Association between the preoperative toe grip strength and functional performance following total knee arthroplasty: A longitudinal observational study

〇Daisuke Uritani[1], Takanari Kubo[2], Hiroshi Morikawa[3], Daisuke Tatara[4]
1)Department of Physical Therapy, Faculty of Health Science, Kio University
2)Department of Rehabilitation, Kashiba Asahigaoka Hospital
3)Department of Rehabilitation, Itami City Hospital
4)Department of Rehabilitation, Fukuoka Shion Hospital

Abstract
The aim of this study was to investigate the association between preoperative toe grip strength (TGS) and postoperative Timed Up and Go (TUG) in patients who underwent total knee arthroplasty (TKA). Participants were sixty-seven patients who underwent TKA. Outcome measures were TGS, isometric knee extension strength (IKES), TUG, and pain during walking. TGS and IKES were measured at the affected side. Outcomes were measured at a few days before TKA and at discharge. TGS and IKES before TKA were standardized by body weight (TGSpre/wt and IKESpre/wt). Outcome measures before and after TKA were compared. The association between TUG and TGSpre/wt was analyzed using multivariate linear regression with covariates (age, sex, postoperative pain during walking, and IKESpre/wt). Significant level was set at 5%. Preoperative TUG (12.5±4.9 sec) was significantly delayed at the postoperative period (vs 14.5±5.1 sec preoperatively). In multivariate linear regression analyses, TUG had a significant association with age (standardised partial regression coefficient [β]=0.30) and TGSpre/wt (β=-0.31). Preoperative TGS was associated with postoperative TUG in patients who underwent TKA.

Key words: toe, strength, total knee arthroplasty

INTRODUCTION

Total knee arthroplasty (TKA) is one of the most common surgical interventions for knee pathologies, such as knee osteoarthritis (OA)[1)2)]. In Japan, more patients with knee pathologies underwent TKA compared with Unilateral Knee Arthroplasty or Tibial Osteotomy[3)]. TKA is effective in reducing knee pain among patients with knee OA[2)]. On the other hand, many reports described surgery-induced loss of knee extensor strength after TKA[4-7)]. In addition, physical function would also decline after TKA. For example, Timed Up and Go (TUG) is significantly delayed after

TKA in the early postoperative period[8)9)].

TUG requires multiple abilities such as standing up and sitting down, walking speed, and controlling dynamic balance. Therefore, TUG is used to evaluate functional performance[10)] and is also used for screening risk of falls in community-dwelling people[11)]. TUG has been used to evaluate functional performance among patients scheduled for TKA[12)] and those who underwent TKA[8)9)13-15)] Loss of knee extensor strength has been associated with decreased functional performance, such as TUG following TKA[15)]. In particular, the involved leg shows stronger correlations to functional performance than the non-involved leg[12)].

In addition to knee extensor strength, toe function is also associated with functional performance. Previous research demonstrated that loss of toe strength was associated with the risk of falling[16)]. Another study demonstrated that TGS was negatively associated with walking speed during fast pace walking among older Japanese[17)]. We reported that TGS had a negative association with TUG independent of age and isometric knee extension strength (IKES) in older Japanese patients[18)]. However, it is unknown whether TGS has an association with functional performance following TKA.

Strength exercise of knee extensor muscle in the preoperative period is often applied to attain better functional performance after TKA[9)]. However, knee extensor strength decreases after TKA, especially in the early postoperative period[9)]. On the other hand, toes are not influenced by surgical stress of TKA. So, we hypothesized preoperative TGS may relate to functional performance after TKA in the early postoperative period. The association between knee extensor strength and functional performance among people who underwent TKA has been reported. However, the association between TGS and functional performance among the same population is unknown. Therefore, the aim of this study was to investigate the association between preoperative TGS and postoperative functional performance, assessed by the TUG, in patients who underwent TKA for knee OA in the early postoperative period. Our hypothesis was that there was a significant negative association between preoperative TGS and postoperative TUG.

METHODS

Study design and population

This study was designed as an observational, non-interventional, longitudinal study. Participants were recruited from three hospitals located in different regions in Japan. Data were collected from July 29, 2015 to September 16, 2017. All data were collected by physical therapists. Inclusion criteria were patients who were scheduled for a unilateral TKA due to knee OA. Participants were screened to exclude those with known neuromuscular or musculoskeletal pathologies; those who undergone any other surgical treatment of the lower limbs or trunk; and those with health conditions, which could influence the function of the lower limbs including neurological or orthopaedic impairments.

Procedures

This study was approved by the local ethics committee, in accordance with the Declaration of Helsinki. Written informed consent was obtained from all participants before study inclusion.

Demographic characteristics were collected from the medical record at initial hospitalization. Outcome measures were TGS, IKES, TUG, and pain during walking. These outcomes were measured before TKA and at discharge.

Data collection

Demographic characteristics recorded included age, sex, height, and weight.

Toe grip strength (TGS) was measured on the involved side. It was measured using a toe-grip dynamometer (T.K.K. 3362, Takei Scientific Instruments, Niigata, Japan), using previously described methods[19)20)]. A previous study reported substantial to almost perfect inter- and intra-rater reliability for this device when used among people 60 to 79 years old[20)]. For measurement, participants sat upright on a chair, without leaning on the backrest, with hips and knees flexed at approximately 90 degrees; the ankles were placed in the neutral position and fixed with a strap. The first proximal phalanx was positioned on the grip bar and the heel stopper was individually adjusted to fit the heel for each participant. The first toe was used as the benchmark for establishing the testing position, because the flexor strength of the hallux has been reported to be most strongly associated with total TGS[21)]. Before the actual measurements, participants practiced the test at a submaximal effort. For the actual measurements, participants were instructed to grip the bar with their toes, exerting the greatest possible force for approximately 3 sec. Two TGS measurements were recorded and the mean value was used for analysis.

Isometric knee extension strength (IKES) was also measured on the involved side. It was measured using a hand-held dynamometer (μ-tas F1, ANIMA, Tokyo, Japan) with participants in a seated position with the knee in 90 degrees of flexion and using previously described methods[22)]. Participants were instructed to gradually increase the intensity of knee extension against the dynamometer for approximately 2 sec, avoiding an explosive contraction, and to maintain their maximal force output for approximately 3 sec. Again, two measurements were obtained, with the mean used for analysis.

TUG was measured using standard test methods[10)]. Briefly, participants were instructed to stand up from a seated position in a chair, walk as quickly and safely as possible (without running) towards a pole, turn around the pole, and then walk back to the chair and sit down. The time needed to complete the TUG was recorded using the TUG meter (T.K.K. 5804, Takei Scientific Instruments, Niigata, Japan). Each participant completed the TUG twice, with the mean time used for analysis.

Participants were asked about pain during walking. It was scaled using a visual analog scale[23)] VAS was presented as a 100-mm line, anchored by verbal descriptors, such as “no pain” and “worst imaginable pain.” Participants were asked to mark the 100-mm line to indicate pain intensity. The score was measured from the zero anchor to the patient’s mark. Using a millimetre scale to measure the patient’s score provided levels of pain intensity.

All outcomes, except IKES, were measured within a few days before TKA (preoperative) and at discharge after TKA (postoperative). Postoperative IKES was not included as an outcome because one of the facilities collaborated in this study did not measure IKES to avoid pain or other potential side effects, and postoperative IKES was not required for statistical analysis in this study. Preoperative TGS and IKES were standardized by body weight (TGSpre/wt and IKESpre/wt, respectively).

Statistical analysis

Descriptive statistics were computed as means and standard deviations. Outcome measures, except IKES, were compared before and after TKA using a paired *t* test. The Pearson's correlation coefficients between postoperative TUG and age, postoperative pain during walking, TGSpre/wt, and IKESpre/wt were calculated. The association between postoperative TUG and TGSpre/wt was analyzed using multivariate linear regression analyses with direct methods. The dependent variable was postoperative TUG and potential related factors (independent variables) were age, sex, postoperative pain during walking, TGSpre/wt, and IKESpre/wt. We also determined the adjusted R^2 value for the multivariate linear regression analyses. Statistical significance was set at 5%. Statistical analysis was performed using IBM SPSS statistics 22 (IBM Japan, Tokyo, Japan).

Statement of ethics and funding

This study was approved by the Research Ethics Committee of Kio university (H27-10). This study was funded by JSPS KAKENHI JP15K16380.

RESULTS

Participants' characteristics

Sixty-seven patients who underwent a primary unilateral TKA due to knee OA were included in this study. Details of subjects' characteristics are summarized in Table I. The age range was from 57 to 90 years old and mean age ± standard deviation was 74.4 ± 7.6 years old. Fifty-two participants (77.6%) were female and 15 participants (22.4%) were male (Table 1).

Comparison between pre and postoperative outcome measures

Outcomes were measured within a few days (2.1±1.1 days) before TKA and at discharge (18.5±3.0 days) (Table 1).

Preoperative TUG (12.5 ± 4.9 sec) was significantly delayed in the postoperative assessment (14.5 ± 5.1 sec) ($p<0.01$). Preoperative pain during walking (48.6±27.3 mm) significantly improved at postoperative assessment (20.8 ± 18.2 mm) ($p<0.01$). There was no significant change between preoperative TGS (7.7 ± 3.8 kg) and postoperative TGS (7.7 ± 3.4 kg) (Table 1).

Association between postoperative TUG and other outcomes

Postoperative TUG was significantly correlated with age (r = 0.38, $p<0.01$) and TGSpre/wt (r = −0.43, $p<0.01$). There were no significant correlations between postoperative TUG, and postoperative pain during walking and IKESpre/wt (Table 2).

In the multivariate linear regression analyses, postoperative TUG was significantly associated with age (unstandardized coefficient [B]: 0.21, 95% confidence interval [95%CI]: 0.04 to 0.38, standardized coefficient [β]: 0.30) and

TGSpre/wt (B: -26.81, 95%CI: -49.57 to -4.05, β: -0.31). The adjusted R^2 was 0.20 (Table 3).

Table 1. Participants' characteristics and outcomes

	Preoperative period (2.1±1.1 before TKA)	Postoperative period (18.5±3.0 after TKA)
Male/Female, N	15/52	
Age, years	74.4 (7.6)	
Height, cm	153.8 (8.1)	
Weight, kg	61.4 (10.8)	
Pain during walking, mm	48.6 (27.3)	20.8 (18.2)**
TGS, kg	7.7 (3.8)	7.7 (3.4)
TGSpre/wt, %	12.5 (5.8)	
IKES, kg	14.3 (6.7)	
IKESpre/wt, %	23.0 (8.9)	
TUG, seconds	12.5 (4.9)	14.5 (5.1)**

Data are expressed as mean (standard deviation), IKES; Isometric knee extension strength, TGS; Toe grip strength, TKA; Total Knee Arthroplasty, TUG; Timed up and go, **p<0.01

Table 2. Correlations between preoperative TUG, and age and other outcomes

	Age	Pain#	TGSpre/wt	IKESpre/wt
Postoperative TUG	0.38**	0.02	-0.43**	-0.22

#Postoperative pain during walking, IKES; Isometric knee extension strength, TGS; Toe grip strength, TUG; Timed up and go, **p<0.01

Table 3. Association preoperative TUG and its potential related factors

	B (95% CI)	β	p	Adjusted R^2
Intercept	2.81 (-12.12 - 17.72)		0.71	0.20
Age	0.21 (0.04 - 0.38)	0.30	0.02	
Sex	-0.17 (-3.10 - 2.76)	-0.01	0.91	
Pain#	0.03 (-0.03 - 0.10)	0.12	0.30	
IKESpre/wt	-4.51 (-18.59 - 9.56)	-0.08	0.52	
TGSpre/wt	-26.81 (-49.57 - -4.05)	-0.31	0.02	

B; Coefficient, 95%CI; 95% confidence interval, β; Standardised partial regression coefficient, #Postoperative pain during walking, IKESpre; Preoperative isometric knee extension strength, TGSpre; Preoperative toe grip strength, TUG; Timed Up and Go, wt; weight

DISCUSSION

The main finding in this study was a significant association between preoperative TGS and postoperative TUG. People with stronger TGS normalized by weight in the preoperative period presented faster TUG in the early postoperative period after TKA. This relationship was independent of age, sex, pain during walking and IKES normalized by weight. Regarding preoperative muscle strength on the involved side, TGS is more important for TUG rather than knee extensor strength.

In general, functional performance declines following TKA[8)9)], while TKA has a beneficial effect on reducing pain[2)]. The results in this study showed similar results.

Postoperative TUG (14.5 seconds) was slower than the cut off value of risk of falling (13.5 seconds)[24]. In terms of knee extensor strength, we could measure postoperative IKES amongst only a subset of participants (n=33). Based on their data, postoperative IKES (10.3 ± 5.8 kg) was significantly weaker than preoperative IKES (16.4 ± 6.8 kg) ($p<0.01$). This indicates that participants in the current study might also present with loss of knee extensor strength, in accordance with the previous reports.

Misu, et al.[17] reported that decreased TGS was correlated with slower walking speed and shorter stride length during fast-pace walking among healthy older Japanese. This suggests that TGS can affect propulsion when people are walking quickly, such as when participants in the current study performed the TUG task. In addition, TUG also requires a standing up ability. Moving ahead of the center of pressure helps forward bending and easy rising during standing up. During this phase in TUG, weight bearing is required around the toes. Therefore, TUG is also affected by TGS through standing up phase. Our previous study described the negative relationship between TGS and TUG among community-dwelling older people[18]. The results in the current study suggested that patients who underwent TKA also had similar relationship compared with community-dwelling older Japanese people.

TUG evaluates multiple abilities such as sit-to-stand motion, walking, and turning around. These movements are repeated frequently during daily life. Therefore, stronger TGS may allow people who undergo TKA a better ability to perform their activities of daily living (ADL) and may facilitate improvement in ADL in the early postoperative period. In other words, preoperative training of TGS may mitigate the decline in in the early postoperative period.

Impairment of knee extensor strength in patients with knee OA is well-known[25]. Chun, et al.[26] demonstrated that decreased knee extensor strength was the main associated factor of reduced functional performance in patients with severe knee OA[26]. That is why preoperative strength exercise of knee extensor muscles has been attempted to attain better results on functional performance after TKA[14]. However, surgical procedures applied in TKA involve trauma to the extensor mechanism and surgery-induced loss of knee extensor strength is unavoidable; as such, knee extensor strength decreases[4-7]. Meanwhile, TGS among patients with knee OA is also significantly weaker than among healthy controls[27]. However, TGS does not change before and after TKA unlike knee extensor strength according to the result in this study because toes are not invaded by surgery. Therefore, preoperative training of TGS may have a beneficial effect on postoperative TGS and may be important for postoperative function as well as preoperative training of knee extensor strength.

Based on the results in this study, TGS did not change before and after TKA. However, several previous research studies described the change of plantar loading parameters before and after TKA. Several studies reported that plantar loading parameters, such as force and pressure, were decreased in the forefoot or toe region after TKA[28][29]. These changes may influence the functional performance after TKA. Therefore, facilitation of weight bearing on the toes to exert TGS on the ground may also have to apply in therapeutic exercise in addition to strength training of TGS.

There were some limitations to this study. First, we measured toe and knee strength on only the involved side, because the involved side shows stronger correlations to functional performance than the non-involved side[12] and is influenced by surgical stress, though several previous research studies investigated both sides[9,12,30]. Therefore, we are not able to assess the influence of the non-involved side on the results. Second, we did not consider the impact of the strength of other muscles in the lower extremity, such as hip and ankle muscles. It may be relevant to investigate the impact of those muscles in future studies. Third, we were not able to determine a causal association between TGS and TUG as this study was an observational study. We have to investigate whether preoperative strength training of TGS would influence TUG after TKA to clarify its causal relationship in the future.

In conclusion, preoperative TGS was associated with postoperative functional performance assessed by TUG irrespective of age, sex, pain, and IKES. In other words, regarding preoperative muscle strength on the involved side, TGS is more associated with TUG rather than knee extensor strength. Preoperative strength training to TGS may have a beneficial effect on functional performance in the early postoperative period after TKA.

REFERENCES

1. Carr AJ, Robertsson O, et al: Knee replacement. The Lancet 379(9823):1331-1340, 2012.

2. Dusad A, Pedro S, et al: Impact of Total Knee Arthroplasty as Assessed Using Patient-Reported Pain and Health-Related Quality of Life Indices: Rheumatoid Arthritis Versus Osteoarthritis. Arthritis Rheum 67(9):2503-2511, 2015.

3. Kawata M, Sasabuchi Y, et al: Annual trends in knee arthroplasty and tibial osteotomy: Analysis of a national database in Japan. Knee 24(5):1198-1205, 2017.

4. Holm B, Kristensen MT, et al: Loss of knee-extension strength is related to knee swelling after total knee arthroplasty. Arch Phys Med Rehabil 91(11):1770-1776, 2010.

5. Holm B, Kristensen MT, et al: The role of pain for early rehabilitation in fast track total knee arthroplasty. Disabil Rehabil 32(4):300-306, 2010.

6. Mizner RL, Petterson SC, et al: Early quadriceps strength loss after total knee arthroplasty. The contributions of muscle atrophy and failure of voluntary muscle activation. J Bone Joint Surg Am 87(5):1047-1053, 2005.

7. Stevens JE, Mizner RL, et al: Quadriceps strength and volitional activation before and after total knee arthroplasty for osteoarthritis. J Orthop Res 21(5):775-779, 2003.

8. Bade MJ, Kohrt WM, et al: Outcomes before and after total knee arthroplasty compared to healthy adults. J Orthop Sports Phys Ther 40(9):559-567, 2010.

9. Skoffer B, Maribo T, et al. Efficacy of Preoperative Progressive Resistance Training on Postoperative Outcomes in Patients Undergoing Total Knee Arthroplasty. Arthritis Care Res (Hoboken) 68(9):1239-1251, 2016.

10. Podsiadlo D, Richardson S. The timed "Up

& Go": a test of basic functional mobility for frail elderly persons. J Am Geriatr Soc 39(2):142-148, 1991.
11. Shumway-Cook A, Brauer S, et al: Predicting the probability for falls in community-dwelling older adults using the Timed Up & Go Test. Phys Ther 80(9):896-903, 2000.
12. Skoffer B, Dalgas U, et al: Functional performance is associated with both knee extensor and flexor muscle strength in patients scheduled for total knee arthroplasty: A cross-sectional study. J Rehabil Med 47(5):454-459, 2015.
13. Mizner RL, Petterson SC, et al: Quadriceps strength and the time course of functional recovery after total knee arthroplasty. J Orthop Sports Phys Ther 35(7):424-436, 2005.
14. Mizner RL, Petterson SC, et al: Preoperative quadriceps strength predicts functional ability one year after total knee arthroplasty. J Rheumatol 32(8):1533-1539, 2005.
15. 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 23(5):1083-1090, 2005.
16. Mickle KJ, Munro BJ, et al: ISB Clinical Biomechanics Award 2009: toe weakness and deformity increase the risk of falls in older people. Clin Biomech (Bristol, Avon) 24(10):787-791, 2009.
17. Misu S, Doi T, et al: Association between toe flexor strength and spatiotemporal gait parameters in community-dwelling older people. J Neuroeng Rehabil 11:143, 2014.
18. Uritani D, Fukumoto T, et al: The Relationship Between Toe Grip Strength and Dynamic Balance or Functional Mobility Among Community-Dwelling Japanese Older Adults: A Cross-Sectional Study. J Aging Phys Act 24(3):459-464, 2016.
19. Uritani D, Fukumoto T, et al: Reference values for toe grip strength among Japanese adults aged 20 to 79 years: a cross-sectional study. J Foot Ankle Res 7:28, 2014
20. Uritani D, Fukumoto T, et al: Intrarater and Interrater Reliabilities for a Toe Grip Dynamometer. J Phys Ther Sci 24(8):639-643, 2012.
21. Kamon M, Toufukuji N, et al: Research regrds to flexional force of foot. Tokai J Sports Med Sci 17:48-54, 2005.
22. Koblbauer IF, Lambrecht Y, et al: Reliability of maximal isometric knee strength testing with modified hand-held dynamometry in patients awaiting total knee arthroplasty: useful in research and individual patient settings? A reliability study. BMC musculoskeletal disorders 12:249, 2011.
23. Williamson A, Hoggart B. Pain: a review of three commonly used pain rating scales. J Clin Nurs 14(7):798-804, 2005.
24. Barry E, Galvin R, et al: Is the Timed Up and Go test a useful predictor of risk of falls in community dwelling older adults: a systematic review and meta-analysis. BMC geriatrics 14:14, 2014.
25. Alnahdi AH, Zeni JA, et al: Muscle impairments in patients with knee osteoarthritis. Sports Health 4(4):284-292, 2012.
26. Chun SW, Kim KE, et al. Muscle strength is the main associated factor of physical performance in older adults with knee osteoarthritis regardless of radiographic severity. Arch Gerontol Geriatr 56(2):377-382,

2013.
27. Uritani D, Fukumoto T, et al: The association between toe grip strength and osteoarthritis of the knee in Japanese women: A multicenter cross-sectional study. PLoS One 12(10):e0186454, 2017.
28. Guven M, Kocadal O, et al: Pedobarographic Analysis in Total Knee Arthroplasty. J Knee Surg 30(9):951-959, 2017.
29. Voronov ML, Pinzur MS, et al: The relationship between knee arthroplasty and foot loading. Foot Ankle Spec 5(1):17-22, 2012.
30. Huber EO, Meichtry A, et al: Construct validity of change scores of the Chair Stand Test versus Timed Up and Go Test, KOOS questionnaire and the isometric muscle strength test in patients with severe knee osteoarthritis undergoing total knee replacement. Man Ther 21:262-226, 2016