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The Nonoperated Knee Predicts Function 3 Years after Unilateral Total Knee Arthroplasty

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Abstract The long-term functional abilities of patients after a unilateral total knee arthroplasty (TKA) are influenced by the status of the nonoperated knee at the time of the TKA. We hypothesized that in the 3 years after TKA, the nonoperated limb would become more painful, and the quadriceps muscles would weaken; pain and strength would influence performance on functional testing by 3 years after TKA. Healthy control subjects were tested over the same time interval; we hypothesized the controls would also decline in strength and function over time. Individuals with unilateral knee pain (less than 4/10 on a verbal analog scale) were recruited preoperatively. We tested patients 1, 2, and 3 years after TKA to determine changes in strength, self-report outcome measures, and performance on a stair climbing test and the 6-minute walk test. Control subjects without osteoarthritis were tested twice, 2 years apart. The nonoperated limb of patients with TKA weakened from 1 to 2 years, and further weakened from 2 to 3 years after TKA; by 3 years after TKA, the nonoperated limb was more painful compared to the operated limb. Three years after TKA, nonoperated knee pain contributed 44% of the variability in the 6-minute walk and 33% of the variability in the stair climbing test. Patients with TKA were weaker, slower, and had lower self-report outcome measures compared with control subjects at both time intervals. Control subjects also weakened over time, yet were stable on self-report outcome measures and the 6 minute walk test. Weakening of the quadriceps muscles in all participants represents changes due to ageing; however on average the nonoperated limb weakened over time, possibly representing not only changes resulting from aging, but progression of osteoarthrosis in some patients with unilateral TKA.
Level of Evidence: Level II, prognostic study. See Guidelines for Authors for a complete description of levels of evidence.

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Each author certifies that his or her institution has approved the human protocol for this investigation, that all investigations were conducted in conformity with ethical principles of research, and that informed consent for participation in the study was obtained.
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Introduction

Unilateral total knee arthroplasty results in a marked decrease in pain and improvement in function, yet these patients remain weaker [6, 12, 19] and slower [6, 12] on tests of functional performance compared to age- and gender- matched counterparts without osteoarthritis. Lower scores on tests of physical function persist at least 1 year after surgery [19, 21, 32] with greater dysfunction during greater strength-demanding activities such as stair climbing [4, 6, 12, 18, 32] and sit-to-stand transfers [18, 31]. Tests that measure functional performance have a low correlation with perceived function when self-reported on outcome questionnaires [23]. Self-report of function improves after the TKA [7], peaks at 3 years after TKA [28], and declines thereafter.

Knee extensor weakness persists after TKA [1, 2, 6, 15, 32], with deficits up to 30% to 40% compared with age-matched control subjects [1]. Conversely, strength of the operated quadriceps before surgery was a major predictor of performance [16]; stronger quadriceps before surgery resulted in better scores on the timed up and go and stair climbing tests after surgery. Long-term functional performance after unilateral TKA is influenced by the status of the nonoperated limb at the time of the index procedure. If no-to-mild osteoarthritis is present, the likelihood of a contralateral TKA is approximately 17%; however, if moderate to severe osteoarthrosis is present, chances of a contralateral TKA rise to nearly 40% [22, 27, 29].

We hypothesized (1) the nonoperated limb would become weaker, while the operated limb would become stronger over time, and by 3 years after TKA, the nonoperated limb would be more painful than the operated limb; (2) self-report outcome measures, the six-minute walk and stair climbing test results would not change over time in patients after unilateral TKA; (3) the influence of strength and pain of both limbs on the stair climbing test and 6-minute walk at 1, 2, and 3 years after TKA; (4) healthy controls exhibit changes in strength, function, and self-report outcome measures over the same time period; (5) individuals after unilateral TKA reach a level of strength, function, and self-report outcome measures, compared to age-matched controls over the same time period.

Materials and Methods

We recruited subjects with TKA from a group of orthopaedic surgeons from the Wilmington, DE, area who perform tricompartmental, cemented TKA with a medial parapatellar surgical approach. All subjects were part of a cohort studied longitudinally [15, 24], and testing of these individuals is ongoing. All subjects were recruited consecutively within the constraints of the inclusion criteria, from 2000–2005, and had primary unilateral TKA for knee osteoarthrosis.

Potential subjects were between the ages of 50 and 85 years and were excluded if they had evidence of (1) musculoskeletal impairments other than the TKA that limit function in the lower extremity to be tested; (2) greater than 4 out of 10 pain at worst on a verbal analog scale or a planned TKA in the contralateral knee; (3) uncontrolled blood pressure; (4) diabetes mellitus; (5) neoplasms; or (6) neurologic disorders (Parkinson's disease, impaired sensation, stroke, head injury). At the time of the index procedure, no subject reported a pain score of 4 or greater in the nonoperated knee (mean, 1.3; standard deviation, 1.7) on a verbal rating scale of 0 (no pain) to 10 (worst pain imaginable). All subjects provided written informed consent.

We tested 183 patients 1 year after TKA; 124 returned for 2-year testing, and 60 returned for testing 3 years after TKA (Table 1). Testing of individuals at 3 years after TKA was added to the investigation in 2005; therefore, some individuals were not tested because they were beyond the

Table 1. Results of changes over time in persons after unilateral TKA*

Variable	1 year after TKA (n = 82 women; n = 101 men)	2 years after TKA (n = 52 women; n = 72 men)	3 years after TKA (n = 23 women; n = 29 men)	Effect	p value	Post hoc t-test changes with time in persons after TKA
Age	66.4 years (8.5)					
Body mass index	30.6 kg/m^2 (5.2)	31.3 kg/m^2 (5.7)	30.9 kg/m^2 (5.7)	Time	0.052	
Stair climbing test	12.5 s (4.4)	12.6 s (4.4)	12.6 s (5.5)	Time	0.242	NA
6-minute walk test	547 m (115)	532 m (119)	551 m (108)	Time	0.180	NA
Quadriceps strength						
Operated limb	21.0 N/BMI (8.5)	20.5 N/BMI (9.0)	20.2 N/BMI (8.2)	Time	0.001	Nonoperated limb declines:
Nonoperated limb	22.6 N/BMI (9.1)	20.9 N/BMI (9.2)	18.7 N/BMI (8.1)	Limb	0.288	1 to 2 years (p = 0.001)
				Interaction	0.015	2 to 3 years (p < 0.001)
Knee Outcome Survey						
Operated limb	85% (11%)	85% (13%)	88% (11%)	Time	0.764	NA
Nonoperated limb			85% (14%)			
Global Rating Scale						
Operated limb	91% (10%)	89% (13%)	86% (18%)	Time	0.074	NA
Nonoperated limb			84% (22%)			

* Demographic data, results of tests of functional performance, quadriceps strength, and self-report scores in persons 1, 2, and 3 years after unilateral TKA; all values are given as the mean with the standard deviation in parentheses; NA = not applicable; BMI = body mass index.

3-year mark (n = 34). Other reasons subjects did not return for testing between 2 and 3 years after surgery included unable to locate, did not respond to telephone messages, or refused testing (n = 31), development of osteoarthrosis or surgeries in the lower extremities or spine (n = 12), or neurologic changes (ie, stroke, n = 4); the remaining subjects have yet to reach 3 years after TKA (n = 20).

We used a cohort of 50 control subjects for comparison (Table 2); 25 of these control subjects returned for repeat testing a mean of 2.0 years (standard deviation, 0.7 years) after the first test session. Healthy control subjects were recruited via fliers and advertisements in the community, and all controls met the same inclusion criteria as patients who underwent TKA; however, they also must have reported no pain or surgeries in their hips, knees, ankles, or low back. Reasons control subjects did not return for testing include death (n = 1); development of osteoarthrosis, a neurologic condition or a surgery in the lower extremities (n = 8); unable to locate (n = 8); or not interested (n = 8).

We measured maximal voluntary isometric contraction of the quadriceps femoris muscles as previously described [14, 17]. Briefly, subjects sat in an electromechanical dynamometer (Kin-Com 500 H; Chattecx Corp, Harrison, TN) with the hip flexed 90° and the knee flexed 75°. The axis of the dynamometer was oriented with the axis of rotation of the knee, and the distal edge of the shin attachment was placed 5.0 cm proximal to the lateral malleolus of the test leg. We used inelastic waist and trunk straps to stabilize subjects' position. Subjects performed two submaximal contractions and one maximal contraction lasting 2 to 3 seconds each to become familiar with the testing procedure and to warm up the muscle. After 5 minutes of rest, we instructed subjects to contract the quadriceps muscle maximally for approximately 3 seconds. Verbal encouragement and visual output of their force were used to motivate the subjects to produce as much force as possible. We measured and recorded the knee extension force using custom-written software (LabVIEW 4.0.1; National Instruments, Austin, TX) with a 200-Hz sampling rate. In patients with TKA, the nonoperated limb is tested first followed by the operated limb. The force produced was normalized to body mass index (BMI) for comparison across subjects.

We assessed disability using self-report questionnaires designed to measure knee function. The Knee Outcome Survey-Activities of Daily Living Scale (KOS) is a 14-question knee-specific self-assessment of whether function is valid, reliable and has the ability to discern changes in impairments over time [11]. Each question is scored on a 5-point scale; 5 represents no difficulty with the task or symptom and zero represents the patient is unable to perform the activity or the symptom prevents them from daily activity. A maximum score is 70 points and results are expressed as a percentage with 100% indicating no disability. The Global Rating Scale asked subjects to rank their overall abilities on a scale of 0% to 100%, in which 0% represents complete loss of function and 100% represents the ability to do all activities without limitation [11]. All individuals tested 3 years after TKA completed Knee Outcome Survey and Global Rating Scale questionnaires for both the operated and the nonoperated knees.

The stair climbing test measures the time it takes a subject to ascend and descend a flight of 12 18-cm high

Table 2. Comparison of regression models used to predict performance on the 6-minute walk test

Model	r	R^2	R^2 change	F change	df*	Significant F change
1 year after TKA						
Operated quadriceps strength	0.547	0.299	0.299	41.44	133	< 0.001
Operated quadriceps strength + nonoperated quadriceps strength	0.571	0.326	0.027	3.81	132	0.054
Operated quadriceps strength + nonoperated quadriceps strength + operated knee pain	0.598	0.358	0.032	4.74	131	0.032
2 years after TKA						
Operated quadriceps strength	0.435	0.189	0.189	16.55	90	< 0.001
Operated quadriceps strength + nonoperated quadriceps strength	0.498	0.248	0.059	5.52	89	0.022
Operated quadriceps strength + nonoperated quadriceps strength + operated knee pain	0.512	0.262	0.014	1.31	88	0.256
3 years after TKA						
Operated quadriceps strength	0.505	0.255	0.225	10.251	59	0.003
Operated quadriceps strength + nonoperated quadriceps strength	0.505	0.255	0.001	0.022	58	0.884
Operated quadriceps strength + nonoperated quadriceps strength + nonoperated knee pain	0.663	0.440	0.185	9.240	57	0.005

* The 6-minute walk test was added to the testing protocol; therefore, the first 80 subjects did not complete this test 1 year after TKA; df = degrees of freedom.

steps. We asked subjects to complete the test as safely and as quickly as possible; use of one handrail is allowed if required. One practice test is performed and the average of two tests used for analysis.

The 6-minute walk (6 MW) is a self-paced functional test used to provide an assessment of the extent to which impairments affect mobility [3]. The 6 MW test measures the distance a person can walk in 6 minutes. We instructed patients to cover as much distance as they could in 6 minutes and we gave them verbal cues on time elapsed at 2, 4, and 5 minutes. The 6 MW test [3] is a reliable measure in healthy, older adult populations ($r = 0.95$) [8] and considered one of the most responsive measures of function after TKA [13].

Patients with TKA were compared over time using an analysis of variance with one repeated measure (time), and quadriceps strength was tested using two repeated measures (limb x time). We performed post hoc t-tests when we found significant differences with the analysis of variance. Hierarchical regressions were used to establish the contribution of operated limb strength, nonoperated limb strength, and knee pain (operated knee pain 1 and 2 years after TKA; nonoperated knee pain 3 years after TKA as reported on the KOS) to scores on the functional tests. We compared control subjects over time using paired t-tests. Control subjects were compared with patients 1 and 3 years after TKA using one-way analysis of variance (group).

Results

Strength of the quadriceps femoris muscles showed an effect of time (Table 1; Fig. 1); the operated limb was weaker ($p = 0.001$) than the nonoperated limb 1 year after TKA. Two years after TKA, the nonoperated limb weakened ($p = 0.001$; Table 1), resulting in no side-to-side difference ($p = 0.367$). It weakened ($p < 0.001$) further from 2 to 3 years after TKA (Table 1), at which point the nonoperated limb was weaker ($p = 0.023$). The nonoperated knee of patients 3 years after TKA was more painful ($p < 0.001$) than the operated knee (Fig. 2), as self-reported on the Knee Outcome Survey.

There were no differences on self-report outcome measures ($p > 0.070$), the stair climbing test ($p = 0.311$), or the 6-minute walk test ($p = 0.180$) over time in patients with TKA (Table 1).

The predictive model for the stair climbing test was affected by strength and pain. One year after TKA, strength of both limbs accounted for 31% of the variance ($R^2 = 0.330$, $p < 0.001$; Table 3) of the time to complete the stair climbing test. By 2 years, strength of both limbs and pain in the operated limb accounted for 33% of the variance in the time ($R^2 = 0.325$, $p = 0.003$; Table 3). Three years after TKA, it was the nonoperated knee pain alone that accounted for 33% of the variance on the stair climbing test ($R^2 = 0.330$, $p < 0.001$; Table 3). The predictive model for the 6 MW was affected by strength and knee pain. Strength of the operated quadriceps and operated knee pain accounted for 36% of the variance in the distance walked ($R^2 = 0.358$, $p = 0.032$; Table 2) 1 year after TKA; by 2 years, strength of both operated quadriceps explained 25% of the variance ($R^2 = 0.248$, $p = 0.022$; Table 2). Three years after TKA, strength of the operated quadriceps and nonoperated knee pain explained 44% of the variance of the distanced walked ($R^2 = 0.440$, $p = 0.005$; Table 2) during the 6 MW.

In healthy control subjects, there were no changes in self-report outcome measures ($p > 0.20$), or 6 MW ($p = 0.1$) with time; however, the stair climbing test declined with time ($p = 0.031$) (Table 4). Quadriceps strength had an effect of time with the right limb weakening ($p = 0.025$); however, there were no side-to-side differences ($p > 0.215$) (Table 4).

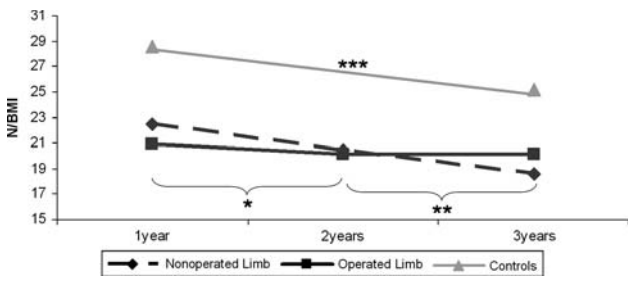

Fig. 1 Quadriceps strength in patients 1, 2, and 3 years after TKA is shown, compared to healthy controls. The nonoperated limb declined from 1 to 2 years after TKA (*$p = 0.005$) and further declines from 2 to 3 years after TKA (**$p = 0.002$). Strength of the controls also declined (***$p < 0.001$) over the same time period. Abbreviations: BMI = body mass index; N = Newtons.

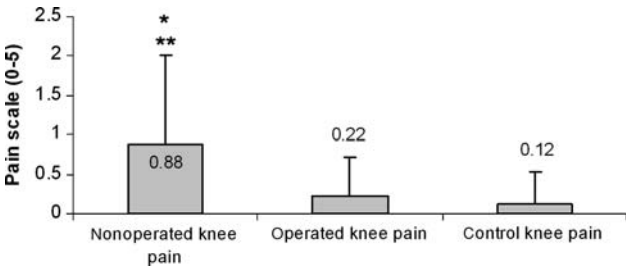

Fig. 2 Knee pain scores from the Knee Outcomes Survey on the nonoperated and operated knee in patients after TKA and both knees of the control group. A score of 5 represents that pain does not affect activities of daily living; a score of 0 represents the inability to perform the activity due to knee pain. The nonoperated knee of patients 3 years after TKA is more painful than the operated knee (*$p < 0.001$) and control knees (**$p < 0.001$).

Table 3. Comparison of regression models used to predict performance on the stairclimbing test after TKA

Model	r	R^2	R^2 change	F change	df	Significant F change
1 year after TKA						
Operated quadriceps strength	0.490	0.240	0.240	54.36	182	< 0.001
Operated quadriceps strength + nonoperated quadriceps strength	0.555	0.308	0.068	16.68	181	< 0.001
Operated quadriceps strength + nonoperated quadriceps strength + operated knee pain	0.562	0.316	0.008	2.09	180	0.150
2 years after TKA						
Operated quadriceps strength	0.451	0.204	0.265	28.90	123	< 0.001
Operated quadriceps strength + nonoperated quadriceps strength	0.520	0.270	0.001	10.25	122	0.002
Operated quadriceps strength + nonoperated quadriceps strength + operated knee pain	0.570	0.325	0.059	4.10	121	0.003
3 years after TKA						
Operated quadriceps strength	0.152	0.023	0.023	2.040	59	0.307
Operated quadriceps strength + nonoperated quadriceps strength	0.267	0.072	0.048	2.29	58	0.137
Operated quadriceps strength + nonoperated quadriceps strength + nonoperated knee pain	0.574	0.330	0.283	16.561	57	< 0.001

df = degrees of freedom.

Table 4. Results of change over time in healthy control subjects and comparison to persons with TKA*

Variable	Test 1 Healthy control subjects (n = 15 women; n = 10 men)	Test 2 Healthy control subjects (n = 15 women; n = 10 men)	Changes with time (p value) in healthy control subjects	p value compared with persons 1 year after TKA	p value compared with persons 3 years after TKA
Time between Test 1 and Test 2		2.0 years (0.7)			
Age	63.1 years (8.4)				
Body mass index	26.8 kg/m^2 (4.2)	26.4 kg/m^2 (3.9)	0.410	0.001	0.005
Stair climbing test	9.5 s (2.4)	10.0 s (2.2)	0.031	< 0.001	0.088
6-minute walk test	668 m (119)	640 m (108)	0.100	< 0.001	0.007
Quadriceps strength					
Right limb	29.6 N/BMI (9.5)	25.2 N/BMI (8.4)	0.025	< 0.001	< 0.001
Left limb	28.3 N/BMI (9.6)	26.2 N/BMI (8.2)	0.060	< 0.001	< 0.001
Knee Outcomes Survey					
Right limb	98% (4%)	96% (7%)	0.230	< 0.001	0.006
Left limb	99% (4%)	96% (6%)	0.340	< 0.001	0.002
Global Rating Scale					
Right limb	98% (5%)	98% (5%)	0.350	< 0.001	0.009
Left limb	99% (5%)	98% (5%)	0.440	< 0.001	0.005

* Demographic data, results of tests of functional performance, quadriceps strength, and self-report scores in healthy control subjects tested 2.0 years apart; all values are given as the mean with the standard deviation in parentheses; BMI = body mass index.

Compared to patients after TKA, the healthy controls were stronger at both intervals ($p < 0.001$, Table 4), performed better on the 6 minute walk test ($p = 0.007$; Table 4), and self-reported better function ($p < 0.1$; Table 4) and less knee pain ($p < 0.001$; Fig. 2). Controls were faster on the stair climbing test when compared to patients 1 year after TKA ($p < 001$; Table 4), but not at 3 years after TKA ($p = 0.088$; Table 4).

Discussion

The objective of this investigation was to assess changes over time in quadriceps strength, self-report outcome measures, and tests of functional performance in patients 1, 2, and 3 years after TKA, as well as in a cohort of controls without a history of osteoarthritis. We sought to determine the influence of quadriceps strength and self-report knee

pain on the results of tests of functional performance in patients after unilateral TKA.

There are limitations to this investigation that warrant consideration when interpreting the results. The diminishing cohort over time in both groups was high, resulting in a dropout rate of nearly two thirds in the TKA group and a dropout rate of 50% in the control group. These subjects were tested longitudinally, and attrition of approximately 20% at each interval was expected, albeit our control subjects dropped out at a higher rate than expected. Our choice of using 4 out of 10 knee pain scores in the contralateral knee at the time of the index procedure was chosen because it represented the patient perception of that knee's pain regardless of the radiographic status. By using it as a screening question, it eliminated from participation individuals with more severe pain in both knees. The lack of radiographic data on the nonoperated knee limits conclusions that can be drawn regarding the status of that knee and how it fared over time; knees with more severe osteoarthritis may not fare as well as knees with little or no osteoarthritis at the time of the index procedure [22]. We also lacked preoperative data; while a baseline comparison is lacking, patients with TKA typically improve substantially compared to their preoperative condition.

Pain plays a role in the ability to use the quadriceps femoris muscles [17, 30]; weakness of the quadriceps has been implicated in the development of knee osteoarthrosis [2]. Strength affects function [20]; reduced physical capacity may be both a cause and a consequence of physical impairment and functional limitations [32]. Patients with TKA were stable on tests of functional performance and self-report outcome measures during this investigation; however, lower scores on functional tests compared to controls indicate their level of function was not as good as individuals without osteoarthrosis. Aging affects strength of the knee extensors [6, 10] and played a role in declining strength [9] in these individuals who were tested over the course of several years. The decline in strength in the nonoperated limb was clearly steeper than that of the control subjects suggesting more than aging was at play. Patients with a history of knee osteoarthrosis that led to a TKA risk more rapid declines in strength and increases in pain in their nonoperated knee compared with healthy counterparts.

Self-report of function plateaued in the 3 years after TKA, and the Global Rating Scale peaked 1 year after TKA in this study, whereas the Knee Outcome Survey remained stable; previously, self-report of function was reported to occur 3 years after TKA [28]. Self-report of function continued to be lower in patients with TKA than in control subjects without osteoarthrosis, similar to other reports in the literature [6]. Although self-report questionnaires can be highly responsive in the early phases after TKA [23], as function improves, tests of function become the best measures of performance [23]. The questionnaires do, however, provide insight into these individuals' perception of function; the Knee Outcome Survey remains stable, thus these individuals may not perceive the decline in strength.

Nonoperated knee pain was the primary contributor to performance on the stair climbing test and 6 MW in patients 3 years after TKA. The results of the stair climbing test and 6 MW did not change with time, yet there was a shift in the determinant of function in these tasks. The strength of both limbs was relatively stable between 1 and 2 years after TKA and both contributed to performance of the 6 MW and stair climbing test. Three years after TKA, however, the nonoperated limb was considerably weaker and more painful and only operated limb strength and nonoperated knee pain were the determinants of 6 MW and stair climbing test performance, suggesting a change to reliance on the operated knee for these subjects.

The cohort of controls without osteoarthritis weakened considerably over time, and slowed on their results of the stair climbing test. As stated, aging affects strength of the knee extensors [6, 10]. We believe the slower stair climbing score is a result of declining strength: stair ascent requires concentric muscle action against gravity repeatedly, while the descent requires eccentric control of the quadriceps. Quadriceps weakness would make this task more challenging; quadriceps function is also influenced by implant design [33, 34], thus altering muscle use in the lower extremity. The 6-minute walk score remained stable in both groups; walking requires many muscle groups; this test was originally designed as a measure of respiratory fitness [3], another factor that was not tested in this investigation.

When folks with TKA were compared to controls, patients with TKA were heavier, weaker, and had lower self-report outcome measures at both intervals. Patients with TKA were slower on the stair climbing test only at 1 year after TKA compared to the first test session of controls. Both groups weakened over time, yet the control slowed on this test at a greater rate than did patients after TKA. These results were puzzling, and may be due to the small sample size; however, aging results in greater demand on the hip extensors [5], and a shift in muscle use may play a role; hip extensors were not tested in this investigation. The 6-minute walk test was originally described as a measure of respiratory fitness [3]. Controls walked at least 100 m further than patients after TKA at both intervals, a difference considered clinically meaningful [35]. Patients with osteoarthritis may have decreased cardiovascular status compared to controls [25], and while cardiovascular fitness may improve after TKA [26], it was not tested in this investigation.

After unilateral TKA, the nonoperated knee worsened over the 2-year period of this study with increased pain and quadriceps weakness. Strength and pain stabilize in the index knee, and self-report outcome measures and functional performance plateau in the 1 to 3 years after TKA. Patients with TKA never reached the levels of function of a comparable group of healthy control subjects despite the fact that controls also declined in strength and function over the same time interval. The use of the nonoperated leg as the so-called healthy limb in patients after a unilateral TKA may underestimate disability; therefore, a comparison group should be the standard for assessments of functional abilities.

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