Muscle Strength and Functional Recovery During the First Year After THA

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Published online: 2 July 2013

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Abstract

Background Patients undergoing total hip arthroplasty (THA) often are satisfied with the decrease in pain and improvement in function they achieve after surgery. Even so, strength and functional performance deficits persist after recovery, but these remain poorly characterized; knowledge about any ongoing strength or functional deficits may allow therapists to design rehabilitation programs to optimize recovery after THA.

Questions/purposes The purposes of this study were to (1) evaluate postoperative muscle strength, function, and

quality of life during the first year after THA; and (2) compare strength and function in patients 1 year after THA with a cohort of healthy peers.

Methods Twenty-six patients undergoing THA were assessed 1, 3, 6, and 12 months postoperatively, and 19 adults with no hip pathology were tested as a control group. Isometric muscle strength (hip flexors, extensors, abductors, knee extensors, and flexors), functional performance (stair climbing, five times sit-to-stand, timed-up-and-go, 6-minute walk, and single-limb stance tests), and self-reported function (Hip Disability and Osteoarthritis Score, SF-36, and UCLA activity score) were compared.

Results One month after THA, patients had 15% less hip flexor and extensor torque, 26% less abductor torque, 14% less knee extensor and flexor torque, and worse performance on the stair climbing, timed-up-and-go, single-limb stance, and 6-minute walk. Compared with healthy adults, patients 12 months after THA had 17% less knee extensor and 23% less knee flexor torque; however, the functional testing (including stair climbing, five times sit-to-stand, and the 6-minute walk) showed no significant differences with the patient numbers available between individuals undergoing THA and healthy control subjects. SF-36 Physical Component Scores, although significantly improved from preoperative levels, were significantly worse than healthy adults 1 year after THA ($p < 0.01$).

This work was supported by NIH/NIA K23AG029978 (JS-L) and supported in part by NIH/NCATS Colorado CTSI UL1 TR000154. Additional funding was provided by the American College of Rheumatology REF/Abbot Health Professional Graduate Student Research Preceptorship Award (DJ). All ICMJE Conflict of Interest Forms for authors and *Clinical Orthopaedics and Related Research* editors and board members are on file with the publication and can be viewed on request. *Clinical Orthopaedics and Related Research* neither advocates nor endorses the use of any treatment, drug, or device. Readers are encouraged to always seek additional information, including FDA-approval status, of any drug or device prior to clinical use. Each author certifies that his or her institution 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. This work was performed at the University of Colorado Anschutz Medical Campus, Aurora, CO, USA.

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Conclusions Patients experience early postoperative strength losses and decreased functional capacity after THA, yet strength deficits may persist after recovery. This may suggest that rehabilitation may be most effective in the first month after surgery.

Level of Evidence Level II, therapeutic study. See the Guidelines for Authors for a complete description of levels of evidence.

Introduction

Individuals are often satisfied with their immediate postoperative pain relief compared with their severe limitations before THA, and most patients report an overall improvement in health-related quality of life during the first year after surgery [17, 34, 39]. However, self-reported quality of life after THA may begin to decline as early as 18 months after THA [33] and functional mobility deficits persist several years after surgery [3, 29, 43, 53]. Therefore, the full recovery of functional mobility for individuals after THA may be a challenge in rehabilitation. The persistent functional deficits present after THA may have substantial consequences [44], including increased fall risk [53]. Furthermore, mobility disability (eg, the inability to independently walk and climb stairs) [20] places a burden on our healthcare system as a result of increased use [42] and is a risk factor for decreased life expectancy in older adults [20].

Although several studies regarding THA have been completed [30, 33, 34, 39], few have included performance-based measures, which represent common activities of daily living. Historically, the success of THA has been based on surgical outcomes and prosthesis survival [19] or has relied on patient self-reports with questionnaires to evaluate functional outcomes after THA [6, 17, 53]. Because self-report measures of function do not correlate well to performance measures of physical function [50] and may overestimate patients' true functional abilities [51], a more comprehensive evaluative strategy is needed. Moreover, although some recent investigations have examined periodic recovery after THA [8, 13], other investigations have been cross-sectional or have examined only two time points after THA. Therefore, the ability to identify the time course of functional recovery for comparison to self-reported outcomes is limited [9, 41, 53]. Furthermore, few have examined both self-reported and performance-based outcomes as early as 1 month after THA to characterize outcomes during early recovery [21]. Information regarding early strength and function decline after THA can guide decision-making not only for surgeons prescribing rehabilitation early after surgery, but also to therapists to design

effective intervention. Finally, no previous study has compared the combination of self-reported and performance-based strength and mobility outcomes with an identically tested cohort of healthy peers.

Considering the limitations of previous investigations, there exists a need to objectively and comprehensively evaluate functional and strength deficits after THA provide insights into modifiable targets for postoperative rehabilitation. We therefore sought to (1) compare measures of postoperative hip and knee strength, functional performance, and quality of life measured over the first year after THA to preoperative levels; and (2) compare the outcomes 1 year post-THA with adults with no hip pathology. We hypothesized that adults undergoing THA will have deficits in postoperative hip and knee strength and demonstrate poorer mobility such that performance on each measure of function would be worse 1 month after THA (primary end point) when compared with preoperative levels. Furthermore, we hypothesized that patients would report worse outcomes on self-reported measures of quality of life and be less physically active 1 month after THA. Additionally, we hypothesized that 1 year after THA, deficits in surgical knee and hip muscle strength, functional performance, and quality of life will persist when compared with healthy peers.

Patients and Methods

This investigation was a prospective, longitudinal study. We enrolled patients undergoing THA between June 2010 and August 2011 and evaluated all outcomes before and 1, 3, 6, and 12 months after THA. We also examined a cross-sectional cohort of healthy older adults for further comparison.

Twenty-six patients undergoing THA, performed through a posterior approach, were recruited from four community hospitals by physician referral or advertisement at preoperative educational sessions. Nineteen healthy adults from the community were recruited by email advertisement. All participants were considered eligible if they were between the ages of 45 and 80 years and had no history of uncontrolled hypertension or diabetes, body mass index $> 40 \text{ kg/m}^2$, additional orthopaedic pathology, or neurologic disorders that impaired daily function. Healthy adults had no known history of knee/hip osteoarthritis or joint arthroplasty. Each participant provided written, informed consent and the study was approved by the Colorado Multiple Institutional Review Board.

Sample size estimates were based on previous work examining lower extremity muscle strength before and 5 weeks after THA [16]. Estimates from the nonsurgical leg were used to represent healthy control subjects. For

Table 1. Baseline characteristics of the THA and healthy adult groups

Variable	Healthy (mean $\pm$ SD)	THA (mean $\pm$ SD)	p value
Age (years)	59.63 $\pm$ 8.78	61.04 $\pm$ 8.18	0.59
Height (m)	1.71 $\pm$ 0.09	1.69 $\pm$ 0.09	0.26
Mass (kg)	79.53 $\pm$ 18.20	79.99 $\pm$ 17.49	0.93
Body mass index (kg/m ²)	28.32 $\pm$ 7.04	27.98 $\pm$ 5.02	0.90
Men (%)	8 (42)	8 (30)	0.38
Women (%)	11 (58)	18 (70)	

p values are based on two-sided, independent t-test for differences in group means or a chi square test for independent proportions.

calculations, differences in hip abductor strength between surgical and nonsurgical legs 5 weeks after THA were (mean $\pm$ SD) 23 $\pm$ 9 kg (surgical) and 37 $\pm$ 13 kg (nonsurgical). This represented a large effect size (1.25 SD). Presently, there is no evidence to determine the minimum clinically meaningful difference. From these numbers, a sample size of 15 subjects per group would provide 90% power to detect differences between patients with THA and healthy control subjects 1 month after surgery. Therefore, we estimated that we should enroll 20 participants with THA to anticipate a 20% dropout rate through 1 year and at least 15 healthy control subjects. Although our focus and sample size estimates centered on the 1-month time point after THA, we chose to additionally follow the trajectory of recovery over 1 year to better characterize recovery.

There were no differences between the THA group and healthy adult group for age, sex, or body mass index (Table 1). During the 1-year follow up, we had eight subjects without complete testing. Two received contralateral THA before the 1-year follow up, one had a dislocation after 6 months, one an intraoperative fracture, and four were unable to be reached at the 1-year time point.

All patients receiving THA had osteoarthritis. All operative procedures were performed using a posterior approach and cementless THA implants. After surgery, patients were directed by their surgeon to adhere to post-surgical movement precautions, including no hip flexion above 90°, hip internal rotation, or hip adduction. All patients received inpatient physical therapy, including education, activities of daily living, and mobility training during a 2- to 3-day postoperative hospital stay. All patients were then discharged to home and received anywhere from zero to eight home and outpatient physical therapy (PT) visits (mean $\pm$ SD, 4.0 $\pm$ 3.0 home PT; 2.0 $\pm$ 3.0 outpatient PT visits). Anecdotally, communication with therapists, chart reviews, and patients' reports indicated that treatment focused on mobility training, ROM exercises, stretching, and functional activity. The combination

of the limited number of PT sessions as well as the low volume and intensity of exercise suggests PT may not have substantially improved the trajectory of recovery.

Outcome Measures

Functional Performance Measures

Measures of functional performance included the stair climb, five times sit-to-stand, timed-up-and-go, 6-minute walk tests, and single-limb stance time. The stair climb test determines the time to ascend and descend 12 stairs and assesses performance on a relatively demanding functional task. This test has excellent reliability (intraclass correlation coefficient [ICC] = 0.90) [23]. Participants were instructed to climb a flight of stairs and turn and descend the same flight as quickly and safely as possible. They were allowed to use the handrail but were encouraged to refrain from bearing weight through the handrail. The five times sit-to-stand test is a test of dynamic balance [4] and measures the time it takes to stand from and sit in a chair five times [56]. This test has high test-retest reliability (0.81) [4] and has shown to be correlated with other tests of dynamic balance ($r = 0.64$) [11]. Each participant was seated in a standard chair (height 46 cm) and instructed to transfer to a standing position and return to a sitting position as quickly as possible five times. Participants were instructed not to use the arms of the chair unless they were unable to stand without upper extremity support. The timed-up-and-go test, which assesses walking and dynamic balance, measures the time to rise from a chair, walk 3 m, turn around, and return to sitting without physical assistance [37]. This test is a reliable (ICC = 0.75) [23] and valid test and provides assessment of fall risk. The 6-minute walk test [45] assesses how far a person can walk in 6 minutes. This test has been used to measure endurance and has been validated as a measure of functional mobility after joint arthroplasty and has excellent reliability (ICC = 0.94) [23, 35]. Each participant performed this test in a 30.5-m hallway and the total distance covered, in meters, was recorded. In the single-limb stance test, a measure of static balance, participants were asked to stand unsupported on their surgical limb. Time, up to 30 seconds, was recorded. The test has excellent reliability in older adults (ICC = 0.86) [10].

Strength Testing Procedures

Surgical limb hip flexor, extensor, and abductor strength, and knee extensor and flexor strength were measured at each testing session using an electromechanical dynamometer (HUMAC NORM; CSMI Solutions, Stoughton, MA, USA). Positions chosen for testing were based on previous literature

and considered patient safety for adherence to postoperative precautions after THA. Maximal voluntary isometric strength of the hip flexors and extensors was performed while participants were supine with the hip flexed to 40° using a strap around the waist to stabilize the pelvis [26]. Strength testing of the hip abductors was performed while participants were sidelying positioned in 0° of abduction/adduction and flexion/extension with a strap to stabilize the pelvis [26, 36]. Maximal strength testing of the knee extensors and flexors was performed while patients were seated and stabilized with a shoulder harness and waist strap in 85° of hip flexion and 60° of knee flexion as previously described [31, 47]. Data were sampled using a BiopacData Acquisition System at a sampling frequency of 2000 Hz (MP 150; Biopac Medical Systems, Inc, Shirley, NY, USA) and analyzed using Acq-Knowledge software, Version 3.8.2 (Biopac Medical Systems, Inc). Strength measurements were expressed in units of torque (Nm). Each set of maximal isometric contractions was preceded by two submaximal warm-up contractions. All patients were given visual targets from the dynamometer's output and strong verbal encouragement during each trial. Maximal voluntary isometric contractions for all muscle groups were performed twice; however, if maximal torque during the first two trials differed by more than 5%, a third trial was performed, as previously described [18, 46–48]. The trial with the highest torque was normalized to body mass (kg) and used for analysis [1].

Patient Perception of Quality of Life/Physical Activity

All participants completed the Medical Outcome Study SF-36 and patients completed the Hip Dysfunction and Osteoarthritis Outcome Score (HOOS) at each visit. The HOOS assesses pain, joint stiffness, physical, social, and emotional function of a person with hip osteoarthritis to determine the overall level of disability. The HOOS is a valid, reliable, and responsive self-administered instrument with ICC values ranging from 0.78 to 0.91 depending on the subscale [24]. The SF-36 is a reliable self-report survey (ICC = 0.75–0.91) [25] for assessing health-related quality of life [5, 7, 55]. All participants reported their physical activity level using the UCLA Activity Scale [57]. This scale consists of 10 activity levels ranging from wholly inactive (level 1) to regular participation in impact sports (level 10) and has been used to monitor physical activity after total joint arthroplasty [52].

Statistical Methods

Study data were collected and managed using REDCap (Research Electronic Data Capture) electronic data capture

tools hosted at the University of Colorado, Anschutz Medical Campus [12]. REDCap is a secure, web-based application designed to support data capture for research studies.

To address the first purpose of our investigation, comparing patient outcomes at various time points with preoperative values, we used a mixed-effects repeated-measures model. We designated the 1-month time point as our primary end point for statistical analysis, but we were interested in the full 1-year time course of recovery. Therefore, the mixed-effects model used data from each measure at each time point to infer the differences in these outcomes over the 1-year follow up period, including the 1-month time point. This mixed-effects model approach is similar to performing a repeated-measures analysis of variance with the benefit of retaining case data if missing values were present at any time point. To address the second purpose of our investigation, comparing patient outcomes with measures in healthy control subjects, we used two-group, two-tailed t-tests to assess differences between healthy control subjects and patients at the 1-year time point. To additionally characterize this patient population, we calculated percent changes from the preoperative time point to the 1-month time point (primary end point) and provided estimates of the percent differences between THA outcomes at 1 year and healthy adults.

Results

As was expected, 1 month after THA, patients had 15% less hip flexor torque ($p = 0.03$), 15% less hip extensor torque ($p = 0.08$), 26% less abductor torque ($p < 0.01$), and 14% less knee extensor ($p < 0.001$) and knee flexor torque ($p < 0.01$) compared with preoperative levels (Table 2). Additionally, patients with THA performed more poorly on the stair climb test ($p < 0.001$), timed up and go test ($p = 0.02$), single-limb stance ($p = 0.03$), and 6-minute walk test ($p = 0.03$) than they did before THA (Table 2). However, performance on the five times sit-to-stand was similar preoperatively and 1 month after THA ($p = 0.49$; Table 2). Despite poorer strength and functional performance 1 month after THA, patients had significantly improved HOOS scores in all domains ($p < 0.01$) except sports and recreation ($p = 0.08$; Fig. 1). Furthermore, with patient data available, there was no difference in the Physical Component Score (PCS) of the SF-36 ($p = 0.08$) one month after THA. Finally, UCLA scores indicated a drop in physical activity 1 month after THA ($p < 0.01$) compared with before surgery and improvement in physical activity levels by the 1-year time point ($p = 0.02$; Fig. 1C).

Table 2. Mean changes and 95% confidence intervals for the primary and secondary outcome measures at 1 month (primary end point) and 3, 6, and 12 months for the THA group*

Variable	Change from baseline to 1 month, mean (95% CI)	p value	Change from baseline to 3 months, mean (95% CI)	Change from baseline to 6 months, mean (95% CI)	Change from baseline to 12 months, mean (95% CI)
Normalized hip flexor strength [†] (Nm/kg)	−0.18 (−0.34 to −0.02)	0.03	−0.03 (−0.19 to 0.14)	0.08 (−0.07 to 0.23)	−0.02 (−0.18 to 0.15)
Normalized hip extensor strength [†] (Nm/kg)	−0.16 (−0.35 to 0.02)	0.08	0.06 (−0.10 to 0.22)	0.04 (−0.17 to 0.26)	0.07 (−0.13 to 0.27)
Normalized hip abductor strength [†] (Nm/kg)	−0.20 (−0.33 to −0.06)	0.006	−0.01 (−0.13 to 0.11)	0.13 (−0.04 to 0.29)	0.10 (−0.04 to 0.25)
Normalized quadriceps strength [†] (Nm/kg)	−0.20 (−0.30 to −0.10)	< 0.001	0.02 (−0.08 to 0.13)	0.13 (0.01 to 0.25)	0.19 (0.08 to 0.29)
Normalized hamstrings strength [†] (Nm/kg)	−0.11 (−0.19 to −0.03)	0.008	0.00 (−0.08 to 0.09)	0.06 (−0.01 to 0.14)	0.07 (−0.05 to 0.18)
Stair climbing test (seconds)	8.19 (3.76 to 12.62)	< 0.001	−2.28 (−4.10 to −0.46)	−2.91 (−4.76 to −1.06)	−3.22 (−4.96 to −1.48)
Five times sit-to-stand (seconds)	0.51 (−0.99 to 2.00)	0.49	−2.16 (−3.35 to −0.98)	−2.44 (−3.63 to −1.24)	−2.56 (−3.83 to −1.29)
Timed-up-and-go (seconds)	2.26 (0.45 to 4.07)	0.02	−0.60 (−1.83 to 0.62)	−0.93 (−2.00 to 0.14)	−1.15 (−2.14 to −0.15)
Six-minute walk distance (meters)	−159.54 (−299.95 to −19.13)	0.03	161.31 (48.77 to 273.86)	206.04 (74.98 to 337.10)	274.46 (−757.65 to 1306.57)
Single-limb stance (seconds)	−4.39 (−8.13 to −0.65)	0.03	0.60 (−1.76 to 2.97)	0.93 (−2.16 to 4.02)	1.62 (−1.33 to 4.57)

* Negative values reflect a deficit from baseline, positive values reflect an improvement from baseline; p values are from the estimated between-group difference in change from baseline; [†]normalized to weight; CI = confidence interval.

Compared with the healthy adults, patients had 17% less knee extensor ($p = 0.01$) and 23% less knee flexor torque ($p < 0.01$; Table 2) after 1 year of recovery after THA. Furthermore, patients were 15% slower on the stair climb test ($p = 0.53$), 9% slower on the five times sit-to-stand test ($p = 0.35$), 11% slower on the timed up and go test ($p = 0.48$), and walked 8% less distance over 6 minutes ($p = 0.24$) (Figs. 2, 3). Furthermore, SF-36 PCS scores improved from preoperative levels ($p < 0.001$) but were worse than healthy adults 1 year after THA ($p < 0.01$;

Fig. 1B). Physical activity levels were also lower than healthy adults 1 year after THA ($p = 0.14$; Fig. 1C).

Discussion

Patients' quality of life after THA may decline as early as 18 months after THA [33] and strength and functional deficits persist several years after THA [3, 29, 43, 53]. Although patients report reduction in pain after surgery,

Fig. 1A–C Self-reported outcomes after THA are shown. **(A)** HOOS subscores during 1 year are shown. *Significant differences ($p < 0.05$) from preoperative levels. †Significant differences ($p < 0.05$) from healthy adults. **(B)** Self-reported SF-36 PCSs over 1 year are shown. *Significant differences ($p < 0.05$) from preoperative levels. †Significant differences ($p < 0.05$) from healthy adults. The THA group is represented by a solid black line; the healthy adult group is represented by a dashed line. **(C)** UCLA Activity Scores over 1 year are shown. *Significant differences ($p < 0.05$) from preoperative levels. †Significant differences ($p < 0.05$) from healthy adults. The THA group is represented by a solid black line; the healthy adult group is represented by a dashed line.

functional deficits that persist (and may worsen with age) suggest postoperative outcomes could be improved. The greatest change in strength and function may occur early

after surgery [21, 22]; however, data quantifying acute postoperative changes are lacking. Furthermore, few studies have measured these outcomes at regular intervals during recovery [8, 13, 21]. Because rehabilitation is most likely to be recommended in this timeframe, information on the deficits present early after surgery is required to make informed decisions regarding rehabilitative intervention. Using a comparison group of healthy older adults, this study identified the deficits in strength and outcomes scores that persist 1 year after THA suggesting a possible need for improvements in postoperative care.

We acknowledge the following limitations to our study. First, postoperative rehabilitation was not standardized. We intended to capture the general course of recovery after THA, including typical patterns of rehabilitation use after surgery from several practices. Although this may introduce variability in our results, we believe this approach makes our results more generalizable. Second, our sample size estimates may not be adequately powered to see differences in all outcomes at the 1-year time point as a result of the fact that these calculations were powered to infer differences in strength 1 month after surgery. As a result of variability in recovery, we may not be adequately powered to see differences 1 year after surgery. However, documenting the trajectory of recovery over the year provides important information. Finally, our inclusion criteria may underestimate deficits present in the general THA population. By limiting contralateral disease and comorbidities, we limited our population to include a higher functioning cohort than the broader THA population. However, by excluding confounding conditions, our results were not influenced by compromised function for other reasons.

We found that individuals experienced muscle strength loss, functional performance deficits, and decreases in physical activity 1 month after THA. Interestingly, strength loss in the surgical limb was not isolated to the hip musculature. Although the hip abductors experienced the greatest percent strength loss of all the musculature evaluated, acute strength loss was more global. Previously, Reardon et al. [40] indicated the presence of quadriceps weakness in this population 5 months after THA. The present study suggests that quadriceps weakness is not only present, but is worse 1 month after THA compared with preoperative values, indicating THA negatively impacts quadriceps strength. Furthermore, Bertocci et al. [3] and Sicard-Rosenbaum et al. [44] demonstrated decreased torque in the hip flexors, extensors, and abductors several months to several years after surgery. Although these studies confirm the presence of prolonged hip muscle weakness after THA, our study provides direct evidence of muscle strength losses early after surgery at the time that rehabilitation could have the biggest impact on improving long-term outcomes. The presence of early strength loss

Fig. 2A–E Muscle strength outcomes for the (A) knee flexors, (B) knee extensors, (C) hip flexors, (D) hip extensors, and (E) hip abductors over 1 year are shown. *Significant differences ($p < 0.05$)

from preoperative levels. †Significant differences ($p < 0.05$) from healthy adults. The THA group is represented by a solid black line and the healthy adult group is represented by a dashed line.

supports the need for early rehabilitation intervention to remediate strength losses to optimize recovery beyond levels seen preoperatively. This may require increasing the frequency and intensity of current rehabilitation practices or require more consistent use of rehabilitation after surgery. Similarly, functional performance after THA was diminished 1 month after surgery. Previous investigations have indicated diminished functional capacity using patient self-report [34, 53] and performance tests [38, 44] several

months to years after THA. However, no previous performance-based studies have evaluated these functional outcomes as early as 1 month after THA. The presence of long-standing deficits in functional performance in previous studies, combined with our findings of acute functional performance deficits, suggests the current approach to postoperative rehabilitation may not optimize recovery. Despite the strength and functional performance deficits 1 month after surgery, patients reported improvements in

Fig. 3A–E Functional performance outcome measures preoperatively to 1 month after THA are shown including (A) the stair climbing test, (B) the five times sit-to-stand test, (C) the timed-up-and-go test, (D) the 6-minute walk test, and (E) the single-limb

balance test. *Significant differences ($p < 0.05$) from preoperative levels. †Significant differences ($p < 0.05$) from healthy adults. The THA group is represented by a solid black line and the healthy adult group is represented by a dashed line.

their self-reported function. This is likely the result of improvements in hip pain after surgery and further supports a growing body of literature indicating that self-reported measures may not correlate well with patients' true ability after joint arthroplasty [32, 49, 51].

We also found differences in lower extremity muscle strength and functional performance in patients 1 year after THA compared with their healthy counterparts. In contrast with our initial projections, strength deficits were seen primarily in the knee extensors and flexors of the surgical lower

extremity rather than in the hip musculature. A previous investigation by Reardon et al. [40] demonstrated quadriceps muscle weakness persists several months after surgery despite decreased hip pain, improvement in function, and participation in rehabilitation. Similarly, our study suggests that quadriceps weakness persists beyond the time point previously evaluated, to at least 1 year after THA. This finding is significant because of the role of quadriceps strength in daily function. Quadriceps weakness negatively effects mobility [14, 15, 28], which may help explain why other researchers have found difficulties with functional performance after THA. Despite the fact that significant functional differences were not seen in our data, possibly related to small sample size, several studies have confirmed the presence of functional deficits and difficulty walking after THA. Specifically, Trudelle-Jackson et al. [53] demonstrated that patients had impaired self-reported function and postural control, whereas Vissers et al. [54] indicated that by 8 months after THA, patients functionally recover to only 80% of that of healthy adults. Still, other investigators indicate that gait mechanics never fully recover after THA when compared with healthy adults [2] and mechanics while climbing stairs are also impaired compared with healthy adults [27]. Although our study has characterized strength and functional performance-based outcomes during the first year after THA, we were unable to quantify the quality of movement, which may be crucial to understanding the difficulties present in these previous investigations. Taken together, there is evidence that, although patients do experience recovery and improvement in strength and functional performance after THA, mobility difficulties and functional deficits remain. The present study not only characterizes the time course of recovery during the first year after THA, but quantifies early postoperative deficits after THA. These measures are needed to plan effective rehabilitation programs. During the first few weeks after THA, patients experience hip and knee strength loss and decreased functional capacity, which improve initially, then plateau from 6 months to 1 year. However, some measures of strength remain less than the level of healthy adults, particularly quadriceps and hamstrings strength, suggesting rehabilitation strategies should be further optimized to include focused strengthening of the knee extensors and flexors in addition to those muscles around the hip.

Acknowledgments We thank Jessica Shenk PT, DPT, for assisting with data collection and entry and Andrew Kittelson PT, DPT, for assisting with data entry. We also thank our patients for their time and participation.

References

1. Bazett-Jones DM, Cobb SC, Joshi MN, Cashin SE, Earl JE. Normalizing hip muscle strength: establishing body-size-independent measurements. *Arch Phys Med Rehabil*. 2011;92:76–82.
2. Beaulieu ML, Lamontagne M, Beaulieu PE. Lower limb biomechanics during gait do not return to normal following total hip arthroplasty. *Gait Posture*. 2010;32:269–273.
3. Bertocci GE, Munin MC, Frost KL, Burdett R, Wassinger CA, Fitzgerald SG. Isokinetic performance after total hip replacement. *Am J Phys Med Rehabil*. 2004;83:1–9.
4. Bohannon RW. Reference values for the five-repetition sit-to-stand test: a descriptive meta-analysis of data from elders. *Percept Mot Skills*. 2006;103:215–222.
5. Brazier JE, Harper R, Munro J, Walters SJ, Snaith ML. Generic and condition-specific outcome measures for people with osteoarthritis of the knee. *Rheumatology (Oxford)*. 1999;38: 870–877.
6. Ethgen O, Bruyere O, Richy F, Dardennes C, Reginster JY. Health-related quality of life in total hip and total knee arthroplasty. A qualitative and systematic review of the literature. *J Bone Joint Surg Am*. 2004;86:963–974.
7. Fortin PR, Clarke AE, Joseph L, Liang MH, Tanzer M, Ferland D, Phillips C, Partridge AJ, Belisle P, Fossel AH, Mahomed N, Sledge CB, Katz JN. Outcomes of total hip and knee replacement: preoperative functional status predicts outcomes at six months after surgery. *Arthritis Rheum*. 1999;42:1722–1728.
8. Foucher KC, Wimmer MA, Moio KC, Hildebrand M, Berli MC, Walker MR, Berger RA, Galante JO. Time course and extent of functional recovery during the first postoperative year after minimally invasive total hip arthroplasty with two different surgical approaches—a randomized controlled trial. *J Biomech*. 2011;44:372–378.
9. Frost KL, Bertocci GE, Wassinger CA, Munin MC, Burdett RG, Fitzgerald SG. Isometric performance following total hip arthroplasty and rehabilitation. *J Rehabil Res Dev*. 2006;43: 435–444.
10. Goldberg A, Casby A, Wasielewski M. Minimum detectable change for single-leg-stance-time in older adults. *Gait Posture*. 2011;33:737–739.
11. Goldberg A, Chavis M, Watkins J, Wilson T. The five-times-sit-to-stand test: validity, reliability and detectable change in older females. *Aging Clin Exp Res*. 2012;24:339–344.
12. Harris PA, Taylor R, Thielke R, Payne J, Gonzalez N, Conde JG. Research electronic data capture (REDCap)—a metadata-driven methodology and workflow process for providing translational research informatics support. *J Biomed Inform*. 2009;42:377–381.
13. Heiberg KE, Ekeland A, Bruun-Olsen V, Mengshoel AM. Recovery and prediction of physical functioning outcomes during the first year after total hip arthroplasty. *Arch Phys Med Rehabil*. 2013 Feb 4 [Epub ahead of print].
14. Hernandez ME, Goldberg A, Alexander NB. Decreased muscle strength relates to self-reported stooping, crouching, or kneeling difficulty in older adults. *Phys Ther*. 2010;90:67–74.
15. Horlings CG, van Engelen BG, Allum JH, Bloem BR. A weak balance: the contribution of muscle weakness to postural instability and falls. *Nat Clin Pract Neurol*. 2008;4:504–515.
16. Husby VS, Helgerud J, Bjorgen S, Husby OS, Benum P, Hoff J. Early maximal strength training is an efficient treatment for patients operated with total hip arthroplasty. *Arch Phys Med Rehabil*. 2009;90:1658–1667.
17. Jones CA, Voaklander DC, Johnston DW, Suarez-Almazor ME. Health related quality of life outcomes after total hip and knee arthroplasties in a community based population. *J Rheumatol*. 2000;27:1745–1752.
18. Judd DL, Eckhoff DG, Stevens-Lapsley JE. Muscle strength loss in the lower limb after total knee arthroplasty. *Am J Phys Med Rehabil*. 2012;91:220–26; quiz 227–230.
19. Judge A, Cooper C, Williams S, Dreinhofer K, Dieppe P. Patient-reported outcomes one year after primary hip replacement in a European Collaborative Cohort. *Arthritis Care Res (Hoboken)*. 2010;62:480–488.

20. Keeler E, Guralnik JM, Tian H, Wallace RB, Reuben DB. The impact of functional status on life expectancy in older persons. *J Gerontol A Biol Sci Med Sci*. 2010;65:727–733.
21. Kennedy DM, Stratford PW, Hanna SE, Wessel J, Gollish JD. Modeling early recovery of physical function following hip and knee arthroplasty. *BMC Musculoskelet Disord*. 2006;7:100.
22. Kennedy DM, Stratford PW, Robarts S, Gollish JD. Using outcome measure results to facilitate clinical decisions the first year after total hip arthroplasty. *J Orthop Sports Phys Ther*. 2011;41:232–239.
23. Kennedy DM, Stratford PW, Wessel J, Gollish JD, Penney D. Assessing stability and change of four performance measures: a longitudinal study evaluating outcome following total hip and knee arthroplasty. *BMC Musculoskelet Disord*. 2005;6:3.
24. Klassbo M, Larsson E, Mannevik E. Hip disability and osteoarthritis outcome score. An extension of the Western Ontario and McMaster Universities Osteoarthritis Index. *Scand J Rheumatol*. 2003;32:46–51.
25. Kosinski M, Keller SD, Ware JE Jr, Hatoum HT, Kong SX. The SF-36 Health Survey as a generic outcome measure in clinical trials of patients with osteoarthritis and rheumatoid arthritis: relative validity of scales in relation to clinical measures of arthritis severity. *Med Care*. 1999;37(Suppl):MS23–39.
26. Krych AJ, Pagnano MW, Coleman Wood K, Meneghini RM, Kaufman K. No strength or gait benefit of two-incision THA: a brief followup at 1 year. *Clin Orthop Relat Res*. 2011;469:1110–1118.
27. Lamontagne M, Beaulieu ML, Beaulieu PE. Comparison of joint mechanics of both lower limbs of THA patients with healthy participants during stair ascent and descent. *J Orthop Res*. 2011;29:305–311.
28. Laroche DP, Cook SB, Mackala K. Strength asymmetry increases gait asymmetry and variability in older women. *Med Sci Sports Exerc*. 2012;44:2172–2181.
29. Long WT, Dorr LD, Healy B, Perry J. Functional recovery of noncemented total hip arthroplasty. *Clin Orthop Relat Res*. 1993;288:73–77.
30. March LM, Cross MJ, Lapsley H, Brnabic AJ, Tribe KL, Bachmeier CJ, Courtenay BG, Brooks PM. Outcomes after hip or knee replacement surgery for osteoarthritis. A prospective cohort study comparing patients' quality of life before and after surgery with age-related population norms. *Med J Aust*. 1999;171:235–238.
31. Mintken PE, Carpenter KJ, Eckhoff D, Kohrt WM, Stevens JE. Early neuromuscular electrical stimulation to optimize quadriceps muscle function following total knee arthroplasty: a case report. *J Orthop Sports Phys Ther*. 2007;37:364–371.
32. Mizner RL, Petterson SC, Clements KE, Zeni JA Jr, Irrgang JJ, Snyder-Mackler L. Measuring functional improvement after total knee arthroplasty requires both performance-based and patient-report assessments: a longitudinal analysis of outcomes. *J Arthroplasty*. 2011;26:728–737.
33. Ng CY, Ballantyne JA, Brenkel IJ. Quality of life and functional outcome after primary total hip replacement. A five-year follow-up. *J Bone Joint Surg Br*. 2007;89:868–873.
34. Nilsson AK, Isaksson F. Patient relevant outcome 7 years after total hip replacement for OA—a prospective study. *BMC Musculoskelet Disord*. 2010;11:47.
35. Parent E, Moffet H. Comparative responsiveness of locomotor tests and questionnaires used to follow early recovery after total knee arthroplasty. *Arch Phys Med Rehabil*. 2002;83:70–80.
36. Piva SR, Teixeira PE, Almeida GJ, Gil AB, DiGiovio AM 3rd, Levison TJ, Fitzgerald GK. Contribution of hip abductor strength to physical function in patients with total knee arthroplasty. *Phys Ther*. 2011;91:225–233.
37. Podsiadlo D, Richardson S. The timed 'Up & Go': a test of basic functional mobility for frail elderly persons. *J Am Geriatr Soc*. 1991;39:142–148.
38. Rasch A, Dalen N, Berg HE. Muscle strength, gait, and balance in 20 patients with hip osteoarthritis followed for 2 years after THA. *Acta Orthop*. 2010;81:183–188.
39. Rat AC, Guillemin F, Osnowycz G, Delagoutte JP, Cuny C, Mainard D, Baumann C. Total hip or knee replacement for osteoarthritis: mid- and long-term quality of life. *Arthritis Care Res (Hoboken)*. 2010;62:54–62.
40. Reardon K, Galea M, Dennett X, Choong P, Byrne E. Quadriceps muscle wasting persists 5 months after total hip arthroplasty for osteoarthritis of the hip: a pilot study. *Intern Med J*. 2001;31:7–14.
41. Rossi MD, Brown LE, Whitehurst MA. Assessment of hip extensor and flexor strength two months after unilateral total hip arthroplasty. *J Strength Cond Res*. 2006;20:262–267.
42. Seeman TE, Merkin SS, Crimmins EM, Karlamangla AS. Disability trends among older Americans: National Health And Nutrition Examination Surveys, 1988–1994 and 1999–2004. *Am J Public Health*. 2010;100:100–107.
43. Shih CH, Du YK, Lin YH, Wu CC. Muscular recovery around the hip joint after total hip arthroplasty. *Clin Orthop Relat Res*. 1994;302:115–120.
44. Sicard-Rosenbaum L, Light KE, Behrman AL. Gait, lower extremity strength, and self-assessed mobility after hip arthroplasty. *J Gerontol A Biol Sci Med Sci*. 2002;57:M47–51.
45. Steffen TM, Hacker TA, Mollinger L. Age- and gender-related test performance in community-dwelling elderly people: Six-Minute Walk Test, Berg Balance Scale, Timed Up & Go Test, and gait speeds. *Phys Ther*. 2002;82:128–137.
46. Stevens-Lapsley JE, Bade MJ, Shulman BC, Kohrt WM, Dayton MR. Minimally invasive total knee arthroplasty improves early knee strength but not functional performance: a randomized controlled trial. *J Arthroplasty*. 2012;27:1812–1819.e2.
47. Stevens-Lapsley JE, Balter JE, Kohrt WM, Eckhoff DG. Quadriceps and hamstrings muscle dysfunction after total knee arthroplasty. *Clin Orthop Relat Res*. 2010;468:2460–2468.
48. Stevens-Lapsley JE, Balter JE, Wolfe P, Eckhoff DG, Kohrt WM. Early neuromuscular electrical stimulation to improve quadriceps muscle strength after total knee arthroplasty: a randomized controlled trial. *Phys Ther*. 2012;92:210–226.
49. Stevens-Lapsley JE, Schenkman ML, Dayton MR. Comparison of self-reported knee injury and osteoarthritis outcome score to performance measures in patients after total knee arthroplasty. *PM R*. 2011;3:541–549; quiz 549.
50. Stratford PW, Kennedy DM, Hanna SE. Condition-specific Western Ontario McMaster Osteoarthritis Index was not superior to region-specific Lower Extremity Functional Scale at detecting change. *J Clin Epidemiol*. 2004;57: 1025–1032.
51. Stratford PW, Kennedy DM, Maly MR, Macintyre NJ. Quantifying self-report measures' overestimation of mobility scores postarthroplasty. *Phys Ther*. 2010;90:1288–1296.
52. Terwee CB, Bouwmeester W, van Elsland SL, de Vet HC, Dekker J. Instruments to assess physical activity in patients with osteoarthritis of the hip or knee: a systematic review of measurement properties. *Osteoarthritis Cartilage*. 2011;19:620–633.
53. Trudelle-Jackson E, Emerson R, Smith S. Outcomes of total hip arthroplasty: a study of patients one year postsurgery. *J Orthop Sports Phys Ther*. 2002;32:260–267.
54. Vissers MM, Bussmann JB, Verhaar JA, Arends LR, Furlan AD, Reijman M. Recovery of physical functioning after total hip arthroplasty: systematic review and meta-analysis of the literature. *Phys Ther*. 2011;92:615–629.
55. Ware JE Jr, Kosinski M, Bayliss MS, McHorney CA, Rogers WH, Raczek A. Comparison of methods for the scoring and

- statistical analysis of SF-36 health profile and summary measures: summary of results from the Medical Outcomes Study. *Med Care*. 1995;33(Suppl):AS264–279.
56. Whitney SL, Wrisley DM, Marchetti GF, Gee MA, Redfern MS, Furman JM. Clinical measurement of sit-to-stand performance in people with balance disorders: validity of data for the Five-Times-Sit-to-Stand Test. *Phys Ther*. 2005;85:1034–1045.
57. Zahiri CA, Schmalzried TP, Szuszczewicz ES, Amstutz HC. Assessing activity in joint replacement patients. *J Arthroplasty*. 1998;13:890–895.