J. Phys. Ther. Sci. 31: 57–62, 2019

The Journal of Physical Therapy Science

Original Article

Different improvement trends in gait function and quadriceps strength early after total knee arthroplasty

Akira Iwata, PT, PhD[1)*], Yuki Sano, PT, MS[2)], Hideyuki Wanaka, PT, MS[2)], Saki Yamamoto, PT, MS[1)], Yuki Yano, PT[1)], Hiroshi Iwata, MD, PhD[3)]

[1)] *Department of Physical Therapy, Faculty of Comprehensive Rehabilitation, Osaka Prefecture University: 3-7-30 Habikino, Habikino city, Osaka 583-8555, Japan*
[2)] *Department of Rehabilitation, Osaka General Medical Center, Japan*
[3)] *Department of Cardiovascular Medicine, Juntendo University Graduate School of Medicine, Japan*

Abstract [Purpose] Improved quadriceps strength is a primary target of rehabilitation early after total knee arthroplasty. However, patients demonstrate varying improvement trends in gait function and quadriceps strength. This study evaluated the relationship between improvements in quadriceps strength and gait function. [Participants and Methods] The study included 49 patients who were scheduled to undergo unilateral total knee arthroplasty. Gait function, bilateral quadriceps strength, and pain were assessed in all patients. All assessments were performed preoperatively and at 2 and 3 weeks postoperatively. [Results] A significant correlation between gait function and the quadriceps strength on the operated side was observed preoperatively and 3 weeks postoperatively. The quadriceps strength on the non-operated side was significantly correlated with gait function at all time points. Multiple regression analysis showed that the quadriceps strength on the non-operated side was significantly associated with gait function, except the gait speed at 2 weeks. However, the quadriceps strength on the operated side was not observed to be an independent variable at all time points. [Conclusion] The quadriceps strength on the operated side is not an important determinant of gait function. It may be necessary to reconsider typical rehabilitation programs by focusing on the quadriceps strength on the operated side in patients undergoing total knee arthroplasty.
Key words: Total knee arthroplasty, Quadriceps strength, Gait speed

(This article was submitted Aug. 8, 2018, and was accepted Oct. 7, 2018)

INTRODUCTION

Knee osteoarthritis (OA) is one of the most prevalent musculoskeletal disorders[1)] and causes of disability[2)]. Total knee arthroplasty (TKA) is a frequently performed surgical intervention to treat end-stage knee OA. Although TKA reliably reduces pain[3)] and improves range of motion[4)] and self-reported physical function[5, 6)] in OA patients, deficits in muscle strength and impairments in gait function often persist for years after TKA[7, 8)].

The majority of improvement in gait function after TKA occurs within the first few weeks[9, 10)], and the degree of improvement during the first few weeks postoperatively reflects gait function beyond 1 year[7, 11)]. Therefore, it is important to improve gait function within the first few weeks after surgery. Various intervention methods focusing on the quadriceps, such as neuromuscular electrical stimulation[7)] and high-velocity training[12)], were examined, and improvement in gait function was recognized. These interventions are thought to be based on the premise that the relationship between gait function and quadriceps strength is strong. Indeed, previous studies showed that there was a significant association between gait limitations and decreases in quadriceps strength[13, 14)]. However, in clinical settings, the gait function of many patients recovers to the normal

*Corresponding Author. Akira Iwata (E-mail: iwata@rehab.osakafu-u.ac.jp)

level, despite the fact that there is considerable reduction in quadriceps strength early after TKA. Conversely, some patients show reduced gait speed, even though the quadriceps strength is restored to the normal level. When we see such patients, we think that the above-named premise is faulty.

Since the recent advances in both implant design and surgical techniques have led to better performance[15], the relationship between quadriceps strength and gait function may have changed. Moreover, the trends in improvement of quadriceps strength and gait function may vary according to the patients' characteristics. Therefore, in this study, we evaluated the relationship between improvements in quadriceps strength and gait function, as well as the improvement ratio of quadriceps strength and gait function at each time point early after TKA. If the relationships between gait function and quadriceps strength are different from those reported in previous studies, our results may be used to provide a more efficient rehabilitation program early after TKA.

PARTICIPANTS AND METHODS

Forty-nine patients (mean age; 76.4 ± 5.8 years; height, 152.1 ± 6.5 cm; weight, 61.8 ± 11.5 kg) at Osaka General Medical Center were recruited for this prospective, observational study. All participants who were scheduled to undergo TKA because of knee OA were evaluated for their eligibility to be included in this study, according to the inclusion criteria. Cartilage lesions were evaluated on preoperative plain weight-bearing radiographs of the knee using the Kellgren-Lawrence (KL) grade[16]. The inclusion criteria were: 1) diagnosed knee OA; 2) unilateral TKA; 3) ability to walk 10 m or more independently, with or without a cane; and 4) the hospitalization period was between 18 and 24 days according to the clinical pathways at the medical center. Patients were excluded if they had uncontrolled hypertension or neurological or muscular diseases that would affect their performance during a gait function test. This study was approved by the ethics committee of Osaka General Medical Center (approval number: 23-0917). Written informed consent was obtained from all participants.

Three experienced surgeons performed all surgeries. The operations were performed with the use of an air tourniquet, which was inflated during draping and released after dressing. A standard medial parapatellar approach was used, and both the anterior and posterior cruciate ligaments were resected.

We evaluated gait function, muscle strength and pain at preoperatively and at 2 and 3 weeks postoperatively. We measured the usual gait speed and timed up and go (TUG) test for gait function. The usual gait speed was measured on an 8 m walkway in a rehabilitation room. The walkway had 1.5-m inactive sections at the beginning and end to allow for acceleration and deceleration. Patients were instructed to walk at their usual pace, and the time taken to walk the middle 5 m of the walkway was measured using a stopwatch. The gait speed was measured twice, and the better of the two gait speeds was used for analysis.

The TUG test was used as described by Podsiadlo and Richardson[17]. Briefly, the patients were asked to stand up from a chair, walk 3 m, cross a line, turn, walk back, and sit down again, at a comfortable pace. The time required to complete this task was measured using the stopwatch. A practice walk-through was given before the test. Each patient performed the test twice, and the better result was used for the analysis. A cane was provided during both gait function tests when physical therapists judged that it was necessary for safety.

Quadriceps strength was quantified bilaterally during isometric contractions using a hand-held dynamometer (Anima Corp., μ-Tas F-1, Tokyo, Japan). For the test, the patients sat on the edge of a bed with the knee in 90° flexion[18], with their hands placed on the bed for stability. The patients were instructed to extend the knee maximally for 5 seconds. During the test, the tester encouraged the patients verbally. The muscle strength was measured twice, and the better result was used for further analyses. The raw force that was measured by the dynamometer, in Newtons, was normalized to each patient's body weight, and this value was used as the quadriceps muscle strength.

The intensity of knee pain during gait speed test was measured with the visual analog pain scale (VAS)[19]. For pain intensity, the scale was anchored by "no pain" (score of 0 mm) and "worst possible pain" (score of 100 mm).

In the statistical analysis, Pearson's correlation coefficients were used to assess the relationships between bilateral muscle strength and gait function at each time point: preoperatively and 2 and 3 weeks postoperatively. A multiple regression analysis with forced entry was conducted with gait function (gait speed and the TUG test) as the dependent variable and age, gender, body mass index (BMI), KL grade, and VAS as independent variables at each time point. All analyses were performed using SPSS Statistics, version 22 (SPSS Japan, Inc., Tokyo, Japan), and p-values <0.05 were considered significant.

RESULTS

The baseline characteristics of the patients are presented in Table 1. The changes in gait function (gait speed and TUG test) and bilateral quadriceps strength (for both the operated and non-operated sides) and the percent change (%) of the preoperative values of these parameters are provided in Table 2. Compared with preoperatively, at two weeks after surgery, the patients' gait speeds decreased by 15.5%, and these patients took 24.5% longer to perform the TUG test. Their quadriceps strength was decreased by 54.1%. Three weeks after surgery, the patients still exhibited decreased gait speed (by 8.2%) and took 12.9% longer to perform the TUG test. Their quadriceps strength was decreased by 43.9%.

The change in the correlation coefficient between gait function (gait speed and TUG test) and bilateral quadriceps strength is shown in Table 3. Preoperatively and at 3 weeks after TKA, the quadriceps strength of the operated side was significantly

Table 1. Baseline characteristics of the patients (n=49)

	Mean (SD)	Range
Age (yrs)	76.4 (5.8)	64.0−88.0
Female n, (%)	39 (79.6%)	
Height (cm)	152.1 (6.5)	138.5−172.0
Weight (kg)	61.8 (11.5)	43.3−89.6
BMI (kg/m^2)	26.9 (3.5)	20.0−33.3
KL grades		
Grade 1 n, (%)	1 (2.0%)	
Grade 2 n, (%)	3 (6.1%)	
Grade 3 n, (%)	23 (46.9%)	
Grade 4 n, (%)	22 (44.9%)	

SD: standard deviation; BMI: body mass index; KL: Kellgren-Lawrence scale.

Table 2. Change in gait function and quadriceps strength over time

		Mean (SD)	Change [% (95%CI)]
Gait speed (m/sec)	PRE	0.98 (0.22)	
	2w	0.82 (0.21)	−15.5 (−19.8 to −11.2)
	3w	0.89 (0.21)	−8.2 (−12.4 to −3.9)
TUG (sec)	PRE	11.5 (3.1)	
	2w	14.0 (3.3)	24.5 (18.7 to 30.3)
	3w	12.7 (3.0)	12.9 (7.3 to 18.6)
Quadriceps strength of the operated side per weight (N/kg)	PRE	2.47 (1.00)	
	2w	1.03 (0.40)	−54.1 (−59.5 to −48.7)
	3w	1.24 (0.44)	−43.9 (−50.5 to −37.2)
Quadriceps strength of the non-operated side per weight (N/kg)	PRE	2.85 (1.07)	
	2w	2.84 (0.93)	3.8 (−2.6 to 10.3)
	3w	2.91 (0.90)	7.0 (0.4 to 13.7)

SD: standard deviation; CI: confidence interval; PRE: preoperatively; TUG: timed up and go test.

Table 3. Change in correlation between gait function and quadriceps strengths

		Quadriceps strength of the operated side per weight	Quadriceps strength of the non-operated side per weight
		r	r
Gait speed	PRE	0.43*	0.56*
	2 weeks	0.21	0.42*
	3 weeks	0.31*	0.57*
TUG	PRE	−0.41*	−0.59*
	2 weeks	−0.22	0.40
	3 weeks	−0.37*	−0.57*

PRE: preoperatively; TUG: timed up and go test.
*p<0.05.

associated with gait speed (preoperatively: r=0.43 and 3 weeks postoperatively: r=0.31) and TUG (preoperatively: r=−0.41 and 3 weeks postoperatively: r=−0.37). No significant relationship was found at 2 weeks after surgery. The quadriceps strength of the non-operated side was significantly and moderately correlated with gait speed (r=0.42 to 0.57) and the TUG test (r=−0.40 to −0.59) at all assessment time points.

Table 4 shows the results of the multiple regression analysis with gait speed as the dependent variable. Preoperatively, the VAS and quadriceps strength of the non-operated side were identified as significant factors that were associated with gait speed. At 2 weeks after surgery, the VAS was selected as a significant independent variable. At 3 weeks, the quadriceps

Table 4. The results of the multiple regression analysis with gait speed as the dependent variable

Independent variable	PRE	2 weeks	3 weeks
	Adjusted β	Adjusted β	Adjusted β
Age	−0.16	−0.20	−0.20
Gender	0.06	−0.01	−0.02
BMI	0.05	−0.19	−0.06
KL	0.00	−0.07	−0.12
VAS	−0.46*	−0.37*	−0.17
Quadriceps strength of the operated side	0.01	−0.01	0.10
Quadriceps strength of the non-operated side	0.41*	0.29	0.45*
	adjusted R^2=0.435	adjusted R^2=0.280	adjusted R^2=0.327

PRE: preoperatively; BMI: body mass index; KL: Kellgren-Lawrence scale; VAS: visual analog scale.
*p<0.05.

Table 5. The results of the multiple regression analysis with the TUG as the dependent variable

Independent variable	PRE	2 weeks	3 weeks
	Adjusted β	Adjusted β	Adjusted β
Age	0.09	0.20	0.20
Gender	−0.06	−0.23	−0.06
BMI	0.02	0.11	0.09
KL	0.16	0.04	0.13
VAS	0.33*	0.19	0.32*
Quadriceps strength of the operated side	0.07	−0.12	−0.16
Quadriceps strength of the non-operated side	−0.52*	−0.34*	−0.43*
	adjusted R^2=0.428	adjusted R^2=0.208	adjusted R^2=0.475

PRE: preoperatively; TUG: timed up and go test; BMI: body mass index; KL: Kellgren-Lawrence scale; VAS: visual analog scale.
*p<0.05.

strength of the non-operated side was independently associated with gait speed.

The results of the multiple regression analysis with the TUG test as the dependent variable are shown in Table 5. Preoperatively, the VAS and quadriceps strength of the non-operated side were independently associated with the TUG test. At 2 weeks, the quadriceps strength of the non-operated side was identified as a significant independent variable. At 3 weeks after surgery, the quadriceps strength of the non-operated side and VAS were selected as independent variables.

DISCUSSION

The main aim of the present study was to investigate the importance of the recovery of the quadriceps strength of the operated leg in the improvement of gait function early after TKA. The results showed that although the association between the quadriceps strength of the operated side and gait function measures was significant at 3 weeks after TKA, the multiple regression analysis showed that the quadriceps strength of the operated side was not a significant independent variable of both gait function measures. Moreover, there was a large gap between the rate of decrease in gait function and rate of reduction in quadriceps strength at 3 weeks after surgery. To summarize these results, although the quadriceps strength of the operated side is little related to gait function, recovery of the quadriceps strength is not a major determinant of the improvement in gait function early after TKA. In addition, the results also showed that the trends in improvement of the quadriceps strength and gait function are quite different early after TKA.

Many previous studies have investigated the relationship between the quadriceps strength of the operated side and gait function measures[13, 14, 20–23]. The Pearson correlation coefficients (r) of gait speed and quadriceps strength were 0.51 at 4 weeks[13] and 0.68 at 3 to 12 months[22] after surgery. The correlation coefficients of the TUG test and quadriceps strength were −0.32 at 4 weeks[14], −0.59 at 3 months[23], and −0.64 at 6 months[14]. Although the basic characteristics of the patients and measuring conditions were different in each study, there is no doubt that there is a low-to-moderate correlation between the quadriceps strength of the operated side and gait function measures in patients with TKA. The results of the present study can be regarded as consistent with those of previous studies.

However, the correlations of this study were lower than those in previous studies, and the quadriceps strength of the oper-

ated side was not associated with gait function in the multiple regression analysis at all time points. There are two possible explanations for these differences. First, there was a difference in the elapsed time after surgery. When considering previous studies from the viewpoint of the elapsed time, the correlations seemed to have increased with the passage of time. Because we observed patients within the first 3 weeks after TKA in this study, which is an earlier stage of recovery than that reported in previous studies, the correlation coefficient may have been lower. Secondly, the characteristics of the patients were different from those of patients in previous studies. The average age of the patients in this study was 76.4 years, and these patients were approximately 10 years older than those in previous studies. As the correlation between quadriceps strength and gait speed declines with increasing age[24], age may have influenced the results. Furthermore, the average body weight of the patients in this study was 61.8 kg, which was more than 20 kg less than that of patients in previous studies[13, 14]. The BMI of the participants in this study was also smaller than that reported in other studies. BMI does not adversely impact gait function[25] and recovery[26] in patients with TKA. However, a higher BMI leads to slower recovery of quadriceps strength[9]. The difference in the number of obese people between this study and previous studies may have influenced the different correlations.

Concurrently, the quadriceps strength of the non-operated side showed a significant correlation with gait speed and the TUG test at almost all time points, and it was identified as a significant predictor of gait function preoperatively and at 3 weeks postoperatively. The obtained results are similar to those of a previous study in which the gait function after TKA was more strongly related to the quadriceps strength of the non-operated side than that of the operated side[27]. Moreover, a longitudinal study showed that the quadriceps strength of the non-operated side early after TKA accounted for most of the gait function at 1 and 2 years after TKA[28]. Based on these facts, we believe that strength training of the non-operated side should be focused upon more in rehabilitation programs after TKA.

VAS score was identified as a significant determinant of gait speed preoperatively and 2 weeks postoperatively, and of TUG preoperatively and 3 weeks after surgery. Moreover, the degree of importance of the pain score may be different for gait speed and TUG. These results indicate that pain affects gait function and the effect of pain may change depending on the assigned task.

There are at least two potential limitations to the present study. First, this study was performed at a single hospital. Therefore, all patients underwent the same surgical technique and postoperative management and rehabilitation programs, which may have influenced the results. A multicenter trial is needed in the future. Second, our sample consisted of mostly female patients. Because gender differences were observed in terms of gait function in elderly people[29], it is necessary to investigate patients based on gender in future research.

The findings of this study highlighted that the quadriceps strength of the operated side is not a good predictor of gait function in older and less obese patients early after TKA. This indicates that the quadriceps strength of the operated side does not play a crucial role in determining gait function early after TKA. Alternatively, as the quadriceps strength of the non-operated side has a good correlation with gait function, we emphasize the necessity of muscle strength training of the non-operated side. However, because the model of the multiple regression analysis could explain up to 48% of the gait measures in this study, there may be more important determinants of gait function after TKA. To provide effective rehabilitation programs after TKA, further studies will be needed to explore other determinants of gait function postoperatively.

Conflict of interest

None.

REFERENCES

1) Duivenvoorden T, Brouwer RW, Baan A, et al.: Comparison of closing-wedge and opening-wedge high tibial osteotomy for medial compartment osteoarthritis of the knee: a randomized controlled trial with a six-year follow-up. J Bone Joint Surg Am, 2014, 96: 1425–1432. [Medline] [CrossRef]
2) Peat G, McCarney R, Croft P: Knee pain and osteoarthritis in older adults: a review of community burden and current use of primary health care. Ann Rheum Dis, 2001, 60: 91–97. [Medline] [CrossRef]
3) König A, Walther M, Kirschner S, et al.: Balance sheets of knee and functional scores 5 years after total knee arthroplasty for osteoarthritis: a source for patient information. J Arthroplasty, 2000, 15: 289–294. [Medline] [CrossRef]
4) Misra AN, Smith RB, Fiddian NJ: Five year results of selective patellar resurfacing in cruciate sparing total knee replacements. Knee, 2003, 10: 199–203. [Medline] [CrossRef]
5) Xie F, Lo NN, Pullenayegum EM, et al.: Evaluation of health outcomes in osteoarthritis patients after total knee replacement: a two-year follow-up. Health Qual Life Outcomes, 2010, 8: 87. [Medline] [CrossRef]
6) Hamel MB, Toth M, Legedza A, et al.: Joint replacement surgery in elderly patients with severe osteoarthritis of the hip or knee: decision making, postoperative recovery, and clinical outcomes. Arch Intern Med, 2008, 168: 1430–1440. [Medline] [CrossRef]
7) Stevens-Lapsley JE, Balter JE, Wolfe P, et al.: Early neuromuscular electrical stimulation to improve quadriceps muscle strength after total knee arthroplasty: a randomized controlled trial. Phys Ther, 2012, 92: 210–226. [Medline] [CrossRef]
8) Walsh M, Woodhouse LJ, Thomas SG, et al.: Physical impairments and functional limitations: a comparison of individuals 1 year after total knee arthroplasty with control subjects. Phys Ther, 1998, 78: 248–258. [Medline] [CrossRef]
9) Pua YH, Seah FJ, Seet FJ, et al.: Sex differences and impact of body mass index on the time course of knee range of motion, knee strength, and gait speed after

total knee arthroplasty. Arthritis Care Res (Hoboken), 2015, 67: 1397–1405. [Medline] [CrossRef]
10) Kennedy DM, Stratford PW, Riddle DL, et al.: Assessing recovery and establishing prognosis following total knee arthroplasty. Phys Ther, 2008, 88: 22–32. [Medline] [CrossRef]
11) Bade MJ, Stevens-Lapsley JE: Early high-intensity rehabilitation following total knee arthroplasty improves outcomes. J Orthop Sports Phys Ther, 2011, 41: 932–941. [Medline] [CrossRef]
12) Doerfler D, Gurney B, Mermier C, et al.: High-velocity quadriceps exercises compared to slow-velocity quadriceps exercises following total knee arthroplasty: a randomized clinical study. J Geriatr Phys Ther, 2016, 39: 147–158. [Medline] [CrossRef]
13) Aalund PK, Larsen K, Hansen TB, et al.: Normalized knee-extension strength or leg-press power after fast-track total knee arthroplasty: which measure is most closely associated with performance-based and self-reported function? Arch Phys Med Rehabil, 2013, 94: 384–390. [Medline] [CrossRef]
14) Mizner RL, Petterson SC, Snyder-Mackler L: Quadriceps strength and the time course of functional recovery after total knee arthroplasty. J Orthop Sports Phys Ther, 2005, 35: 424–436. [Medline] [CrossRef]
15) Ilalov K, Cohn RM, Slover J: High-performance total knee replacement. Bull Hosp Jt Dis 2013, 2013, 71: 79–88. [Medline]
16) Kellgren JH, Lawrence JS: Radiological assessment of osteo-arthrosis. Ann Rheum Dis, 1957, 16: 494–502. [Medline] [CrossRef]
17) 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. [Medline] [CrossRef]
18) Bohannon RW: Test-retest reliability of hand-held dynamometry during a single session of strength assessment. Phys Ther, 1986, 66: 206–209. [Medline] [CrossRef]
19) Hawker GA, Mian S, Kendzerska T, et al.: Measures of adult pain: Visual Analog Scale for Pain (VAS Pain), Numeric Rating Scale for Pain (NRS Pain), McGill Pain Questionnaire (MPQ), Short-Form McGill Pain Questionnaire (SF-MPQ), Chronic Pain Grade Scale (CPGS), Short Form-36 Bodily Pain Scale (SF-36 BPS), and Measure of Intermittent and Constant Osteoarthritis Pain (ICOAP). Arthritis Care Res (Hoboken), 2011, 63: S240–S252. [Medline] [CrossRef]
20) Marmon AR, Milcarek BI, Snyder-Mackler L: Associations between knee extensor power and functional performance in patients after total knee arthroplasty and normal controls without knee pain. Int J Sports Phys Ther, 2014, 9: 168–178. [Medline]
21) Pua YH, Seah FJ, Clark RA, et al.: Factors associated with gait speed recovery after total knee arthroplasty: a longitudinal study. Semin Arthritis Rheum, 2017, 46: 544–551. [Medline] [CrossRef]
22) Lienhard K, Lauermann SP, Schneider D, et al.: Validity and reliability of isometric, isokinetic and isoinertial modalities for the assessment of quadriceps muscle strength in patients with total knee arthroplasty. J Electromyogr Kinesiol, 2013, 23: 1283–1288. [Medline] [CrossRef]
23) Yoshida Y, Mizner RL, Ramsey DK, et al.: Examining outcomes from total knee arthroplasty and the relationship between quadriceps strength and knee function over time. Clin Biomech (Bristol, Avon), 2008, 23: 320–328. [Medline] [CrossRef]
24) Brown M, Sinacore DR, Host HH: The relationship of strength to function in the older adult. J Gerontol A Biol Sci Med Sci, 1995, 50: 55–59. [Medline]
25) Stevens-Lapsley JE, Petterson SC, Mizner RL, et al.: Impact of body mass index on functional performance after total knee arthroplasty. J Arthroplasty, 2010, 25: 1104–1109. [Medline] [CrossRef]
26) Bonnefoy-Mazure A, Martz P, Armand S, et al.: Influence of body mass index on sagittal knee range of motion and gait speed recovery 1-year after total knee arthroplasty. J Arthroplasty, 2017, 32: 2404–2410. [Medline] [CrossRef]
27) Mizner RL, Snyder-Mackler L: Altered loading during walking and sit-to-stand is affected by quadriceps weakness after total knee arthroplasty. J Orthop Res, 2005, 23: 1083–1090. [Medline] [CrossRef]
28) Zeni JA Jr, Snyder-Mackler L: Early postoperative measures predict 1- and 2-year outcomes after unilateral total knee arthroplasty: importance of contralateral limb strength. Phys Ther, 2010, 90: 43–54. [Medline] [CrossRef]
29) Callisaya ML, Blizzard L, Schmidt MD, et al.: A population-based study of sensorimotor factors affecting gait in older people. Age Ageing, 2009, 38: 290–295. [Medline] [CrossRef]