Research Report

Physical Impairments and Functional Limitations: A Comparison of Individuals 1 Year After Total Knee Arthroplasty With Control Subjects

Background and Purpose. The purpose of this study was to examine the physical impairments and functional limitations of individuals with total knee arthroplasty (TKA), as compared with individuals with no diagnosed knee disease (control subjects). **Subjects.** Twenty-nine individuals 1 year following TKA (13 women, 16 men) and 40 age- and gender-matched control subjects (18 women, 22 men) were assessed. **Methods.** Walking speed, stair-climbing ability, knee torque (in newton-meters), and total work performed during 15 repeated contractions were evaluated. **Results.** Walking speeds for men with TKA were 13% and 17% slower at normal and fast speeds, respectively. Their stair-climbing ability was even more compromised (51% slower). Walking speeds for women with TKA were 17% and 18% slower at normal and fast speeds, respectively. Similarly, their stair-climbing time was more compromised (43% slower). Men with TKA were 37% to 39% weaker and performed 36% to 37% less total work of their knee extensors compared with the control subjects. Similarly, women with TKA had knee extensor strength deficits of 28% to 29% and performed 24% less total work. **Conclusion and Discussion.** One year after TKA, marked physical impairments and functional limitations persisted. [Walsh M, Woodhouse LJ, Thomas SG, Finch E. Physical impairments and functional limitations: a comparison of individuals 1 year after total knee arthroplasty with control subjects. *Phys Ther.* 1998;78:248–258.]

Key Words: *Functional outcome, Knee arthroplasty, Knee osteoarthritis, Knee strength, Physical impairment.*

Marianne Walsh

Linda J Woodhouse

Scott G Thomas

Elspeth Finch

In North America and in other industrialized nations, the high prevalence of osteoarthritis (OA) of the knee[1–3] and OA's severe impact on disability have been well documented.[4] When conservative management is ineffective, the surgical treatment of choice for individuals with severe, end-stage OA is often total knee arthroplasty (TKA).

Previous research evaluating surgical success following TKA focused on either end of the disability spectrum (impairment-disability). We believe that a complete description of treatment outcome requires measures across all levels (ie, pathology, impairment, functional limitations, and disability) of Nagi's model of disablement.[5] The pathophysiology of OA of the knee[6] and the effects of alternative surgical interventions have been investigated.[7,8] Isolated measurements of impairment, including measurements of pain and knee range of motion (ROM), have frequently been made.[9] The current trend is to evaluate the effectiveness of surgical interventions using patient-reported quality-of-life measures.[10–12] Extensive research regarding disability has led to an appreciation of the gains expected in patient-reported quality of life following TKA.[11,12] What is not well described in the literature is the degree of physical impairment and functional limitation in individuals following TKA compared with individuals without knee disease.

Kroll and colleagues[13] quantified functional limitations of male and female patients preoperatively and at 5 and 13 months following TKA. They noted a reduced walking speed (22%–16%) in patients with TKA relative to that of older men with no diagnosed knee disease. Berman et al[14] compared knee flexor (hamstring) muscle function between limbs with TKA and limbs without TKA. Their results suggest that maximal recovery of hamstring muscle peak torque occurs by 7 to 12 months postsurgery. It may not be appropriate, however, to use the side without surgery for comparison[15] because bilateral OA or reduced activity consequent to OA and the TKA may also impair function of the side without

M Walsh, MSc, BSc(PT), is Clinical Research Physiotherapist, Centre for Studies of Physical Function, Orthopaedic and Arthritic Hospital, 43 Wellesley St E, Toronto, Ontario, Canada M4Y 1H1 (m.walsh@utoronto.ca). The Centre for Studies of Physical Function is a joint venture between the Department of Rehabilitation, Orthopaedic and Arthritic Hospital, and the Faculty of Medicine, Department of Physical Therapy, University of Toronto. Address all correspondence to Ms Walsh.

LJ Woodhouse, is a PhD candidate, Department of Community Health, University of Toronto, and Research Associate, Centre for Studies of Physical Function at the Orthopaedic and Arthritic Hospital.

SG Thomas, PhD, is Associate Professor, Department of Physical Therapy, University of Toronto, and Research Associate, Centre for Studies of Physical Function at the Orthopaedic and Arthritic Hospital.

E Finch, MHSc(PT), is Assistant Professor, Department of Physical Therapy, University of Toronto, and School of Rehabilitation Science, McMaster University, Hamilton, Ontario, Canada. She is also Research Associate, Centre for Studies of Physical Function at the Orthopaedic and Arthritic Hospital.

Ethics approval for this study was granted by the University of Toronto and the Orthopaedic and Arthritic Hospital.

This work was supported by funding from the Orthopaedic and Arthritic Hospital.

This article was submitted September 10, 1996, and was accepted July 22, 1997.

surgery. Jevsevar et al[15] compared men and women who had undergone TKA 1 or more years previously with a control group of subjects with no diagnosed knee disease and found that the subjects with TKA had deficits in angular velocity during the stance phase while performing activities of daily living, including walking and stair climbing.

There is a need to document the persistent physical impairments and functional limitations in men and women following TKA. The direct goals of physical therapy are often related to function. The purpose of our study was to examine the physical impairments (knee ROM, muscle torque, and total work) and functional limitations (walking and stair climbing) of individuals 1 year after TKA, as compared with of age- and gender-matched individuals with no diagnosed knee disease. We considered the peak torque (in newton-meters) developed during five maximal contractions to be an indication of muscle strength. We considered the total work (in joules) performed during 15 concentric contractions at angular velocities of 90° and 120°/s to be an indicator of isokinetic knee extensor and flexor endurance.

Method

Subjects

The subjects with TKA were 29 consecutive, consenting individuals (13 women, 16 men) who had undergone TKA at a single tertiary care orthopedic hospital. All individuals were assessed approximately 1 year after surgery ($\bar{X}$=12.6 months, SD=1.5, range=11–17). Eight of these individuals had bilateral knee replacements. Forty similarly aged, control subjects (18 women, 22 men) were recruited from the community through public service announcements and oral communications. The control subjects were free of any known knee pathology and reported no functional limitations during walking or stair climbing. Control subjects were matched to patients with TKA based on gender and age (±2 years).

Written informed consent was obtained from each subject prior to clinical testing, and the University of Toronto's guidelines for the conduct of research involving humans were followed. All participants were offered a nominal reimbursement for transportation costs.

Procedure

Standardized methods for measuring weight (wt), height (ht), and girths at the waist and the hip[16] were used. Chumlea et al[17] reported a technical error of measurement of waist girth of 0.48 cm in elderly men and of 1.15 cm in elderly women. Malina et al[18] reported a technical error of measurement of hip girth of 1.23 cm for intrameasurer errors. Wilmore and Behnke[19] reported a correlation of .99 between measurements obtained 1 day apart in young male subjects. Body mass index (BMI: wt/ht^2) and waist-to-hip ratios (WHR: waist girth/hip girth) were calculated from the measurements. Percentage of body fat was estimated from measurements of body reactance and resistance obtained with a bioelectric impedance device (BIA 101 Body Composition Analyzer*). Muscle volume of the thigh was estimated from anthropometric measurements using the method of Jones and Pearson.[20]

Knee active range of motion (AROM) was measured bilaterally, to the nearest degree, using a goniometer. It is generally reported[21–23] that the reliability of goniometric measurements improves when the assessment is performed by the same individual, who uses the same measurement tool with a standard test position and protocol. In our study, the same physical therapist using the same goniometer assessed knee AROM. Subjects lay on a plinth in the supine position with the knee to be measured maximally flexed and the foot flat on the plinth. Specifically, as described by Norkin and White,[24] the fulcrum of the goniometer was aligned with the lateral midline of the femur using the greater trochanter for reference. Finally, the distal arm of the goniometer was aligned with the lateral midline of the fibula using the lateral malleolus for reference. Goniometer alignment for measuring knee extension was identical. While in the supine position, the knee was fully extended and a 10.2-cm (4-in) rolled towel was placed under the ankle of the lower extremity to be assessed. Subjects were asked to maximally straighten their knee, and the measurement was recorded.

There was no difference in height between the groups. The subjects with TKA, however, were heavier, with higher BMI scores and greater percentages of body fat, than the age- and gender-matched control subjects (Tab. 1). Despite a difference in AROM of knee flexion between groups, all individuals with TKA had a knee AROM of ≥90 degrees of flexion, which is adequate for everyday function. Similarly, subjects with TKA had an extension loss of ≤10 degrees, although the men showed a difference between groups in extension. Estimated thigh muscle volume did not differ between groups for the men. Women with TKA had a higher estimated muscle volume value than the women in the control group had (Tab. 2).

Concentric isokinetic knee torque and total work were evaluated on both lower extremities using a LIDO Active isokinetic dynamometer.† Subjects with one TKA were tested so that the limb that did not undergo surgery was

* RJL Systems, 33955 Harper Ave, Clinton Township, MI 48035.
† Loredan Biomedical Inc, 2121-B Second St, Davis, CA 95616.

Table 1.
Physical Characteristics and Activity Level of Study Participants by Group and Gender[a]

Variable	TKA Group (n=29)		Control Group (n=40)	
	Female (n=13)	Male (n=16)	Female (n=18)	Male (n=22)
Physical characteristics				
Age (y)	61.3±1.3[b]	66.4±1.7	61.9±1.1[b]	63.6±1.4
Weight (kg)	76.0±2.9[b,c]	89.1±3.9[c]	64.2±2.6[b]	76.4±1.8
Height (cm)	160.8±1.9[b]	170.3±1.8	158.3±2.1[b]	171.5±1.3
WHR	0.81±0.2[b]	0.93±0.01	0.77±0.01[b]	0.93±0.008
BMI (kg/m^2)	29.5±1.3[c]	30.9±1.4[c]	25.2±0.91	25.9±0.45
Percentage of body fat	37.8±2[b,c]	25.3±2[c]	31.3±2[b]	21.2±1
Knee active range of motion				
Flexion (°)	114±4.65[c]	110±3.74[c]	143±1.54	142±1.16
Extension[d] (°)	−1±1.43	−0.4±1.18[c]	−7±1.37	−6±0.56
Total score on physical activity questionnaire for elderly people[30]	23.6±3.71	15.3±2.23	18.2±2.43	19.5±1.56

[a] Values are mean (±SEM). Analysis of variance revealed no group×gender interactions ($P>.05$). TKA=total knee arthroplasty, WHR=waist-to-hip ratio (waist girth/hip girth), BMI=body mass index (wt/ht^2).
[b] Values for female subjects were different ($P\leq.05$) from values for male subjects within the TKA and control groups.
[c] Values for the TKA group were different ($P\leq.05$) from values for the control group within each gender.
[d] Negative values for extension refer to hyperextension.

Table 2.
Muscle Thigh Volume and Cross-sectional Area of Study Participants by Group and Gender[a]

Variable	TKA Group (n=28)		Control Group (n=34)	
	Female (n=13)	Male (n=15)	Female (n=16)	Male (n=18)
Thigh muscle volume (cm^3)				
Limb with TKA	3,413.7±119.8[b,c]	3,921.3±159.9	. . .	. . .
Limb without TKA	3,453.7±217.2[b,c]	3,979.2±200.2	2,852.7±155.0[b]	4,020.0±199.3
Thigh muscle cross-sectional area (cm^2)				
Limb with TKA	13.1±0.4[b,c]	13.9±0.4[d]	. . .	. . .
Limb without TKA	12.7±0.2[b,c]	13.3±0.4	11.7±0.3[b]	13.5±0.2

[a] Values are mean (±SEM). Analysis-of-variance differences were deemed significant at $P\leq.05$. Individuals with bilateral total knee arthroplasty (TKA) did not have a "limb without TKA," explaining the smaller number of subjects with a TKA in that category. Values for all control subjects reflect a mean of both lower limbs. Ellipsis=not applicable.
[b] Values for female subjects were different from values for male subjects within the TKA and control groups.
[c] Values for the TKA group were different from values for the control group within each gender.
[d] Values for the limb without TKA were different from the values for the limb with TKA within each gender for the TKA group.

tested first. This limb was tested first to limit apprehension that would interfere with testing. For all other subjects, the choice of limb to be tested first was determined by convenience. All tests were performed while the subjects were in a seated position with the hips flexed to approximately 80 degrees. The dynamometer was preset, using software controls, to evaluate torque (peak torque developed during five voluntary maximal contractions) through a preset knee range of motion from 20±2 to 90±2 degrees of flexion in the sagittal plane. The manufacturer of the LIDO Active system claims that the device is self-calibrating, and we did not test this claim. Prior to each test session, the device is supposed to compensate for gravity by weighing the patient's limb through the preset range of motion at an angular velocity of 5°/s. We did not check whether these determinations were correct. The validity and reliability of measurements obtained with the LIDO Active isokinetic system have previously been reported by Patterson and Spivey.[25]

After the subjects practiced bending and straightening their knee for two to three repetitions, they were instructed to "bend and straighten your knee as hard and as fast as you can" to elicit five continuous maximal voluntary contractions of the knee extensors and flexors. Verbal encouragement was standardized by repeating the same phrase (ie, "kick up, pull down, kick up, pull down; work as hard and as fast as you can") during all isokinetic tests. Torque curves were accepted only when the coefficient of variation for the five repetitions was less than 10%. Mean peak torque (in newton-meters) was calculated as the average of the highest torque values for the five repetitions. Thus, the mean peak torque

recorded during five concentric contractions at angular velocities of 90° and 120°/s was used as an indicator of muscle strength of the knee extensors and flexors.

Total work (in joules), which we considered an indicator of local muscular endurance, was evaluated during 15 maximal concentric contractions, also at angular velocities of 90° and 120°/s. The protocol was then repeated on the contralateral lower extremity.

Two self-paced walk (SPW) tests were performed using a modification of the protocol described by Bassey et al.[26] The SPW tests involved walking 160 m (eight lengths of a 20-m indoor course) in response to each of two pace instructions: (1) "walk at a normal pace, neither fast nor slow" and, after a 3- to 4-minute rest, (2) "walk rather fast, but without overexerting yourself." Heart rate recordings were taken at 5-second intervals using a Polar™ Vantage XL heart rate recorder.[‡] Heart rate was recorded as the average of the last three heart rates (ie, last 15 seconds) recorded during the SPW tests. The walking speed for each 20-m segment of the test was determined using a dedicated photo cell system to trigger a computerized timing device. Immediately following each test, a 10-cm visual analog scale was used to evaluate pain and the 10-point Borg Scale[27] was used to evaluate perceived exertion. The reliability and responsiveness of the SPW test has been demonstrated in a healthy elderly population.[28]

During a timed (to the nearest second) stair-climbing test, the subjects' stepping pattern, use of aids, heart rate, pain, and perceived exertion were evaluated while they ascended and descended one flight of 10 steps (step height=20 cm). This measure[29] was developed at the Centre for Studies of Physical Function at the Orthopaedic and Arthritic Hospital, Toronto, Ontario, Canada, and has been pilot tested in a similar sample of persons with TKA.

Physical activity over the year before the study was assessed using a physical activity questionnaire for elderly people,[30] which has been validated for use in an older population. Total physical activity scores using the physical activity questionnaire for elderly people are reported to be reliable over a 20-day period (test-retest $r=.89$) and valid for determining high, medium, and low levels of physical activity in elderly individuals (determined by pedometer readings and questionnaire recall, $r=.72–.78$).[30] Based on the activity questionnaire of Baecke et al,[31] components include household, sporting, and leisure activities. A maximum household score is 10, and sporting and leisure activities are graded according to the specific activity and the number of hours per week (maximum of 8 hours) and number of months per year (maximum of 9 months) that the individual engages in the activity. Activity intensity codes are based on energy costs from earlier work by Bink and van der Sluys.[32]

All measurements were made by a single examiner. The physical performance measures were interspersed with questionnaires to allow for adequate rest during the test session. The total test session lasted approximately 2 hours for each subject.

Data Analysis

Data analyses were done using SAS software.[§] Descriptive statistics included calculation of means, standard deviations (SD), and the standard error of the mean (SEM). Comparisons between groups (TKA versus control) by gender were made using an analysis of variance. Differences were deemed to be statistically significant at $P \leq .05$.

Results

Knee Peak Torque

Angular velocity of 90°/s. As expected, mean peak torque of the knee extensors was greater than that of the knee flexors. The ratios ($\bar{X} \pm SEM$) of extensor-to-flexor knee torque for the women and men with TKA (1.50 ± 0.18 and 1.64 ± 0.08) were considerably less than the ratios for women and men in the control group (1.78 ± 0.07 and 1.83 ± 0.06).

Isokinetic mean peak torques of the knee extensors and flexors of the limb with the TKA for women 1 year after surgery were only 71% and 73%, respectively, of those of the matched control subjects. Similarly, mean peak torques of the knee extensors and flexors of the limb with the TKA for men 1 year after surgery were only 61% and 65%, respectively, of those of the matched control subjects. Although the female subjects' quadriceps femoris and hamstring muscles were stronger in the limb without the TKA than in the limb with the TKA, their extensor and flexor mean peak torques in the limb without the TKA were only 73% to 88% of those of the control subjects (Tab. 3). The mean peak torques of the extensors and flexors of the limb without the TKA for men were 73% to 85% of those (mean of both limbs) of the control subjects.

Angular velocity of 120°/s. Compared with the angular velocity of 90°/s, mean peak torque values were lower at the faster speed in all subjects except the women with TKA. For these individuals, the mean peak torques were slightly higher for both muscle groups (extensors and flexors) on the side without the TKA and for the knee

[‡] Polar CIC Inc, 99 Seaview Blvd, Port Washington, NY 11050.

[§] SAS Institute Inc, PO Box 8000, Cary, NC 27511.

Table 3.
Knee Muscle Peak Torque (in Newton-meters) for Concentric Isokinetic Knee Extension and Flexion at an Angular Velocity of 90°/s[a]

	TKA Group		Control Group	
Muscle Group	**Female**	**Male**	**Female**	**Male**
Knee extensors				
Limb with TKA	44.8±7.5[b,c] (n=8)	69.5±8.7[c] (n=11)	. . .	. . .
Limb without TKA	46.3±8.1[c] (n=6)	82.6±13.0[c] (n=8)	63.0±3.5 (n=13)	113.6±6.4 (n=15)
Knee flexors				
Limb with TKA	26.3±6.9 (n=8)	40.0±6.3[d] (n=11)	. . .	. . .
Limb without TKA	31.7±5.0 (n=6)	51.9±6.8 (n=8)	36.0±1.7 (n=13)	61.4±2.3 (n=15)

[a] Values are mean (±SEM) peak torques generated during three consecutive maximal repetitions. Analysis-of-variance differences were deemed significant at $P \leq .05$. Individuals with bilateral total knee arthroplasty (TKA) did not have a "limb without TKA," explaining the smaller number of subjects with a TKA in that category. Values for all control subjects reflect a mean of both lower limbs. Ellipsis=not applicable.
[b] Values for female subjects were different from values for male subjects within the TKA and control groups.
[c] Values for the TKA group were different from values for the control group within each gender.
[d] Values for the limb without TKA were different from the values for the limb with TKA within each gender for the TKA group.

Table 4.
Knee Muscle Peak Torque (in Newton-meters) for Concentric Isokinetic Knee Extension and Flexion at an Angular Velocity of 120°/s[a]

	TKA Group		Control Group	
Muscle Group	**Female**	**Male**	**Female**	**Male**
Knee extensors				
Limb with TKA	42.6±6.0[b,c] (n=8)	66.4±6.9[c] (n=11)	. . .	. . .
Limb without TKA	48.8±8.2[b,c] (n=6)	77.8±10.4[c] (n=8)	59.0±2.3 (n=13)	105.2±5.7 (n=15)
Knee flexors				
Limb with TKA	30.2±6.0[b,c] (n=8)	40.3±4.7[c,d] (n=11)	. . .	. . .
Limb without TKA	32.3±4.9[b,c] (n=6)	48.9±4.8[c] (n=8)	35.7±1.5 (n=13)	62.0±2.8 (n=15)

[a] Values are mean (±SEM) peak torques generated during three consecutive maximal repetitions. Analysis-of-variance differences were deemed significant at $P \leq .05$. Individuals with bilateral total knee arthroplasty (TKA) did not have a "limb without TKA," explaining the smaller number of subjects with a TKA in that category. Values for all control subjects reflect a mean of both lower limbs. Ellipsis=not applicable.
[b] Values for female subjects were different from values for male subjects within the TKA and control groups.
[c] Values for the TKA group were different from values for the control group within each gender.
[d] Values for the limb without TKA were different from the values for the limb with TKA within each gender for the TKA group.

flexors on the side with the TKA at 120°/s compared with their values at 90°/s.

When assessed at the angular velocity of 120°/s, knee peak torque of the women with TKA improved relative to that of the female control subjects. For example, their limb with the TKA had achieved extensor and flexor mean peak torques of 72% to 85%, respectively, of the values of the female control subjects. In the male subjects with TKA, the decrement in mean peak torque relative to that of the control subjects was markedly greater at 120°/s than at 90°/s. At the faster angular velocity, extensor and flexor mean peak torques were just 63% to 65% of those of the male control subjects. At the angular velocity of 120°/s, knee peak torque torque of the limb with the TKA of all individuals who had undergone surgery was diminished when compared with that of the control subjects (Tab. 4).

Knee Total Work

Angular velocity of 90°/s. Deficits in knee extensor and flexor concentric peak torque and total work were still present 1 year postoperatively, not only in the limb with the TKA but in the limb without the TKA of individuals who had undergone surgery.

On average, total work of the extensors and flexors of the subjects with TKA was 76% to 73%, respectively, of the values for the control subjects. Extensor endurance performance, measured as the total work of the limb without the TKA in women who had undergone surgery, was assessed to be 18% less than in the control subjects.

Compared with the control subjects, the performance of the male subjects with TKA on muscular endurance testing was generally poorer than on peak torque testing. The total work of the extensors and flexors at 90°/s accomplished by the male subjects with TKA was only 64% and 55%, respectively, of that of the control subjects (Tab. 5).

Angular velocity of 120°/s. As expected, less work was produced at the faster angular velocity of 120°/s compared with the angular velocity of 90°/s. This pattern was evident across both genders and groups. Similar to

Table 5.
Total Work (in Joules) for Concentric Isokinetic Knee Extensors and Flexors at an Angular Velocity of 90°/s[a]

	TKA Group		Control Group	
Muscle Group	**Female**	**Male**	**Female**	**Male**
Knee extensors				
Limb with TKA	621.8±87.3[b,c] (n=8)	892.8±90.7[c] (n=11)	. . .	. . .
Limb without TKA	666.8±112.2[b,c] (n=6)	1,043.6±133.5[c] (n=8)	816.8±28.6 (n=13)	1,397.4±73.0 (n=15)
Knee flexors				
Limb with TKA	350.8±84.7[b,c] (n=8)	470.9±57.8[b,d] (n=11)	. . .	. . .
Limb without TKA	430.0±67.5[b,c] (n=6)	678.6±60.0[c] (n=8)	482.5±19.8 (n=13)	849.4±31.4 (n=15)

[a] Values represent mean (±SEM) for the total work generated during 15 consecutive maximal repetitions. Analysis-of-variance differences were deemed significant at $P \leq .05$. Individuals with bilateral total knee arthroplasty (TKA) did not have a "limb without TKA," explaining the smaller number of subjects with a TKA in that category. Values for all control subjects reflect a mean of both lower limbs. Ellipsis=not applicable.
[b] Values for female subjects were different from values for male subjects within the TKA and control groups.
[c] Values for the TKA group were different from values for the control group within each gender.
[d] Values for the limb without TKA were different from the values for the limb with TKA within each gender for the TKA group.

Table 6.
Total Work (in Joules) for Concentric Isokinetic Knee Extensors and Flexors at an Angular Velocity of 120°/s[a]

	TKA Group		Control Group	
Muscle Group	**Female**	**Male**	**Female**	**Male**
Knee extensors				
Limb with TKA	523.3±75.8[b,c] (n=8)	810.1±66.7[c,d] (n=11)	. . .	. . .
Limb without TKA	600.2±112.1[b,c] (n=6)	934.4±124.9[c] (n=8)	690.6±35.3 (n=13)	1,285.3±65.4 (n=15)
Knee flexors				
Limb with TKA	331.2±64.8[b,c] (n=8)	440.0±42.9[c,d] (n=11)	. . .	. . .
Limb without TKA	401.8±70.5[b,c] (n=6)	563.4±47.6[c] (n=8)	447.9±23.5 (n=13)	766.1±32.4 (n=15)

[a] Values represent mean (±SEM) for the total work generated during 15 consecutive maximal repetitions. Analysis-of-variance differences were deemed significant at $P \leq .05$. Individuals with bilateral total knee arthroplasty (TKA) did not have a "limb without TKA," explaining the smaller number of subjects with a TKA in that category. Values for all control subjects reflect a mean of both lower limbs. Ellipsis=not applicable.
[b] Values for female subjects were different from values for male subjects within the TKA and control groups.
[c] Values for the TKA group were different from values for the control group within each gender.
[d] Values for the limb without TKA were different from the values for the limb with TKA within each gender for the TKA group.

patterns at the slower angular velocity of 90°/s, deficits in total work at 120°/s during 15 maximum repetitions were evident in the female subjects with TKA. Specifically, they achieved 76% and 74% of the extensor and flexor work, respectively, of that achieved by the female control subjects. Extensor and flexor total work decrements were less in the limb without the TKA (87% and 90%, respectively) of the subjects who had undergone surgery compared with the control subjects. Male subjects who had undergone surgery produced similarly low extensor and flexor total work values (63% and 57%, respectively) in the limb with the TKA compared to the male control subjects (Tab. 6).

Self-Paced Walking

Individuals with TKA achieved over 80% of the normal and fast walking speeds of their age- and gender-matched counterparts 1 year after surgery (Tab. 7). Ratings of perceived exertion and heart rates were similar between the groups, despite the slower walking speeds at both normal and fast selected paces in the subjects with TKA. A perceived exertion rating of 2, anchored by the expression "slight" on the Borg Scale, was frequently reported by the subjects with TKA. Persistent knee pain was reported by the subjects with TKA following fast walking. Mean (±SD) pain scores were 0.8±0.98 for the men with TKA and 1.8±2.69 for the women with TKA, where 0 represents "no pain" and 10 represents "maximal pain." These scores were both statistically significant ($P \leq .02$) and clinically significant compared with those of the control group.

Stair-Climbing Performance

Both women and men with TKA took more than twice as long to ascend and descend a flight of 10 stairs than it took the control subjects (Tab. 8). Although both men and women performed at a slower pace, the women with TKA reported a greater perceived effort and pain in completing the stair-climbing task. Although all subjects were instructed to try to ascend and descend the stairs without using a handrail, six subjects with TKA (including one subject with bilateral TKA) required this assis-

Table 7.
Performance for the 160-m Walk Test at Normal and Fast Self-Paced Walking Speeds[a]

Variable	TKA Group (n=29)		Control Group (n=40)	
	Female (n=13)	Male (n=16)	Female (n=18)	Male (n=22)
Normal self-paced walking speed				
Speed (m/s)	1.17±0.05[b]	1.31±0.05[b]	1.38±0.03	1.51±0.03
Pain (0–10)	1.0±0.7	0.5±0.3[b]	0.0±0.0	0.0±0.0
RPE (0–10)	1.2±0.4	2.2±0.4[b]	0.5±0.2	0.7±0.2
Fast self-paced walking speed				
Speed (m/s)	1.36±0.1[b]	1.53±0.06[b]	1.65±0.03	1.84±0.03
Pain (0–10)	1.6±0.7[b]	0.8±0.4[b]	0.0±0.0	0.0±0.0
RPE (0–10)	1.6±0.4	2.6±0.5	1.6±0.2	1.8±0.3

[a] Values represent mean (±SEM). Analysis-of-variance differences were deemed significant at $P \leq .05$. TKA=total knee arthroplasty, RPE=rating of perceived exertion.
[b] Values for the TKA group were different ($P \leq .05$) from values for the control group within each gender.

Table 8.
Group×Gender Performance While Ascending and Descending One Flight of 10 Steps[a]

Variable	TKA Group (n=29)		Control Group (n=40)	
	Female (n=13)	Male (n=16)	Female (n=18)	Male (n=22)
Stair time (s)	31.10±0.49[b]	23.33±2.3[b]	13.45±0.47	11.81±0.31
Pain (0–10)	1.9±1.0[b]	0.9±0.6	0.0±0.0	0.0±0.0
RPE (0–10)	2.4±0.6[b]	2.2±0.4	0.4±0.2	1.2±0.5

[a] Values represent mean (±SEM). Analysis-of-variance differences were deemed significant at $P \leq .05$. TKA=total knee arthroplasty, RPE=rating of perceived exertion.
[b] Values for the TKA gronp were different ($P \leq .05$) from values for the control group within each gender.

tance. All except eight subjects with TKA (including two subjects with bilateral TKA) used a reciprocal stepping pattern. One individual declined performing this task due to fatigue.

Physical Activity

The subjects with TKA did not differ from the control subjects in their reported total level of physical activity, as measured ($\bar{X}$±SEM) using the physical activity questionnaire for elderly people[30] (19±2.2 versus 19±1.4, respectively). Large standard deviations for all groups indicate the diverse physical activity habits of our study participants (Tab. 1).

Discussion and Conclusions

Our findings indicate that marked impairments and some functional limitations persist in individuals even 1 year following TKA. The relative absence of pain but elevated rating of perceived exertion and heart rate responses to physical activity and decreased concentric muscle strength suggest that physical deconditioning may strongly contribute to the decreased function in these individuals. Alternative explanations for the observations include differences in body composition or biomechanical efficiency of walking between the subjects with TKA and the control subjects. The subjects with TKA were heavier (12–13 kg) and had a higher percentage of body fat (4%–6%) compared with their age- and gender-matched control subjects. Osteoarthritis is typically associated with increased body fat even in earlier stages of the disease,[33] but our study provides evidence that differences persist even 1 year after TKA. The values for BMI obtained for the subjects with TKA are associated with increased risk of morbidity and mortality.[16] One of the limitations of our study is that the subjects with TKA had increased body fat compared with the control subjects. We are unable, therefore, to delineate the effects of obesity from those of TKA on function.

Volunteers are known to have better health and higher functional abilities than the general population.[34] The results of both the subjects with TKA and the control subjects may have been influenced by this volunteer effect. The body composition measurements (weight, BMI), although different between the subjects with TKA and the control subjects, were similar to age- and gender-matched normative values from a Canadian survey.[16] Walking speed was within approximately 1 standard deviation of age-predicted values for men and women at both self-selected paces.[35] These comparisons suggest that our control sample was representative of healthy older people.

Although no survey data on individuals with TKA are currently available, data from other studies suggest that our subjects with TKA may have had higher-than-average functional levels. Berman et al[14] reported a normal walking speed for men and women who were tested 2 to 3 years after TKA (0.90 m/s) that was slower than our mean value (1.25 m/s) at the normal walking speed. Mattsson and colleagues[36] reported a maximal walking speed over 4 minutes of 1.25 m/s for 2 men and 6 women who were tested 1 year after TKA. Free walking speed 1 year after TKA for 7 men and 11 women was 1.07 m/s in the study by Kroll et al.[13] The higher walking speed observed for our subjects suggests that our estimates of the degree of impairment 1 year after TKA may be conservative relative to other individuals who have TKA surgery.

Osteoarthritis is associated with altered gait mechanics.[37] Previous studies,[38,39] however, suggest that biomechanical differences in gait between subjects with TKA and subjects with no diagnosed knee pathology are minor. Our observation of only minor deficits in ROM supports those observations.

Reduced physical activity may be both a cause and a consequence of physical impairment and functional limitation. Pain associated with OA limits physical activity, and surgical intervention that decreases pain should allow resumption of normal activities. If reduced physical activity has become habitual, however, this might contribute to continuing obesity and deficits in physical capacity. Our findings indicate no differences in total physical activity scores between subjects with TKA and control subjects. The physical activity questionnaire for elderly people[30] used in our study divides activities into low, medium, and high categories. It was evident that few of either the control subjects or the subjects with TKA were active in more physically demanding activities (ie, sporting activities). Only 38% of the subjects with TKA and only 47% of the control subjects reported involvement in any sporting activity during the previous year. Spontaneous resumption of low-intensity activities did not appear to be an adequate stimulus to rebuild muscle torque, total work, or aerobic condition, nor was the resumption of active living adequate to reduce obesity.

Impairment in muscle function was evident from the reductions in mean peak torque and total work for knee flexion and extension. Force generation is expected to decrease as the speed of movement increases,[40] but this decrease was not observed in our female subjects with TKA. We also expected that functional deficits would relate to the degree of muscle atrophy assessed by anthropometry. We found no such relationship. No reduction in muscle volume was evident in the male subjects with TKA when compared with the control subjects, and the female subjects with TKA had a greater muscle volume and estimated cross-sectional area compared with the control subjects (Tab. 2). Clinical examination of the study participants ruled out thigh edema as a contributing factor. Given Overend and colleagues' poor success in validating estimates of thigh cross-sectional area and volume using computed tomography (CT) in groups of young and old men[41] and Sipila and Suominen's finding of no relationship between either cross-sectional area or lean tissue to isometric quadriceps femoris muscle strength when measured by CT scan and ultrasonography in 66- to 85-year-old female athletes and age-matched controls,[42] perhaps our finding is not surprising. The explanation for this discrepancy may be twofold. First, changes in intramuscular fat would not be detectable with the anthropometric measures used in our study. Second, changes in neuromuscular recruitment that may alter mean torque output were not evaluated.

Using the limb without the TKA as a control, as other researchers[43,44] have done, may underestimate the magnitude of the deficit in the limb with the TKA. Jevsevar et al[15] suggested that it may not be appropriate to use the side without the TKA as a comparison because bilateral OA or reduced activity consequent to OA may impair function of the limb without the TKA. The subjects with TKA had lower peak torque and total work values for the limb without the TKA compared with the control subjects. The reduced muscle performance may be due to continuing effects of inactivity both before and following surgery or to nonsymptomatic OA of the knee without the TKA. Questionnaire responses did not reveal differences in physical activity between the control subjects and the subjects who had undergone TKA. The absence of a difference in thigh cross-sectional area and estimated muscle volume suggests that decreased muscle size does not explain all of the group differences (Tab. 2).

Walking and stair climbing have been identified by clinicians and patients[15,45,46] as critical functional activities. Our findings suggest that although TKA is very successful in reducing knee pain (a prime motivation for surgery), patients are still limited in their functional activities compared with their age-matched counterparts. When the normal SPW speed of our subjects with TKA was compared with the locally required speed to cross a traffic intersection (1.2 m/s),[47] it became clear that a large proportion of these individuals (55%, n=16) must walk at a faster pace than they normally use in order to successfully clear the intersection before the light changes. Indeed even at the fast walking pace, 17% (n=5) of these individuals would not be able to cross safely at a typical city intersection.

Our analyses suggest that men and women are affected to differing degrees by TKA. Female subjects with TKA demonstrated greater functional limitations on the stair-climbing test, with slower times and increased pain and exertion. Male subjects with TKA demonstrated smaller deficits during the stair-climbing test but larger decreases in muscle strength and local muscular endurance. Performance on the SPW test at both normal and fast paces was reduced more in the female subjects, placing many more of them (62% at a normal pace and 31% at a fast pace, compared with 25% and 6%, respectively, for the male subjects) below the threshold required for safe crossing of street intersections. Our findings suggest that data for men and women regarding walking, stair-climbing performance, and concentric knee strength and local muscular endurance should not be pooled.

Pain is a critical aspect of disability due to OA that can be resolved successfully by surgery.[48] One year postoperatively, little pain was reported in activities such as walking, stair climbing, and concentric muscle strength testing.[29] Yet, in the relative absence of pain, physical capacity remains diminished. The consequences of a diminished physical capacity are evident in slower walking speeds and a higher physiological cost demanding greater exertion during physical activity.

The most serious consequences of reduced physical capacity may be evident as aging further reduces the reserve capacity of these individuals. Adequate reserve capacity is an important factor in the ability of older adults to maintain their independence. A rehabilitation program that focuses on weight reduction and aerobic conditioning may enhance the ability of individuals with TKA to perform important activities such as walking and stair climbing. This program may benefit patients with orthopedic problems in the years immediately following the surgery and, perhaps more importantly, may also help preserve their reserve capacity and allow them to maintain functional independence for a longer period in the future.

Acknowledgments

We express our appreciation to Deborah Kennedy, BSc(PT), for her contribution to the development of measures and proposal design; to the study participants for their enthusiasm; and to Sharon Thornton, BSc(PT&OT), Director of Rehabilitation, Orthopaedic and Arthritic Hospital, for providing an environment that fosters rehabilitation research.

References

1 Felson DT, Naimark A, Anderson J, et al. The prevalence of knee osteoarthritis in the elderly. *Arthritis Rheum.* 1987;30:914–918.

2 Kovar PA, Allegrante JP, Mackenzie CR, et al. Supervised fitness walking in patients with osteoarthritis of the knee: a randomized controlled trial. *Ann Intern Med.* 1992;116:529–534.

3 Quam JP, Michet CJ, Wilson MG, et al. Total knee arthroplasty: a population-based study. *Mayo Clin Proc.* 1991;66:589–595.

4 Verbrugge LM. Women, men, and osteoarthritis. *Arthritis Care & Research.* 1995;8:212–220.

5 Nagi S. Disability concepts revisited: implications for prevention. In: Pope AM, Tarlov AR, eds. *Disability in America: Toward a National Agenda for Prevention.* Washington, DC: National Academy Press; 1991:309–327.

6 Bland JH, Cooper SM. Osteoarthritis: a review of the cell biology involved and evidence for reversibility—management rationally related to known genesis and pathophysiology. *Semin Arthritis Rheum.* 1984;14:106–133.

7 Laughman RK, Stauffer RN, Ilstrup DM, Chao EYS. Functional evaluation of total knee replacement. *J Orthop Res.* 1984;2:307–313.

8 Andriacchi TP. Biomechanics and gait analysis in total knee replacement. *Orthop Rev.* 1988;17:470–473.

9 Flett JL, Burnham RS, Saboe L, et al. Effect of measurement time and mode on amount of flexion following total knee arthroplasty. *Canadian Journal of Rehabilitation.* 1992;5:145–149.

10 Kantz M, Harris W, Levitsky K, et al. Methods for assessing condition-specific and generic functional status outcomes after total knee replacement. *Med Care.* 1992;30:MS240–MS252.

11 Ritter MA, Albohm MJ, Keating EM, et al. Comparative outcomes of total joint arthroplasty. *J Arthroplasty.* 1995;10:737–741.

12 McGuigan FX, Hozack WJ, Moriarty L, et al. Predicting quality-of-life outcomes following total joint arthroplasty. *J Arthroplasty.* 1995;10:742–747.

13 Kroll MA, Otis JC, Sculco TP, et al. The relationship of stride characteristics to pain before and after total knee arthroplasty. *Clin Orthop.* 1989;239:191–195.

14 Berman AT, Bosacco SJ, Israelite C. Evaluation of total knee arthroplasty using isokinetic testing. *Clin Orthop.* 1991;271:106–113.

15 Jevsevar DS, Riley PO, Hodge WA, Krebs DE. Knee kinematics and kinetics during locomotor activities of daily living in subjects with knee arthroplasty and in healthy control subjects. *Phys Ther.* 1993;73:229–242.

16 *Canadian Standardized Test of Fitness (CSTF) Operations Manual.* 3rd ed. Ottawa, Ontario, Canada: Fitness and Amateur Sport Canada; 1987.

17 Chumlea WC, Roche AF, Rogers E. Replicability for anthropometry in the elderly. *Hum Biol.* 1984;56:329–337.

18 Malina RM, Roche AF. *Manual of Physical Status and Performance in Childhood, Volume 2: Physical Performance.* New York, NY: Plenum Publishing Corp; 1983.

19 Wilmore JH, Behnke AR. An anthropometric estimation of body density and lean body weight in young women. *Am J Clin Nutr.* 1970;23:267–274.

20 Jones P, Pearson P. Anthropometric determination of leg fat and muscle plus bone volumes in young male and female adults. *J Physiol Paris.* 1969;294:63–66.

21 Clarkson HM, Gilewich GB. *Musculoskeletal Assessment: Joint Range of Motion and Manual Muscle Strength.* Baltimore, Md: Williams & Wilkins; 1989:14.

22 Watkins MA, Riddle DL, Lamb RL, Personius WJ. Reliability of goniometric measurements and visual estimates of knee range of motion obtained in a clinical setting. *Phys Ther.* 1991;71:90–97.

23 Rothstein JM, Miller PJ, Roettger RF. Goniometric reliability in a clinical setting: elbow and knee measurements. *Phys Ther.* 1983;63: 1611–1615.

24 Norkin CC, White DJ. *Measurement of Joint Motion: A Guide to Goniometry.* Philadelphia, Pa: FA Davis Co; 1987:88.

25 Patterson LA, Spivey WE. Validity and reliability of the LIDO Active isokinetic system. *J Orthop Sports Phys Ther.* 1992;15:32–36.

26 Bassey EJ, Fentem PH, MacDonald IC, Scriven PM. Self-paced walking as a method for exercise testing in elderly and young men. *Clin Sci.* 1976;51:609–612.

27 Borg GAV. Psychophysical bases of perceived exertion. *Med Sci Sports Exerc.* 1982;14:377–381.

28 Cunningham DA, Rechnitzer PA, Donner AP. Exercise training and the speed of self-selected walking pace in men at retirement. *Canadian Journal of Aging.* 1986;5(1):12–26.

29 Walsh M. *Functional Outcome Measures: Individuals One Year Post Total Knee Arthroplasty Versus Healthy Controls.* Toronto, Ontario, Canada: University of Toronto; 1995. Master's thesis.

30 Voorrips LE, Ravelli AC, Dongelmans PC, et al. A physical activity questionnaire for the elderly. *Med Sci Sports Exerc.* 1991;23:974–979.

31 Baecke JA, Burema J, Frijters JE. A short questionnaire for the measurement of habitual physical activity in epidemiological studies. *Am J Clin Nutr.* 1982;36:936–942.

32 Bink B, van der Sluys BH. Assessment of the Energy Expenditure by Indirect Time and Motion Study. In: Edang EK, Anderson KL, eds. *Physical Activity in Health and Disease: Proceedings of the Bertostolen Symposium.* Oslo, Norway: Oslo University; 1996:207–214.

33 Hochberg MC, Lethbridge-Cejku M, Scott WWJ, et al. The association of body weight, body fatness, and body fat distribution with osteoarthritis of the knee: data from the Baltimore Longitudinal Study of Aging. *J Rheumatol.* 1995;22:488–493.

34 Sackett DL. Bias in analytic research. *J Chronic Dis.* 1979;32:51–63.

35 Himann JE, Cunningham DA, Rechnitzer PA, Paterson DH. Age-related changes in speed of walking. *Med Sci Sports Exerc.* 1988;20:161–166.

36 Mattsson E, Brostom LA, Linnarsson D. Changes in walking ability after knee replacement. *Int Orthop.* 1990;14:277–280.

37 Messier SP, Loeser RF, Hoover JL, et al. Osteoarthritis of the knee: effects on gait, strength, and flexibility. *Arch Phys Med Rehabil.* 1992;73:29–36.

38 Weidenhielm L, Olsson E, Brostrom LA, et al. Improvement of gait one year after surgery for knee osteoarthritis: a comparision between high tibial osteotomy and prosthetic replacement in a prospective randomized study. *Scand J Rehabil Med.* 1993;25:25–31.

39 Andriacchi TP. Functional analysis of pre- and post-knee surgery: total knee arthroplasty and ACL reconstruction. *J Biomech Eng.* 1993; 115:575–581.

40 Lieber RL. *Skeletal Muscle Physiology: Skeletal Muscle Structure and Function—Implication for Rehabilitation and Sports Medicine.* Baltimore, Md: Williams & Wilkins; 1992:60–61.

41 Overend TJ, Cunningham DA, Paterson DH, Lefcoe MS. Anthropometric and computed tomographic assessment of the thigh in young and old men. *Can J Appl Physiol.* 1993;18:263–273.

42 Sipila S, Suominen H. Knee extension strength and walking speed in relation to quadriceps muscle composition and training in elderly women. *Clin Physiol.* 1994;14:433–442.

43 Gross MT, Credle JK, Hopkins LA, Kollins M. Validity of knee flexion and extension peak torque prediction models. *Phys Ther.* 1990;70:3–10.

44 Krebs DE. Isokinetic, electrophysiologic, and clinical function relationships following tourniquet-aided arthrotomy. *Phys Ther.* 1989;69: 804–815.

45 Bellamy N, Buchanan WW. A preliminary evaluation of the dimensionality and clinical importance of pain and disability in osteoarthritis of the hip and knee. *Clin Rheumatol.* 1986;5:231–241.

46 Ettinger WH, Afable RF. Physical disability from knee osteoarthritis: the role of exercise as an intervention. *Med Sci Sports Exerc.* 1994;26: 1435–1444.

47 Homberger WS, Keefer LE. Driver and pedestrian characteristics. In: Baerwald JE, ed. *Transportation and Traffic Engineering Handbook.* 2nd ed. Englewood Cliffs, NJ: Institute of Traffic Engineers; 1982:58–61.

48 McAlindon TE, Cooper C, Kirwin JR, Dieppe PA. Determinants of disability in osteoarthritis of the knee. *Ann Rheum Dis.* 1993; 52:258–262.