

Tai Chi Inspired Exercise Early Following Total Knee Arthroplasty: A Case Report

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Abstract

Background: In total knee arthroplasty (TKA) recipients, losses in quadriceps' strength in the immediate post-operative period are related to physical function and mobility. Therefore, this period should be a target of rehabilitation to prevent strength losses in the short-term. This case report describes the early post-operative changes in muscle and physical function associated with a Tai Chi inspired rehabilitation program.

Case Description: A 62 year-old woman presented with bilateral OA and underwent unilateral TKA surgery in her most symptomatic knee. The subject participated in one pre-operative study visit, and a 6-week, Tai Chi inspired rehabilitation program from 4 to 10 wks post-operatively. Outcome measures, evaluated at 4 wks, 10 wks, and 6 months post-operatively, included maximum voluntary isometric contraction, lower extremity power, quadriceps force control, 6-minute walk test, timed up-and-go test, stair climbing test, gait speed, SF-36 Total Health Status Survey, and the lower extremity functional scale.

Outcomes: In the surgical leg, the subject improved in all muscle and physical function measures from the pre-operative to 6-month post-operative study visit. Self-report outcome measures also improved from pre- to post-operative study visits, with the exception of the mental component summary of the SF-36 at 6 months.

Discussion: The subject exhibited clinically relevant improvements in muscle and physical function in the surgical leg, suggesting that the Tai Chi inspired rehabilitation program may be an effective and safe addition to range of motion, stretching and gait exercises in the early post-operative period. These results support further exploration of this rehabilitation approach in future trials.

Keywords: Osteoarthritis; Tai Chi; Muscle function

Background

Total knee arthroplasty (TKA) is a common surgical intervention for older individuals with advanced knee osteoarthritis (OA). TKA has been repeatedly shown to reduce the chronic knee pain associated with OA and improve physical functioning. [1-4]. Regardless, studies have also shown that individuals with OA who undergo TKA continue to have reduced quadriceps strength compared to age-matched counterparts with native knees [1,4,5].

Persistent quadriceps weakness is clinically important due to its relation to physical function and mobility, as well as force output variability [6]. Indeed, muscle atrophy, muscle weakness, and neuromuscular activation deficits are all factors that have been implicated in residual post-operative strength impairments [7,8].

Our team has previously developed a resistance exercise program that utilizes specialized equipment and licensed clinical staff to produce eccentric contractions and negative work that improves muscle and physical function. Eccentric exercise is typically considered higher intensity therapy, however, no adverse knee joint responses have been reported following knee surgery [9-12]. Furthermore, the low metabolic cost required to produce the eccentrically-induced negative work results in a compliance rate that is greatly enhanced, making it ideally suited to an older, adult population [9]. These same eccentric-negative work principles can be utilized during rehabilitation with Tai Chi inspired Movements that are Eccentrically-biased (MOVE), thus eliminating the need for specialized equipment and specialized staff. The benefits of Tai Chi are supported by a study by Lu et al. [13], that showed that implementation of a Tai Chi training program in elderly adults for 16 weeks can significantly improve both arterial compliance

and eccentric knee extensor strength [13]. Additionally, preliminary work in our clinic suggests that the TKA rehabilitation benefits of eccentric exercise may be experienced without costly equipment by utilizing the simple, low-cost MOVE program.

The MOVE rehabilitation suite of exercises is founded on the principle that an external load (e.g., a weight or mass) must exceed the force being produced by the muscle, thereby inducing an eccentric lengthening of the muscle. The external load in MOVE consists of an individual's body mass. During these exercises (Tai Chi inspired movements plus functional weight-bearing exercises), the eccentric loading consists of the individual's body mass and the movement patterns are designed to progressively transfer more of an individual's body mass over a single leg in an eccentric fashion.

The potential benefits of this program include improved proprioception and ability to control submaximal muscle forces, the latter of which has been shown to be an independent risk factor of age-related impairment of physical performance [6,14,15]. More specifically, quadriceps muscle force steadiness (MFS), which assesses

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the ability to maintain constant submaximal muscle forces, has been positively correlated with physical performance in patients with hip OA [16], and with functional performance in elderly women [6], elderly fallers compared to non-fallers [15], and in individuals with knee OA compared to healthy controls [17].

To understand the potential of MFS as a rehabilitation target, it is important to understand the mechanisms that influence muscle deficits post-operatively and hence, physical function. In particular, the first few months following surgery are associated with decreases in physical function when compared with pre-operative levels, and quadriceps' strength is linked to levels of mobility and physical function [1-3,7,8]. Furthermore, in individuals with OA who undergo TKA, the greatest losses in quadriceps' strength occur in the immediate post-operative period [1-3,7,8,18]. Therefore, this period should be a primary target of rehabilitation, as preventing functional loss in the short-term is more likely to be effective than working to reverse losses months or years after surgery.

Thus, the purpose of this case report is twofold. First, to describe the early post-operative changes in muscle and physical function associated with a Tai Chi inspired rehabilitation program, and second, to describe the effect of TKA surgery and rehabilitation on quadriceps MFS.

We hypothesized that subjects participating in early Tai Chi inspired MOVE rehabilitation would safely and feasibly improve muscle function and that MFS would improve from pre- to post-surgery, both of which would carry over to physical function improvements. This case report discusses the results of one subject who underwent TKA surgery and participated in the MOVE rehabilitation program.

Case Description

This case report describes a female subject with bilateral OA who underwent unilateral TKA surgery in her most symptomatic (painful) knee. Prior to surgery, the subject was enrolled in a clinical study (Study 1) that included evaluation of quadriceps MFS in both legs at two time points; 1 week prior to surgery (T1) and at 6 months post-operatively (T4). The purpose of Study 1 was to assess muscle and physical function outcomes pre- and post-surgery, including stair climbing tasks, gait function, and quadriceps MFS. The subject was subsequently enrolled

in the MOVE study (Study 2) at two weeks post-operatively, after she had been discharged to home. The subject was enrolled in the MOVE Study 2 to evaluate the effects of this training regimen on similar muscle and physical function parameters, which were measured before MOVE was initiated (i.e., at 4 wks post-operatively [T2]) and after MOVE (i.e., at 10 wks post-operatively [T3]).

For both studies, the subject was recruited from the joint arthroplasty surgical group at the University of Utah Orthopedic Center (Salt Lake City, UT). Upon enrollment prior to surgery, the subject was 62 years of age, 172 cm tall, and 96.8 kg (BMI 32.8 kg/m²). She did not have neurological conditions affecting mobility, but had ongoing medications that included hydrochlorothiazide, ezetimibe/simvastatin, and levothyroxine. The diagnosis of OA was confirmed pre-operatively with radiographs and careful review of past medical conditions. Additional examination of the subject's extremities was performed to rule out signs/deformities of rheumatologic disease.

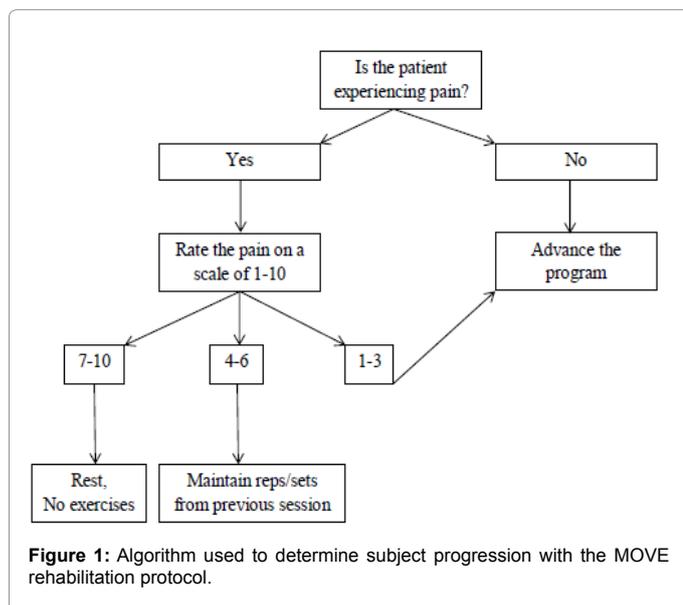
Movements that are Eccentrically-Biased (MOVE)

The Tai Chi inspired, MOVE rehabilitation program was initiated on post-operative day 28 and continued for 12 sessions (two times per week for six weeks) with the final session on post-operative day 63. The subject performed a maximum of five separate Tai Chi exercises during each session, without specialized equipment, under the guidance of a non-licensed staff member who was supervised by a licensed physical therapist. These varying Tai Chi inspired movement patterns focused on strengthening the quadriceps, calves and hamstrings, as well as to a lesser degree the gluteals and abdominal musculature.

The Tai Chi inspired MOVE exercises were progressed by adding one Tai Chi movement per week until all eight movements were learned (See Table 1A Appendix A for a description of the eight Tai Chi inspired exercises). However, a maximum of five Tai Chi inspired movements were used during each session, alternating exercises for variety. Up to 40 minutes per session were dedicated to the Tai Chi inspired movements. The number of repetitions, sets, and duration of movements were progressively altered based on the subject's ability. The Tai Chi inspired movements were supplemented with functional exercises, which were performed for 20 minutes or less during each session and included sit-to-stand, hip abduction, heel raises, and stair ascent and descent. MOVE exercises were performed for the remainder of each session (Table 1B Appendix A).

In addition to monitoring any pain responses (Figure 1), the subject's ability and performance were used to evaluate the decision to progress, halt, or even regress the MOVE program. Criteria to stop advancing and reduce the workload included, but were not limited to: an inability to perform the movement, safety concerns due to imbalance or weakness, or if the movement acted as a stimulus for additional joint pain. In such cases, the movement was stopped and attempted at a later session. The program was not progressed in situations where the subject was unable to perform the movement correctly or could not complete the desired number of repetitions or sets due to fatigue. Advancing the program using more challenging movements occurred as the subject mastered the previous movement and completed the desired repetitions with ease. Safety and feasibility were assessed by measuring pain levels (0-10), circumferential knee measures of swelling (cm), and knee range of motion (degrees) at each training session, along with compliance with the MOVE program.

As the subject progressed, the knee and hip flexion range of motion during the movement patterns increased and/or the speed in which the movements were performed was slowed. The goal of each exercise



session was to dedicate 75% to the Tai Chi inspired MOVE and 25% to more functional, lower extremity exercises.

Outcome measurements over all time points included muscle function, physical function, and self-report outcome measures, as follows:

- Muscle function testing included maximum voluntary isometric contraction (MVIC) measured on a KinCom 500H dynamometer (Isokinetic International, Chattex Corporation, Harrison, TN), lower extremity power measured on the Nottingham Power Rig (Nottingham, UK), and the coefficient of variation (CV) of quadriceps MFS;
- Physical function was assessed using the 6-minute walk test, timed up-and-go test, stair climbing test, and gait speed; and
- Self-report outcome measures included the 1-week and 4-week recall of the SF-36 Total Health Status Survey (SF-36) and the lower extremity functional scale (LEFS).

Maximal Voluntary Isometric Contraction and Power

The subject's maximal voluntary isometric contraction (MVIC) was assessed on the KinCom dynamometer (Harrison, TN) pre-operatively (T1) and at 6 months post-operatively (T4). Strength was measured at 90 degrees of hip flexion and 45 degrees of knee flexion, which corresponded to the midpoint of the range of quadriceps MFS testing. Prior to the recorded tests, the subject performed three sub-maximal practice trials to become familiar with the testing procedure. The actual test involved three trials. The coefficient of variation (CV) of the peak force for the three trials had to be $\leq 8\%$ for the test to be considered acceptable. The subject met the acceptance criteria on the first set of three trials for both the surgical and non-surgical legs at all-time points and therefore, additional trials were not required.

Power was assessed using the Nottingham power rig before and after MOVE rehabilitation at study visits T2 and T3. The subject performed one warm-up effort each at 50%, 75%, and 100% effort followed by 6 efforts of maximal exertion, with the average of the 6 maximal efforts recorded.

Quadriceps Muscle Force Steadiness (MFS)

One week prior to TKA surgery (T1) and at 6 months post-operatively (T4), the subject was assessed for quadriceps MFS on a KinCom dynamometer. To establish the target force for MFS testing, the subject's quadriceps MVIC was measured bilaterally as described above. The peak force from the three MVIC tests on each leg was used to calculate the target force for MFS testing, which was 50% of MVIC.

Quadriceps MFS was assessed concentrically and eccentrically, in both legs, by assessing the subject's ability to maintain a constant force over two seconds. Concentric MFS was tested from 75 to 15 degrees of knee flexion and eccentric MFS was tested from 15 to 75 degrees of knee flexion. MFS testing was performed isokinetically at a fixed speed of 15 degrees/second, and data were sampled at 1000 Hz. Thus, a total of 4 seconds of data were collected for each of the concentric and eccentric contractions, with the middle two seconds, corresponding to knee flexion between 30 and 60 degrees, used for data analysis.

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 contrast on the screen. A target force line representing 50% of the subject's MVIC was visible on the screen.

During testing, the subject was instructed to apply resistance against the lever arm attached to their lower leg and produce enough force to reach and maintain the target force line on the computer monitor, as steadily as possible, over the entire range of motion (i.e., 75 deg to 15 deg of knee flexion). The same procedure was used for the eccentric MFS testing, with the exception that the force produced occurred during quadriceps muscle lengthening (i.e., 15 deg to 75 deg of knee flexion).

The MFS testing included one non-recorded practice trial each, for concentric and eccentric contractions, to become familiar with the testing procedure, followed by 24 recorded trials. Following data collection, the CV of both the concentric and eccentric force-time curves of the MFS data were calculated for all trials. Data analysis included the middle two seconds (60 deg to 30 deg of knee flexion) of data, filtered at 100 Hz, and de-trended to remove any slope to the data. The slope was not relevant to the CV, as we were interested in the degree of fluctuation about a straight line. The data were then normalized by subtracting the average force attained from the force target (i.e., 50% MVIC). The CV of MFS was then calculated as the ratio of the standard deviation, σ , to the absolute value of the mean, μ , of the de-trended data as follows:

$$CV = \sigma / \text{abs}(\mu) \quad (1)$$

The CV for both the concentric and eccentric contractions for all recorded tests was used for data analysis.

SCT and Gait Speed

The stair climbing test and gait speed were assessed at all four time points. The stair climbing test consisted of three trials each of stair ascent and stair descent on a set of 10 stairs. Self-selected, "normal" gait speed was also assessed using the GAITRite system (CIR Systems, Inc., Sparta, NJ). The GAITRite system automates measuring temporal and spatial gait parameters via an electronic walkway. For each time point, gait speed was averaged over 6 trials, each of which consisted of approximately 6 total footfalls per trial.

6-Minute Walk and Timed Up-and-Go

The 6-minute walk test measured the distance the subject was able to walk over a total of six minutes on a hard, flat surface. The timed up-and-go test was performed by measuring the time it took the subject to rise from a chair, walk three meters, turn around, walk back to the chair, and sit down.

SF-36 and Lower Extremity Functional Scale

Additional outcome measures included the self-report SF-36 health outcomes survey, which is a multi-purpose, short-form health survey of functional health and well-being, and the Lower Extremity Functional Scale (LEFS) which is a questionnaire regarding physical activity level specifically related to the lower extremity. The 4-week recall version of the SF-36 survey was used at the pre-operative (T1) and 6 months post-operative (T4) visits, and the 1-week recall version of the SF-36 was used before (T2) and after (T3) the MOVE rehabilitation program. The 4-week recall was appropriate for the pre- and 6 months post-operative assessments due to the relatively long-duration between measurements. However, the 1-week recall was used for the pre- and post-MOVE assessments due to its sensitivity to recent, acute changes in health status [19].

Table 1 includes a summary and schedule of tests performed at each of the 4 time points; one week prior to surgery (T1), and 4 wks (T2), 10 wks (T3), and 6 months post-operatively (T4).

Description	Pre-operative		Post-operative		
	T1 (1 wk prior)	T2 (4 wks)	T3 (10 wks)	T4 (6 mos)	
Muscle Function Parameters					
MVIC (N)	X	-	-	X	
Power (W)	-	X	X	-	
CV of Quadriceps MFS (%)	X	-	-	X	
Physical Function Parameters					
SCT (sec)	X	X	X	X	
Gait Speed (m/s)	X	X	X	X	
6MW (m)	-	X	X	-	
TUG (sec)	-	X	X	-	
Self-Report Measures					
LEFS (0-100)	X	X	X	X	
SF-36 (1-week recall)	-	X	X	-	
SF-36 (4-week recall)	X	-	-	X	

Table 1: Muscle function, physical function, and self-report testing schedule.

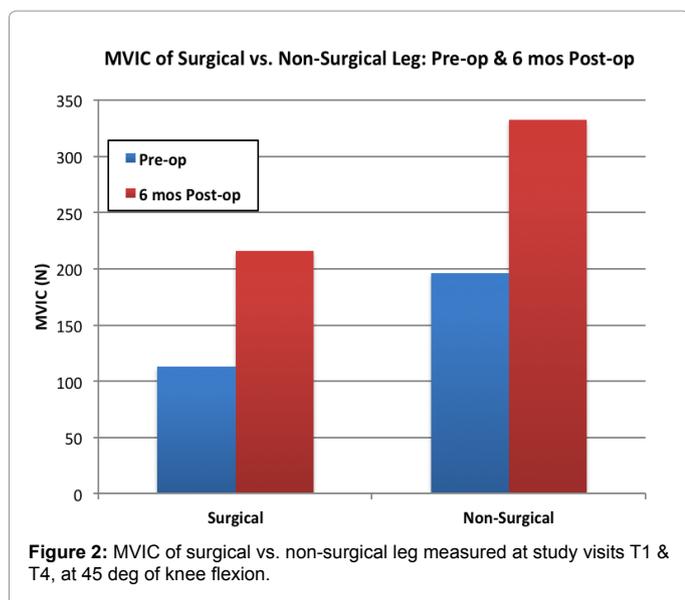


Figure 2: MVIC of surgical vs. non-surgical leg measured at study visits T1 & T4, at 45 deg of knee flexion.

Statistical Analysis

Descriptive statistics including mean and standard deviation were calculated for all parameters except quadriceps MFS. For MFS, a t-test, assuming unequal variances, was performed using SPSS Statistical Software (IBM Corporation; Armonk, NY) for comparisons between study visits, contraction type, and for surgical vs. non-surgical leg.

Outcomes

The subject attended one pre-operative visit, 1 wk prior to surgery (T1); one study visit prior to initiation of the MOVE program (T2); 12 out of 12 rehabilitation sessions from 4 weeks to 10 weeks post-operatively; one study visit following the MOVE program (T3); and one 6 months post-operative visit (T4). From 4 weeks to 10 weeks post-operatively, the subject's pain decreased from a score of 3 to 0 on a 0-10 Visual Analog Scale, and swelling decreased from 43.0 cm to 42.5 cm. Knee range of motion also improved from 10 to 110 degrees at T2 to 1 to 114 degrees at T3. The subject's BMI remained the same at 32.8 kg/m² from the pre-operative study visit (T1) to the 6 months post-operative study visit (T4).

Muscle Function

The subject's MVIC was assessed on the KinCom dynamometer pre-operatively (T1) and at 6 months post-operatively (T4). Strength was measured at 45 degrees of knee flexion, which corresponded to the midpoint of the range of quadriceps MFS testing. Strength improved by 91% on the surgical leg and 69% on the non-surgical leg (Figure 2).

From T2 to T3, the average maximal power output on the surgical leg improved nearly 100% from 74.3 W to 147.5 W and on the non-surgical leg, power increased 67% from 99.5 W to 166.0 W.

Prior to surgery, the subject was only able to complete 9 and 12 MFS trials on the surgical and non-surgical legs, respectively, due to knee pain and fatigue. However, at the 6 months post-operative visit, the subject was able to complete 24 MFS trials on both legs.

On the surgical leg, the average \pm standard deviation (SD) CV of MFS at the pre-operative and 6 months post-operative study visits was 18.03 \pm 8.06% vs. 11.31 \pm 4.80% (p=0.040), respectively, for concentric contractions, and 10.83 \pm 4.95% vs. 4.85 \pm 1.65% (p=0.007), respectively, for eccentric contractions (Figure 3).

On the non-surgical leg, the average \pm SD CV of MFS at the pre-operative and 6 months post-operative study visits was 9.16 \pm 2.46% vs. 7.79 \pm 2.40%, respectively, (p=0.127) for concentric contractions, and 5.81 \pm 2.03% vs. 5.31 \pm 3.65%, respectively, (p=0.600) for eccentric contractions (Figure 4).

Physical Function

Physical function was assessed by the stair climbing test, gait speed, 6-minute walk test, and timed up-and-go. The stair climbing test and gait speed were assessed all four time points, T1, T2, T3 and T4, whereas 6-minute walk and timed up-and-go were assessed only at study visits T2 and T3.

The stair climbing test improved from the pre-operative to 6 months post-operative (T1 to T4) study visits for stair ascent (6.71 sec vs. 5.01 sec) and stair descent (6.97 sec vs. 4.03 sec). Similarly, stair climbing test improved from 4 wks to 10 wks post-operatively (T2 to T3) for stair ascent (9.68 sec vs. 6.53 sec) and stair descent, (9.01 sec vs. 6.26 sec). Gait speed also improved from T1 to T2 to T3 (1.06 m/s vs. 1.20 m/s vs 1.36 m/s, respectively), but declined slightly from T3 to T4 (1.36 m/s vs. 1.19 m/s, respectively) (Figure 5). The 6-minute walk and timed up-

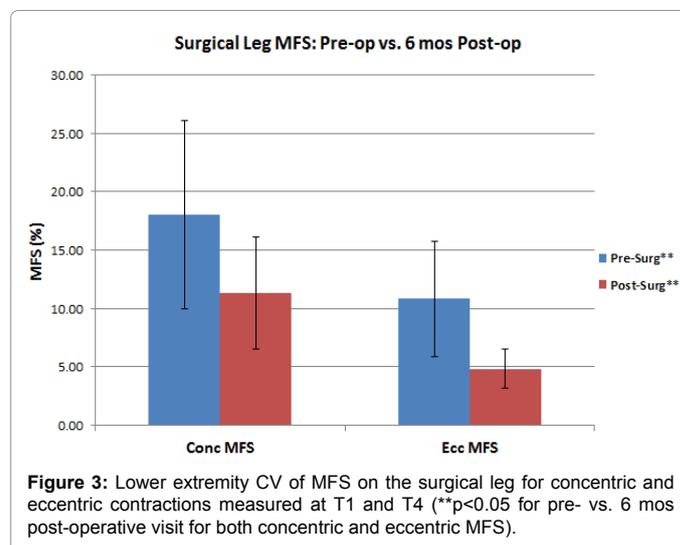
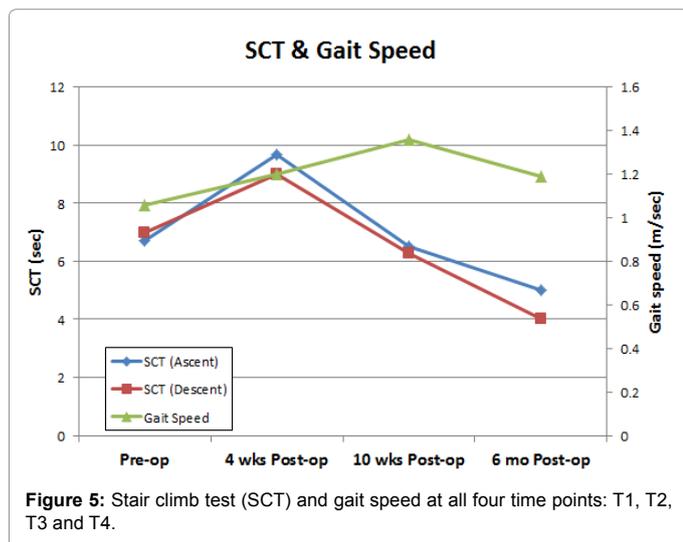
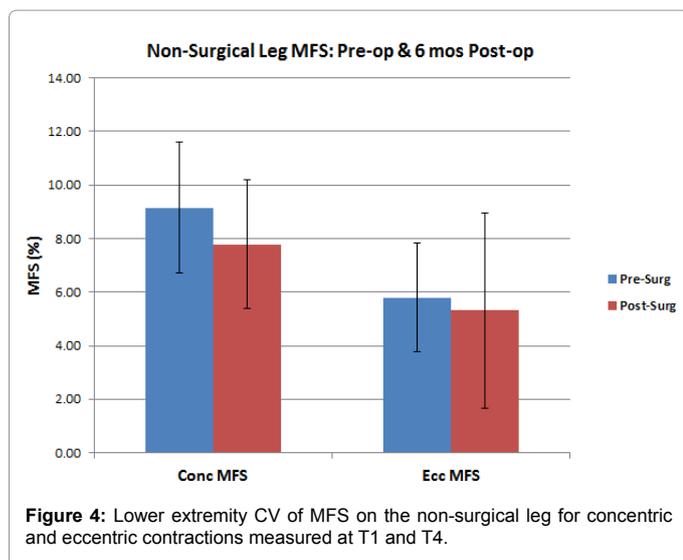


Figure 3: Lower extremity CV of MFS on the surgical leg for concentric and eccentric contractions measured at T1 and T4 (**p<0.05 for pre- vs. 6 mos post-operative visit for both concentric and eccentric MFS).



and-go were evaluated at 4 wks (T2) and 10 wks (T3) post-operatively, and improved by 21% and 23%, respectively (Table 2).

Self-Report Outcome Measures

The 4-week recall of the SF-36 showed improvements in physical component summary between T1 and T2, but the mental component summary showed no improvement and actually declined slightly from T1 to T4. However, the 1-week recall results of the SF-36 showed substantial improvements from before (T2) to after (T3) MOVE, suggesting an acute response to the rehabilitation protocol (Table 3).

The LEFS improved from T2 to T3 and T4 (39 vs. 62 vs. 66), but declined between study visits T1 and T2 (49 vs. 39) (Table 3).

Discussion

This case report describes a patient with OA who was a candidate for TKA based on pain, clinical examination, and radiographic findings and who participated in a novel post-operative rehabilitation approach. The purpose of this case report is to describe the early post-operative changes in muscle and physical function that were associated with a Tai Chi inspired MOVE rehabilitation program, as well as the effect of

TKA surgery and this novel rehabilitation approach on a potentially important muscle function parameter, quadriceps MFS.

The results demonstrated that Tai Chi inspired movements can be completed safely and feasibly without specialized equipment or licensed clinical staff direct supervision. The fact that quadriceps steadiness improved after participating in MOVE rehabilitation and in parallel with physical function and without adverse consequences provides initial evidence that this cost effective approach to early post-operative rehabilitation should be pursued in a larger trial.

The potential benefits of Tai Chi inspired exercises in the present study were evident by the pre- and post-rehabilitation muscle and physical function measures. Namely, quadriceps strength, lower extremity power output, and performance on the 6-minute walk and timed up-and-go improved substantially, with clinically significant improvements occurring in gait speed and performance on the stair climbing test. The subject also improved in self-reported outcome measures, SF-36 and LEFS, at all-time points with the exception of the mental component summary, which declined at 6 months post-operative visit compared to the pre-operative measure.

The clinically significant improvements in 6-minute walk observed in this study contrast somewhat with a larger study that showed only modest, but consistent, improvements in 6-minute walk following an intensive rehabilitation protocol from 2 to 4 months post-op [20]. In particular, Moffet et al. [20] showed that the effects of an intensive rehabilitation program were diminished at 8 months post-operative and therefore, suggested that more intensive rehabilitation be performed in the subacute recovery period following TKA to optimize long-term functional outcomes [20], a recommendation that is also supported by Meier et al. [7], Petterson et al. [21] and Bade et al. [1]. The Tai Chi inspired MOVE rehabilitation program performed by the subject of this case report was initiated immediately following discharge to home, which may provide some explanation for the improved results in 6-minute walk following MOVE. Nonetheless, due to the lack of a control group and long-term follow-up, it is acknowledged that the substantial improvements in 6-minute walk following the MOVE program may be anomalous. Further, the subject also described undergoing outpatient rehabilitation at an unknown facility for 4 weeks and this clearly could have influenced the muscle and mobility outcomes. She described the outpatient experience, however, as being focused on ROM exercises, stretching and modalities for pain relief. That said, it is also possible

Description	Post-op		% Change
	T2 (4 wks)	T3 (10 wks)	
TUG (sec)	9.6	7.4	23%
6MW (m)	353	426	21%

6MW = 6-minute walk; TUG = Timed up-and-go.

Table 2: Physical function outcomes pre- and post-op

Description	Pre-operative	Post-operative		
	T1 (1 wk prior)	T2 (4 wks)	T3 (10 wks)	T4 (6 mos)
1-week recall SF-36 (PCS)	-	41	76	-
1-week recall SF-36 (MCS)	-	71	86	-
4-week recall SF-36 (PCS)	38	-	-	55
4-week recall SF-36 (MCS)	61	-	-	56
LEFS (0-100)	49	39	62	66

PCS = Physical Component Summary; MCS = Mental Component Summary; LEFS = Lower extremity functional scale.

Table 3: Self-report outcomes measures pre- and post-operative

that the improvements following MOVE rehabilitation are real and widely applicable, suggesting a greater potential for sustained benefits with eccentrically-biased rehabilitation that is initiated in the early post-operative period.

While both muscle and physical function improvements occurred after the MOVE program, it is noteworthy that the subject of this case report exhibited declines in some of the measures at the 4-week, post-operative time point (T2). This is not unexpected, however, as research has shown that TKA patients exhibit reduced quadriceps strength [1,22] and performance on the stair climbing test [1,23] at one month post-operatively compared to pre-operative values, but continue to improve up to 6 months post-operatively [7,2,8,22]. More specifically, Bade et al. [1], compared strength, range of motion, and function in TKA patients at 2 wks pre-operatively to healthy controls, as well as to one month and six months, post-operative measures. The results showed significant declines in all measures, including 6-minute walk and timed up-and-go, at the one-month post-operative visit compared to pre-operative values. Although at 6 months, subjects recovered to pre-operative levels on all measures except range of motion [1]. We observed a similar response in stair climbing test for the subject of this case report, wherein stair climbing test measurements declined at the 4-week post-operative visit compared to pre-operatively, but then continued to improve up to 6 months post-operatively. Results of LEFS in this case report paralleled this finding, with the result declining at T2, but improving at T3 and T4, at which time the results exceeded the pre-operative value. While we do not have strength measurements at 4 weeks post-operatively, we suspect that a similar decline in strength would have been observed at that visit. Additionally, the subject's strength measurements indicate an overall improvement from T1 to T4 suggesting a similar trend of temporal improvement through the 6-month, post-operative time point.

The second objective of this case report was to describe the effect of TKA surgery and MOVE rehabilitation on quadriceps MFS, which was assessed at the one week pre-operative visit (T1) and the 6 months post-operative visit (T4). While MFS has not been previously measured in TKA subjects either pre- or post-operatively, we believe it may have implications to physical function, such as stair ascent and descent.

The MFS results for the subject of this case report showed significant improvements in the surgical leg, but not the non-surgical leg, from the pre-operative to 6 months post-operative study visits. These results suggest a positive effect of TKA surgery, as well as post-operative rehabilitation. More specifically, knee joint OA has been shown to reduce the ability to fully activate the quadriceps muscles, which leads to pronounced quadriceps weakness that can impair physical function [24]. In addition, individuals with OA exhibit impaired proprioception compared to individuals without OA, but it is not clear whether this neurologic impairment is a cause or consequence of intra-articular pathology [25]. The functional consequences of impaired proprioception may include lower gait velocity and slower stair walking time [26] both of which were observed in the subject described in this case report pre-operatively.

The surgical intervention, TKA, explicitly results in the removal of damaged tissue, but also improves range of motion and reduces pain, all of which have been reported to affect proprioceptive feedback in individuals with OA [25,27]. Thus, the fact that the OA was not treated in the non-surgical leg may provide some explanation for the lack of improvement in MFS at the post-operative time points, despite consistent improvements in quadriceps strength. Again, these results may point to a greater influence of TKA surgery on this particular measure.

Case studies have obvious limitations. Specifically, this case describing only a single patient lacks consistent test measures across all time points, and lacks a control for other rehabilitation protocols. To further support the claims presented herein, the MOVE program needs to be tested on a larger, more diverse patient population and compared to a control group using standard, non-eccentrically-biased rehabilitation protocols. Additionally, the rehabilitation measures should be tested over a longer duration to identify whether there is a point of diminishing returns or whether this type of rehabilitation will sustain its effects long-term. With regard to lower extremity MFS, future studies should investigate potential physical mobility measures, such as kinematics and kinetics of stair walking, that may correspond to reduced steadiness. This may offer a potential rehabilitation target to improve functional ability and potentially, reduce risk of falling, in both OA and TKA patients. In particular, while MFS has previously shown no relation with external knee adduction moments during gait, future research should focus on kinematic measures of steadiness during closed chain functional tasks such as gait and stair climbing. Finally, future research directions should concentrate on identifying rehabilitation protocols that are cost-effective and easy to perform that will sustain improved physical function post-operatively over the long-term.

Conclusions

The Tai Chi inspired MOVE rehabilitation program shows promise as an effective and safe addition to range of motion exercises in the early post-operative period following TKA. The subject exhibited clinically relevant improvements in muscle and physical function in the surgical leg, as well as improvements in quadriceps MFS. While these improvements cannot be directly attributed to this novel rehabilitation program due to the limitations noted above, the positive results suggest that this rehabilitation approach should be further explored in future trials.

Financial Disclosure and Conflict of Interest

I affirm that I have no financial affiliation (including research funding) or involvement with any commercial organization that has a direct financial interest in any matter included in this manuscript, except as disclosed in an attachment and cited in the manuscript.

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Institutional Review Board

IRB approval of the study protocol was provided by the University of Utah.

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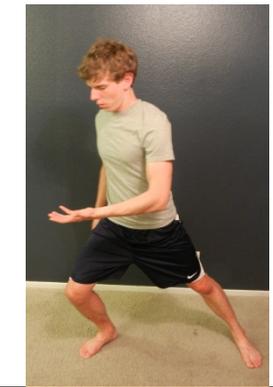
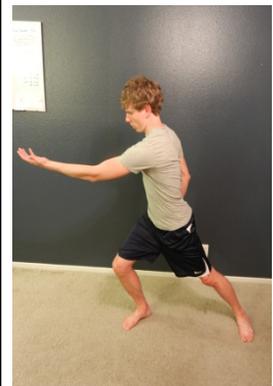
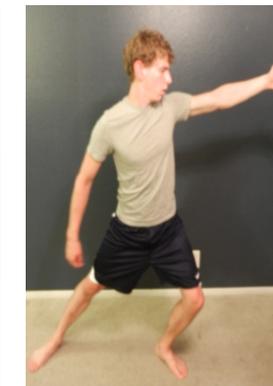
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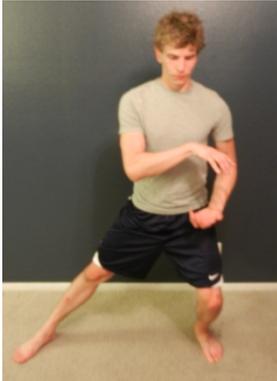
Appendix A

FORM	Description ^a	Target Muscles	
Form 1: Commencing Form	<ol style="list-style-type: none"> 1. Start with even weight on both legs, legs slightly bent, both feet planted at shoulder width apart, and arms slightly bent and extended with palms facing down. 2. Slowly squat and hold momentarily then raise back to the start position. Arms should be at shoulder height with elbows bent when in start position, then extended and lowered to waist height during the squat phase. 3. Move arms in a fluid wave-like motion that is slightly circular, drawing closer to the body when standing and pushing out from the body while squatting. Torso is kept upright throughout the motion. 	Quadriceps, gluteals, hamstrings	
FORM 2: Push	<ol style="list-style-type: none"> 1. Start with a slight outward turn of the toe on the back leg and a step forward with the opposite leg. 2. Weight should begin on the back leg with trunk erect and hands on either side of each hip with wrists nearly resting on the abdomen, palms facing down. 3. The entire body weight should slowly shift to the front leg while the arms extend with palms lifting to face forward, as if pushing against a wall. This “push” is held momentarily then weight is shifted from the front to the back leg while the arms simultaneously draw back to the abdomen. 	Quadriceps, calves	

FORM	Description ^a	Target Muscles		
				
FORM 3: Roll Back and Press	<ol style="list-style-type: none"> 1. Start with legs staggered and weight on the forward, bent leg. Arms are positioned as if holding a medium-sized ball (i.e. 12-inch diameter) in front of the body with palms facing each other. Torso is facing forward. 2. This form transitions to weight shifted to the back leg (bent) while the torso turns and the imaginary ball is rolled from chest height down to the waist near the hip of the back leg. 3. Weight is then shifted from the back leg to the front leg while rolling the imaginary ball from waist back to chest height in start position. 	Quadriceps, calves, external obliques, internal obliques, transversus abdominus		

FORM	Description ^a	Target Muscles		
<p>FORM 4: Wave Hands Like a Cloud</p>	<ol style="list-style-type: none"> 1. Start with both legs parallel, shoulder width apart, slightly bent and weight evenly balanced. Feet should be pointed slightly outward. Only one arm completes the following motion at a time. 2. If starting with the right arm, begin with the arm bent and the hand above the right leg with the palm facing the left. As the weight is shifted to the left, move the right arm to the left in a straight line as if scooping water, allowing the torso to rotate while maintaining an upright position. Once full extension is reached and the weight has been shifted over the left leg, the weight is shifted back across the midline to the right leg. 3. As the weight shift occurs bring the right arm back across the body with the palm facing the body, continue to pull the arm as the torso rotates. 4. Extend the arm and turn the palm up as the torso rotates to the right. Return to starting position and continue movement. 	<p>Quadriceps, external obliques, internal obliques, transversus abdominus</p>		
		 		

FORM	Description ^a	Target Muscles	
<p>FORM 5: Curve Back (Repulse the Monkey)</p>	<ol style="list-style-type: none"> 1. Start with weight on the back leg, back foot turned slightly outward (about 45 degrees) and back leg slightly bent. 2. The front leg is extended forward with only the heel touching the floor. Both arms are extended forward over each ipsilateral leg, the forward-most palm faces down while back palm faces up. 3. The front leg is lifted and brought behind the stationary back leg. The leg base is then the exact opposite as the starting position. 4. Simultaneously with leg motion the arms are then brought in toward the abdomen, cross over each other, then extend outward to start position. Palm positions will be opposite.. 	<p>Quadriceps, gluteals, calves</p>	

FORM	Description ^a	Target Muscles		
<p>FORM 6: Part Wild Horse's Mane</p>	<ol style="list-style-type: none"> 1. Start with weight on the moderately bent back leg, back foot turned outward, and front leg e x tended, staggered and slightly bent. The hands are held as if cradling a horse's neck with the hand ipsilateral to the forward leg slightly e x tended and cradling the underside of the "horse's neck," with palm facing upward. The other hand is held near the abdomen, cradling the topside of the "horse's neck," with palm facing downward. 2. From the start position, the weight is shifted from the back leg to the forward leg while the forward arm strokes up the "horse's neck" and the back arm strokes down the "horse's mane." Weight is then slowly shifted to the back leg with the legs and arms returning to start position. 	<p>Quadriceps, gluteals, calves</p>		
				

FORM	Description ^a	Target Muscles	
FORM 7: Kick	<ol style="list-style-type: none"> 1. Start with legs slightly bent, close together and arms at the sides. Weight is shifted to the post leg as the other leg is brought across the midline as if kicking a ball. 2. Bring leg back across midline and step both forward and away from the midline, entering a lunge. 3. As the 'kick' leg is brought up and across the midline, extend the arms as they shift to the same side as the post leg. Arms then shift over the 'kick' leg as the lunge is being initiated. 	<p>Quadriceps, gluteals, calves, hamstrings</p>	
FORM 8: Push and Brush Knee	<ol style="list-style-type: none"> 1. Start with back leg moderately bent, foot turned outward, ipsilateral arm extended backward near mid-torso level with palm facing up, torso facing the side and head looking at the palm of the rear hand. 2. The front leg should be bent with only the toe touching the ground and slightly forward while the ipsilateral hand is held in front of the chest with palm facing downward. All weight should be on the rear leg at the beginning of form eight. 3. From start position, step forward with the front leg, shifting the body weight from back to front while rotating the torso from side-facing to front-facing. During this shift of weight, the rear hand should push past the face and extend forward while the other hand drops down and brushes past the thigh of the forward, stepping leg. 	<p>Quadriceps, gluteals, calves, external obliques, internal obliques, transversus abdominus</p>	

^a Following all repetitions, the leg positioning was reversed and the motions repeated.

Table 1A: Tai Chi inspired e x ercises used for MOVE rehabilitation program

E x ercise	Description / Difficulty	Progression/Requirements/Volume
Sit-to- Stand	<ol style="list-style-type: none"> 1. In chair with legs parallel to floor, stand up. Sit back down (controlled, UE support PRN) 2. In chair with legs parallel to floor, stand up. Sit back down (controlled, No support) 3. Up with both legs, down with one (UE support PRN) 4. Up with both legs, down with one at 2 x slower (min UE support PRN) 	<ol style="list-style-type: none"> 1. Wk 1-3: 1 x 10, 2 x 10, 3 x 10 2. Wk 4-6: 1 x 10, 2 x 10, 3 x 10 3. Wk 7-9: 1 x 5, 2 x 5, 3 x 5 4. Wk 10-12: 1 x 5, 2 x 5, 3 x 5 5. Wk 13-16: 3 x 8 6. Wk 17-20: 3 x 10 7. Wk 21-24: 3 x 12
Hip Abduction	<ol style="list-style-type: none"> 1. Single Leg Stand (UE support 2 hands) 2. SLS (UE support 1 hand) 3. Single Leg Stand with opposite hip abduction (No UE support) 4. Side stepping, band resistance around hip with partner 	<ol style="list-style-type: none"> 1. Wk 1-3: 10-30 secs, 1 set, 2 sets, 3 sets 2. Wk 4-6: 10-30 secs, 1 set, 2 sets, 3 sets 3. Wk 5-8: 10-30 secs, 1 set, 2 sets, 3 sets 4. Wk 9-12: 10-30 secs, 1 set, 2 sets, 3 sets 5. Wk 13-16: 3 sets of 30s 6. Wk 17-20: 3 sets of 40s 7. Wk 21-24: 3 sets of 50s <i>ALL done on each leg</i>
Heel Raises	<ol style="list-style-type: none"> 1. Bilateral HR (UE support – 2 hands) 2. Bilateral HR, 2 x slower (UE support PRN) 3. Bilateral HR, no UE support 4. Unilateral HR 	<ol style="list-style-type: none"> 1. Wk 1-3: 1 x 10, 2 x 10, 3 x 10 each leg 2. Wk 4-6: 1 x 10, 2 x 10, 3 x 10 each leg 3. Wk 7-9: 1 x 10, 2 x 10, 3 x 10 each leg 4. Wk 10-12: 1 x 10, 2 x 10, 3 x 10 each leg 5. Wk 13-16: 3 x 10 6. Wk 17-20: 3 x 12 7. Wk 21-24: 3 x 12
Stairs	<ol style="list-style-type: none"> 1. Descent only (UE support PRN) 2. Ascent and Descent (UE support PRN) 3. More volume 4. Ascent, Descent at 2 x slower 	<ol style="list-style-type: none"> 1. Wk 1-3: 1 flight, 2 flights, 3 flights 2. Wk 4-6: 1 flight, 2 flights, 3 flights 3. Wk 7-9: 3 flights, shorter rest periods 4. Wk 10-12: 1 flight, 2 flights, 3 flights 5. Wk 13-16: 1 flight, 2 flights, 3 flights 6. Wk 17-24: 3 flights

UE = Upper e x tremity; PRN = Pro Re Nata (as needed); SLS = Single Leg Stance; HR = heel raises

Table 1B: Additional e x ercises performed for up to 20 minutes during each MOVE session