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Stance time variability during stair stepping before and after total knee arthroplasty: a pilot study

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Abstract

The main objectives of this pilot study were to: 1) investigate stance time variability (STV) during stair stepping in older adults with osteoarthritis (OA) before and after total knee arthroplasty (TKA), and compare to an age- and sex-matched group of healthy controls with native knees and 2) evaluate the relationship between quadriceps strength and STV during stair stepping before and after TKA. A prospective, observational, pilot study was carried out on 13 individuals (15% male, mean age 62.71 ± 6.84 years) before and after TKA using an instrumented stairway, patient-reported outcomes, timed stair stepping test, and quadriceps strength measures. At 6-months post-operatively, STV during stair descent was significantly greater in the TKA-GROUP compared to the CONTROL-GROUP, but was not significantly different at 12-months compared to controls. There were no significant differences in STV for stair ascent between the pre- and post-operative visits, or compared to controls. There was a trend toward significance for the relationship between quadriceps strength and STV during stair ascent ($P=0.059$) and descent ($P=0.073$). Variability during stair stepping may provide an important, short-term rehabilitation target for individuals following TKA and may represent another parameter to predict declines in functional mobility.

Keywords

Rehabilitation; Motor Processes; Sensory Perception

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Introduction

Osteoarthritis (OA) is one of the leading causes of disability in the United States (Addison et al., 2014), affecting approximately 4.3 million adults over age 60 years of age (Dillon, Rasch, Gu, & Hirsch, 2006). The knee is one of the most common joints affected by this debilitating condition (Dillon et al., 2006), accounting for significant difficulty with activities of daily living (Lawrence et al., 2008). As a result, increasing numbers of individuals with advanced OA are opting to undergo a total knee arthroplasty (TKA) (Yan, 1999). However, emerging evidence indicates that a significant number of individuals still report continual knee pain and functional disability following TKA (Hawker, 2006; Meier et al., 2008; Stevens, Mizner, & Snyder-Mackler, 2003).

Further evidence suggests that functional impairments are precipitated by pre-operative limitations due to the arthritic joint and later compounded by the ramifications associated with the surgical procedure post-operatively (Fortin et al., 1999; Jones, Voaklander, & Suarez-Alma, 2003). Investigators have continually shown that individuals with end-stage knee OA display significant quadriceps femoris weakness, decreased proprioception, and associated functional limitations (Fitzgerald, Piva, Irrgang, Bouzubar, & Starz, 2004; Swanik, Lephart, & Rubash, 2004). Notably, these impairments persist post-operatively and can result in difficulty with stair stepping, ambulation, and increased fall risk, particularly during stair descent (Mizner & Snyder-Mackler, 2005; Yoshida, Mizner, Ramsey, & Snyder-Mackler, 2008).

In fact, one of the primary reasons for dissatisfaction following TKA is difficulty in stair climbing (Du, Tang, Gu, & Zhou, 2014). Lower extremity muscle weakness, persistent pain, and compensatory strategies following TKA have all been associated with impaired stair stepping ability (Andriacchi, 1993; Bjerke, Ohberg, Nilsson, & Stensdotter, 2014). Further evidence has indicated that altered joint biomechanics are present following TKA (McClelland, Webster, & Feller, 2007) and similar trends in variability during level walking in older individuals with knee OA may also be present during stair stepping (Whitchelo, McClelland, & Webster, 2014). Variability during stair stepping, similar to variability during level walking, may be another important rehabilitation target for individuals following TKA. This novel approach could help predict future falls and decline in functional mobility post-operatively. While prior studies have shown that TKA influences gait parameters (Fuchs, Floren, Skwara, & Tibesku, 2002; A. J. Smith, Lloyd, & Wood, 2006), to our knowledge, variability during stair stepping before and after TKA, has not been investigated.

In an attempt to better understand why a subset of individuals following TKA struggle with returning to a desired level of function, some studies suggest a causative link to impaired neural control and proprioception (Barrack, Skinner, Cook, & Haddad, 1983; Brandt, 2004; Swanik C, 2000; Swanik et al., 2004). Indeed, these factors have been shown to contribute to altered spatio-temporal, kinematic and kinetic mechanics when compared to healthy controls (Fallah-Yakhdani et al., 2010; Hausdorff, 2007; Kiss, 2011). More recently, researchers have identified stance time variability (STV) during level walking as a particularly important measure since it is correlated with fall risk and central nervous system

impairment in older adults (Brach, Studenski, Perera, VanSwearingen, & Newman, 2008; Hausdorff, 2007; Maki, 1997). While STV has not been studied in stair stepping, it is hypothesized that similar correlations may exist between STV and stair stepping as with level walking, and may potentially be a more sensitive predictor of post-operative fall risk. Acknowledging that this is a pilot study, the level of variability during stair stepping, particularly, stair descent, may provide insight into not only post-operative rehabilitation status, but also whether there are significant changes relative to pre-operative status as well as compared to healthy controls without a history of falling.

Thus, the purposes of this pilot study were to: 1) investigate STV during stair ascent and descent in older adults before and after TKA, and compare to an age- and sex-matched group of healthy controls with native knees, 2) evaluate the relationship between quadriceps strength and STV during stair stepping before and after TKA, and 3) compare time to ascend and descend stairs between pre- and post-operative time-points and between groups. Self-report health outcomes were also evaluated across time-points and between groups.

We hypothesized that, prior to TKA surgery, STV during stair ascent and descent in older adults with knee OA would be significantly greater than a group of age- and sex-matched healthy controls with native knees. Moreover, following TKA, STV during stair ascent and descent would improve and return to a level similar to healthy controls, but time to ascend and descend stairs would be significantly slower than healthy controls both pre- and post-operatively. Finally, we hypothesized that there would be an inverse relationship between quadriceps strength and STV during stair ascent and descent before and after TKA surgery.

Materials and Methods

Subjects

The University of Utah Institutional Review Board approved the study and all subjects provided their consent to participate prior to enrollment. A total of 13 TKA subjects (TKA-GROUP) were recruited from the University Orthopaedic Center (Salt Lake City, UT, USA) and 11 healthy controls (CONTROL-GROUP) with native knees were recruited from local advertisements and the University of Utah Department of Physical Therapy (Salt Lake City, UT, USA) subject database.

Subjects included men and women between the ages of 50 and 75 years. The CONTROL-GROUP, making up the healthy subjects with native knees, had knee pain levels < 3 on a visual analog scale with walking or stair climbing in either knee and no history of joint replacement or other joint surgery that would interfere with functional activity. Subject characteristics at the pre-operative time-point for the TKA-GROUP and CONTROL-GROUP were collected and are included in Table 1.

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 disease, multiple sclerosis, or other

neurological conditions; or current diagnosis of a chronic inflammatory condition, and participation in another investigational study involving an exercise protocol < 30 days before enrollment in the current study. Additional inclusion criteria for the TKA-GROUP subjects included diagnosis of OA in both knees, which was confirmed pre-operatively with radiographs, a careful review of medical records to rule out rheumatoid arthritis, and planned unilateral TKA surgical procedure. TKA subjects underwent three study visits; the pre-operative study visit occurred between 2 months and 1 week prior to TKA surgery; the 6-months post-operative visit occurred at 6 months $\pm$ 3 weeks of the TKA surgery, and the 12-months post-operative visit occurred at 12 months $\pm$ 1 month of the TKA surgery. The healthy controls underwent one study visit.

Surgical Intervention

All TKA-GROUP subjects underwent a primary, unilateral 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 hours and single shot popliteal fossa block. All procedures were performed using a medial parapatellar arthrotomy. All implants consisted of cemented or cementless cruciate retaining (CR) femoral components, cemented modular titanium tibial components and either a CR or anterior stabilized bearing (Vanguard, BIOMET, Inc., Warsaw, Indiana, USA).

Self-Report Health Outcomes

Self-report outcome measures were used to characterize each individual subjects perceived functional abilities. TKA subjects were characterized using the Lower Extremity Functional Scale (LEFS) and the Short Form 36 Health Survey (SF-36) at both the pre- and post-operative study visits. The TKA-GROUP completed the surveys at both time-points, and the CONTROL-GROUP completed the SF-36 at their one study visit. LEFS was not completed by the CONTROL-GROUP as it is used to measure dysfunction related to lower extremity conditions.

The LEFS questionnaire (Binkley, Stratford, Lott, & Riddle, 1999) has become a standard clinical evaluation for patients with a wide variety of lower extremity orthopedic conditions. The lower the score the greater the disability. Test-retest reliability is high (0.94) and construct reliability was determined by comparison with the SF-36 (Stratford, Kennedy, & Riddle, 2009). The SF-36 survey (Ethgen, Bruyere, Richy, Dardennes, & Reginster, 2004) is one of the most common health scales used in a TKA population. The physical component summary (PCS), which is an average of the responses for physical functioning, role physical, bodily pain, and general health, and mental component summary (MCS), which is an average of the responses for vitality, social functioning, role emotional, and mental health, were compared between groups and across time points. The SF-36 has been shown to be reliable, internally consistent and easy to administer (Ware et al., 1995) and has been repeatedly used in the literature as a generic health measure in populations of TKA and knee OA (Ethgen et al., 2004).

Timed Stair Climbing

The timed stair climbing test (SCT) measure is a physical performance outcome that evaluates the time it takes an individual to ascend and descend a flight of 10 steps, 0.27 meters high x 0.18 meters deep. Participants were instructed to perform the test as quickly and safely as possible, while having the option of using a single handrail for support as needed. A total of three ascents and three descents were recorded. The SCT demonstrates good test-retest reliability (0.93) (Rejeski et al., 1995) and responsiveness to detecting initial deterioration ($ES = -.71$) then subsequent improvement ($ES = .84$) (Mizner et al., 2011).

Muscle strength

Each subject's quadriceps maximal voluntary isometric contraction (MVIC) peak force (N) was evaluated on a KinCom 500H dynamometer (Isokinetic International, Harrison, TN, USA) with the hip flexed to 90 degrees and the knee flexed to 45 degrees. TKA-GROUP subjects were evaluated pre- and post-operatively, and the CONTROL-GROUP subjects were evaluated at the one study visit. Strength was tested in the surgical limb for the TKA-GROUP, and in the self-declared dominant limb for subjects in the CONTROL-GROUP. Prior to the MVIC test, subjects completed three sub-maximal practice trials to become familiar with the testing procedure. A total of three, consecutive MVIC tests were then recorded that consisted of a three seconds maximal contraction with one to two minutes rest between each test. MVIC was adjusted for BMI for all subjects and data comparisons. The highest of the three, recorded MVIC/BMI values on the surgical limb, was used for data analysis.

Variability during Stair Stepping

Assessments of stair stepping performance were performed in the Motion Capture Core Facility at the University of Utah, Department of Physical Therapy. The facility includes a 10 camera Vicon motion analysis system (200 Hz), two AMTI OR-6 series force platforms (1000 Hz; Watertown, MA, USA), and a Force Platform Stairway (AMTI; Watertown, MA, USA) which consisted of three, instrumented steps rigidly connected to the AMTI force platforms to capture kinematics and kinetics during stair ascent and descent. For testing on the stairs, participants wore a form-fitting top and bottom, and shoes that were constrained on their feet. A custom MATLAB program (The MathWorks, Natick, MA, USA) was used to correlate kinetics and temporal data to confirm the onset and offset of stance time. For the purpose of calculating STV, stance time was initiated upon first contact with the step and ended with last contact of the same foot on the same step. Participants performed a total of eight stair stepping trials. For each stair stepping trial, subjects were asked to walk, step over step, either up or down the stairs, at a self-selected pace. Participants were supervised closely during all trials with an adequate amount of rest to prevent fatigue and/or missteps during testing. Disqualification of a trial and an additional trial was performed, if they were able, if a participant was unable to perform "step over step" for all three steps.

The coefficient of variation (CV) of ST was calculated for stair ascent and stair descent for the surgical limb in the TKA-GROUP and on both lower extremities for the CONTROL-GROUP ($CV = \text{standard deviation}/\text{mean} \times 100$). For the TKA-GROUP, the CV of ST was calculated for the surgical limb and at each time-point (pre-operative, 6- and 12-month post-

operative visits). At each time point, the average of three trials was used for comparison with the control group. For the CONTROL-GROUP, measures of the CV of ST were averaged for both lower extremities and compared to the TKA-GROUP. As a safety measure, knee pain was assessed at several time-points during the stair stepping test procedure by asking the subject to rank their perceived amount of pain on a 0–10 visual analog scale. If the subject had pain > 3 or verbalized that they were in too much pain or too fatigued to continue, a rest period of up to 5 minutes was provided, and if the subject's status did not change, the testing procedure was stopped.

Statistical Analysis

Subject demographics were evaluated using descriptive statistics and compared between groups using a Student's t-test, after testing for homogeneity of variance. Comparisons between pre- and post-operative time-points and TKA and CONTROL groups were performed using an independent sample t-test and comparisons between study visits was performed using a repeated measures analysis of variance (ANOVA). Two-tailed, bivariate correlations were used to evaluate the relationship between quadriceps strength relative to BMI (MVIC/BMI) and STV during stair ascent and stair descent. All correlations were performed using Spearman's correlations for non-normally distributed data. Comparisons between self-report outcome measures were performed using an independent sample t-tests for mean differences between groups and repeated measures ANOVA was used to compare self-report measures between study visits for the TKA-GROUP. All statistical analyses were performed using SPSS (IBM Corporation) using a significance level of 0.05 and power of 0.80 to accept the null hypothesis.

Results

Of the 13 TKA subjects enrolled, nine subjects completed the first study visit, and 11 subjects each completed the 6- and 12-month study visits. Of these, there were a total of seven (7) subjects that completed all three study visits. All subjects who started testing finished the entire testing session. For the TKA-GROUP, only subjects that completed all three study visits were included in the within subjects data analysis. There were a total of 11 controls that were included in the data analysis.

Subject Demographics

Table 1 includes a summary of baseline subject demographics for both the TKA-GROUP and CONTROL-GROUP. BMI was significantly lower in the CONTROL-GROUP compared to the baseline measures of the TKA-GROUP ($23.07 \pm 2.16 \text{ kg/m}^2$ vs. $30.96 \pm 4.14 \text{ kg/m}^2$; $P < 0.001$), and remained essentially the same at the post-operative study visits for the TKA-GROUP; $31.08 \pm 4.36 \text{ kg/m}^2$ and $30.22 \pm 3.71 \text{ kg/m}^2$ at the 6- and 12-months study visits, respectively.

Self-Report Health Outcomes

For self-report outcome measures, LEFS improved significantly from the pre-operative compared to the 6- and 12-month post-operative visits (40.08 ± 16.58 vs. 57.69 ± 11.99 vs. 60.64 ± 13.96) with a higher score indicating better function (Figure 1). The minimum

detectable change (MDC) for LEFS is ± 9 scale points and the minimal clinically important difference (MCID) is also approximately 9 scale points (Binkley et al., 1999). Therefore, the individuals in this study showed clinically meaningful improvements at both the 6- and 12-months post-operative visits.

The results of the SF-36 health outcomes survey were evaluated using the physical component summary (PCS) and mental component summary (MCS) scores. The PCS score increased significantly between the pre- and post-operative study visits (36.06 ± 8.67 vs. 48.49 ± 6.03 vs. 48.89 ± 6.21), but remained significantly lower than the CONTROL-GROUP at the pre-operative ($P < 0.001$) and 6-month ($P < 0.001$) and 12-month post-operative ($P < 0.001$) study visits. For MCS, there were no significant differences between the TKA-GROUP and CONTROL-GROUP for any study visit or between any of the pre- and post-operative study visits for the TKA-GROUP (Figure 2).

Stair Climbing Test

For the TKA-GROUP, mean SCT at the pre-operative, and 6- and 12-month postoperative visits for stair ascent were 6.32 s, 5.08 s, and 4.72 s, respectively, and for stair descent were 6.00 s, 4.24 s, and 3.90 s, respectively. For the CONTROL-GROUP, mean SCT for stair ascent and stair descent were 3.71 s and 3.16 s, respectively. There was a significant decrease in SCT during stair ascent and stair descent between the pre-operative and 12-month post-operative study visit ($P = 0.026$ and $P = 0.032$, respectively). There was also a significant difference between the CONTROL-GROUP and TKA-GROUP at all visits, with the CONTROL-GROUP being significantly faster compared to the TKA-GROUP ($P < 0.05$ for all comparisons).

Muscle Strength

At both the pre- and post-operative (6- and 12-month) study visits, MVIC relative to BMI (MVIC/BMI) was significantly lower in the TKA-GROUP compared to the CONTROL-GROUP. MVIC/BMI for the CONTROL-GROUP was 12.57 ± 3.86 N/BMI compared to the TKA-GROUP pre-operative study visit (6.64 ± 2.87 N/BMI; $P = 0.001$), 6-month post-operative study visit (7.84 ± 2.31 N/BMI; $P = 0.003$), and 12-month postoperative study visit (8.59 ± 2.58 N/BMI; $P = 0.01$). Additionally, MVIC/BMI did not significantly improve from the pre-operative visit compared to the 6- or 12-month postoperative visits in the TKA-GROUP.

Variability during Stair Stepping

In the TKA-GROUP, the CV of ST during stair descent was significantly higher at the 6-month post-operative study visit compared to the CONTROL-GROUP (14.42% vs. 7.39% ; $P = 0.027$), but was not significantly different between the pre-operative and 6- and 12-month post-operative visits. There was also no difference found between the TKA-GROUP at the pre-operative and 12-month post-operative visits when compared to the CONTROL-GROUP. For stair ascent, the CV of ST exhibited a non-significant increase, between the pre-operative and 6-month post-operative visits, and there were no significant differences between the TKA-GROUP and CONTROL-GROUP at any visits. Figures 3 and 4 show the

results of CV of ST for stair ascent and descent, respectively, for the TKA-GROUP and CONTROL-GROUP.

When the relationships between quadriceps strength (as measured by MVIC/BMI) and CV of ST during stair ascent and descent were evaluated in the TKA-GROUP, there was no significant correlation for either comparison, although there was a trend toward significance for an inverse relationship between MVIC/BMI and stair ascent (Spearman's $\rho = -0.332$, $P=0.059$) and stair descent (Spearman's $\rho = -0.316$, $P=0.073$) (Figure 5).

Discussion

The purposes of this study were to: 1) investigate STV during stair stepping in older adults before and after TKA, and compare to an age- and sex-matched group of healthy controls with native knees, 2) evaluate the relationship before and after TKA between quadriceps strength and STV during stair stepping, and 3) compare time to ascend and descend stairs between pre- and post-operative time-points and between groups. Self-report health outcomes were also evaluated across time-points and between groups. The principal findings were: (a) older adults with knee OA exhibit no significant change in STV during stair ascent between pre- and post-operative visits, and are not significantly different than a group of controls with native knees; (b) older adults with knee OA exhibit no significant change in STV during stair descent between pre- and post-operative visits, but are significantly different than a group of controls with native knees at the 6-month postoperative visit; (c) there was a trend toward significance for the correlation between quadriceps strength and STV during stair ascent or descent; and (d) there was a significant decrease in SCT during stair ascent and stair descent between the pre-operative and post-operative study visits, but the TKA-GROUP remained significantly slower, even at 12-months post-operatively, in their speed to ascend and descend stairs compared to a group of healthy controls with native knees. Additionally, despite the lack of change in STV at 12-months post-operatively, the TKA-GROUP did show clinically meaningful improvements in LEFS at both the 6- and 12-month post-operative visits.

Movement Variability in Elderly Individuals with and without OA

Movement variability in older populations, in addition to those suffering from knee OA, is generally considered characteristic of a pathological or impaired state (J. W. Smith, Christensen, Marcus, & LaStayo, 2014). These trends in movement variability have been associated with reduced physical function and increased risk of mobility deficits (Brach et al., 2008; Brach, Wert, VanSwearingen, Newman, & Studenski, 2012). This pilot study aimed to explore various components of movement variability through means of fluctuations in temporal, spatial and kinematic outcomes to better understand irregularities in negotiating stairs. Although STV during level walking has been identified as a potential indicator of dysfunction in older individuals with OA, little is known about whether the same trends exist during more demanding tasks such as stair stepping in elderly individuals suffering from OA or following TKA.

Stance Time Variability Before and After TKA

Fallah-Yakhdani et al. (Fallah-Yakhdani et al., 2010) evaluated variability during level walking and showed a significant decline from pre- to post-operative time-points in individuals who received a TKA. Specifically, the investigators found that variability during treadmill walking in TKA recipients was reduced compared to controls pre-operatively, and was even lower 12-months post-operatively.

While it is acknowledged that level walking is significantly less demanding than stair stepping, we hypothesized that TKA recipients would also exhibit a decline in STV during stair ascent and descent, and would reach a level similar to controls postoperatively. Thus, the decline in STV at 12-months post-operatively in the present study, to a level similar to healthy controls, is consistent with our hypothesis. Alternatively, our findings showed that individuals following TKA demonstrated a significant difference in STV compared to controls during stair descent at 6-months. It should be noted, however, that there were no significant differences in STV between the TKA-GROUP at the pre-operative or 12-month post-operative time points and the CONTROL-GROUP. Also, the decrease in STV between the 6- and 12-month post-operative time points was non-significant. These findings do not contradict the significant differences between the 6-month post-operative time point and CONTROL-GROUP, but do raise awareness of the importance of further research with additional subjects to establish the validity of these results. That said, the results of this study provide further evidence that individuals following TKA still have functional deficits several months after being released from rehabilitation to return to higher-level function (Hawker, 2006; Meier et al., 2008). The present data also indicate that STV does improve in a TKA sample and was similar to an age-matched control group at 12-months, suggesting that progress in movement variability can continue to be made well beyond 6-months following surgery. This is also consistent with the notable improvements in LEFS scores that exceeded the level of a true clinically important change.

Prior studies have shown that improvements in functional ability following the 6-months post-operative time point are minimal (Fortin et al., 2002; Rissanen, Aro, Sintonen, Slati, & Paavolainen, 1996), but for stair stepping, the results of the present study suggest otherwise. It is possible that the combined effects of adaptations between coordinated joint movements following a TKA surgery and associated increases in neuromuscular control are critical to improvements in stair stepping tasks, in concert with improvements in strength, and that these improvements continue until at least 12-months following surgery.

Stance time variability during level walking has been shown to be a strong predictor of mobility disability and fall risk in older adults (Brach et al., 2012). While our sample was not large enough to determine fall risk potential based on STV with negotiating stairs, we believe this could be an important component of post-operative rehabilitation in the TKA population. More specifically, since stair descent is associated with fall risk, particularly in older individuals, and STV during level walking is also correlated with fall risk (Brach et al., 2012), STV during stair descent may help predict those at high risk of falling post-operatively. STV during stair descent may prove to be a more sensitive measurement post-operatively and if correlated with other functional deficits such as quadriceps strength, specific muscle imbalances, or proprioceptive deficits, it could provide an important

rehabilitation target. In particular, essential components of functional-based dynamic neuromuscular control, promoting gait speed, and intensive lower extremity strength training may play a vital role in normalizing variability and minimizing fall risk in this vulnerable population.

Relationship between Quadriceps Strength and Stance Time Variability

Further findings in the present study suggest that isometric quadriceps strength may be associated with STV during stair stepping. Considering the demanding nature of stair stepping on the quadriceps muscles, the muscle and mobility deficits that are typically present following a TKA surgery are likely contributors to the post-operative STV findings during stair stepping. Subjects with knee OA have been shown to use compensatory joint coordination strategies during gait (Suter & Herzog, 2000), and the results of the present study suggest that these strategies may have been employed during stair stepping, which were more evident at the 12-month visit compared to the 6-month visit. While we did not find a significant correlation between quadriceps strength and STV in the present study, the trend toward significance, even considering the small sample size suggests that a continued focus on quadriceps strength beyond 12-months post-operatively may be an important rehabilitation focus for improving functional ability for demanding tasks such as stair stepping. One could also argue that an alternative quadriceps strength measure may be needed to identify the coordinated dynamic concentric and eccentric muscle demands associated with stair stepping, and how these relate to STV. Alternative muscle groups, more specifically the gluteal muscles, may also play a critical role in STV and is a suggested focus for future clinical trials. Addison et al. (Addison et al., 2014) recently demonstrated that increased gait variability was related to intramuscular adipose tissue (IMAT) of the hip abductors and poorer balance. Support for these findings was demonstrated by Inacio et al. (Inacio et al., 2014), wherein fallers were differentiated from non-fallers by hip joint muscle composition and strength, suggesting a link between impaired balance function and increased risk for falls.

Stair Climb Time before and after TKA

Our data also showed a significant decrease in stair climb time between the pre-operative and 12-month post-operative visits. These findings are consistent with the literature (Whitchelo et al., 2014) and suggest that individuals following TKA demonstrate pain reduction and lower extremity strength gains leading to quantitative functional performance improvement specifically with stair climbing. Although TKA populations have been shown to demonstrate altered strategies for stair stepping (Suter & Herzog, 2000), it is important to appreciate temporal gains in a functional task. Postoperative rehabilitation should not only focus on the temporal variables associated with different functional movements, but also on the quality of movement. Future research that focuses on the effectiveness of targeting quality of movement variables post-operatively, such as STV, may provide critical information for not only identifying those that are at risk of poor functional mobility following TKA, but also those at risk of future falls.

Study Limitations

Limitations of this study include a small sample size, and lack of control for implant type, rehabilitation course, duration, or other physical activities between study visits. The results may have also been confounded by different TKA-GROUP subjects analyzed at each time point for comparisons between the TKA-GROUP and CONTROL-GROUP. Additionally, despite the inclusion criteria of BMI < 40, subjects were not BMI-matched, and the TKA-GROUP was less active and had more comorbidities compared to the CONTROL-GROUP. Our study sample was also found to be unbalanced with respect to gender. Finally, the possibility that statistical power less than 80% may have contributed to the lack of significant differences cannot be ruled out. Nonetheless, this study was performed considering these limitations, as it was designed as a pilot study to identify the feasibility and potential applicability of STV for evaluating and predicting functional ability during stair stepping in knee OA and TKA populations.

Conclusions

The potential significance of the findings of this study is evident in that variability during stair stepping may provide another parameter to predict functional mobility following TKA. The results may also provide insight into rehabilitation targets that address the qualitative nature of demanding functional activities such as stair stepping. Additional research is needed to elucidate the significance of this movement parameter during stair stepping and functional acuity following TKA.

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Highlights

- Stance time variability during stair stepping has not been previously evaluated pre- and post-TKA.
- Quadriceps strength was significantly lower both pre- and post-op compared to healthy controls.
- Variability during stair descent post-TKA is significantly greater compared to controls.
- The correlation between quadriceps strength and variability during stair stepping showed a trend toward significance.

Figure 1.
Comparison of Lower Extremity Functional Scale (LEFS) results between pre- and post-operative study visits for TKA Group.
‡ $P < 0.05$, significant difference between the pre-operative and 6- and 12-months post-operative study visits.

Figure 2.

Comparison of Short Form 36 (SF-36) Health Survey results between TKA-GROUP and CONTROL-GROUP.

PCS, physical component summary; MCS, mental component summary

* $P < 0.001$, significant difference between pre- vs. 6- and 12-months post-operative study visits.

† $P < 0.001$, significant difference between pre- and post-operative study visits and controls.

Figure 3.

CV of stance time during stair ascent for the surgical leg in the TKA-GROUP and CONTROL-GROUP.

Notes. TKA pre-operatively, n=9; TKA 6-mos post-operatively, n=13; TKA 12-mos postoperatively, n=11; Controls, n=11. TKA-GROUP data reported for the surgical leg.

Figure 4.

CV of stance time during stair descent for the surgical leg in the TKA-GROUP and CONTROL-GROUP.

Notes. TKA pre-operatively, n=9; TKA 6-mos post-operatively, n=13; TKA 12-mos postoperatively, n=11; Controls, n=11. TKA-GROUP data reported for the surgical leg.

[‡] $P < 0.05$, significant difference between the 6-mos post-operative study visit and CNTRL-GROUP.

Figure 5.

Relationship between quadriceps strength and CV of stance time during stair ascent and descent for the surgical leg in the TKA-GROUP.

Notes. TKA pre-operatively, n=9; TKA 6-mos post-operatively, n=13; TKA 12-mos postoperatively, n=11; MVIC, maximal voluntary isometric contraction; BMI, body mass index; ASC, ascent; DESC, descent. TKA-GROUP data reported for the surgical leg.

Table 1

Baseline subject demographics; preoperative TKA-GROUP vs. CONTROL-GROUP

Variable	TKA-GROUP (n=13)	CONTROL-GROUP (n=11)	P-value*
Age (SD) (yrs)	62.71 (6.84)	62.66 (8.61)	0.99
Height (SD) (m)	1.67 (0.09)	1.64 (0.10)	0.52
Weight (SD) (kg)	86.40 (11.73)	62.15 (10.48)	< 0.001
BMI (SD) (kg•m ⁻²)	30.96 (4.14)	23.07 (2.16)	< 0.001
Gender (% Males)	15%	18%	-

* Pre-operative TKA-GROUP vs. CONTROL-GROUP.