTROL-GROUP.

Variable	TKA-GROUP (n = 13)	CONTROL-GROUP (n = 11)	P Value ^a
Age (years)	62.71 (6.84)	62.19 (8.61)	0.99
Height (m)	1.67 (0.09)	1.64 (0.10)	0.52
Weight (kg)	86.40 (11.73)	62.15 (10.48)	<0.001
BMI (kg/m ²)	30.96 (4.14)	23.07 (2.16)	<0.001
Gender (% Males)	15%	18%	–
RAPA ^b	4.23 (1.36)	6.27 (0.90)	<0.001

Data presented as mean ± SD.

^a P value represents the comparison of pre-operative TKA-GROUP vs. CONTROL-GROUP.

^b RAPA scale is 0–7, with 7 being the highest level of activity.

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