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Quadriceps Strength and the Time Course of Functional Recovery After Total Knee Arthroplasty

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Study Design: Prospective study with repeated measures.
Objectives: The overall goal of this investigation was to describe the time course of recovery of impairments and function after total knee arthroplasty (TKA), as well as to provide direction for rehabilitation efforts. We hypothesized that quadriceps strength would be more strongly correlated with functional performance than knee flexion range of motion (ROM) or pain at all time periods studied before and after TKA.
Background: TKA is a very common surgery, but very little is known regarding the influence of impairments on functional limitations in this population.
Methods and Measures: Forty subjects who underwent unilateral TKA followed by rehabilitation, including 6 weeks of outpatient physical therapy, were studied. Testing occurred at 5 time periods: preoperatively, and at 1, 2, 3, and 6 months after surgery. Test measures included quadriceps strength, knee ROM, timed up-and-go test, timed stair-climbing test, bodily pain, and general health and knee function questionnaires.
Results: Subjects experienced significant worsening of knee ROM, quadriceps strength, and performance on functional tests 1 month after surgery. Quadriceps strength went through the greatest decline of all the physical measures assessed and never matched the strength of the uninvolved limb. All measures underwent significant improvements following the 1-month test. Quadriceps strength was the most highly correlated measure associated with functional performance at all testing sessions.
Conclusions: Functional measures underwent an expected decline early after TKA, but recovery was more rapid than anticipated and long-term outcomes were better than previously reported in the literature. The high correlation between quadriceps strength and functional performance suggests that improved postoperative quadriceps strengthening could be important to enhance the potential benefits of TKA. *J Orthop Sports Phys Ther 2005;35:424-436.*

Key Words: *disability, muscle, outcome, replacement*

Osteoarthritis (OA) is the largest source of physical disability in the United States,[30] and the joint most commonly affected by OA is the knee.[15] Total knee arthroplasty (TKA) is frequently implemented as a treatment for knee OA when more conservative options have been attempted and have failed to relieve disabling symptoms.[40] The incidence of TKA has been steadily rising and is predicted to result in a rate of nearly half a million surgeries performed annually in the United States by the year 2030.[1] Despite a rise in utilization of TKA, very little is known regarding the influence of residual impairment on functional limitations in people with knee OA after TKA.

The time course for change in physical function after TKA, as measured by self-report questionnaire, is fairly well known. Function worsens substantially from the preoperative condition in the first postoperative month.[17] By the third postoperative month, scores on self-report questionnaires usually surpass preoperative values.[14] The majority of improvement in questionnaire scores is achieved by 6 months after TKA, showing a marked improvement from the preoperative condition.[14,29] Al-

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though functional questionnaire scores are substantially improved, they typically remain below age-matched population norms in long-term assessments.[3,16,18,35] Scores usually level off 6 months after TKA, with incremental increases over the next 1 to 2 years,[28,46] followed by a slow and steady decline over time, even in those patients without implant-related problems. Functional decline is associated with greater assistive-device use and diminished stair-climbing and walking ability.[46]

Performance-based functional assessments are rarely performed, but the results from these tests reveal that recovery of function to preoperative levels takes longer,[42] as compared to questionnaire scores, and functional performance of TKA cohorts never approach age-matched population norms.[39,64] The extent of deficits can be dramatic. For example, at 12 months after surgery, patients with TKA perform stair climbing at approximately half the speed of healthy age-matched groups.[64] Physically demanding tasks, such as stair climbing, squatting, gardening, and heavy domestic duties, are typically associated with greater functional limitations and less improvement after surgery relative to walking tasks, which are typically less demanding.[25,29,67] The residual disability following TKA has a large potential for societal impact, as hundreds of thousands of people undergo TKA each year.

The use of rehabilitation services to influence outcome is perhaps the most understudied aspect of the perioperative management of patients with TKA.[1] Costs associated with TKA are high and recent efforts have been made to minimize postoperative interventions. The average hospital stay has decreased substantially with an average length of stay of 4 days.[1,21] The potential benefit of outpatient physical therapy for patients after TKA has recently been contested in the literature. Some investigators have suggested that an intensive and prolonged rehabilitation intervention would accelerate recovery and improve overall functional outcome,[39,41,53,62] while other literature has questioned the efficacy of outpatient therapy after TKA.[44]

To better direct potential rehabilitative care, an improved understanding of how postoperative impairments influence functional ability is necessary. While gender, age, socioeconomic factors, and social support can have some influence on functional outcomes,[17,26,64] these factors are not mutable with postoperative care. Three of the most common modifiable impairments included in a clinical exam that represent alterable factors with postoperative treatment are pain, knee range of motion (ROM), and quadriceps strength. For the vast majority of patients, TKA provides considerable relief of knee pain and reductions in knee pain contribute to a large portion of the improvements in self-assessment health questionnaires.[25,29,59] Recent studies report that average knee flexion ROM after TKA ranges from 105° to 113°.[2,19,29,38] This ROM should provide adequate mobility to perform the majority of tasks of daily living.[49]

Changes in quadriceps strength after TKA are not nearly as well studied as changes in knee pain and ROM. A shortage of information regarding quadriceps weakness is surprising, as it is a hallmark impairment in knee OA.[9,54,55] The disability associated with knee OA has been linked to many factors, but weakness of the quadriceps muscle is considered one of the single most important predictors of disability.[37] Surgical procedures used in TKA involve trauma to the extensor mechanism and preoperative quadriceps weakness is dramatically compounded in early postoperative assessments.[62] In fact, substantial residual quadriceps weakness has been found years after surgery.[8,23,53] Enduring weakness in the quadriceps muscle appears to be a prime factor related to residual postoperative disability.

An increasing incidence of knee OA and greater utilization of TKA stresses the need for a better understanding of how postoperative care can influence the disability associated with knee OA. The overall goal of this investigation is to describe the time course of recovery of impairments and function, as well as to provide direction to rehabilitation efforts designed to improve function for individuals with TKA. We hypothesized that (1) quadriceps strength would be more strongly correlated with functional performance than knee flexion ROM or pain at all time periods studied before and after TKA, and (2) patients with stronger quadriceps muscles would have superior functional outcomes to those with weaker quadriceps.

METHODS

Subjects

Forty subjects (22 males, 18 females) who were scheduled for unilateral TKA for OA were recruited from an experienced group of local orthopaedic surgeons. A tricompartmental, cemented TKA with a medial parapatellar surgical approach was utilized. Patients were included in the study on a consecutive basis and are part of an ongoing clinical trial of rehabilitation after TKA. Potential subjects were excluded from the study if they had musculoskeletal involvement other than unilateral TKA limiting their function or if they were diagnosed with uncontrolled blood pressure, diabetes mellitus, neoplasms, neurological disorders, or a body mass index (mass in kg/height in m^2) of greater than 40 (morbidly obese). The uninvolved knee was not screened for radiographic arthritic changes but, if patients had an average knee pain greater than 4 out of 10 on a verbal analog scale or planned to have surgery on

TABLE 1. Outpatient rehabilitation program

Range of motion	• Exercise bike (10-15 minutes), started with forward and backward pedaling with no resistance until enough ROM for full revolution; progression: lower seat height to produce a stretch with each revolution • Active assistive ROM for knee flexion, sitting or supine, using other leg to assist • Knee extension stretch with manual pressure (in clinic) or weights (at home) • Patellar mobilizations: 3 sets of 30 reps superior/inferior; medial/lateral as necessary
Strengthening	• Quad sets, straight leg raises (with full knee extension), hip abduction (side lying), standing hamstring curls, seated knee extension, standing terminal knee extension from 45°-0°, step-ups (5- to 15-cm block), wall slides to 45° knee flexion; 1-3 sets of 10 reps for all strengthening exercises • Criteria for progression: exercises are to be progressed (eg, weights, step height, etc) once the patient can complete the exercise correctly and feels maximally fatigued at the end of each set • Progression: 0.5- to 1.0-kg weights added to exercises, step-downs (5- to 15-cm block), front lunges, and wall slides towards 90° knee flexion
Pain and swelling control	• Ice and compression as needed
Incision mobility	• Soft tissue mobilization until incision moves freely over subcutaneous tissue
Functional activities	• Ambulation training with assistive device as appropriate with emphasis on heel strike, push-off at toe-off, and normal knee joint excursions • Emphasis on heel strike, push-off at toe-off, and normal knee joint excursions when able to walk without assistive device • Stair ascending and descending step-over-step when patient has sufficient concentric and eccentric quadriceps strength
Monitoring vital signs	• Blood pressure and heart rate are monitored at initial evaluation and as appropriate

Abbreviations: ROM, range of motion; reps, repetitions.

their uninvolved knee within a year, they were excluded from the study. Subjects were of an average age (±SD) of 64 ± 9 years (range, 48-80 years), an average (±SD) height of 1.72 ± 0.09 m (range, 1.52-1.88 m), average (±SD) body mass of 93 ± 14 kg (range, 59-128 kg), and an average (±SD) body mass index of 31.4 ± 3.7 kg/m^2 (range, 25.4-39.6 kg/m^2).

All subjects agreed to participate in the study and signed written informed consent forms approved by the Human Subjects Review Board at the University of Delaware prior to commencement of the study.

Postsurgical Rehabilitation

Following the TKA, subjects underwent 3 days of inpatient physical therapy, followed by 2 to 3 weeks of home physical therapy visits. Inpatient care followed a standard protocol of training to improve independence in activities of daily living (ADL), light isometric and active assisted exercises (eg, heel slides, quadriceps isometrics, hip extensor isometrics, ankle pumps) to initiate strengthening and prevent secondary complications, such as deep vein thrombosis, and stretching to improve knee ROM. Home physical therapy consisted of continued isometric exercises, active ROM exercises, training in ADL, and walking (weight bearing as tolerated) with an assistive device.

At approximately 4 weeks after surgery, subjects started 6 weeks (2 to 3 times per week; mean, 17 visits) of outpatient rehabilitation at the University of Delaware Physical Therapy Clinic. Outpatient physical therapy included interventions designed to control pain and swelling, stretching and patellar mobilizations to improve knee ROM, progressive high-intensity volitional exercises to increase lower extremity strength, and training to improve functional ability (Table 1).[61] Each patient was treated based on individual impairments, according to the guidelines for intervention suggested in Table 1. Subjects underwent testing at 5 different times: (1) approximately 2 weeks preoperatively, (2) 1 month postoperatively, (3) 2 months postoperatively, (4) 3 months postoperatively, and (5) 6 months postoperatively.

Quadriceps Strength Assessment

Quadriceps strength was measured isometrically using a burst superimposition technique.[62] In brief, subjects were seated in an electromechanical dynamometer (Kin-Com 500 H; Chattecx Corporation, Harrison, TN) with the hip flexed to 90° and the knee flexed to 75°. Three subjects were not able to achieve 75° of flexion at the 1-month test session and were tested at 60° of flexion at each subsequent testing session. The axis of the dynamometer motor was adjusted to match the axis of rotation of the tibiofemoral joint, while the distal edge of the shin attachment was placed approximately 5 cm proximal to the lateral malleolus of the test leg. Both waist and trunk straps were used for stabilization. The positioning of the dynamometer was recorded at the initial testing of each subject and an identical setup was used for each subsequent strength assessment. Subjects performed 2 submaximal contractions and 1 maximal voluntary isometric contraction lasting 2 to 3 seconds, to familiarize themselves with the testing procedure.

After 5 minutes of rest, subjects were instructed to maximally contract the quadriceps for approximately 3 seconds. Verbal encouragement and visual force output were used to facilitate maximal volitional force production. Approximately 2 seconds into the contraction, an electrical stimulator (Grass S8800 with a Grass model SIU8T stimulus isolation unit; Grass Instruments, Braintree, MA) delivered a supramaximal electrical stimulus to the quadriceps muscle. The stimulator was set at 135 V to deliver a burst of 10 monophasic rectangular pulses at a rate of 100 pulses per second, with each pulse length set at 100 milliseconds. If maximum volitional force output was achieved and no augmentation of force was observed with the application of the stimulation, testing was concluded for that limb. If augmentation was present during the application of the electrical stimulus, the test was repeated for a maximum of 3 trials. Five minutes of rest was provided between test contractions. The trial with the highest volitional force production was used for analysis. Burst superimposition testing was performed on the uninvolved limb first followed by the involved leg. The determination of isometric quadriceps strength is highly reliable when using a burst superimposition technique in repeated testing of subjects without knee pathology (ICC = 0.98).[56]

Pain Assessment

The influence of subject's pain on functional tasks was measured using the bodily pain subscore from the SF-36 Health Survey. This score was derived from 2 items (11-level scale) from the questionnaire: (1) asked the subject's intensity of bodily pain or discomfort and (2) measured the extent to which pain interfered with the patient's normal work (including both work outside the home and housework). Scores were transformed to a 0- to 100-point scale where 100 represented the best score possible. The bodily pain score was chosen because it is commonly used in studies involving patients with TKA[14] and has potential to provide a wide range of pain scores; the score represents both the intensity of pain and how pain influences daily activities. Bodily pain has a good test-retest reliability coefficient of 0.85 within the general population.[66]

Knee ROM Measurement

Knee ROM was measured using a standard long-arm goniometer. The axis of the goniometer was aligned with the center of the lateral epicondyle of the femur. The distal arm of the goniometer was aligned with the lateral malleolus and the proximal arm was aligned with the greater trochanter of the femur. To determine knee flexion ROM, patients were positioned in supine and asked to actively slide the heel towards the buttocks. The angle of maximal active knee flexion was measured. Knee extension ROM was also assessed while in supine, with the patient's heel propped off the treatment table on a 10-cm-high wooden block. Subjects were asked to activate the quadriceps, extending the knee. The angle of maximal extension was recorded. Positive values were used to indicate a position of flexion at maximal knee straightening and negative numbers were used to represent positions in knee hyperextension. Examination of knee ROM in patients with knee OA has adequate reliability with a coefficient of 0.96 for flexion and 0.81 for extension.[12]

Functional Testing

Timed Up-and-Go Test (TUG) The TUG measures the time it takes a patient to rise from an armed chair (seat height of 46 cm), walk 3 m, turn, and return to sitting in the same chair. Subjects were instructed to walk as quickly as they felt safe and comfortable. The use of the arms of the chair was permitted to stand up and sit down. The TUG is widely used to measure mobility in older adults. Excellent test-retest reliability ($ICC_{2,1}$ = 0.97) was reported in a group of community-dwelling elderly people (age range, 61-89 years).[58]

Stair Climbing Test (SCT) The SCT measures the time it takes a subject to ascend and descend a flight of 12 18-cm-high steps with a depth of 28 cm. Subjects were asked to complete the test as quickly as they felt safe and comfortable and 1 handrail was allowed if required. Rejeski et al[45] described a similar functional performance test that used only 5 steps. They found that the stair-climbing task has an excellent test-retest reliability (coefficient of 0.93).[45]

For both the TUG and SCT, 1 practice trial was performed and the average of 2 subsequent trials was used for analysis. Assistive devices were allowed only if the subject was unsafe or could not complete the test without the assistance of a cane or walker.

Self-Assessment Questionnaires

Short Form-36 Health Questionnaire (SF-36) Health status questionnaires were completed by all subjects prior to the functional testing and strength assessment. The Medical Outcomes Survey Short Form 36 (SF-36) was used as a general health outcome measurement. The SF-36 is a commonly used generic health measure and has been repeatedly included in assessments of patients with TKA and knee OA.[10,14,66]

This questionnaire covers 8 domains of health: physical function, bodily pain, role physical, general health, vitality, role emotional, social function, and mental health. The physical component summary (PCS) and mental component summary (MCS) represent a composite score for the respective physical and mental domains of the questionnaire. The PCS and MCS scores are norm-based scores where an average of 50 and a standard deviation of 10 represent the average of general US population.[66] The SF-36 was utilized in this study as it is reliable, internally consistent, and easy to administer.[10,65]

The extent of general physical limitations was assessed using the physical functioning subscale of the SF-36. This scale captures both the presence and extent of physical limitations using a 3-level response continuum from 10 items designated to the physical functioning domain of health on the 36-item questionnaire.[66,65] Scores range from 0 to 100, with higher score representing better level of physical functioning.

Knee Outcome Survey—Activities of Daily Living Scale (KOS-ADLS) The KOS-ADLS is a 14-item questionnaire with items designated to assess how knee symptoms and knee condition affect the ability to perform daily functions.[24] A maximum of 5 points is allotted to each item. Scores are presented as a percentage of the maximal score, with 100% representing full, perceived knee function for activities of daily living. This questionnaire has been shown to have excellent psychometric properties, including good responsiveness to treatment for patients with disorders of the knee.[24,36]

Data Management and Statistical Analysis

Maximal isometric force during quadriceps strength testing was normalized to body mass index. Differences in the means over time of the strength measures, questionnaire scores, and performance-based functional tests were analyzed using a repeated-measures analysis of variance (ANOVA). An alpha level of .05 was chosen for determination of significance. If significance was achieved in the repeated-measures assessment, then paired t tests were performed to assess if there were differences in means between testing sessions. Paired t tests were also used to assess the difference between limbs in quadriceps strength at the preoperative and 6-month assessments. A Bonferroni post hoc correction for multiple comparisons was used to adjust the alpha level to determine significance for the paired t tests. There were no more than 5 comparisons made for each variable over time for an adjusted alpha level of .01 (original alpha .05 for 5 comparisons). The relationships between the physical measures (involved and uninvolved quadriceps strength, bodily pain, and involved knee flexion ROM) and the time taken to complete the functional tests were assessed for each given testing session using Pearson correlation coefficients.

Percent change in quadriceps strength, bodily pain, ROM, and questionnaire scores were determined by subtracting the preoperative value from the 6-month value and dividing that difference by the preoperative value. As lower times on the TUG and SCT represent better performance, we altered the determination of percent change for these tests so that a positive value for percent change would represent improvement for all measures. Therefore, percent change in the TUG and SCT were determined by subtracting the 6-month value from the preoperative value and dividing that difference by the preoperative value.

RESULTS

All physical measures, questionnaire scores, and performance-based functional tests demonstrated a main effect for change over time ($P<.001$) (Tables 2 and 3), except the uninvolved quadriceps strength (P = .354) (Figure 1). Involved quadriceps strength

TABLE 2. Knee range of motion (deg), quadriceps strength (N per body mass index), and performance-based functional assessments at all testing sessions and the Knee Outcome Survey scores. Values represent mean ± SD (range).

Test Period	Max Involved Knee Ext*	Max Involved Knee Flex	Involved Quad MVIC	Uninvolved Quad MVIC	TUG	SCT	KOS-ADLS
Pretesting	3 ± 4	119 ± 12	18 ± 8	23 ± 10	9.6 ± 2.4	20.0 ± 9.1	53% ± 15%
	(–5-15)	(95-142)	(3-38)	(8-53)	(5.5-15.8)	(8.2-55.7)	(21%-91%)
1 mo	5 ± 5	94 ± 15	7 ± 4	22 ± 9	12.0 ± 4.1	26.2 ± 9.7	54% ± 14%
	(–3-18)	(57-122)	(3-24)	(3-42)	(7.0-29.9)	(10.6-57.5)	(30%-80%)
2 mo	3 ± 4	109 ± 12	11 ± 5	23 ± 9	9.1 ± 2.4	16.7 ± 5.8	69% ± 13%
	(–2-15)	(83-130)	(4-26)	(7-46)	(5.5-20.8)	(8.2-30.6)	(40%-97%)
3 mo	2 ± 3	114 ± 11	15 ± 6	23 ± 10	7.9 ± 1.5	12.8 ± 3.6	78% ± 12%
	(–4-10)	(80-132)	(6-31)	(9-47)	(5.3-12.5)	(6.9-24.7)	(53%-100%)
6 mo	1 ± 2	116 ± 11	18 ± 8	23 ± 10	7.6 ± 1.6	11.9 ± 3.2	83% ± 8.0%
	(–4-6)	(84-135)	(7-34)	(5-44)	(5.0-11.2)	(6.7-19.3)	(66%-100%)

Abbreviations: Ext, extension; Flex, flexion; KOS-ADLS, Knee Outcome Survey Activities of Daily Living Scale; MVIC, maximal voluntary isometric contraction (N per body mass index); SCT, stair-climbing test; TUG, timed up-and-go test.
* Positive numbers indicate positions in flexion and negative numbers indicate positions in hyperextension.

TABLE 3. Comparison between Short Form 36 (SF-36) scores over time in other studies of patients with total knee arthroplasty and the scores of the current study. Values given in the table represent means (SD).

	Pretest	1 mo	2 mo	3 mo	6 mo
Physical Component Summary (PCS)					
Hartley[20]	34.3				40.8
Moffet[39]			34.1 (8.1)	4 mo, 38.5 (9.8)	41 (9.2)
Mahomed[33]	30 (8)				40 (9)
Beaupre[5]	30 (6)			35 (8.0)	37 (9)
Jones[25]	25.9 (7.5)				34.6 (10.1)
Bert[7]	29 (7)				12 mo, 41 (11)
Mizner	34.2 (7.6)	28.7 (5.4)	36.8 (6.6)	43.0 (7.1)	47.1 (6.9)
SF-36 Physical Function Score (PF)					
van Essen[63]	31.3			40.2	
Brazier[10]	21				34.5
Dawson[13]	18.5				42.6
Lingard[32]	27.4				12 mo, 53.8
Heck[22]	24.2				47.6
Sharma[51]	33.2 (19.0)			56.7 (22.4)	
Moffet[39]				4 mo, 57.8 (23.7)	60.3 (21.3)
Fitzgerald[17]	37.7 (21.6)				
Salmon[50]	20	22			35
Mahomed[33]	28 (22)				56 (27)
Beaupre[5]	31.5 (18)			46 (21)	50 (21)
Jones[25]	21 (18.1)				44.8 (25.3)
Bachmeier[3]	25.2 (17.2)			38.6 (19.9)	47.9 (22.4)
Shields[52]	32.1			58.7	63.3
Bayley[4]	33				53
Ritter[46]	15.9				17.6
Kiebzak[27]	28			47	51
Mizner	47.1 (19.3)	32.0 (17.5)	52.4 (17.1)	70.4 (15.9)	75.5 (18.9)
SF-36 Bodily Pain Score (BP)					
van Essen[63]	32.8			51.6	
Bennett[6]	37.9			45.9	
Sharma[51]	33.1 (12.0)			48.6 (21.8)	
Brazier[10]	35.2				51.8
Dawson[13]	31.9				59
Lingard[32]	35				12 mo, 59.7
Heck[22]	38				62.1
Moffet[39]				4 mo, 58.1 (21.1)	63.4 (22.5)
Fitzgerald[17]	38.4 (18.7)	49 (22)			71 (22)
Salmon[50]	27	40			48.5
Mahomed[33]	42 (24)				61 (25)
Beaupre[5]	39.5 (14.5)			55.5 (19.5)	58 (18.5)
Jones[25]	30.8 (17.6)				53.4 (22.8)
Bachmeier[3]	33 (18.6)			48.5 (19.4)	54.1 (21.9)
Shields[52]	39.3			62.3	70.5
Ritter[46]	4.8				8.6
Kiebzak[27]	32			48	
Mizner	43.8 (19.5)	35.5 (18.2)	55.4 (17.6)	65.8 (16.2)	71.4 (18.7)

decreased by 62% from the preoperative value at the 1-month postoperative test ($P<.001$) (Figure 1). Significant improvements occurred in the involved quadriceps strength with each subsequent assessment ($P<.001$). There were no significant differences between involved quadriceps strength at the preoperative and the 6-month tests ($P = .506$). The quadriceps strength of the involved knee was less than the uninvolved knee prior to surgery ($P = .002$) and at the 6-month assessment ($P<.001$).

Bodily pain score did not differ significantly from the preoperative testing session by the first postoperative test ($P = .016$, Figure 2). There was a significant improvement in bodily pain scores (less pain) between each testing session from the 1-month test to the 3-month test ($P<.001$). There was no significant

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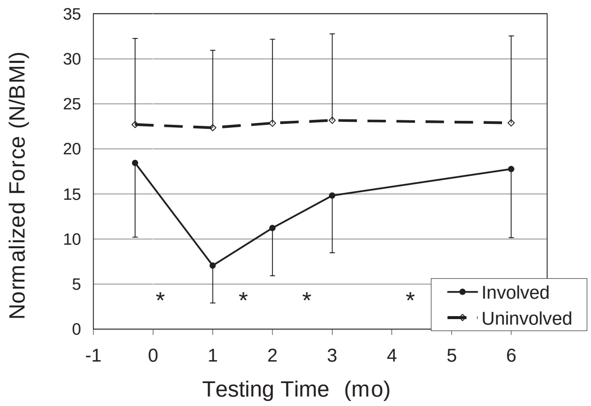

FIGURE 1. Line graph of the mean isometric quadriceps strength for the involved and uninvolved limbs at all testing sessions. The first data point is presurgery, the other data points are postsurgery. Strength is shown as normalized knee extension force (N) to body mass index (body mass in kg/height in m^2). Error bars represent standard deviations at each testing session. There were no statistically significant differences between the involved quadriceps strength at the preoperative and 6-month tests. Involved quadriceps strength was less than the uninvolved prior to surgery and at the 6-month assessment.
*Significant changes between testing sessions.

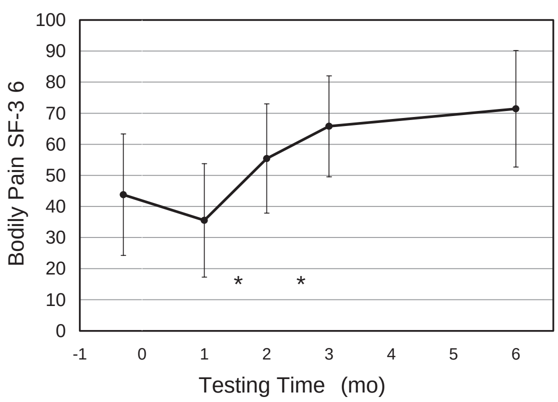

FIGURE 2. Line graph of the mean pain scores at each testing session assessed by the bodily pain subset of the SF-36 questionnaire. The first data point is presurgery; the other data points are postsurgery. Scores can range from 0 to 100, with 100 being the best score. An increase in score represents less bodily pain and a reduced influence of bodily pain on physical function. Error bars represent standard deviations at each testing session. Bodily pain score improved 63% from the preoperative condition at the final follow-up.
*Significant changes between testing sessions.

change between the 3- and 6-month tests ($P = .044$). Bodily pain scores improved 63% from the preoperative condition at the final follow-up.

Knee flexion ROM declined 21% from the preoperative value by the 1-month assessment ($P < .001$) (Figure 3). Improvements in flexion ROM occurred with each subsequent assessment ($P < .001$, except between the 3-month and 6-month assessments, where $P = .004$). Preoperative involved knee flexion ROM did not significantly differ from the last assessment ($P = .242$).

Subjects lost 2° of knee extension ROM between the preoperative and 1-month test ($P = .006$) (Figure 3). By the 6-month test, the average knee extension ROM was 2° better than before surgery ($P = .001$).

Time to complete the TUG and SCT increased significantly ($P < .001$) at the 1-month postoperative assessment (Figure 4). Performance on both tests improved significantly with each subsequent testing period up to the 3-month test ($P < .001$). There was no difference between the mean times on the TUG test between the 3-month and 6-month tests ($P = .023$), but the SCT test did continue to improve between the last 2 testing sessions ($P = .002$). Preoperative testing times did not differ significantly from the times of the 2-month testing session for the TUG ($P = .070$), but the SCT had improved ($P = .006$). There was a 21% improvement in the TUG and a 40% improvement in the SCT from the preoperative test to 6 months postsurgery.

While the scores on the KOS-ADLS did not significantly change between the preoperative and 1-month assessments ($P = .673$), the scores on the SF-36 PCS significantly worsened by the 1-month assessment ($P < .001$) (Figures 5 and 6). Improvements occurred in both scores between each subsequent testing session ($P < .001$, except for the KOS between 3 months and 6 months postsurgery [$P = .002$]). There was a 38% improvement in SF-36 PCS score and 57% improvement in the KOS-ADLS 6 months postsurgery compared to before surgery.

The scores on the physical function subset of the SF-36 worsened by the 1-month assessment ($P < .001$), but the score improved each month for the following

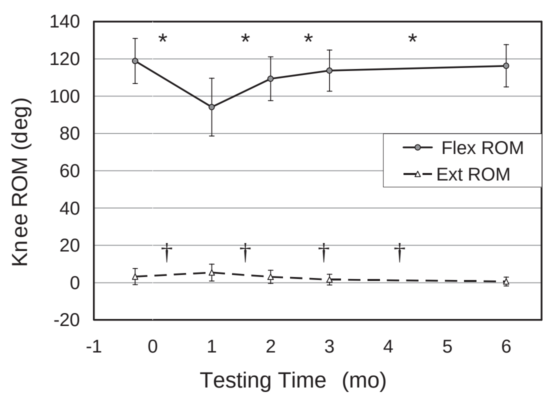

FIGURE 3. Line graph of the mean maximal knee flexion and extension range of motion (ROM) measurements for the involved knee at each testing session. The first data point is presurgery, the other data points are postsurgery. Error bars represent standard deviations at each testing session. Preoperative knee flexion ROM did not differ significantly from the last assessment, while the average 6-month knee extension ROM was 2° better than before surgery.
*Significant changes between testing sessions for knee flexion ROM.
†Significant changes between testing sessions for knee extension ROM.

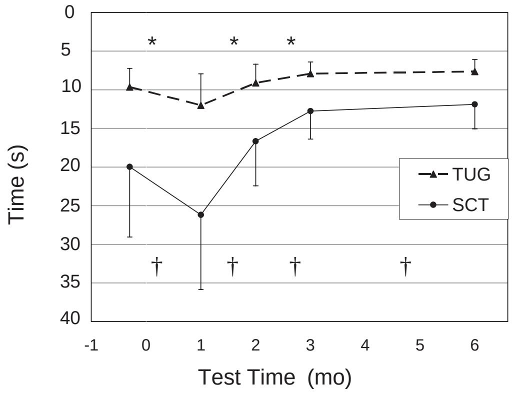

FIGURE 4. Line graph of the mean time to complete the timed up-and-go test (TUG) and the stair-climbing test (SCT) at each testing session. The first data point is presurgery; the other data points are postsurgery. Mean times are given in seconds and the vertical axis is oriented downwards so that improvement in test performance (ie, less time) would follow the same pattern as the rest of the measures taken in this study. Error bars represent standard deviations at each testing session. Preoperative testing times did not differ significantly from the 2-month testing session for the TUG, but the SCT had improved. There was a 21% improvement in the TUG and a 40% improvement in the SCT from the preoperative test to 6-month postsurgery (*P* = .001).
*Significant changes between testing sessions for the TUG.
†Significant changes between testing sessions for the SCT.

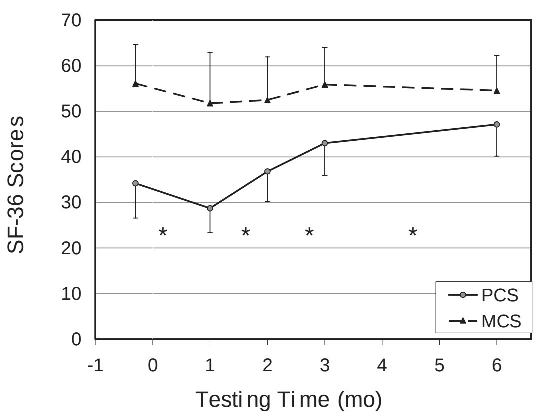

FIGURE 5. Line graph of the mean scores of the physical composite score (PCS) and mental composite score (MCS) of the SF-36 questionnaire at each testing session. Scores are normalized where 50 represents the adult US population mean, and ±10 points represent 1 standard deviation. The first data point is presurgery; the other data points are postsurgery. Error bars represent standard deviations at each testing session. There was a 38% improvement in the SF-36 PCS score 6 months postsurgery compared to before surgery.
*Significant changes between testing sessions.

2 months ($P < .001$) (Figure 7). There was no significant change in the physical function score following the 3-month test ($P = .032$). The physical function score made a 60% improvement from the preoperative test to the 6-month assessment.

Quadriceps strength in the involved and uninvolved limb at each testing session had a significant inverse correlation with the time taken to complete the corresponding TUG and SCT tests (Figures 8 and 9). The strength of correlation in the involved leg varied from –0.319 to –0.640 for the TUG ($P < .05$) and –0.338 to –0.634 for the SCT ($P < .05$). The strength of correlation in the uninvolved leg varied from –0.365 to –0.553 for the TUG and –0.365 to –0.666 for the SCT ($P < .05$). Knee flexion ROM exhibited a significant inverse correlation with the TUG ($r = –0.388$, $P < .05$) and SCT ($r = –0.354$, $P < .05$) at the 1 month and 2 month tests only (TUG, $r = –0.355$; SCT, $r = –0.321$; $P < .05$).

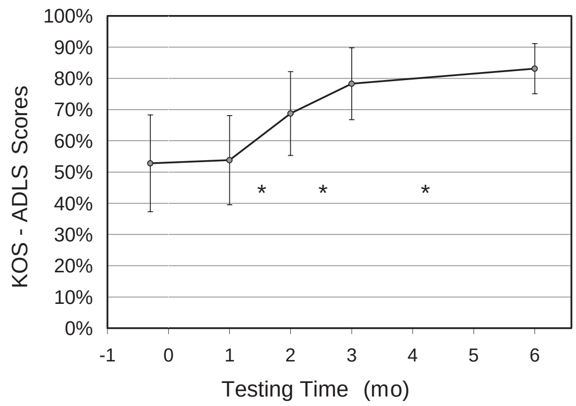

FIGURE 6. Line graph of the mean scores of the Knee Outcome Survey Activities of Daily Living Score (KOS-ADLS) at each testing session. The first data point is presurgery; the other data points are postsurgery. A score of 100% represents the highest possible score. Error bars represent standard deviations at each testing session. There was a 57% improvement in the KOS-ADLS score 6 months postsurgery compared to before surgery.
*Significant changes between testing sessions.

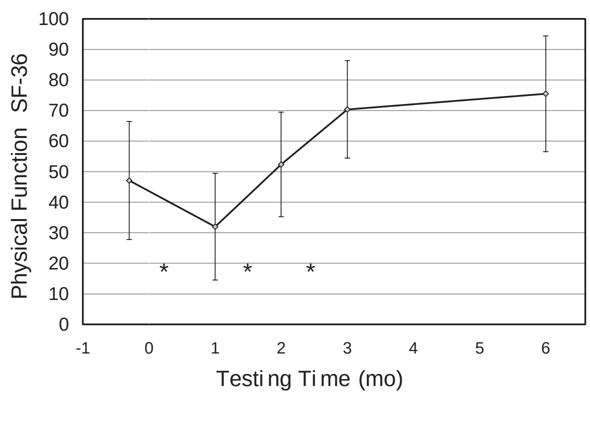

FIGURE 7. Line graph of the mean scores of the physical function subscale of the SF-36 questionnaire at each testing session. The first data point is presurgery; the other data points are postsurgery. Higher scores represent better values with a maximum score of 100. Error bars represent standard deviations at each testing session. There was a 60% improvement in the physical function subscale score from the preoperative test to the 6-month assessment.
*Significant changes between testing sessions.

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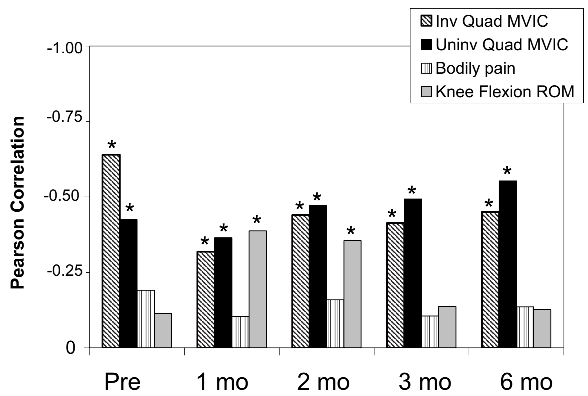

FIGURE 8. Bar graph representing the strength of relationship between the measures of strength, pain, and knee range of motion (ROM) and the time taken to complete the timed up-and-go test (TUG) at each testing session. The first data point is presurgery; the other data points are postsurgery. The vertical axis is oriented in reverse so a relationship with improvement in the physical measure (eg, more strength) would relate to improvement in test performance (ie, less time).
*$P<.05$.

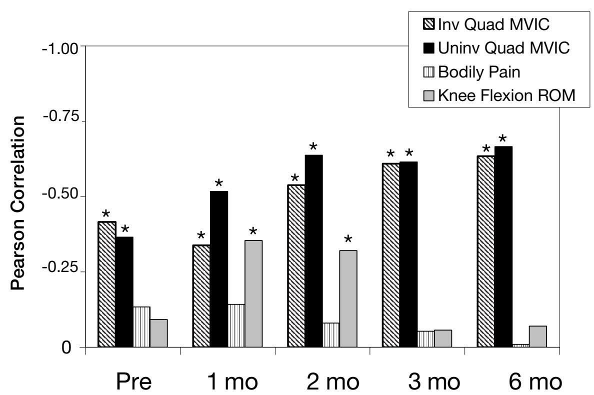

FIGURE 9. Bar graph representing the strength of relationship between the measures of strength, pain, and knee range of motion (ROM) and the time taken to complete the stair-climbing test (SCT) at each testing session. The first data point is presurgery; the other data points are postsurgery. The vertical axis is oriented in reverse so a relationship with improvement in the physical measure (eg, more strength) would relate to improvement in test performance (ie, less time).
*$P<.05$.

Bodily pain score was not significantly correlated to functional performance in either the TUG or the SCT at any testing point (r values no stronger than -0.191, $P \geq .237$).

DISCUSSION

Patients who underwent TKA had an expected worsening of ROM, quadriceps strength, and function 1 month after surgery. All measures recovered significantly over the first half of the postoperative year, including noteworthy improvements in functional ability from the preoperative condition. Functional recovery was more rapid than expected and long-term outcomes surpassed the best results of previous reports in the literature.[5,14,39,41,64,66] Quadriceps strength went through the greatest decline of all the physical measures and was the most highly correlated impairment with functional performance.

Quadriceps weakness was a primary impairment in individuals with TKA. Prior to surgery, the quadriceps strength in both limbs was weak in relation to similarly aged comparison subjects (n = 76; average ± SD age, 65 ± 10 years; 55% male) previously tested in our laboratory (mean normalized force, 28.7 ± 10 N/BMI).[31,57,60] A significant difference in strength between the involved and uninvolved leg was expected, as the exclusion criteria was designed for individuals planning only a unilateral surgical intervention. The dramatic worsening of the preoperative weakness in the involved quadriceps is a consistent finding with previous work.[43,48,62] Additionally, quadriceps strength underwent the greatest decrement from the preoperative value of all the impairments assessed in this study.

As hypothesized, quadriceps strength was correlated with functional performance at all testing sessions. A weaker relationship was observed between strength and the TUG as compared to the SCT; but this is expected, as the SCT is a more physically demanding activity. Preoperatively, the amount of quadriceps strength in the involved leg was more highly correlated to functional performance than the strength of the uninvolved leg. Early after surgery, there was a decrease in the correlation between the involved quadriceps strength and the functional tests, with a corresponding increase in the correlation between the uninvolved limb's strength and functional performance. This shift in relationships was especially evident in the SCT. The acute strength loss in the involved quadriceps places an emphasis on the uninvolved leg's quadriceps strength as an important factor in functional performance. As involved strength improved, there was a concomitant improvement in the relationship between involved quadriceps strength and function.

While pain is often the main impetus to undergo TKA,[34] bodily pain did not correlate with performance on the TUG or SCT at any testing point in this study. These findings do have potential limitations as the bodily pain measure does not specifically focus on knee pain and the pain associated with other conditions may have influenced our findings. The average preoperative bodily pain score is equivalent to the highest scores previously reported in literature involving subjects about to undergo TKA (Table 3).[6,13,14,17,22,27,32,47,50-52,63] Bodily pain score showed the most substantial improvement of any measure in this study, with an increase in average (±SD) score to 71.4 ± 19.0 and closely approximates the norm bodily pain for the general US population (mean ± SD, 75.2 ± 24.0).[66]

Knee ROM after TKA was only significantly correlated to the performance-based tests during the acute test sessions, which is when flexion was most restricted. The results of this study support the findings of Miner et al,[38] who reported that knee flexion ROM 1 year after TKA has a relatively low correlation (rho = 0.29), with functional assessment. Subjects in the present study achieved excellent results in ROM, surpassing the values of many other investigations of TKA outcome.[2,29,38] Our average knee flexion ROM at most of the testing sessions was above 110°, which has been defined to be adequate for the majority of activities of daily living.[49]

The average time to complete the performance-based functional tests returned to preoperative levels only 2 months after surgery. Our results are in stark contrast to the findings of Ouellet and Moffet,[41] who used the TUG and the 6-minute walk test to assess function in individuals with unilateral TKA. They reported substantial functional declines from the preoperative level 2 months postsurgery (30% greater time to complete TUG, 19% less distance in the 6-minute walk test). They advocated careful postoperative follow-up and a prolonged, intensive rehabilitation program early after TKA. Others have expressed conflicting opinions, recommending that the initiation of strengthening exercises be delayed because they can exacerbate postoperative symptoms and slow recovery of knee ROM (personal communication, physicians, February 2001 and November 2003). Our results show that the addition of progressive strengthening exercises can be applied early, with resultant functional recovery superior to that in the findings of previous literature, while preserving good pain and knee ROM outcomes.

Not only was early recuperation of this group of patients enhanced compared to the results of other literature, but the overall functional results were higher than expected. The average (±SD) time taken to complete the TUG (7.6 ± 1.6 seconds) 6 months postsurgery was similar to the average (±SD) time reported by Steffen et al[58] for healthy individuals in their sixties (8.0 ± 2.0 seconds). Walsh and colleagues[64] have used a stair-climbing assessment where subjects ascend and descend 1 flight of 10, 20-cm-tall steps at their comfortable and preferred speed. They reported an average time of 12.5 seconds in a comparison group of 40 healthy individuals (22 male; average age, 62 years) compared to an average time of 26.8 seconds for 29 individuals (16 male; average age, 61 years) at 1 year following TKA (8 bilateral). The subjects with TKA in the current investigation had comparable performance to Walsh's controls 6 months postsurgery as they completed the SCT in 11.9 ± 3.2 seconds. This study is the first to our knowledge to report functional performance outcomes in patients with TKA comparable to results of age-matched controls.

Functional outcome, as assessed with questionnaires, also exceeded the results of previous studies. A table summarizing the results of a representative sample of previous findings of research with individuals with TKA has been included as a reference to the findings in this investigation (Table 3).[4] Preoperatively, the average SF-36 PCS score was within the range of previous studies of patients awaiting TKA.[5,7,20,25,33] While there was not a significant change at 1 month postsurgery, the improvement by 6 months postsurgery was sizeable. The average (±SD) 6-month score of 47.1 ± 6.9 very closely matches the norm score (±SD) for individuals between ages 55 to 64 years (47 ± 11)[66] and is much higher than the 1-year scores reported in previous studies of individuals that have undergone TKA.[5,7,20,25,33,39] The physical function score follows a similar pattern of change as the PCS scores. Preoperatively, average physical function score was similar to previous preoperative findings, but the average physical function score at 6 months postsurgery was greater than previous findings.[5,10,13,25,32,33,39,50,63]

Improved functional ability becomes increasingly important as patients with TKA advance in age. Functional outcomes usually decline over time with a resultant increased dependence on assistive devices and diminished community functional ability.[46] Subjects with higher functional ability after surgery will have a larger functional reserve beyond what is needed for basic activities of daily living. If outpatient therapy assists in maximizing functional improvement following TKA, with a resultant higher plateau in improvement, then people with TKA may be more likely to maintain functional independence for a longer time.

Postoperative functional outcomes have been positively correlated with preoperative functional score[18,25] and the relatively high initial physical function score in this sample may explain some of the success in 6-month functional results. Our sample also has a higher proportion of males, which is not commonly found in studies involving TKA. Men who undergo TKA have been reported to have physical function scores that are significantly higher when compared to those of women,[14,17] and an interventional study with a greater percentage of males would be expected to have higher functional performance. We feel the amount of influence these factors have on the overall results is slight, as the magnitude of difference in preoperative function and gender distribution is small in relation to the difference found at the 6-month assessment.

Our patients, who underwent a course of outpatient physical therapy emphasizing progressive strengthening exercises had superior functional outcomes to those in any reported studies in the literature and matched the norms of age-matched, healthy cohorts. Several previous investigations have suggested that more rigorous exercise interventions in rehabilitation may be beneficial in addressing impaired strength and functional deficits after TKA.[11,41,53,62] The high correlation between quadriceps strength and functional performance in this study corroborate the premise that postoperative quadriceps strengthening could optimize the potential benefits of TKA as a treatment for advanced knee OA.

CONCLUSIONS

Patients who undergo TKA should expect significant declines in functional performance early after surgery. In the first month following TKA, quadriceps strength is affected more severely than other clinical measures, such as knee flexion ROM or bodily pain. In this cohort receiving outpatient therapy that included a progressive strengthening program, all outcome measures improved significantly from the 1-month postsurgery assessment, with long-term (6-month) functional outcomes, substantially exceeding preoperative functional performance and most previously published outcomes. Overall, quadriceps strength was more strongly related to functional outcomes than knee flexion ROM or bodily pain. Quadriceps strength is an important factor to consider in the functional performance of patients with TKA.

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