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Preliminary investigation of rate of torque development deficits following total knee arthroplasty

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ABSTRACT

Background: To assess changes in maximal strength and rate of torque development (RTD) following TKA, and examine the relationships between these measures and physical function.

Methods: Thirty-five TKA patients and 23 controls completed isometric knee extensor torque testing preoperatively, 1, and 6 months after surgery. Maximal strength was calculated as the peak torque during a maximal voluntary isometric contraction (MVIC) of the knee extensor muscles, peak RTD (RTD_{peak}) was calculated as the maximum value from the 1st derivative of the isometric knee extension torque data, $RTD_{25\%}$ and $RTD_{50\%}$ were calculated as the change in force over the change in time from force onset to 25% and 50% MVIC. Physical function was measured using a timed-up-and-go (TUG) and stair climbing test (SCT).

Results: RTD was significantly lower in the TKA group, at all-time points, compared to the Controls. MVIC and RTD significantly decreased 1-month following surgery ($p = 0.000$ for all measures). RTD_{peak} measures added to linear regressions with strength improved the prediction of TUG scores ($p = 0.006$) and the SCT scores ($p = 0.015$) 1-month post-surgery. Adding $RTD_{50\%}$ to the regression model, following MVIC, improved predicting both TUG ($p = 0.033$) and SCT ($p = 0.024$). At 6-months, the addition of $RTD_{25\%}$ to the regression model, following MVIC, improved the prediction of TUG ($p = 0.037$) and SCT ($p = 0.036$).

Conclusion: Following TKA, physical function is influenced by both the maximal strength and the rate of torque development of the knee extensors, and the prediction of function is improved with the addition of RTD compared to that of maximal strength alone.

1. Introduction

Knee osteoarthritis (OA) is the leading cause of disability among older adults [1] often resulting in total knee arthroplasty (TKA). TKA is one of the most common elective surgical procedures performed in older adults with over 600,000 performed each year; costing approximately $9 billion/year [2]. Evaluating the effectiveness of TKA surgery is often based upon patient-centered outcome measures, such as pain and physical function following surgery [3]. These outcomes are reliant not only upon surgery-related factors such as surgical technique and surgeon experience/skill, but also by rapidly regaining functional independence through an active physical rehabilitation process [3]. Current rehabilitation efforts focus on improving surgical outcomes with an emphasis on strengthening the knee extensors. This rehabilitation approach often results in significant functional improvement, but is often not sufficient to restore performance to that of healthy older adults [4]. Deficits in both strength and physical function exist prior to TKA and become significantly worse 1 month after surgery, often returning to preoperative levels six months following surgery [5]. Yet, while physical function returns to preoperative levels following TKA, function rarely returns to levels of healthy older adults. Deficits persist in tasks such as rising to standing and climbing stairs [4].

While knee extensor strength is a key component, the speed of a muscle contraction, also has an important influence on physical function. Many aspects of physical function are dependent not only on strength, but also the speed with which force is developed (e.g. crossing a street or climbing stairs quickly). Studies are beginning to demonstrate the link between rapid force generation and functional task performance capabilities [6–8]. As such, older adults with mobility limitations have reduced ability to produce muscle force rapidly compared to healthy adults of similar age [8]. People with hip OA exhibit deficits in rapid knee extensor force generation that are larger than deficits in maximum knee extensor strength [9]. Three months following TKA, significant deficits in the rapid development of knee extensor force have been reported [10]. In addition, asymmetries in rapid knee extensor force generation between surgical and nonsurgical legs correlate to self-reported measures of function more strongly than the knee extensor strength asymmetries [11]. Identifying the inability to rapidly generate force, or torque, as a key factor associated with physical function would have important implications for rehabilitation strategies designed to optimize functional recovery following TKA.

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Long term functional deficits persist following TKA [4,12] and indicate that current rehabilitation practices are not sufficient in restoring function to levels similar to that of healthy older adults. The importance of rapid torque generation in function and disability has prompted the development of exercise programs with a focus on improving the ability to rapidly generate torque in older adults [6], yet following TKA, muscle strengthening is still commonly recommended without emphasis on the rate of torque development (RTD). Impaired rate of torque development of the knee extensors is a modifiable risk factor for diminished functional recovery following surgery that could be addressed with appropriate rehabilitation. Therefore, the purpose of this study was to assess maximal knee extensor strength and rate of torque development preoperatively, 1, and 6 months following TKA and 1) examine changes in maximal knee extensor strength and RTD following TKA, and compared to that of healthy older adults, 2) examine the correlation between knee extensor RTD and muscle activation deficits following TKA, and 3) determine if knee extensor RTD contributes to a timed-up-and-go (TUG) and stair climbing time (SCT) beyond that of knee extensor strength alone.

2. Methods

2.1. Subjects

Patients following TKA were retrospectively identified from 2 previous studies [13,14]. Both studies were approved by the Colorado Multiple Institutional Review Board and informed consents were obtained from all subjects prior to participating in either of the 2 studies. Patients with TKA from the control groups for each trial were included in the TKA group for this secondary analysis focused on rate of torque development. All patients had a primary unilateral TKA secondary to knee osteoarthritis and participated in a standardized rehabilitation programs following surgery as previously described [14]. Exclusion criteria were similar, but not identical for both studies [13,14]; both studies previously sought to recruit a patient population with unilateral OA, with minor differences in age and BMI targets. Exclusion criteria included uncontrolled hypertension, uncontrolled diabetes, significant neurologic impairments, contralateral knee OA (as defined by pain greater than 4/10 with activity), or other unstable lower-extremity orthopedic conditions. Patients were included in this study if they were between 45 and 85 years of age, had a body mass index > 40 kg/m^2, and underwent a tri-compartmental, cemented TKA with a medial parapatellar surgical approach. Rate of torque development was obtained from all control group participants who were able to perform a rapid maximal isometric contraction of the quadriceps. Subjects that could not produce a rapid maximal contraction, experienced technical difficulties during the data collection, or did not have a stable resting baseline prior to force initiation were excluded from this analysis. In addition, a cohort of healthy adults was recruited from the community and informed consent was obtained from each participant. The healthy control group subjects had no history of hip or knee osteoarthritis or joint replacement and were of similar age to the TKA subjects.

2.2. Knee extensor strength, rate of force development, and activation

Maximal strength was calculated as the peak torque measured during a maximal voluntary isometric contraction (MVIC) of the knee extensor muscles, rate of torque development (RTD), and activation of the knee extensors were assessed at the preoperative, 1-month and 6-month post-surgery testing sessions. A HUMAC NORM (CSMi, Stoughton, Massachusetts) electromechanical dynamometer was used to measure knee extensor muscle torque. Data were collected with a Biopac Data Acquisition System (BIOPAC Systems Inc, Goleta, California) and AcqKnowledge software, version 3.8.2 (BIOPAC Systems Inc). Subjects were positioned in an electromechanical dynamometer with 60 degrees of knee flexion. Subjects were asked to perform a maximal voluntary isometric contraction (MVIC) of the knee extensors using both visual and verbal feedback up to 3 times unless the first 2 attempts were within 5% of each other. The trial with the steepest linear rise in force from rest was then used for data analysis. Peak RTD (RTD_{peak}) was calculated for the surgical limb as the maximum value from the 1st derivative of the isometric knee extension torque data. RTD was also calculated as the change in force over the change in time from force onset to 25% MVIC ($RTD_{25\%}$) and 50% MVIC ($RTD_{50\%}$) [15]. The torque onset was calculated as the point above 1.25 N (~2% of the average MVIC for the lowest testing point, which was 1 month post-surgery).

Activation was assessed using methods described in previous research [16]. Briefly, a two pulse (doublet) with a 10 ms interpulse interval, supramaximal electrical stimulus was delivered to the muscle during a maximal voluntary isometric contraction (MVIC) of the quadriceps and again to the muscle at rest. In the absence of central activation deficits, no increase in muscle force is measured when the stimulus is delivered. Central activation of the knee extensors was quantified using the ratio of the force produced with resting and superimposed stimuli as previously described [14].

2.3. Measures of physical function

The timed-up-and-go (TUG) measures the time it takes to rise from a chair, walk 3 meters, turn around and return to a seated position in the chair [17]. Subjects began seated with their feet on the floor and began the test upon the investigator's command. Subjects were permitted to use the arms of the chair for support during rising and sitting if needed. The faster of two trials was used for analysis. The TUG has excellent test–retest reliability and is commonly used to measure functional ability in older adults [17]. Stair climbing time (SCT) evaluates an individual's ability to ascend and descend a set of twelve steps. The steps were 18 cm high with a depth of 28 cm. Subjects were asked to ascend, turn around, and then descend the steps as quickly as possible in a safe manner. The handrail was available for use if needed. The faster of two trials recorded on a stopwatch to the nearest one hundredth of a second was used. A similar SCT was shown to have excellent test–retest reliability after TKA [18–20].

2.4. Statistical analysis

All statistical analyses were performed using IBM SPSS statistics for Windows, version 21 (IBM corp, Armonk, NY). Independent samples *t*-tests were used to assess differences between the TKA patients and control subjects in MVIC and RTD preoperatively, 1, and 6 months following TKA. Linear mixed models were used to analyze within subject differences for the repeated measures variables of MVIC, RTD_{peak}, $RTD_{25\%}$, and $RTD_{50\%}$ for the TKA group. Linear mixed models were chosen for this analysis to avoid the listwise deletion of patients from the entire analysis who did not have complete data sets. Post-hoc pairwise comparisons were performed using Bonferroni corrections to protect against a Type I statistical error. In the TKA group, hierarchical linear regressions were used to examine whether RTD provided a significant additional contribution to the explanation of the variability in TUG and SCT after accounting for the influence of MVIC. In hierarchical regression, variable(s) that are known to explain the variance in the dependent measure are added to the model first, in this case strength. [21] When additional variables are added to the model, the change in r^2 (Δr^2) is reported. If the Δr^2 is significant, then that variable is said to explain a unique portion of the variability in the dependent variable, after having accounted for the previous variable(s) entered in the model. Pearson correlation coefficients were used to investigate the MVIC and RTD relationships with activation, TUG, and SCT at each time point in the TKA group. Tolerance and variance inflation factor statistics were used to examine collinearity between MVIC and RTD measures during the regression analyses. For all tests, statistical significance was