A COMPARISON OF LOADING CHARACTERISTICS DURING THE TIMED UP AND GO TEST PRE- AND POST- TOTAL KNEE ARTHROPLASTY IN PATIENTS WITH OSTEOARTHRITIS.

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Abstract

The timed up and go (TUG) test is commonly used to measure functional ability in a variety of patient populations. However, improved assessment of function could be attained with the addition of kinetics during the TUG test. A longitudinal, repeated measures evaluation of 12 osteoarthritic patients, set to undergo TKA and 12 control subjects was conducted using the TUG test pre-TKA and six months post-TKA. Kinetic variables during stance and push-off, collected from two forces plates, and time to completion for the TUG test were examined. Separate one-way, repeated measures ANOVAs were completed to examine change over time in each dependent variable. Data from both subject samples were combined, revealing significant correlation between TUG time to completion and loading rate ($p=0.000$, $r=-0.795$), anteroposterior maximum ground reaction force ($p=0.000$, $r=-0.753$) and contact time ($p=0.000$, $r=0.882$) during both time periods. There were significant increases in loading rate ($p=0.023$) and significant decreases in TUG time to completion ($p=0.016$) and contact time ($p=0.013$) in TKA subjects at six months. Significant main effects were reported between TKA and control subjects for loading rate ($p=0.003$), TUG time to completion ($p=0.017$), and contact time ($p=0.007$). Post-hoc analysis revealed TKA patients have a decreased loading rate ($p<0.001$), increased TUG time to completion ($p=0.007$), and increased contact time ($p=0.004$) when compared to controls prior to surgery. Based on these results, a decrease in time to completion may not only be due to an increase in walking speed post-TKA, but also the ability to load the limb more quickly upon standing. Therefore, a decrease in time to completion of the TUG test could indicate a better ability to accept weight and a greater overall function within the involved limb.

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List of Abbreviations

OA- Osteoarthritis

TKA- Total Knee Arthroplasty

GRF- Ground Reaction Force

CT-Contact Time

mAP- Maximum Anteroposterior Force

LR- Loading Rate

TUG- Timed up and Go Test

ADL- Activities of Daily Living

BMI- Body mass index

Introduction

Knee osteoarthritis (OA), a prevalent disorder in older adults, is often treated with total knee arthroplasty (TKA) which has been shown to reduce pain and increase quality of life in 90% of patients[1,2]. Patient surveys have been found to reliably measure pain and function post-TKA and have revealed a decrease in pain as well as an increase in self-reported functional capabilities[2,3]. Biomechanical researchers have previously reported an initial decrease in functional scores post-TKA before surpassing pre-TKA numbers after six months[1,4]. However, other studies contradict these findings, revealing functional deficits up to two years post-TKA when compared to healthy individuals, indicating that the decrease in perceived pain could lead to overestimated functional ability[1,2].

Functional assessment prior to TKA has revealed substantial deficits in OA patients when compared to healthy controls, usually displayed by increased time to complete a test, increased pain, or the inability to complete a test without assistance[1,2,4-6]. Kinetic variability, specifically within the ground reaction force (GRF) waveform, was also significantly associated with lower functional scores in OA patients[6]. Kinetic deficits appear to continue post-TKA, with previous research reporting deficits in variables such as GRF and loading symmetry, as well as velocity and other compensatory motions during walking and functional tests[1,2,4,5]. Most functional tests, however, have limited application to the patients' capacity to perform activities of daily living, and instead, measure a patients' ability to perform a single task[7].

The timed up and go (TUG) test is commonly used to measure functional abilities, such as standing, sitting, walking velocity, and direction change, simulating several activities of daily living[1,2,3,7,8]. The TUG test has been reported to be a reliable and valid method of assessing mobility that requires little training of administrators[1,3,7]. However, previous studies have reported only an increased time to completion pre- and post-TKA as a measurement of overall functional ability in OA and TKA patients[1,2,4]. The TUG test may provide more valuable outcome data with the inclusion of kinetic measures, to evaluate patient loading and push off response[8]. For example, the inclusion of loading rate (LR), to measure the patients' ability to quickly accept weight onto the limb, maximum anteroposterior force (mAP), to measure the patient's ability to forcefully push-off and transition into walking, and contact time (CT) to measure the time spent in transition between sitting and walking, could provide valuable information about the specific function or deficits of the patient during the TUG test. To our knowledge, only the sit to stand and stand to sit tests, measuring only two tasks, has been used with kinetic analyses but these results cannot be directly compared to the TUG test because of inconsistent methodologies[5,9,10,11].

Greater insight into overall functional abilities may be gained by collecting kinetic data during the TUG test, instead of relying on time to completion as the sole indicator of functional gains[8]. Additionally, by collecting kinetic data pre- and post-TKA, changes in functional deficits may be evaluated more objectively, potentially giving insight to better rehabilitation and recovery. Therefore, the purpose of this study was to (1) compare kinetic data and time to completion during the TUG test between OA patients prior to TKA and at six months post-TKA, (2) compare kinetic data and time to completion during the TUG test between TKA patients and controls at pre-TKA and at six month follow up, (3) determine the relationship between kinetic variables and TUG time to completion in TKA patients and controls, and (4) determine the difference in kinetic variables between the involved and uninvolved limb during the TUG test. We hypothesized that OA patients would have an increased TUG time to completion and CT as well as a decreased LR and mAP when compared to TKA patients 6 months post-TKA. We hypothesized that OA patients would initially exhibit an increased TUG time to completion and contact time as well as decreased loading rate and mAP Pre-TKA, but all variables would reach levels of controls by six months post-TKA. We hypothesized that TUG time to completion would be negatively correlated with loading rate and mAP but would be positively correlated with contact time. Lastly, we hypothesized that there would be no significant difference in kinetic variables between involved and uninvolved limbs at each time period.

Methods

Research Design

A longitudinal, repeated measures evaluation of TKA data were conducted using the TUG test prior to TKA and at six months post-TKA and compared to healthy controls. The independent variables were time and group. The dependent variables were TUG time to completion, LR, mAP, and CT.

Participants

Twelve patients (five male and seven female) were included in the study and were compared to twelve control subjects (seven male and five female) of similar demographics (Table 1). Inclusion criteria included: 1) less than 85 years of age, 2) no previous history of lower extremity fracture, osteotomy, or joint replacement, 3) unilateral TKA, and 4) ability to walk without an aid. Inclusion criteria for the control group were: no previous surgery to the lower extremity, ability to walk without an aid, and absence of rheumatoid or inflammatory arthritis. Patients in the TKA group were screened prior to study participation and underwent unilateral

TKA for the treatment of OA by the same surgeon. Prior to the study all patients signed an informed consent form approved by the Institutional Human Studies Program.

Procedures

All data were collected at the University Gait Laboratory. All data collection sessions were performed by National Athletic Trainers' Association, Board of Certification certified, athletic trainers. Anthropometric data collected included height, measured with a wall mounted stadiometer (Seca Corp., Hanover, Maryland, USA), and weight, measured with a Detecto Certifier scale (Detecto Scale Co., Webb City, Missouri, USA). Two force plates (Advanced Mechanical Technology Incorporated, Boston, MA) embedded flush with the floor were used to collect kinetic data during the TUG test. Kinetic data were collected at 480 Hz and processed with Vicon Nexus software (Vicon, Inc., Centennial CO). Raw kinetic data from three trials were averaged and used for data analysis. A 20 N threshold was used to identify the beginning and end of the GRF impulse in order to eliminate "noise" from the data. Loading rate was reported as the application of body weights per second to measure the rate of weight acceptance onto the limb. Maximum anteroposterior forces were reported as percentage of body weight and used to determine the magnitude of forward component of GRF. Contact time was reported in seconds from time of initial loading to push off, to measure the time in transition between sitting and walking. Only data collected from the push limb, designated by the foot that was in contact with the force plate last during each trial were analyzed.

The TUG protocol was conducted consistent with the previously validated methods described by Podsiadlo and Richardson[7]. Participants were asked to sit in a chair with a base height of 45 cm, their backs against the chair back, arms relaxed on the arm rests, with their bare feet placed on the floor in front of them. The chair was placed behind the embedded force plates in such a way that when the patient got up from the seated position, each foot would be placed fully within the adjacent force plates. When given the "ready, go" command, participants were instructed to rise from the chair, using the arm rest to rise if necessary, placing their feet forward on the adjacent force plate. They were then instructed to walk as quickly as possible a distance of three meters to a strip of tape placed on the floor, turn around, walk back to the chair, and return to the seated position. Time data were collected using a stopwatch (CEI Gardena, CA), beginning on the command "go" and ending when the participants back contacted the backrest of the chair.

Statistical Analysis

Descriptive statistics including means and standard deviations, were generated for all demographics and independent *t*-tests were used to compare demographics between groups. In order to evaluate the first purpose statement, one-way, repeated measures ANOVAs were used to examine kinetic data and time to completion during the TUG test over time in TKA patients. To evaluate the second purpose statement, mixed method, repeated measures ANOVAs were used to determine potential main effects for group. When significant main effects were revealed, independent *t*-tests were used to determine differences between TKA patients and controls at each time period. To evaluate the third purpose statement, multiple Pearson correlation tests were performed to determine the relationship between LR, mAP and CT with TUG time to completion for TKA patients, then both TKA patients and controls combined. Finally, to evaluate the fourth purpose statement, independent t-tests were used to determine differences in kinetic variables between involved and uninvolved limbs at each time period. All statistical analyses were conducted using SPSS version 21.0 (IBM, Armonk, NY, USA) with an alpha level of p<0.05.

Results

Table 1. Demographic variables (mean ± SD) by group at baseline

	N	Age(y)*			Height(m)			Weight(kg)			BMI		
TKA	12	67.0	±	5.83	1.62	±	0.086	72.6	±	16.3	27.23	±	4.58
Control	12	62.2	±	3.62	1.64	±	0.088	70.9	±	7.2	26.37	±	2.43

TKA= Total Knee Arthroplasty, SD= Standard Deviation, BMI= Body Mass Index, n= Sample Size; y= Years; m= Meters; kg= Kilograms; *=Significant difference; p<0.05

Twelve patients were included in the current study and were compared to twelve controls of similar demographics. Age was the only variable that was significantly different between groups, with the TKA group average age higher than controls (p=0.03) (Table 1). Height, mass and body mass index were not significantly different which allowed kinetic variables to be compared without an effect from anthropometrics.

Table 2. Comparison of dependent variables within groups over time (mean ± SD)

	TKA							Control						
	Pre			Post			p-value	Pre			Post			p-value
LR	1.03	±	0.23	1.21	±	0.22	0.023	1.53	±	0.34	1.47	±	0.40	0.316
TTC	10.85	±	2.48	9.61	±	1.89	0.016	8.19	±	1.76	8.23	±	1.94	0.901
mAP	18.17	±	6.51	19.20	±	4.43	0.467	22.98	±	6.35	22.71	±	6.37	0.846
CT	1.35	±	0.43	1.06	±	0.20	0.013	0.89	±	0.17	0.92	±	0.24	0.436

SD=Standard Deviation; TKA=Total Knee Arthroplasty; LR=Loading rate; TTC=Tug Time to Completion; mAP=Maximum Anteroposterior Force; CT=contact time

p-value: between pre- and post- data collections

There was a significant increase in loading rate (1.03±.27 to 1.21±.22; p=0.023) and a significant decrease in TUG time to completion (10.85±2.48 to 9.61±1.89; p=0.016) and contact time (1.35±.43 to 1.06±.20; p=0.013) in TKA subjects between pre- and six months (Table 2). Changes in mAP were not significant over time, potentially due to the small effect size and high standard deviations.

Table 3. Comparison of dependent variables between groups over time (mean ± SD)

	Pre-			Post-		
	TKA	Control	p-value	TKA	Control	p-value
LR	1.03 ± 0.23	1.53 ± 0.34	<0.001	1.21 ± 0.22	1.47 ± 0.40	0.053
TTC	10.85 ± 2.48	8.19 ± 1.76	0.006	9.61 ± 1.89	8.23 ± 1.94	0.091
mAP	18.17 ± 6.51	22.98 ± 6.35	0.081	19.2 ± 4.43	22.71 ± 6.37	0.133
CT	1.35 ± 0.43	0.89 ± 0.17	0.004	1.06 ± 0.20	0.92 ± 0.24	0.137

SD=Standard Deviation; TKA=Total Knee Arthroplasty; LR=Loading rate; TTC=Tug Time to Completion; mAP=Maximum Anteroposterior Force; CT=contact time

p-value: between TKA and control data

Significant main effects were reported between TKA and control subjects for loading rate (p=0.003), TUG time to completion (p=0.017), and contact time (p=0.007). Post-hoc analysis reveal TKA patients had a decreased loading rate (p<0.001), increased TUG time to completion (p=0.006), and increased contact time (p=0.004) when compared to controls prior to surgery (Table 3). However, no significant difference was present between TKA patients and controls at the six month time period.

Table 4. Correlations with TUG Time to Completion in TKA and TKA and Controls Combined

	TKA n=24			TKA & Controls n=48		
	LR	mAP	CT	LR	mAP	CT
Correlation	-0.729*	-0.725*	0.857*	-0.795*	-0.753*	0.882*

LR=Loading Rate; mAP=Maximum Anteroposterior Force; CT=Contact Time; n= Number of Samples; TKA= Total Knee Arthroplasty

*=significant at *p*<0.001

Significant correlations between TUG time to completion and loading rate (r=-0.729, p<0.001), max anteroposterior (r=-0.725, p<0.001) and contact time (r=0.857, p<0.001) were revealed for TKA patients (Table 4). Data from both subject samples were combined, revealing a strengthened significant correlation between TUG time to completion and loading rate (r=-0.795, p<0.001), anteroposterior max (r=-0.753, p<0.001) and contact time (r=0.882, p<0.001) during both time periods (Table 4).

Trial data for both time periods were separated and placed into groups based on which limb the patient used to push off with, involved or uninvolved. No significant differences were found between limbs at each time period. Groups were not compared over time because of the variability in the limb patients used to push off with as well as the suspected effects from TKA.

Discussion

Commonly, TUG time to completion is the sole variable reported to describe the functional progression or decline of a pathological patient during the TUG test[7]. Specifically in the TKA population, previous research has reported an initial increase in TUG time to completion up to 6 months post-TKA[1,4], but may decrease below pre-TKA values out to two-year post-TKA[2]. The current study contradicts these findings, in which the TKA group completed the TUG test in an average of 9.61±1.89 seconds six months post-TKA, which was significantly faster than pre-TKA levels (10.85±2.48 seconds). However, TUG time to completion in the current study were consistent with other studies that reported completion times ranging from 6.7 seconds in patients two years post-TKA[2] to greater than 30 seconds in older individuals[1,4,7,12]. Decreases in TUG time to completion have been reported to represent better function and a better ability to perform ADL[7]. Although previous research has suggested that TKA may not reach TUG time to completion values comparable to controls at six months post-TKA[1], TUG time to completion in the current study was not significantly different at six months between TKA patients and controls. It is difficult to determine the cause for this difference between studies, as current activity level and rehabilitation protocols were not collected for comparison.

Although time to completion provides valuable information about the functional progression after TKA, little can be inferred about specific tasks involved within the TUG test. The collection of kinetic data, specifically during the standing phase of the TUG test, may provide further information on the ability of patients to not only stand, but transition into walking quickly. In the current study, contact time was identified as the time from initial loading to push-off. Previous research has reported a decrease in contact time as a variable commonly found in patients with higher functional scores[6] and could indicate a decrease chance of falling during transition between standing and walking[12]. The results from the current study support these findings, revealing a positive correlation between TUG time to completion and contact time, with TKA patients having a significant decrease in contact time and decreased TUG time to completion between pre- and six months post-TKA. Compared to controls, contact time for pre-TKA patients was significantly greater but reached levels of controls by six months post-TKA. This decrease in contact time could indicate patients are not only walking faster but have a greater capacity to transition into walking after rising from a chair.

To our knowledge, the current study is the first to report loading rate, considered the first phase of contact time, when rising from a chair during functional tasks. Similar to contact time and TUG time to completion, loading rate in TKA patients significantly increased between pre- and post-TKA. Additionally, the significant negative correlation between loading rate and TUG time to completion, supported by a significant increase of loading rate to levels of controls in TKA patients between pre- and post-TKA, could further add merit to the increase in function corresponding to the decrease in TUG time to completion. Therefore, increased TUG time to completion in TKA patients prior to surgery could indicate their limited ability to load their limb quickly and transition into walking. Furthermore, a decrease in TUG time to completion post-TKA may indicate the patients were more capable of loading their limb, as well as, possessing a greater sense of stability when transitioning into walking.

Following loading rate, contact time is completed by the ability to push-off, measured in this study by mAP. Subtle changes and high variability within the data limited our ability to find significant differences in mAP between pre-TKA and six months post-TKA ($p=0.47$). However, the significant negative correlation ($r=-0.753$, $p<0.001$) between mAP and TUG time to completion emphasizes the ability to complete the TUG test quickly could rely on both loading the limb quickly and the ability to push-off and transition into walking. No previous research has described mAP during the transition between standing and walking, however, mAP deficits have been reported in the involved limb following knee arthroplasty when compared to the uninvolved limb during walking[10]. Interestingly, when data from the involved and uninvolved limb were separated, no significant differences were reported, suggesting no asymmetries or compensations between limbs existed.

Due to the variability in preferred push limb, TKA patients were further separated into involved or uninvolved push limb. The small number of trials in each group made statistical evaluation difficult and the lack of significant difference could be due to low statistical power. However, the lack of statistical difference in all dependent variables between involved and uninvolved could indicate the absences of compensatory loading during standing and pushing off post-TKA. Therefore, it may be appropriate for future studies to allow subjects to push with their preferred limb to ensure natural gait tendencies, without biasing data.

Limitations

Although these results can add greater value to the clinical application of the TUG test, a few limitations experienced in the current study must be addressed. In order to more accurately simulate ADLs and elicit a natural loading response, the use of chair handrails during the TUG test was allowed. The use or non-use of handrails may have caused differences in loading characteristics, perhaps resulting in lower mean loading values. Additionally, the initial step limb was not controlled for during the TUG test to help ensure natural, comfortable function. Chair height was fixed in the current study and caused shorter patients to reach for the floor to begin the test. While other studies have used adjustable seat heights proportionate to the patients height or limb length for other functional tasks, the chair used in the current study is likely to elicit loading responses that a patient would experience in the real world during activities of daily living. Great variability in choice step limb was present between TKA patients, between data collections, and within data collections, with no visible trend towards or away from the involved limb. However, with no significant differences between limbs reported in the current study, the use of the push limb, regardless of involved or uninvolved, for statistical analysis appears justified.

The current study recognizes the influence that patients pushing off with their uninvolved limb might have on the data, but attempted to treat each patient as a unit instead of as separate parts based on involved or uninvolved limb. It may have been even more detrimental to the results of this study to control for which limb patients could push off with, as it may have forced an unnatural loading response that would have inaccurately represented forces that patients would experience during activities of daily living. Therefore, it may be appropriate for future studies to allow subjects to push with their preferred limb to ensure natural loading, without biasing data.

Clinical Application

The ability to evaluate kinetic variables during rehabilitation is limited in most clinical settings. Although TUG time to completion is commonly used to measure patient function, this outcome measure was previously only a vague assessment of the exact improvements or deteriorations experienced by the patient. The results from the current study established significant correlations with kinetic variables, suggesting a decrease in TUG time to completion may be interpreted as not only the ability to walk faster but the ability to quickly load the limb while standing and forcefully push-off while transitioning between standing and walking. Positive changes of these functional characteristics may imply greater dynamic functional ability, as well as, an increase in patient confidence during functional activities.

Conclusion

The TUG test has been used to measure function in a wide range of populations but information about overall function of these patients is limited. The current study identifies kinetic variables, specifically contact time, loading rate, and mAP, which are significantly correlated with TUG time to completion. Additionally, improvement within the TKA population was noted by a significant increase in loading rate and mAP six months post-TKA, to the levels of controls. This information can be used in addition to overall TUG time to completion to better evaluate the overall dynamic functional performance of pathological patients or during the rehabilitation process.

Review of Literature

Knee osteoarthritis (OA) is a common cause of pain and impaired functional mobility in older adults[1,2]. 500,000 patients underwent TKA for the treatment of knee OA in 2006 and incidence of this surgery is predicted to increase in coming years[1,2]. Although TKA has been found to reliably treat knee OA in older adults and increase quality of life, functional deficits, including slower walking velocities, slower stair climbing times, and decreased quadriceps strength, were observed post-TKA at one year when compared to healthy adults[1]. These deficits are not as pronounced in patients who had simultaneous bilateral TKA who displayed comparable or better functional outcomes than patients undergoing unilateral TKA[2]. Long term function of unilateral TKA patients was based on the health of both the involved and uninvolved limbs, and unbalanced loading may have led to further dysfunction[11].

Loading Patterns in Asymptomatic Populations

Many studies have investigated the biomechanical effects of TKA, but to determine the long-term success, TKA patients should be compared to healthy control subjects. Burnett et al[9] studied 35 subjects (19 male, 16 female) with a mean age of 23.0 years for symmetry between non-dominant and dominant sides during walking sit to stand (SitTS) and stand to sit (StandTS) activities. The dominant side of subjects was determined by which foot they would use to kick a ball, and 34 of 35 subjects were right leg dominant. Biomechanical data were collected using a multi-camera motion tracking system with a modified Helen Hays marker arrangement, and force plates were embedded in the floor to collect GRF during trials. While kinetic and kinematic data were collected, electromyography (EMG) of erector spinae, rectus abdominis, rectus femoris and hamstring muscles were collected by surface electrodes. For walking data, three trials were collected for the dominant and non-dominant sides and values were averaged per side. For sitting and standing activities, the subjects initially began seated upright on a bench with no back rest or arm rest, and were instructed to stand and return to sitting as many times as possible during a 30 second period. This test was completed twice in order to perform the task with force plate under the dominant and non-dominant leg. Although the data for both the SitTS and StandTS were collected together, data were separated for each test based on the knee extension angle increasing for SitTS and the knee flexion angle increasing for StandTS. Peak GRF was found for each task and averaged between repetitions for the dominant and non-dominant leg. To identify the symmetry between sides, the difference in data between the dominant and non-dominant sides were determined using a Bonferroni corrected paired *t*-test at an alpha level of 0.05, as has been used in previous studies. A symmetry index was used to assess symmetry between limbs. An intrasubject standard deviation was also calculated to assess reliability of vertical GRF (VGRF). Nearly perfect symmetry was found during walking trials between dominant and non-dominant sides in several parameters, including VGRF, and no significant differences were found. During the StandTS and SitTS tests all parameters including VGRF were found to be symmetrical, except for hamstring activity which was the only significantly different parameter. Muscle activity and VGRF between sides were found to be very symmetrical, with 13 of the 16 variables examined having a power of more than .80. Symmetry has been previously defined as “perfect agreement of the external kinetics and kinematics of the left and right leg” by Herzog et al., 1989. Based on this definition of symmetry, stance phase of gait, SitTS and StandTS were symmetrical in asymptomatic healthy individuals. Near perfect agreement was found with peak VGRF at heel strike, toe off and sit to stand tasks between sides of asymptomatic subjects. Stance time between limbs was found to be statistically symmetrical which agrees with previous research on asymptomatic subjects, while research on THA (total hip arthroplasty) and TKA patients found extended stance time on the non-operated side. Greater muscle activity of the quadriceps and hamstrings were found on the non-dominant side during walking trials, but there is no evidence as to why. During SitTS and StandTS tests, muscle activity was fairly symmetrical minus hamstring activity, with average SI values consistently between 1 and 1.35, meaning neither side was heavily favored. Only one chair height was used during tests, which is a point future studies should address.[9]

Elderly populations are at increased risk of falling, which can cause physical and psychological challenges with ADL, however few studies have directly investigated the cause of increased risk of falling. In an effort to identify variables that may predict the risk of falling, Melzer et al[12] used 100 healthy elderly subjects (age 65-91 years) to compare the Berg Balance Test (BBS), TUG and the Voluntary Step Execution Test (VSET). Of the 100 subjects used in this study, 13 were considered multiple fallers, falling at least twice in the previous six months and would be compared to the other subjects who would act as controls. The VSET required the subject to stand barefoot on a force plate, and take a step of at least 30 cm as quickly as possible after a tap was administered on their heel by a researcher. Subjects completed three trials of the VSET in a forward, lateral and backwards direction for both dual and single task states, making 18 total trials for each subject. For the single task portion, subjects were to look at an **'X'** on a screen three meters to their front while completing the stepping after a tap to their heel. For the dual task component, subjects performed a modified Stroop task in addition to the single task protocol. Ground reaction force and center of pressure data were measured by a force plate, and all trials were performed on the dominant leg of the subject. There were no significant differences between the three directions of stepping during the VSET so the averages of all were used for statistical analysis. A two way repeated measures ANOVA was completed for all dependent variables between groups. For all significant findings a student's *t*-test was run using a Bonferroni corrected p-value. A backwards stepwise regression model was used but only the single step execution test remained in the model. The goodness-of-fit line was improved with the addition of the BBS, TUG and single step execution test. Age alone failed to predict risk of falls in this study as the average age of fallers was younger (74.7 years) than the average age of non-fallers (78.9 years) and TUG and BBS results were not significantly different between the two groups. The current study divided the step response into three phases; initiation phase was described as the time between sensory impulse and efferent nerve conduction, preparatory phase was described as activation of APA (associated postural adjustments), and swing phase was described as the neuromuscular mechanisms activating in order to take a step. No significant differences were present between subject groups for the VSET during single task testing, but differences were clear with dual task testing. Fallers took 17.5% longer to prepare for stepping than non-fallers and swing times were 27% longer in fallers than non-fallers. Time to foot contact was significantly longer in fallers compared to non-fallers (1414 ms to 1168 ms). A significant increase of the initiation response time of about 170% was present in both groups from single to dual task during the VSET showing the added cognitive challenge of dual task testing. These results agree with similar studies that suggest balance in elderly populations may be linked to capacity of attention as well as physical ability. The present study found dual task stepping to be a challenge of cognition in the elderly, and those who have difficulty multitasking are associated with 500% increased risk of falling during ADL. Melzer et al.[12] suggested that the VSET test may be a reliable and sensitive test to predict falls in the elderly and can be used to identify individuals that may benefit from balance training.[12]

Strength Deficits and Functional Tests in OA and TKA Patients

Quadriceps weakness is a persistent problem for TKA patients, however no studies have examined the relationship it has on function and movement patterns. Mizner and Snyder-Mackler[5] used 14 patients (nine men and five women) who had a tricompartmental cemented TKA with a medial parapatellar surgical approach. Patients received six weeks of physical therapy with a mean of 17 visits. Patients were tested for isometric quadriceps strength as well as kinetics, kinematics and EMG activity during walking and sit-to stand (STS) test. Timed up and go, SCT (stair climb test) and the six-minute-walk (6MW) test were used to asses function and all data were collected at three months post TKA. Nonparametric tests were run for all dependent variables and EMG, specifically the Wilcoxon Sign Rank tests. Several Spearman Correlation Coefficients were used to determine relationships between dependent variables. The involved limb quadriceps strength was observed to be 65% of the strength of the uninvolved limb. Functional tests results were correlated with compensation from the uninvolved side. Walking velocity and stair climbing speed decreased by 20% and 50% respectively in TKA patients compared to healthy age matched adults. During the STS test, peak vertical ground reaction force (VGRF) was 14% lower on the involved limb. TKA patients had increased hip and knee moments on the uninvolved side when standing from a seated position, and stood more slowly than controls. The involved side quadriceps had decreased

EMG activity when compared to the uninvolved limb, especially the vastus lateralis muscle. Bilateral activities allow the uninvolved limb to compensate for the involved limbs weakness which may explain the persistent weakness observed in TKA studies. Unilateral exercises should be used during rehabilitation to combat compensation.[5]

Kinetics during Functional Testing

The knee joint is a large complex joint that is subject to a variety of forces and magnitudes during ADL. The forces acting on the knee are typically estimated by complex equations, such as inverse dynamics, because it is impossible to directly measure these forces without invasive means. Mu¨ndermann et al[13] studied a subject with a force transducing knee implant, in order to directly measure the forces acting on the knee during different activities. The subject was a healthy 81 year old male (170cm, 64.5kg) with an in vivo force transducing knee implant in his right knee, which was fitted 1.5 years prior to the study. Three-dimensional motion capture was taken with tibial force measurements during all activities. Activities included; normal self-selected speed walking, sit to stand and stand to sit with chair height adjusted to 95% of tibial height (47 cm), stair ascending and descending (step height of 20.3 cm), squatting from a standing position, and a golf swing. All activities that included squatting were performed with feet shoulder width apart, and no arm rests or hand rails were used during any test. Descriptive statistics were calculated for each activity and used to compare results. The highest compressive forces about the knee were experienced during stair ascent and decent, and the lowest compressive forces were observed during sit to stand. Peak compressive forces were measured to be over two and a half times the body weight at a wide range of angles depending on the activity; as low as 8.5 degrees of flexion during walking and as high as 91.8 degrees during squatting. Peak compressive forces during stand to sit were observed between 60.7 and 77 degrees of flexion. All activities except for golf placed increased compression on the medial compartment of the knee compared to the lateral compartment, making higher medial to lateral compression ratios at peak compressive load (walk: 1.7; stair ascent: 1.0; stair descent: 1.2; sit to stand: 2.2; stand to sit: 1.3; squat: 2.7; golf: 0.7). Despite the peak compression measurement, stair ascent, stair descent and the golf swing were observed to have the most balanced loading between medial and lateral compartments throughout the activity. In contrast, the sit to stand peaked at up to four times more compression on the medial side, and during deep squatting the medial compartment peaked eight times the compression of the lateral side. Activities were categorized by qualities such as magnitude of loading, rate of loading, and range of flexion during peak loading. Walking was alone in the "High Cycle Loading" category, with a moderate peak loading magnitude, high rate of loading and peak loading was experienced at low angles of flexion. Medial and lateral compartment loading balance was likely due to limb alignment and affected by variables that contribute to knee adduction moment. Stair ascent, stair descent and golf swing comprised the "High Loading" category, with a high peak loading magnitude, moderate rate of loading, and peak loading was experienced at mid-range of flexion. Medial and lateral compartment loading was balanced in this category compared to others. Sit to stand, stand to sit and squatting comprised the "High Flexion" category, with a moderate peak loading magnitude, low rate of loading, and peak loading was experienced at high angles of flexion. The different categories represent the different types of loads a knee implant should be able to withstand in order to be a successful replacement device. Although compression ratios of the medial and lateral compartment of the knee may differ between a natural knee and the implanted knee tested, all activities except for stair descent experienced the highest compression load at a lower flexion angle than the flexion angle where peak compression ratio between medial and lateral compartments was measured. An implant designed specific to a patient's natural medial and lateral plateaus may increase functional outcomes and help to more accurately predict joint loading during ADL. While limitations such as device error, soft tissue compression and surgical technique may have reduced the reliability of this study, the results suggest that TKA patients should avoid squatting or improvement in implant design is needed to cope with the stresses from this activity. Peak loading forces measured in this study were significantly less than previous mathematical predictions, similar to findings of a previous study that used in vivo force measurements in the hip. Although early results of this study have been reported in previous literature, the patient continued to improve after eight months to the 1.5 year data collection for the current study. During the sit to stand test at six weeks post TKA, the patient used the uninvolved limb more, while at 1.5 years post-TKA the GRF between the limbs were nearly balanced. While previous studies have reported medial to lateral compression ratios at the angle of peak loading, this study reported peak loading and peak loading ratio separately, as they occurred at different angles of flexion during activity. The findings of this study were specific to one subject and may differ significantly between individuals. Despite the limitations of this study the goal of categorizing activities was to offer insight on the specific demands placed on the knee during ADL to benefit implant and rehabilitation design.[13] Ground reaction force is a reliable characteristic of gait that is affected by walking speed and fluctuates the entire time a subject's foot is on the ground, however little research has been done to analyze and classify VGRF in patients with knee OA. Takahashi et al[6] used 130 elderly females with knee OA to identify if there was any association with "single hump" or "double hump" VGRF and pain during walking, TUG and functional reach test (FR). The Japan Orthopaedic Association (JOA) score was used to classify subjects based on their pain. The average age of the subjects was 80 years, and they were split into three groups; 45% with no pain, 28% had unilateral pain and 26% had bilateral pain. The FR test measured the maximum distance a subject could reach away from midline past the length of their arm without moving their feet while standing. Differences between groups were assessed using a Kruskal Wallis test for the analysis of knee pain and a Mann-Whitney U test for the analysis of VGRF and statistical significance was set at $p = 0.05$. Knee pain was significantly associated with body weight but not with any effect to TUG, FR or gait parameters. Association was observed between a double hump VGRF and shorter TUG time to completion and increased FR, as there was an association with subjects with a single hump VGRF, longer TUG time to completion and short FR. Subjects that displayed a double hump VGRF also displayed faster walking speed, longer stride length and less time in contact with the ground on each step when compared to the subjects who had a single hump VGRF. Takahashi et al[6] found functional test results to be significantly associated with VGRF and gait parameters while other studies have failed to analyze these variables, or found decreased peaks of VGRF on the involved limb of OA subjects. No correlation was observed between pain and mechanism to affect gait parameters. A change in VGRF from one to two humps seems to be crucial to improve gait parameters and functional tests and future studies should explore how to make these changes.[6]

Recent studies have found that the long-term function of TKA patients is strongly related to the increased joint loading of the uninvolved knee post-TKA. Increased loading of the uninvolved knee has been recognized to cause OA progression and has required 35%-43% patients to undergo a secondary TKA within ten years of the first. Despite the role knee joint loading plays in patient outcomes, prediction equations used to calculate the forces are recognized to be inaccurate but continue to be used because of the difficulty involved in directly measuring the forces between the tibia and femoral condyles. Therefore, little is known about the true joint forces experienced by the knee pre- and post-TKA. Worsley et al.[10] recruited 20 healthy subjects (nine men and eleven women, mean age of 62 years) and 34 patients (14 men and 20 women, mean age of 64 years) and tested them at four weeks pre- and six months post-KA (knee arthroplasty) (14 unicompartmental KA and 20 TKA). Walking and sit-stand trials were performed three times each and analyzed by a Vicon motion capture system. Previously published musculoskeletal model processing was used but made specific to each subject using vertical force plate reaction, vertical TFJ (tibiofemoral joint) force, posterior–anterior TFJ force, TFJ flexion moment and TFJ adduction moment. Final joint forces and moments were calculated from force plate readings, body segment mass, and optimized muscle forces about each joint and the knee joint was simplified to a hinge joint for calculation purposes. Kinetic forces were normalized to patient height and body weight, and both peaks and waveforms of forces were analyzed. Differences between limb loading were detected by paired sample t-tests and changes in loading differences between limbs pre-KA and post-KA were analyzed by a two-way repeated measure ANOVA. To compare healthy vs. pre-KA and healthy vs. post-KA between limb loading Mann Whitney U tests were performed. Healthy subjects showed no significant difference between sides while pre-KA patients showed significantly greater contralateral mean peak vertical TFJ force and TFJ adduction impulse while walking. The sit to stand activity revealed a significantly higher peak vertical force plate reaction, as well as greater peak vertical forces, anterior-posterior forces, flexion moment, adduction moment and adduction impulse about the TFJ in the contralateral limb of the pre-KA patients. During walking post-KA contralateral limb loading was significantly increased with a mean peak vertical force of the contralateral limb of 0.4 $*$ BW greater than on the involved limb. Peak adduction moment and adduction impulse from pre- to post-KA were significantly different, but GRF and TFJ forces did not change significantly during gait. In post-KA patients the vertical force plate reaction, TFJ reaction, peak flexion moment adduction impulse, and GRF asymmetries remained significantly greater on the contralateral side during the sit-stand test. However, between pre- and post-KA no statistically significant changes were observed in limb loading differences. The findings of this study support previous research on similar subject groups, although direct comparison was made difficult due to different techniques of normalizing data. Asymmetries in loading both pre- and post-KA were more significant during sit-stand than during gait. The most significant change in gait was the reversal of involved limb TFJ adduction peak and adduction impulse post-KA when compared to pre-KA. This finding agrees with previous research and could be explained by the altered TFJ alignment from surgical procedures. The asymmetry of loading during the sit-stand trials were relatively unchanged from pre- to post-KA, however other studies suggestion that asymmetry of loading decrease as recovery times increase. Loading during sit-stand maneuvers is an uncommon point of research, and more focus is needed to determine the contribution of contralateral limb to patient function three years post-KA.[10]

Biomechanics research has reported weight-bearing asymmetries (WBA) in unilateral TKA patients following surgery and may be related to poor long-term functional outcomes. Known modifiable variables that potentially contribute to WBA are lower extremity muscle weakness, impaired quadriceps activation, pain and knee joint motion. By identifying predictors of WBA, rehabilitation efforts post-TKA may prove to be more successful and patient function may improve. Christiansen et al.[11] used regression analysis to identify predictive factors of WBA for unilateral TKA patients one month post-TKA. Two weeks prior to TKA, 59 patients (65.1 years, ±8.6) completed baseline testing. Following TKA, patients completed a mixture of home based and outpatient phases of therapy with a licensed physical therapist that followed a standard protocol before retesting at one month post-TKA. Patients completed the Five Times Sit-to-Stand Test (FTSST), which measures the time required for a patient to transition between sitting and standing from a chair five times continuously as naturally and quickly as possible with force plates under each foot. Patients were encouraged not to use their hands for assistance to stand, but were allowed to if needed, and notation was made. For each limb VGRF was averaged across the five transitions and normalized to body mass for analysis. Limb weight-bearing ratio was calculated by dividing the average involved limb values by the average uninvolved limb values. Potentially predictive variables identified for WBA at one month post-TKA were peak isometric quadriceps and hamstring strength, quadriceps and hamstring strength ratio, volitional quadriceps activation deficit, self-reported surgical knee pain, knee extension motion, knee flexion motion, preoperative WBA, upper extremity support during the FTSST, sex, age, and BMI.

Isometric hamstring and quadriceps strength were measured in a position of 85 degrees of hip flexion and 60 degrees of knee flexion while volitional muscle activation was measured using a doublet-twitch interpolation technique through two self-adherent electrodes. Pain was measured verbally by a 0-10 pain scale before and after the FTSST. Analysis began with a regression of individual screening of measured impairments, demographic, anthropometric, and movement compensation variables using a correlation coefficient. For all significant correlations ($\alpha < 0.2$), multiple regression model were created to determine the model accounting for the most variability in WBA. The model accounting for the most variable included: age, hamstrings ratio and quadriceps ratio variables representing 30% of the variability in WBA. Results revealed the TKA patients averaged 13% and 31% less application of body weight to their involved limb compared to their uninvolved limb during FTSST at pre-TKA and one month post-TKA respectively. The primary indicator of WBA post-TKA was WBA pre-TKA, suggesting that habitual compensatory motions developed prior to intervention carry over to the rehabilitation phase. Disparity in the ratio of hamstring to quadriceps strength between involved and uninvolved limbs was a better predictor of WBA than unilateral strength assessments. The correlation between pre-TKA WBA and post-TKA WBA suggests that specific functional movement patterns focusing on symmetric loading should be retrained during rehabilitation. The few studies that have implemented rehabilitation focused on symmetric loading have reported improvement in movement symmetry and functional outcomes. Similarly, the correlation reported between hamstring and quadriceps strength ratios and WBA between limbs suggests rehabilitation for TKA patients should focus on developing symmetrical strength ratios in the involved limb like that of the uninvolved limb. Although deficits in voluntary activation of the quadriceps muscle are known to influence quadriceps strength post-TKA, it was not predicting of WBA in this study. Variables such as surgical knee pain, knee extension motion, knee flexion motion, age, sex, BMI and upper extremity support during testing were not significant predictors of WBA at one month post-TKA. This study was limited by reporting WBA only while completing the FTSST.[11]

TUG Test and Reliability

Designing a method to test elderly adult's basic mobility skills and risk for falling has been a topic of debate for the last few decades. Special equipment and machines have been designed for testing elderly patients balance and mobility however they are typically found to be too expensive and impractical for most clinical practices. In attempts to design a reliable and practical test that is relevant to elderly adults daily basic needs for mobility, Mathias et al came up with the "Get-up and Go' Test". This test required subjects to rise from a seat, walk three meters, turn around walk back to the chair, and sit down again. The test was scored on a scale of 1-5 based on their risk of falling. Although this test was a great step in the right direction of testing a subject's basic mobility skills, the scaling system was reported to be vague and difficult to determine. In attempt to correct this short coming of the "Get-up and Go' Test" Podsiadlo and Richardson[7] replaced the 1-5 scale scoring system with a time (in seconds) to completion score, and called it the timed "Up & Go" test. The patient would wear his normal shoes, and would be able to use his usual walking aid device. The patient would begin seated in a standard armchair with a seat height of 46cm. The patient was instructed that on the word "go", he would rise from the chair and walk to the three meter line marked on the floor, turn, return to the chair and sit down again. The subject was allowed to have a walk through trial before being tested in order to become comfortable with the test, and a wrist watch with a second hand or a stop watch was used to time the patient during the test. Sixty consecutive patients from a local community hospital were used in this study as test subjects and ten active and healthy individuals over the age of 70 were used as controls. Reliability testing was completed at two locations using three administrators with similar but not identical chairs. Although there were no previous studies to compare to, interclass correlations for intra- and inter-rater reliability were 0.98 and 0.99 respectively with alpha at .96. Basic mobility maneuvers were also tested independently and ratings were determined by 14 items each rated on a scale 1-4. Walking speeds were measured from the middle 15 meters of a 20 meter walkway, allowing the subject to use their normal walking aids. Patient's functional capacities were measured by the Barthel index of ADL questionnaire. Patients were also evaluated on their ability to go outside alone, and placed into three groups. The intra-class correlation coefficient was used to estimate the timed "Up & Go" tests reliability. The Pearson correlation coefficient was used to determine the relationship of the timed "Up & Go" test and the other tests used. The ten controls had an average time of 8.5 seconds on the timed "Up & Go" test while the test subjects ranged widely from 10-240 seconds to complete the test. Similarly the test subjects scored in a very wide range on the other tests, although it was stated that they were capable of completing ADL with fair independence. No relationship was found between each subject's time for the "Up &Go" test and their medical diagnosis. A secondary group of patients (22) with similar medical diagnosis as the first group were used for a reliability study of the "Up & Go" test. Inter- and intra-rater correlation coefficients were both 0.99. The correlation between how subjects performed on the timed "Up & Go" test and other tests were as follows; Berg Balance Scale (r=-0.72), gait speed (r=-0.55), and Barthel Index of ADL (r=-0.51).

The correlations become stronger when scores are log-transformed (r= -0.81, -0.61 and -0.78 respectively). The timed "Up & Go" test was found to be a reliable and practical performance test for elderly community dwelling adults, and seems to be an effective tool to track functional changes over time. Subjects who completed the timed "Up & Go" test in less than 20 seconds were able to perform basic mobility skills and ADL on their own, while subjects who took longer than 30 seconds to complete the test were more likely to need assistance with ADL. The subjects who were between the two previously described groups varied the most on their performance during all of the tests, making their functional performance difficult to predict. The reliability studies found that subjects with stable health varied little in their time score, and that the time score alone could be used to predict difficulties in balance, mobility maneuvers and gait speed. Improvements in the time score may also be valuable for tracking changes in patients in response to therapy where other tests may not be sensitive enough to detect gains.[7]

The TUG test was developed to measure elderly adult's functional mobility, but the test has never been used on amputees. Schoppen et al[3] used 32 subjects (23 men and 9 women), with a mean age 73.3 years that could ambulate at least six meters with or without a device for help. Twenty seven subjects had a transtibial and five subjects had a transfemoral amputation with a mean time of 3.7 years prior to the study. Subjects performed the TUG test on a 46cm tall chair, the Sickness Impact Profile (SIP68) and Groningen Activity Restriction Scale (GARS) questionnaires to compare the correlation between the tests. The SIP68 is a 68 item questionnaire designed to measure health-related changes in behavior associated with accomplishing ADL. The GARS is a shorter 18 question survey designed to measure disability experienced during ADL. Two physiotherapists who received little training on administrating the TUG test went to the subject's homes with a standardized chair (46cm) and carpet to perform the TUG test on the same subject at different times of the same day. The TUG test is practical and doesn't require a highly trained administrator or extensive equipment. A correlation coefficient was calculated to identify the relationship between results while the Wilcoxon test and *t*-tests were used to measure the differences between groups. Spearman correlation coefficients were used to identify the relationship between the TUG test and questionnaires with level of significance set at p=.05. An intra-rater reliability coefficient of .93 and inter-rater reliability of .96, showed that the TUG test was reliable within the same and between different administrators of the test at measuring the physical capability of the subjects. The average TUG time to completion was 24.5 seconds, which was much longer than the average of 15 seconds previously reported in the literature. There was a significant correlation between the TUG test and the GARS survey, and a good correlation between the Tug test and the physical component of the SIP68 survey. The lower correlation between the TUG results and the mental component of the SIP68 survey may be attributed to the SIP68 design intended for less capable subjects. The TUG test had good interrater and intrarater reliability in this study, and proved to be an effective tool for measuring physical mobility of lower extremity amputee patients. Future studies should try to establish a "gold standard" of functional mobility by comparing the results of other tests to the TUG test.[3]

TUG and TKA Outcomes

Numerous studies have reported the results of TKA at one year post operation and later, but little effort has been made to measure the initial recovery up to six months post-TKA. Bade et al[1] investigated functional disparities between

17 healthy adults and 24 TKA patients, reported at pre-TKA, two weeks and one, three and six months post-TKA. Isometric quadriceps torque as well as passive and active range of motion were measured and subjects completed functional tests including single limb stance time, SCT, TUG, and six minute walk test. A one way repeated measures analysis of variance (ANOVA) was used to compare preoperative, one, three and six month postoperative data. Where significance was found, post hoc testing was performed using linear contrasts of pairwise comparisons. For all statistical tests, the α level was set to .05. Bade et al[1] reported TKA patients performed as well as healthy controls on the single limb stance time test. Total knee arthroplasty patients reported similar sensation of pain at two weeks pre-TKA and one month post-TKA, and at three and six months post-TKA. Before TKA, patients were 74.7% ± 42.4% slower at performing the TUG test when compared to controls, and took 49.0% longer at one month post-TKA. Patients returned to their pre-TKA times by three months, but were still 62.9% ± 35.1% slower at the TUG test than healthy controls at six months post-TKA. Patients lacked extreme knee flexion at six months post-TKA, averaging 113.4 degrees, instead of the 125 degrees which is required for most squatting activities. Total knee arthroplasty patients displayed a significant deficit in functional ability six months after surgery when compared to healthy adults, which suggests rehabilitation was not aggressive enough. Decreased quadriceps strength is a primary contributor to decreased functional performance and more aggressive early intervention may increase functional recovery in TKA patients. Studies may over estimate patient recovery of function compared to true TKA populations because so few patients actually receive rehabilitation. Only 26% of TKA patients complete outpatient therapy because it is not commonly prescribed. Previous studies used surveys to measure patient function, which may over estimate

patient recovery because TKA patients may interpret decreased pain during activity as an increase in functional ability. Future studies should look at outcomes of different therapy interventions.[1]

Following unilateral TKA, patients have been reported to have unequal strength in their lower extremities, and therefore, simultaneous bilateral TKA may increase long term functional outcomes by replacing the joint surfaces and decreasing pain in both limbs. Zeni and Snyder-Mackler[2] collected self-reported data from the Knee outcome Score Activities of Daily Living Scale (KOS) and Medical Outcomes Survey Short Form 36 Physical Component Summary (PCS) and functional data from the Timed up and Go test (TUG) and Stair climb test (SCT). Data were collected prior to surgery and at one and two years post-TKA for both unilateral (n=15) and simultaneous bilateral (n=15) patients, while control subjects (n=21) data were collected initially and at a two year follow up. All bilateral TKA-patients were diagnosed with end stage OA in both knees prior to TKA. The KOS and the PCS tests were used to record patient perception of their functional ability. A repeated measure ANOVA was used to compare test results and independent *t*-tests were used to find the difference between groups at each time interval. The bilateral pre-TKA group TUG time to completion was 8.7 ± 1.8 seconds and decreased to 6.7 ± 1.3 s at two year follow up. The unilateral pre-TKA group TUG time to completion was 10.7 ± 3.9 seconds and decreased to 7.7 ± 2.6 seconds (= .004) at the two year follow up. No significant difference was present between bilateral and unilateral groups in patient perceived (KOS and PCS) or objective functional tests (TUG and SCT) during all time periods, but controls scored significantly better on all tests than both pre-TKA patient groups. At two years, both surgical groups showed a significant decrease in SCT and TUG test times, and only the KOS scores remained different between the two groups, with the bilateral group remaining ten percent lower than controls. No difference was observed in recovery time, level of function or ability to complete out-patient physical therapy between unilateral and simultaneous TKA patients. TKA patients who underwent unilateral TKA had a significant increase in BMI when compared to simultaneous bilateral TKA patients who showed no change in BMI. Simultaneous bilateral TKA patients display a similar recovery pattern as unilateral TKA patients, and would require less recovery time and medical expenses when compared to having two separate TKA operations.[2]

The mid and long term effects of TKA have been well documented however, the early changes in locomotion and function are not as well addressed in the literature. Ouellet and Moffet[4] compared 16 (eight men and eight women) TKA patients to healthy controls (2 groups, 18 and 21) at two months post-TKA, and compared pre-TKA data to post-TKA data. Patients completed a gait lab evaluation, SCT, TUG and six minute walk test. A Student's *t*-test was used to compare data between controls and both groups of TKA patients with a level of significance set at p=.05. Upon initial evaluation two TKA patients used the handrail during SCT while seven TKA patients used the handrail two months post-TKA, and only 12 of 16 patients could complete the SCT post TKA. Total knee arthroplasty patients took 31% and 69% longer to complete the SCT when compared to healthy controls at pre-TKA and post-TKA data collections respectively. Compared to controls, TKA patients took 21% and 58% longer to complete the TUG test at pre-TKA and two months post-TKA respectively. During the six minute walk test TKA patients initially walked 72% of the distance healthy controls achieved, while at two months post-TKA, patients walked 58% of the distance of healthy controls. The current study reported that there were significant deficits in locomotion and function of TKA patients two months after surgery. Less force was generated in the lower limbs of TKA patients when compared to healthy controls, especially about the knee. During single limb stance of gait, there was nearly zero force moments acting on the TKA patient's knee as it maintained a rigid partially flexed position. Because of the lack of force acting at the knee, the extension moment at the hip was significantly increased due to hip flexion from an anterior trunk lean which was similar to findings of patients with meniscus lesions. Patients were found to be missing the last seven degrees of knee extension, both statically and dynamically. Although the vastus lateralis muscle was found to be over active in the knee during single limb stance there was no knee extension moment found to match the muscle activity. Patients displayed an increased double limb stance time and a decreased single limb stance time during walking when compared to healthy controls. The deficits observed during walking and functional tests for post-TKA patients seem to be most significantly associated with walking speed and stair climbing speed, and TKA patients displayed similar abnormalities during SCT as seen with walking. Patient deficits were worse at two months post-TKA than they were at pre-TKA, as walking speed was 20% slower, stair climbing took 29% longer, TUG time to completion was 30% longer and patients covered 19% less distance during the six minute walk test. These deficits show that TKA patients require increased rehabilitation and follow up care because they still have not recovered to the level of function that justified TKA.[4]

Elderly patients commonly experience decreased strength and increased fall related injuries, however there is no agreement of which tests properly measure a patient's functional ability. Runge and Hunter[8] propose the following tests: self-selected gait velocity test, chair rise test (timed 5 chair rises), tandem standing, tandem walking, TUG, and a clinical gait analysis focused on regularity of steps; as a means of qualifying the condition of a patients functional ability or to track their progress after intervention. Timed ambulation and functional tests can be clinically valuable however there is no direct conversion to scientific measurements of power or force. A recently developed force plate (Leonardo system) allows for a measurement of ground reaction force (GRF) over time, acceleration and vertical changes in center of gravity (COG) of the patient, a process known as "mechanography". A common use of mechanography is measuring peak exertion double legged jump to analyze the different phases of a jump. Combining mechanography and clinical locomotor tests may reveal a highly reproducible and objective method of measuring a patient's functional ability and variables that describe a threat of falling. Future studies should investigate GRF with different exercises focusing on the characteristics of the forces the body exerts on the ground.[8]

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