Indoor and Outdoor Mobility following Total Knee Arthroplasty

Ava S.T. Storey, MPT, BSc;* Ainslie M. Myrah, MPT, BKin;* Robyn A. Bauck, MPT, BKin;* Danielle M. Brinkman, MPT, BSc;* Shawn N. Friess, MPT, BKin;* Sandra C. Webber, PhD, MSc, BMR (PT)[†]

ABSTRACT

Purpose: To determine the relationship between indoor and outdoor mobility capacity in older adults with unilateral total knee arthroplasty (TKA) and, secondarily, to determine walking intensity in the same population and to compare all outcomes to a control group of older adults without knee pathology. **Method:** In this cross-sectional study, participants (TKA = 16, mean 22.9 (SD 9.7) mo post TKA; control = 22) completed indoor walking tests and a 580 m outdoor course that included varying terrain (e.g., curbs, grass, sidewalk) and frequent changes in direction. Walking capacity was assessed using stopwatches, global positioning system watches and accelerometers. **Results:** Outdoor walking time was moderately correlated ($p < 0.05$) with the timed up-and-go (TUG) test ($r = 0.65$), stair-climb test (SCT) ($r = 0.67$ ascending, $r = 0.79$ descending), 10 m walk test (10 mWT) ($r = 0.73$), and 6-minute walk test (6 MWT) ($r = -0.75$). Based on activity counts, walking intensity levels for participants in both groups were moderate (outdoor walk and 6 MWT). There was no significant difference in walking capacity between groups (TUG, SCT, 10 mWT, 6 MWT, outdoor walk). **Conclusions:** Common clinical walking tests are moderately correlated with outdoor mobility. Mobility capacity of individuals post TKA was similar to controls in both indoor and outdoor environments, and participants in both groups achieved moderate physical activity levels with walking.

Key Words: aged; osteoarthritis; outcome assessment; walking.

RÉSUMÉ

Objectifs : En premier lieu, établir la relation entre la capacité de mobilité à l'intérieur et à l'extérieur chez les aînés qui ont subi une arthroplastie unilatérale totale du genou (TKA); en second lieu, évaluer l'intensité de la marche chez les mêmes individus et comparer tous les résultats à l'aide d'un groupe de contrôle composé d'aînés n'ayant aucune pathologie du genou. **Méthodologie :** Dans le cadre d'une étude transversale, les participants (TKA = 16, moyenne de 22,9 [écart-type 9,7] mois après TKA; groupe de contrôle = 22) ont effectué des tests de marche à l'intérieur et ont marché sur un parcours extérieur de 580 m sur divers types de surfaces (p. ex. bordure de chaussée, gazon, trottoir), avec changements de direction fréquents. La capacité de marche a été évaluée à l'aide de montres chronomètres, de GPS et d'accéléromètres. **Résultats :** Le temps de marche à l'extérieur était modérément corrélé ($p < 0,05$) avec un test TUG (*timed up-and-go*); ($r = 0,65$), un test de l'escalier (*stair-climb test*, SCT) ($r = 0,67$ en montée, $r = 0,79$ en descente), un test de marche de 10 mètres (10 mWT); ($r = 0,73$), et un test de marche de 6 minutes (6 MWT); ($r = -0,75$). En fonction du décompte des activités, les niveaux d'intensité pendant la marche pour les participants des deux groupes étaient modérés (marche à l'extérieur et 6 MWT). Il n'y a pas eu de différence significative dans la capacité de marche entre les deux groupes (pour le TUG, le SCT, le 10 mWT, le 6 MWT, et la marche à l'extérieur). **Conclusions :** Les tests de marche cliniques habituellement utilisés sont corrélés de façon modérée avec la mobilité à l'extérieur. La capacité de mobilité chez les personnes post-TKA était similaire aux participants du groupe de contrôle à l'intérieur comme à l'extérieur, et les participants des deux groupes sont parvenus à un niveau d'activité physique modérée grâce à la marche.

Osteoarthritis is one of the leading causes of functional limitation in older adults.¹ Severe knee osteoarthritis is often treated surgically with total knee arthro-

plasty (TKA). There has been a steady increase in the number of TKA surgeries performed each year in Canada, from approximately 14,000 in 2003–2004 to more than

From the: *School of Physical Therapy, College of Medicine, University of Saskatchewan, Saskatoon; †Department of Physical Therapy, School of Medical Rehabilitation, Faculty of Medicine, University of Manitoba, Winnipeg.

Correspondence to: Dr. S. Webber, Department of Physical Therapy, School of Medical Rehabilitation, Faculty of Medicine, University of Manitoba, R106–771 McDermott Ave., Winnipeg, MB R3E 0T6; sandra.webber@med.umanitoba.ca.

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21,000 in 2009–2010.² Although this procedure is highly successful in reducing the pain associated with osteoarthritis, some research suggests that strength and functional deficits may persist beyond the initial stages of surgical recovery.^{3–7}

Typically, the most substantial gains in physical function occur in the first few months following TKA.⁸ Early recovery (up to 6 months after surgery) has been studied extensively in terms of changes in pain, strength, range of motion, and functional mobility.^{6,7,9–11} However, there is limited information about mobility capacity (i.e., mobility measured in standardized environments) beyond this time frame in people with TKA.^{5,12} Moreover, existing studies rely largely on self-report measures, rather than objective measures of function, for longer-term follow-up.^{4,12–14} Although subjective measures are often more cost effective and easier to administer, they have been shown to be both less reliable and less effective than objective measurements at detecting changes in functional mobility.⁸ Because community mobility makes a positive contribution to quality of life and continuing independence for older adults,^{15,16} functional assessments should reflect a person's ability to perform in a variety of environmental conditions. Studies have found that after TKA, more than one-quarter of people continue to have difficulty in completing daily activities such as shopping, and in general gait speeds remain slower than those without TKA.^{12,17,18} However, there has been little research into the relationship between objective clinical walking tests and mobility capacity in more unpredictable outdoor environments.

While *mobility* can be broadly defined as the ability to move oneself (e.g., by walking, wheeling, or driving) within community environments, expanding from one's home to regions beyond,¹⁹ Patla and Shumway-Cook²⁰ developed a framework specific to outdoor ambulatory mobility that describes the impact of the physical environment and emphasizes eight environmental dimensions: the ability to walk a minimum distance and to deal with varying time constraints, ambient conditions, terrain characteristics, external physical loads, attentional demands, postural transitions, and traffic levels.²⁰ A recent review by Corrigan and McBurney²¹ supported this conceptual framework, noting that the most common environmental factors identified by researchers as influencing community ambulation are walking distance, gait speed, and terrain characteristics (e.g., curbs, inclines, stairs; different surfaces such as carpet or sand). Corrigan and McBurney also identified 14 research assessment tools that incorporate elements relevant to community ambulation, but none of these tools evaluates more than 4 of Patla and Shumway-Cook's 8 environmental dimensions, and the majority are designed to be conducted indoors, often with in-patients (e.g., Functional Index Measure,²² Stroke Impact Scale,²³ Dynamic Gait Index²⁴).

In response to the lack of tools available for comprehensive assessment of outdoor mobility and the discrep-

ancies noted between subjective and objective outcome measures, researchers have become increasingly interested in exploring the use of technology to track outdoor mobility. Thanks to the development of commercially available global positioning system (GPS) devices, we now have economical and reliable ways to collect objective data in free-living outdoor environments.^{25–28} GPS receivers can provide information about the timing, location, elevation, and speed of outdoor movement. Because they cannot reliably track indoor movement,^{27,29} however, other devices such as accelerometers can be used (both indoors and outdoors) to provide additional relevant information about the timing of activity bouts, steps (e.g., step counts, steps/minute), and intensity of physical activity. Used together, these technologies have the potential to deliver comprehensive information about people's mobility in both indoor and outdoor environments.

People who require TKA surgery are frequently overweight or obese and at higher risk for decreased mobility, leading to a more sedentary lifestyle, which in turn can negatively affect overall health and quality of life. The primary purpose of our study was to evaluate both indoor and outdoor mobility in people more than 6 months post TKA to determine the relationship between common objective clinical walking tests and mobility capacity in an outdoor environment. We chose several common indoor walking tests to represent many of the dimensions important for community ambulation (short- and long-distance timed walks and tests that involve transitions from sitting to standing, turning around cones, and negotiating stairs). Similarly, the outdoor walking course was designed to include many of these features (e.g., timed walking sections, varying terrain, attention to traffic, and frequent changes in direction). Secondarily, we were interested in determining the levels of physical activity (PA) intensity achieved during indoor and outdoor walking tests of similar duration with varying environmental challenges (e.g., temperature, terrain characteristics) and in comparing the mobility capacity of post-TKA patients to that of a control group without knee pathology.

METHODS

Study design and recruitment

Our study used a cross-sectional design. We recruited participants between April and September 2011, using posters, newspaper advertisements, and a mail-out by two local surgeons.

Participants

People aged 55–80 years who had undergone unilateral TKA (for osteoarthritis) more than 6 months but less than 5 years before the study were eligible to participate. Potential TKA participants were excluded if they used a gait aid, had undergone bilateral TKA surgery, or planned further TKA surgery within the next 12 months. We also

recruited control participants without knee pathology; potential participants were excluded if they were unable to walk short distances or had underlying medical conditions that limited their participation in physical activities (screened using the Physical Activity Readiness Questionnaire, PAR-Q).³⁰ Answers to the PAR-Q were reviewed by a physical therapist, and if potential contraindications to participation were identified (e.g., suspected or confirmed recent or uncontrolled cardiovascular or neuromusculoskeletal condition), participants were required to have their physician fill out a Physical Activity Readiness Medical Examination (PARmed-X)³¹ in order to participate. The Biomedical Research Ethics Board of the University of Saskatchewan granted ethical approval for this study, and participants provided written informed consent before testing began.

Procedures

Testing was conducted on the University of Saskatchewan campus in Saskatoon between June and September 2011. Each participant attended one session lasting 75–90 minutes. Participants attended in groups of three or four and completed the testing stations in random order after vital signs and knee active range of motion (AROM) were recorded and the questionnaires were completed. Six evaluators (five Master of Physical Therapy students and a physical therapist) were trained in the testing procedures and assigned to consistent stations for testing.

Outcome measures

Vitals signs and knee active range of motion

Before each participant performed the walking tests, his or her weight, height, heart rate (HR), blood pressure (BP), and knee AROM were measured. Radial pulse was monitored over 30 seconds to determine HR; BP was measured with a manual sphygmomanometer. AROM was measured with a goniometer for the surgical knee for TKA participants and for the dominant leg (the leg the participant reported using to kick a ball) for control participants.

Knee Outcome Survey—Activities of Daily Living (KOS-ADL) questionnaire

The KOS-ADL questionnaire, used to assess patient-reported functional limitations caused by knee pathology and impairment during ADL,³² is a 14-item scale that includes 6 questions about how knee symptoms affect ability to perform general daily activities (e.g., “How much does pain affect daily activity?”) and 8 questions about how the respondent manages specific functional tasks (e.g., walking, squatting). Each item is scored from 0 to 5, for a maximum possible score of 70; higher scores indicate higher levels of function.

Accelerometry

For all tests, each participant wore an ActiGraph GT3X+ activity monitor (4.6 × 3.3 × 1.5 cm, 19 g; ActiGraph, Pensacola, FL) on an elastic belt around the waist, with

the activity monitor positioned over the right anterior axillary line. Step counts and information on PA intensity were acquired from the accelerometer data. ActiLife5 analysis software (ActiGraph, Pensacola, FL) was used to initialize the GT3X+ monitors to collect tri-axial data (vertical, antero-posterior, and medio-lateral planes) at a sampling frequency of 100 Hz. The GT3X+ detects accelerations ranging between −6g and +6g. A total of 14 GT3X+ activity monitors were used in this study.

Outdoor walking capacity

For the outdoor walking test, each participant wore two Garmin Forerunner 305 GPS watches (5.3 × 6.9 × 1.8 cm, 77 g; Garmin International Inc., Olathe, KS), one on each wrist. Garmin GPS devices have been shown to accurately measure a variety of walking speeds in similar testing situations.^{26,27} All participants walked the same outdoor route, located outside the Physical Activity Complex on the University of Saskatchewan campus. The route involved walking approximately 75 m on a sidewalk, crossing a two-lane road with a curb on each side, ascending and descending a 75 m ramp, walking 100 m on grass, crossing a two-lane road with a curb on each side, walking 100 m on a sidewalk, and walking approximately 70 m in a parking lot (including ascending and descending a set of 4 stairs). Participants were asked to pause for approximately 10 seconds between sections on the outdoor course, both to ensure that they understood where the next checkpoint was located and to facilitate later recognition of the different sections of the course in the accelerometer data. On the outdoor course, participants were supervised by two testers, who always stayed one and two checkpoints ahead of the participant, respectively, so as not to influence participants' walking speed. (When the participant left a checkpoint, the tester at that station would then proceed to the station after the next.) Generally, participants encountered light pedestrian and vehicular traffic during testing. They were instructed to walk at their normal walking speed, and all used identical footwear and eyeglasses (if required) for both indoor and outdoor tests. Data gathered on the outdoor walk included physical activity intensity (accelerometry), number of steps during 100 m sections on grass and sidewalk (accelerometry), time (stopwatch and GPS), best pace, and distance (GPS).

Weather conditions were noted, based on Environment Canada data (http://www.weatheroffice.gc.ca/canada_e.html), at the start of testing for each group of participants. No testing was conducted if it was raining or if the temperature was >25°C. Temperatures on the testing days ranged from 13°C to 24°C, with a mean of 20°C (SD 4°C); winds ranged from 5 to 43 km/h, with a mean of 16 (SD 9) km/h.

6-minute walk test (6 MWT)

Participants completed the 6 MWT on a 200 m oval indoor track. Total distance walked in 6 minutes was

recorded (in metres), and accelerometry data were collected throughout the test to allow for quantification of PA intensity. Participants were instructed to walk at a comfortable pace that they could maintain for 6 minutes. The 6 MWT, a sub-maximal functional walking test used to measure exercise endurance,³³ has been shown to predict community independence and mobility and to be valid and reliable in older adults.^{34,35}

10 m walk test (10 mWT)

For the 10 mWT, participants walked 14 m, only the middle 10 m of which were timed (2 m were added at each end to allow for acceleration and deceleration). Each participant performed the test twice; the second trial was recorded. They were instructed to walk at a fast pace. The 10 mWT has been shown to be valid and reliable in older adults.^{36,37}

Timed up-and-go (TUG)

Participants performed the TUG test using a chair with a height of 46 cm and a walking distance of 3 m. They were instructed to stand up from the chair (using the armrests if necessary), walk forward until they crossed the taped line on the floor (3 m from the chair), turn around, and return to a seated position in the chair. Each participant performed two trials at a normal walking pace; the second trial was recorded. The TUG test has been shown to be reliable and to have functional content validity in measuring basic functional mobility in older adults after TKA.^{38,39}

Stair-climb test (SCT)

For the SCT, participants were timed as they descended, then ascended, a flight of 13 stairs with a step height of 17.8 cm. Participants were instructed to walk at a fast but safe pace. Ascending and descending times were recorded separately. Longer times for the SCT have been shown to indicate poorer function.⁴⁰

Data analysis

Data used to examine the relationship between indoor and outdoor walking tests in this study included the timed results from the outdoor walk (total time, time for 100 m on grass, time for 100 m on sidewalk, time on ramp), 10 mWT, TUG, and SCT, as well as the distance achieved in the 6 MWT. Data relevant to our secondary objectives included PA intensity measures derived from the accelerometers for the 6 MWT and the outdoor walk, as well as a comparison of the measures listed above for TKA and control participants. In addition, we compared distance walked and best pace (determined by GPS), along with the accelerometer step recordings for the grass and sidewalk sections of the outdoor walk, which we used to determine step length on these sections of the route.

To review the accelerometer data, we downloaded the ActiGraph GT3X+ activity monitor data using ActiLife5 analysis software (ActiGraph, Pensacola, FL). Files were created with step counts calculated in 1-second epoch

lengths. We calculated total steps for the outdoor walk grass and sidewalk sections, as well as calculating average stride length (m), using 100 m/number of steps, for each participant on grass and on the sidewalk. In addition, we created files in 60-second epochs and used ActiLife5's data-screening function to determine periods of activity during the outdoor walking test. For both the 6 MWT and the outdoor walk, activity counts per minute recorded in the vertical axis and vector magnitude counts (incorporating data from all three axes) were then exported to SigmaPlot version 11.0 (Systat Software, Inc., Chicago, IL) to allow for comparison of PA intensity levels during walking bouts using cut-points taken from existing literature.^{41–43} These cut-points (based on activity counts per minute determined from accelerometry data) are used to categorize PA intensity levels as light (<3 metabolic equivalent units [METs]), moderate (3–6 METs), or vigorous (>6 METs).^{42,44}

We uploaded GPS data for the outdoor walk to the Garmin Connect Web site (<http://connect.garmin.com/>), which allowed us to generate summary reports that included moving time, elapsed time, average moving pace, distance, best pace, and average pace. The data were also saved in KML format appropriate for spreadsheet analysis (MS Excel 2010, Microsoft Corp., Redlands, CA) and for viewing in Google Earth (Google, Inc., Mountain View, CA). We used Google Earth's mapping service to review each participant's exact path on the outdoor course. Although all participants were accompanied by two testers on the outdoor route and continually pointed in the direction of the next checkpoint, they did not all walk exactly the same path, and the differences produced slight variations in route distance. Because each participant wore two GPS watches, if GPS data from the primary watch did not represent a complete route, as was the case for three of our participants, data from the second watch were used. For two participants, no useful GPS data were acquired from either watch.

Statistical analyses were conducted using SigmaPlot and Minitab version 15.1.30.0 (Minitab Inc., State College, PA). Our sample-size calculations were based on 6 MWT distances recorded for people after TKA^{11,18} and on normative values⁴⁵ (expected mean difference = 110 m, expected SD = 100 m, two groups with $\alpha = 0.05$, desired power = 0.8). We determined that 15 individuals were required in each group (two-tailed *t*-test).

We calculated descriptive statistics as mean and standard deviation for normally distributed variables and as median and range for those not normally distributed. Independent *t*-tests and Mann–Whitney rank sum tests were used to examine group differences (for parametric and non-parametric data respectively) in the demographic data. We calculated effect sizes (delta index)⁴⁶ when group differences were found.⁴⁷

Multivariate analyses (MANOVAs) were used because the study included multiple related dependent variables

Table 1 Characteristics of the Participants

Variable	Group, mean (SD)*		<i>p</i> -value	Effect size
	Control (<i>n</i> = 22)	TKA (<i>n</i> = 16)		
Age, y	66.3 (4.8)	68.4 (6.5)	0.25	–
BMI, kg/m ²	27.0 (5.5)	29.3 (4.8)	0.45	–
Self-reported health conditions, median no. (range)	2 (0–6)	3 (2–5)	0.028†	0.60
AROM knee, degrees	128 (7)	114 (9)	<0.001†	1.98
KOS-ADL score, median (range)	66.5 (50–70)	62.0 (42–70)	0.030†	0.97

*Except where indicated. Non-normally distributed variables are reported as median (range).

†Significant at *p* < 0.05.

TKA = total knee arthroplasty; BMI = body mass index; AROM = active range of motion; KOS-ADL = Knee Outcome Survey—Activities of Daily Living.

Table 2 Correlation Coefficients among Indoor and Outdoor Test Scores*

Indoor parameters	Total outdoor time	Outdoor parameters		
		Time on		
		Grass	Sidewalk	Ramp
TUG	0.65	0.47	0.61	0.49
SCT (ascending)	0.67	0.49	0.49	0.44
SCT (descending)	0.79	0.62	0.61	0.66
10 mWT	0.73	0.60	0.66	0.63
6 MWT distance	–0.75	–0.73	–0.69	–0.71

*All correlations were statistically significant at *p* < 0.05.

TUG = timed up-and-go test; SCT = stair-climb test; 10 mWT = 10 m walk test; 6 MWT = 6-minute walk test.

(indoor and outdoor walking tests). We used separate MANOVAs to test for group differences among the indoor walking tests (6 MWT, 10 mWT, TUG, stair ascent, stair descent) and the outdoor walking components (total time, best pace, 100 m grass time, 100 m sidewalk time, average stride length on grass, average stride length on sidewalk, ramp ascent, ramp descent). The relationships among indoor and outdoor walking tests were evaluated with Pearson product-moment and Spearman rank-order correlation coefficients.

RESULTS

Participants

A total of 38 people (16 TKA, 22 control) participated in the study; their mean time since TKA was 22.9 (SD 9.7) months. Two participants in the TKA group had resting BP values >160/105 and were not permitted to attempt the 6 MWT, the SCT, or the outdoor walking test. Table 1 shows descriptive characteristics for the participants. The TKA group showed significantly less knee flexion AROM (*p* < 0.001), lower KOS-ADL scores, (*p* = 0.030), and more self-reported health conditions (*p* = 0.028) than the control group.

Relationship between indoor and outdoor walking test measures

Correlation coefficients for relationships among indoor tests and outdoor walking components are shown in Table 2. All correlations were found to be statistically significant (*p* < 0.050). All indoor tests were moderately correlated with the outdoor walking test as a whole, as well as with separate parts of the test (e.g., ramp ascent, 100 m on grass); we found the strongest relationships between outdoor walk time and time to descend stairs (*r* = 0.79), 10 mWT (*r* = 0.73), and 6 MWT distance (*r* = –0.75).

Comparison of TKA and control groups

The MANOVA group × test interactions were not significant for either indoor walking tests (*p* = 0.92) or outdoor walking tests (*p* = 0.93), which indicates that there were no significant differences in walking results between control participants and those with TKA. Group results are presented in Table 3.

Intensity of physical activity

Average PA intensity was evaluated for each participant during the 6 MWT and the outdoor walk test, using established vertical acceleration cut-points^{41,44} and re-

Table 3 Comparison of TKA Group and Control Group for Indoor and Outdoor Walking Tests

Variable	Group; mean (SD) or median (range)*	
	Control, <i>n</i> = 22†	TKA, <i>n</i> = 14‡
Indoor tests		
6 MWT distance, m	591.1 (70.6)	576.4 (108.8)
10 mWT, s	7.0 (1.1)	6.3 (1.1)‡
TUG time, s	8.0 (1.2)	7.4 (1.2)‡
SCT ascending, s	6.9 (4.6–11.1)	6.3 (4.6–8.5)
SCT descending, s	6.6 (4.1–12.1)	6.4 (3.7–8.7)
Outdoor tests		
Total walk time, s	497 (444–696)	505 (445–577)
Best pace, m/s	1.92 (0.28)§	1.99 (0.27)
Outdoor walk distance, m	580 (560–600)§	580 (530–600)
100 m grass time, s	61 (55–82)	64 (54–76)
Average stride length on grass, m	0.80 (0.11)	0.79 (0.08)
100 m sidewalk time, s	62 (7)	62 (6)
Average stride length on sidewalk, m	0.81 (0.10)	0.80 (0.08)
Ramp ascent time, s	46 (42–64)¶	49.5 (50–59)
Ramp descent time, s	48 (7)¶	49 (6)

*Variables found to be normally distributed are reported as mean (SD); all other variables are reported as median (range).

† Unless otherwise noted.

‡ *n* = 16.

§ *n* = 20.

¶ *n* = 21.

TKA = total knee arthroplasty; 6 MWT = 6-minute walk test; 10 mWT = 10 m walk test; TUG = timed up-and-go test; SCT = stair-climb test.

cently developed vector magnitude cut-points.⁴² Although the vertical cut-points were originally proposed for an older ActiGraph model (model 7164),^{41,44} Sasaki and colleagues recently determined that vertical counts are comparable between older ActiGraph accelerometers and the newer GT3X models.⁴² Vertical acceleration cut-point analysis categorized the majority of participants' PA levels as "moderate" (3–6 METS)^{41,44} for the outdoor walk (20/22 control, 12/14 TKA) and the 6 MWT (20/22 control, 13/14 TKA). For the remaining participants in both groups, PA intensity was categorized as "light" (<3 METS). Categorizations of PA intensity using vertical acceleration cut-points and vector magnitude results agreed 87% of the time (538/617 min of data).

DISCUSSION

Our main objective in this study was to examine mobility capacity of older adults >6 months after TKA in both indoor and outdoor environments. The outdoor walking test used in the study included a ramp, stairs, curbs, and walking on concrete and grass. We found that results of common clinical walking tests were moderately correlated ($r = 0.65$ to 0.79) with the outdoor walking test time. The indoor and outdoor mobility capacity of the TKA participants, who, on average, had

undergone surgery 23 months earlier, was not significantly different from that of control participants.

While the outdoor walking route and the indoor walking assessments in our study included several different tests, all were chosen because they incorporated one or more dimensions important for community mobility.²⁰ It is not surprising, therefore, that indoor and outdoor mobility capacity were moderately correlated. The indoor walking tests included timed short distances (10 mWT) and moderate distances (6 MWT), sit-to-stand transfers (TUG), turning (TUG), and negotiating stairs (SCT). Thus, four mobility dimensions important for community mobility were evaluated indoors (minimum distance, time constraints, terrain, and postural transitions). These dimensions were also evaluated on the outdoor course, which was timed and covered approximately 580 m on different types of terrain (concrete, grass, curbs, stairs, and a ramp) as well as involving postural transitions (turning around cones), increased attentional demands to traffic (participants crossed a road twice), and variable weather conditions (temperatures from 13°C to 24°C and wind speeds from 5 to 43 km/h). Thus, the outdoor course used in our study represents a measure of outdoor ambulation capacity that may more realistically evaluate ability in the community environment than

Figure 1 Gait speed (continuous line—m/s) and steps/second data (dots—averaged over 10 s epochs) for a representative participant on the outdoor walking route: (A) walking to ramp, (B) walking up ramp, (C) walking down ramp, (D) walking 100 m on grass, (E) crossing a road, (F) walking 100 m on sidewalk, (G) walking in parking lot.

other tools designed to assess this characteristic using tests conducted indoors.

Our study represents the first comparison of indoor and outdoor walking capacity after TKA, but these relationships have previously been examined in people with chronic obstructive pulmonary disease (COPD),⁴⁸ peripheral arterial disease,²⁵ and stroke.^{49–51} Brooks and colleagues found no significant differences in 6 MWT distances, rest times, or ratings of perceived dyspnea in people with COPD when tests were conducted indoors and outdoors;⁴⁸ in their study, the outdoor 6 MWT was done on a sidewalk and proceeded only on days when the weather was reasonable for people with COPD (10–25°C, no precipitation, wind <20 km/h, air quality index <32). Similarly, studies comparing 6 MWT parameters measured in a typical clinical environment, along a suburban street, and in a shopping mall for people with stroke found small differences in speed, cadence, and step length that were not clinically significant.^{50,51} In people with peripheral arterial disease, maximal walking distance achieved in the park was found to be highly correlated with maximal walking distance on a treadmill (Spearman $r = 0.81$, $p = 0.001$),²⁵ the “gold standard” for estimating walking capacity of people with intermittent claudication. Similar to our study, Le Faucheur and colleagues^{25,26} used GPS devices to measure walking distances and speeds and to identify bouts of activity versus rest.

To illustrate the utility of using GPS for continuous monitoring of gait speed (and bouts of activity), Figure 1 shows data for a representative participant in our study. Gait speeds recorded with the GPS watch were plotted along with steps-per-second data from the accelerometer for the outdoor walk. As Figure 1 shows, GPS can provide much more detailed information about performance during different components of an outdoor walk than

can be gained from timing ambulation and calculating average gait speed over a certain distance. This information may be particularly valuable in evaluating mobility performance in non-standard environments when participants are not accompanied by testers around a pre-determined route. The results of this study build on previous research that has determined that GPS devices are accurate for identifying and quantifying defined bouts of activity^{26,27,29} when issues associated with wearing devices over a full day or many days (e.g., battery failure, incomplete GPS data acquisition) are less of a problem.^{27,29,52}

In addition to using GPS to measure outdoor walking parameters, we used accelerometry to detect participants' steps and quantify PA intensity during the 6 MWT and the outdoor walk. The majority of the walking tests for all participants were classified as “moderate” intensity,^{41,44} which suggests that participants were able to exert themselves at a level of 3–6 METS. Because the relationship between accelerometer counts and energy expenditure varies across age groups and patient populations, it is possible that our study participants were actually working at a higher intensity.^{43,53} For example, using cut-points specifically recommended for older adults⁵³ would have classified all 6 MWTs and outdoor walk tests in our study as moderately vigorous; using ActiGraph cut-points developed for older overweight people with type 2 diabetes mellitus⁴³ would have classified 90% of the walking tests (outdoor walks and 6 MWTs) as vigorous (6–9 METs). Regardless of the choice of cut-points used for analyses, participants in our study were, for the most part, able to sustain at least a moderate level of PA for the walking tests, which suggests that they were able to achieve intensity levels recommended for improved health⁵⁴ and more than adequate for independent function in the community.

The moderately strong correlations between components of the outdoor walking test and the clinical walking tests have positive implications for physical therapists and researchers using clinical tests to measure mobility in the TKA population after the acute recovery phase. Of the indoor walking tests we evaluated, the 6 MWT was the most consistently highly correlated with components of the outdoor walking test (see Table 2). The correlations between outdoor walking time and indoor walking test results ranged from 0.65 to 0.79; none of the values reached >0.80. Unpredictable factors that have the potential to affect outdoor mobility (e.g., vehicular or pedestrian traffic, variability in walking surface and lighting conditions, changes in wind speed or direction) may have influenced the relationships between indoor and outdoor results. Nevertheless, we found that people who performed well on typical mobility measures also functioned reasonably well in the outdoor environment, which is fundamental for active ageing, continuing independence, and quality of life.^{15,16}

Indoor and outdoor mobility capacity did not differ significantly between the TKA group and the control group. TKA participants in our study walked an average of 576 (SD 108.8) m in the 6 MWT, not significantly different from the control participants, who walked an average of 591.1 (SD 70.6) m. These 6 MWT distances are comparable to those reported for the 60- to 69-year-old age group in a previous study evaluating 444 healthy adults from seven countries.⁴⁵ They are also similar to those reported by Yoshida and colleagues for participants 12 months after TKA (mean 630 [SD 136] m, $n = 12$, mean age 61.3 (SD 6.9) y)¹⁷ and to results reported for people 6 months after surgery by Bade and colleagues (mean 543 [SD 118] m, $n = 102$, mean age 64.8 [SD 9.2] y)⁵⁵ and by Stevens-Lapsley and colleagues (mean 532 [SD 113] m, $n = 106$, mean age 65.3 [SD 9.2] y).⁵⁶ However, other reports have suggested that 6 MWT distances measured 6 months after surgery may be <500 m in this patient population.^{11,18} TUG results for our TKA participants averaged 7.4 (SD 1.2) seconds, slightly slower than times reported by Yoshida and colleagues (6.8 [SD 1.5] s)¹⁷ but faster than those reported by Bade and colleagues (9.1 [SD 2.4] s¹⁸ and 7.9 [SD 1.8] s⁵⁵) and by Stevens-Lapsley and colleagues (8.0 [SD 1.8] s). Taken together, these findings are promising, suggesting that many people are able to attain a post-TKA mobility level similar to that of age-matched peers who do not suffer from osteoarthritis or other disabling neuromuscular conditions and that improvements in mobility capacity may continue beyond 6 months after surgery.

In our study, the TKA group had significantly less knee flexion (114° [SD 9°] for TKA, 128° [SD 7°] degrees for control, $p < 0.001$) and significantly lower scores on the KOS-ADL questionnaire (62.0 for TKA, 66.5 for control, $p = 0.030$). These results concur, since several KOS-ADL items ask about kneeling, bending, and squatting abilities, which require large amounts of flexion. However, this ROM limitation did not appear to affect mobility capacity in the TKA group, likely because average flexion range was >110°, which has been determined to be the minimum flexion range required to perform common activities of daily living.⁵⁷

LIMITATIONS

Study participants attended the testing site and participated in the indoor and outdoor walking tests during a single visit. While the order of testing was randomized, and the reliability of the indoor walking tests has been established in previous studies,^{34,36,39} the reliability of the outdoor walking test was not evaluated. Despite this limitation, the fact that outdoor walking time was strongly correlated with the common indoor tests suggests that participants demonstrated consistent walking capacity across indoor and outdoor environments. Sample-selection bias and a relatively small sample size are also limitations of this study. People with higher levels of

function may be more likely to volunteer for mobility studies. However, it should be noted that our participants' 6 MWT and TUG results were comparable to those previously reported by other authors,^{17,55,56} which indicates that our participants were not highly unusual for this population. Our study also had a large component of outdoor testing, and weather variability between testing days may have affected performance; traffic variability may have also caused slight variations in time on the outdoor test. Although the results showed moderate relationships between indoor and outdoor mobility, the findings are specific to this population (e.g., relationships may differ for patients at different stages of recovery) and do not suggest that standardized tests can predict future performance. It should also be noted that our tests focused on ambulation in an outdoor environment and did not include any challenges such as carrying loads or walking in crowds, which are also important factors for ambulation in the community.²⁰

CONCLUSION AND RECOMMENDATIONS

Common clinical walking test results were found to be moderately correlated with outdoor mobility capacity in people more than 6 months post TKA and in healthy control participants. Despite significant reductions in knee AROM, the TKA group performed similarly to control participants walking in both indoor and outdoor environments that included managing stairs, ramps, longer distances, and different terrains. This suggests that, at least for some people, full recovery of outdoor walking capacity is possible after TKA surgery.

Because ours is one of the first studies to examine both indoor and outdoor mobility capacity objectively in people after TKA, further research is required to substantiate these results in a larger sample and to examine capacity at different stages of recovery. Using GPS and accelerometry is feasible and practical for evaluating walking on specific outdoor testing routes and for monitoring general PA. Because GPS devices and accelerometers have the capability to assess mobility in non-standardized environments (e.g., during daily life), further studies should make use of this technology to evaluate long-term mobility in indoor and outdoor free-living environments among older adults and different surgical populations.

KEY MESSAGES

What is already known on this topic

Although pain is significantly improved after total knee arthroplasty (TKA) for the majority of patients, strength and subjective follow-up measurements indicate that deficits remain, indicating a need for a more in-depth look at functional recovery. Very little is known about long-term mobility and relationships between indoor and outdoor walking capacity in people after TKA.

What this study adds

Findings from this study demonstrate that commonly used objective clinical measures such as the timed up-and-go, 6-minute walk test, stair-climb test, and 10 m walk test are moderately correlated with outdoor mobility capacity in this clinical population. The results also suggest that despite limitations in knee active range of motion, people with unilateral TKA can achieve mobility levels comparable to those of healthy older adults.

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