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Abstract

Introduction: Total knee arthroplasty (TKA) reduces pain and improves physical function; however, not all patients have successful outcomes after surgery. To identify these patients would be critical information for improving rehabilitation programs. The purpose of this study was to clarify the cut-off values of lower extremity muscle strength for predicting postoperative good walking ability.

Materials and Methods: Timed Up and Go test of 105 patients was measured at 6 months postoperatively, and participants were divided into good (< 9.1 seconds) and poor (≥ 9.1 seconds) walking ability. Both sides of knee extensor strength (KES) and hip abductor strength (HAS) were measured using hand-held dynamometer preoperatively. Receiver operating characteristic (ROC) curve analysis was used to identify cut-off values for classifying the participants into the 2 groups.

Results: Of the 105 patients, 54 were allocated in the poor walking ability group, whereas 51 were allocated in the good walking ability group. KES and HAS were significantly greater in the good walking ability group than in the poor walking ability group. ROC curve analysis revealed that the cut-off value for KES was 0.79 Nm/kg (area under the curve (AUC), 0.68; sensitivity, 64.7%; specificity, 68.5%) on the involved side and 0.86 Nm/kg (AUC, 0.73; sensitivity, 84.6%; specificity, 55.6%) on the uninvolved side, and for HAS was 0.57 Nm/kg (AUC, 0.71; sensitivity, 60.8%; specificity, 71.7%) on the involved side and 0.61 Nm/kg (AUC, 0.76; sensitivity, 66.7%; specificity, 77.4%) on the uninvolved side.

Conclusion: The cut-off values of preoperative KES and HAS for predicting good walking ability after TKA are 0.79 Nm/kg on the involved side and 0.86 Nm/kg on the uninvolved side, and 0.57 Nm/kg on the involved side and 0.61 Nm/kg on the uninvolved side, respectively. We should provide enhanced pre- and post-operative rehabilitation programs for patients with muscle strength lower than these values.

Keywords

Total knee arthroplasty, knee extensor strength, hip abductor strength, cut-off values, Timed Up and Go test

Declarations

Ethics approval and consent to participate

Ethics approval for this study was obtained from the Ethics Committee of Kobe City Medical Center General Hospital (No. zn210608). Informed consent was obtained in the form of opt-out on the web-site of Kobe City Medical Center General Hospital.

Consent for publication

The authors provided informed consent for publication in the form of opt-out on the web-site of Kobe City Medical Center General Hospital.

Availability of data and materials

The dataset of the current study is available from the corresponding author on reasonable request.

Competing interests

The authors declare that they have no conflict of interest.

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Authors' contributions

D.T and H.M conceived and designed this study. D.T, Y.Y, K.S, K.S, and T.I collected and analyzed the data. D.T wrote the first draft of the manuscript and K.I, T.Y, and H.M commented on previous versions of the manuscript. All authors read and approved the final manuscript.

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1. Introduction

Total knee arthroplasty (TKA) is standard treatment for patients with end-stage osteoarthritis (OA), and the number of patients who require TKA is increasing worldwide. Although TKA reduces pain and improves physical function, recovery of walking ability is delayed in some patients after surgery [1, 2] . To identify these patients would be critical information for improving pre- and post-operative rehabilitation programs. Preoperative lower extremity muscle strength might be a predictor of the patients with impaired postoperative walking ability, since preoperative muscle strength has an effect on postoperative outcomes [3, 4].

Of lower extremity muscle strength, knee extensor strength (KES) is one of the important anti-gravity muscles. It controls knee flexion during ambulation and reduces knee joint loading [5] . KES is associated with walking ability in TKA patients [6]. Some studies reported cut-off values for predicting walking ability or risk of falling in older people [7] and stroke patients [8, 9]. However, these cut-off values should not be applied to TKA patients because OA patients and TKA patients have impaired physical function and muscle strength compared to healthy older people of similar age [10-12].

Similar to KES, hip abductor strength (HAS) is also important anti-gravity muscle. It is crucial in stabilizing the trunk and hip during ambulation, which controls limb alignment and transfers forces to the pelvis. HAS is also associated with walking ability in OA or TKA patients [13-15], and some studies have reported the efficacy of HAS strengthening in improving physical function such as balance, pain, and walking ability [16-18].

Taken together, preoperative lower extremity muscle strength may be an important predictor of postoperative walking ability after TKA. However, to the best of our knowledge, no studies are available on cut-off values of preoperative KES or HAS for predicting good walking ability in TKA patients. Thus, the purpose of this study was to clarify the cut-off values of preoperative KES and HAS for predicting postoperative good walking ability.

2. Materials and Methods

2.1 Study design

This study was a retrospective and longitudinal observational design. The study was conducted with approval of the Ethics Committee of our hospital. Baseline assessments were done 1 to 3 days preoperatively, and patients were followed up at 6 months after surgery. The 6 month time point was chosen because patients recovering from TKA typically plateau in strength and functional gains by this time point [19-21].

2.2 Participants

Patients with knee OA who were scheduled to undergo primary unilateral TKA in our hospital between October 2018 and March 2021, and who were assessed for physical function before and after surgery were enrolled in this study. Exclusion criteria were: (1) patients who were forbidden postoperative rehabilitation due to intraoperative or postoperative complications, (2) patients who had neurological disorder, cardiovascular disorder, psychiatric disorder, or cognitive disorder that affected their physical function, (3) patients who had severe obesity (body mass index [BMI] > 40kg/m^2), or (4) patients who could not walk without assistance.

Patients characteristics and medical information including age, sex, height, body weight, BMI, and previous joint replacement were collected using clinical records.

2.3 Surgery

All patients underwent cemented TKA with replacement of the patella. The medial parapatellar approach was used. The inserted implant was BS5 PS-type (Kyocera), Initia PS-type (Kyocera), Triathlon PS-type (Stryker), ATTUNE PS-type (Depuy), or JOURNEYII PS-type (Smith & Nephew). We also collected the data about surgery including the surgical time, the tourniquet usage, and the length of incision.

2.4 Postoperative rehabilitation

All patients received the same postoperative rehabilitation protocol. In brief, patients stayed in the hospital for about 10 days and received daily physical therapy. After 10 days stay in the hospital, patients were discharged to their home or rehabilitation hospitals. Patients started physical therapy and full weight-bearing was allowed on the next day after surgery. Patients received continuous passive motion for 30 minutes every day from the second postoperative day. The physical therapy program consisted of active or passive knee range of motion exercise, resistance training, gait exercise with or without ambulation aids, and activities of daily living training.

2.5 Measurement of physical function

Timed Up and Go test

Timed Up and Go test (TUG) was measured as the main outcome. TUG is a standard measure of function, balance, and walking ability for people with knee OA and TKA patients, and it has an excellent test-retest reliability [22]. TUG is also commonly used as a performance-based outcome measure for TKA patients [23, 24] . We measured the time it takes to stand up from a standard chair with armrests, walk 3 meters, turn, walk back to the chair, and sit down [25]. The patients were asked to walk as quickly and safety as possible using assistive devices if needed.

Muscle strength

Both sides of maximal isometric muscle strength was measured with a hand-held dynamometer (Anima, Tokyo, Japan), as described by the other report [26].

Fig. 1 shows the setup during KES measurements. For assessment of KES, participants were positioned on a platform in a sitting position with 90° hip and knee flexion, with legs perpendicular to the floor and feet not touching the ground. Sensor pad were placed on the anterior legs just proximal to the ankle. The length of the lever arm was measured from joint fissure gap of the knee to the center of the sensor pad.

Fig. 2 shows the setup during HAS measurements. For assessment of HAS, participants were placed in a supine position with neutral hip adduction/abduction. Sensor pad were placed on the lateral aspects of the thigh just proximal to the knee joint. The length of the lever arm was measured from greater trochanter to the center of the sensor pad.

The dynamometer variable (Newtons, N) and lever arm length (m) were multiplied to obtain the torque (Nm). Then, the torque value (Nm) was used to obtain the torque to body weight (Nm/kg) ratio. Verbal encouragement was used to facilitate maximal volitional force production. The strength was measured twice and the maximal value was used for the analysis.

2.6 Statistical analysis

We first evaluated if the variables were normally distributed using Shapiro-Wilks test. Normally distributed variables were expressed as mean (standard deviation), and non-normally variables were median (interquartile range). Chi-squared test, t-test, or Mann-Whitney U test were used to compare patients' characteristics and clinical measurements between groups. A multiple linear regression was used to identify the predictors associated with the postoperative physical function. The dependent variable was TUG at 6 months after TKA. Both sides of KES and HAS were separately entered into the models as independent variables to account for multicollinearity. For model 1, independent variables were age, sex, BMI, and involved side of KES. For model 2, independent variables were age, sex, BMI, and involved side of HAS. For model 3, independent variables were age, sex, BMI, and uninvolved side of KES. For model 4, independent variables were age, sex, BMI, and uninvolved side of HAS.

The participants were divided into 2 groups according to the 6th postoperative month TUG time based on a previous study [10] as the good (< 9.1 seconds) and poor (≥ 9.1 seconds) walking ability groups, as in refs [25]. Receiver operating characteristic (ROC) curve analysis was used to identify cut-off values based on Youden index for classifying the participants into the 2 groups and calculate the area under the curve (AUC), sensitivity, and specificity.

The anticipated AUC was 0.7. With a two-sided alpha error of 5% and 90% of power, we determined the total sample size of 90 patients (45 in each) would be necessary [27].

Data were analyzed using EZR (Saitama Medical Center, Jichi Medical University, Saitama, Japan), which is a graphical user interface for R (The R Foundation for Statistical Computing, Vienna, Austria). More precisely, it is a modified version of R commander designed to add statistical functions frequently use in biostatistics. The level of significance was set at $P < 0.05$.

3. Results

In total, 105 patients were included in the analysis. Of the 105 patients, 83 (79%) were women. The patients had a median age of 76.0 (71.0-81.0) years. Table 1 presents the characteristics of the participants. As a result of analysis, 54 (51%) patients were allocated in the poor walking ability group, whereas 51 (49%) were allocated in the good walking ability group. The median age was significantly lower in the good walking ability group (74.0

[70.0-77.5] vs 79.0 [75.0-81.8] [years], $P < 0.001$). The involved side of KES and HAS were significantly greater in the good walking ability group than in the poor walking ability group (0.84 [0.69-1.14] vs 0.72 [0.52-0.83] [Nm/kg], $P = 0.002$; 0.61 [0.44-0.82] vs 0.44 [0.30-0.60] [Nm/kg], $P < 0.001$). The uninvolved side of KES and HAS were also significantly greater in the good walking ability group than in the poor walking ability group (1.12 [0.91-1.35] vs 0.82 [0.64-1.07] [Nm/kg], $P < 0.001$; 0.70 [0.50-0.85] vs 0.46 [0.34-0.60] [Nm/kg], $P < 0.001$).

Table 2 presents the results of the multiple linear regression model for predicting postoperative TUG. Age, both sides of KES and HAS were significantly associated with postoperative TUG.

ROC curve analysis revealed that the AUC for KES was 0.68 on the involved side and 0.73 on the uninvolved side. The cut-off value for KES was 0.79 Nm/kg (sensitivity, 64.7%; specificity, 68.5%) on the involved side and 0.86 Nm/kg (sensitivity, 84.6%; specificity 55.6%) on the uninvolved side (Fig. 3). The AUC for HAS was 0.71 on the involved side and 0.76 on the uninvolved side. The cut-off value for HAS was 0.57 Nm/kg (sensitivity, 60.8%; specificity, 71.7%) on the involved side and 0.61 Nm/kg (sensitivity, 66.7%; specificity, 77.4%) on the uninvolved side (Fig. 4).

4. Discussion

We provided the cut-off value of preoperative lower extremity muscle strength for predicting good walking ability at 6 months after surgery in TKA patients. The value of preoperative KES was 0.79 Nm/kg on the involved side and 0.86 Nm/kg on the uninvolved side (Fig. 3), and that of preoperative HAS was 0.57 Nm/kg on the involved side and 0.61 Nm/kg on the uninvolved side, respectively (Fig. 4).

The multiple linear regression analysis indicated that both sides of preoperative

KES and HAS were independently associated with walking ability at 6 months after surgery (Table 2). Our results are in line with published studies [3, 4, 13] , and we confirmed the importance of preoperative muscle strength in TKA patients to improve postoperative outcomes. In the present study, the median (interquartile range) of preoperative KES was 0.76 (0.59-0.98) Nm/kg and that of preoperative HAS was 0.51 (0.41-0.70) Nm/kg (Table 1) on the involved side. These values are lower than published studies [25, 28] using the similar methods of muscle strength measurement. This can be attributable to the fact that our participants were older age [76.0 (71.0-81.0) years] compared to these studies [25, 28]. These results indicate that preoperative muscle strength is important for improving postoperative outcomes in older TKA patients as well, which would be crucial for current aging societies. In addition to involved side of muscle strength, uninvolved side of muscle strength was also associated with walking ability at 6 months after TKA. These results are congruent with the published study reported by Murao et al [29]. They reported that patients with preoperative HAS greater than 0.66 Nm/kg achieved better functional mobility at 6 months postoperatively, when compared with healthy subjects [29]. The cut-off value of HAS on the uninvolved side in our study (0.61 Nm/kg) is close to their study [29] and may be a valid value. Moreover, our results have enough statistical power which has sufficient sample size to prevent a beta error; therefore, our cut-off values should have sufficient internal validity.

Besides the both sides of lower extremity muscle strength, multiple linear regression analysis indicated that age was associated with TUG at 6 months postoperatively (Table 2). Older patients also had a higher frequency of postoperative complications and longer hospital stay [30]; therefore, exercise therapy should be enhanced especially in elderly patients.

Recently, preoperative rehabilitation has been reported to be effective in improving postoperative outcomes [31, 32]. We believe that patients suffering from knee OA should participate in preoperative rehabilitation programs, if preoperative KES and HAS are lower than these cut-off values. Additionally, we recommend these patients to use these values as the target muscle strength values for preoperative rehabilitation, and to engage in resistance training before surgery. On the other hand, we note that the accuracy of cut-off values is based on AUC value. In the present study, the AUC value of KES was 0.68 on the involved side, which indicates low accuracy, and that was 0.73 on the uninvolved side, which indicates moderate accuracy. The AUC value of HAS was 0.71 on the involved side and 0.76 on the uninvolved side, which indicates moderate accuracy. Keep in mind that not all patients have delayed recovery of walking ability after surgery, even if preoperative muscle strength is lower than these cut-off values.

Our study has several limitations that should be considered when interpreting the results. First, we were unable to assess physical function beyond 6 months postoperatively. Some studies have shown that TKA patients generally plateau in their recovery of muscle strength and physical function by 6 months after surgery [19-21]. On the other hand, some patients have had clinically significant improvement beyond 6 months postoperatively [33]. Studies with longer follow-up period are needed to verify the results. A second limitation is that most of the participants were women, and our findings therefore cannot be generalized to men. Third, we divided the patients into 2 groups according to TUG time at the 6th postoperative month based on a previous study [10] as the good (< 9.1 seconds) and poor (≥ 9.1 seconds) walking ability groups. However, the cohort of patients in our study (mean age of 75) were older than the cohort of patients in a previous study [10] (mean age of 65). The TUG time of 9.1 seconds at 6 months may have been a high target for our cohort of patients, and the clinical significance of the TUG time of 9.1 seconds is unclear. Forth, some surgeons operated on patients with various implants. Variability in surgeons and implants may have affected postoperative outcomes. Fifth, some patients were discharged to their home directly, whereas others were admitted to rehabilitation hospitals after surgery. The differences in discharge destinations could have influenced postoperative physical function. On the other hand, a systematic review [34] revealed a lack of superiority of clinic-based or inpatient rehabilitation programs, when compared with home-based programs in improving physical function. Moreover a few patients were discharged to their home directly (only 6%) in our study; therefore, the influence of differences in discharge destinations could be small. Finally, our study is a single-center retrospective study and may have a selection bias. Caution should be taken with generalizing the cut-off values of this study. On the other hand, since the number of older female patients who require TKA is increasing [35], we believe that the results of this study are likely to be generalizable.

5. Conclusion

In conclusion, the cut-off values of preoperative knee extensor strength and hip abductor strength for predicting good walking ability after TKA are 0.79 Nm/kg on the involved side and 0.86 Nm/kg on the uninvolved side, and 0.57 Nm/kg on the involved side and 0.61 Nm/kg on the uninvolved side, respectively. We should provide enhanced pre- and post-operative rehabilitation programs for patients with muscle strength lower than these values.

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Figure legends

Fig. 1

Setup for knee extensor strength measure by hand held dynamometer.

Fig. 2

Setup for hip abductor strength measure by hand held dynamometer.

Fig. 3

Receiver operating characteristic curves for knee extensor strength for predicting postoperative good walking ability. Circle = cut-off value on involved side (0.79 Nm/kg); square = cut-off value on uninvolved side (0.86 Nm/kg).

Fig. 4

Receiver operating characteristic curves for hip abductor strength for predicting postoperative good walking ability. Circle = cut-off value on involved side (0.57 Nm/kg); square = cut-off value on uninvolved side (0.61 Nm/kg).

Figure 1

Figure 2

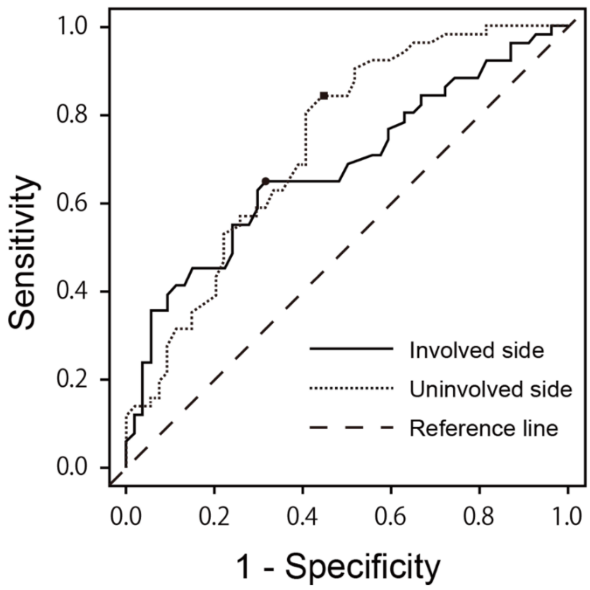
Sensitivity
1 - Specificity
0.0
0.2
0.4
0.6
0.8
1.0
Involved side
Uninvolved side
Reference line

Figure 3

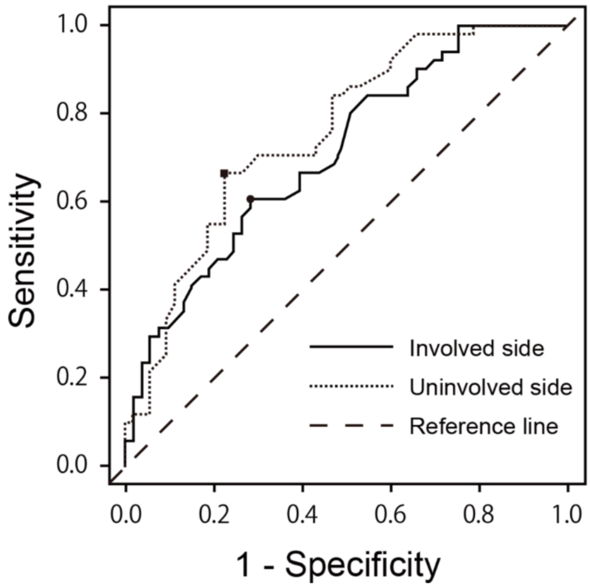
Sensitivity
1 - Specificity
0.0
0.2
0.4
0.6
0.8
1.0
Involved side
Uninvolved side
Reference line

Figure 4

Table. 1 Demographics characteristics of the participants

	total (n=105)	poor (n=54)	good (n=51)	$P-$value
Age (years)	76.0 (71.0-81.0)	79.0 (75.0 - 81.8)	74.0 (70.0 - 77.5)	< 0.001
Sex, n (%)				
Male/Female	22 (21%)/83 (79%)	13(24%)/41(76%)	9 (18%)/42 (82%)	0.569
Height (cm)	152.1 (147.2 - 158.8)	149.8 (144.7 - 158.7)	154.4 (148.6 - 158.8)	0.062
Body weight (kg)	60.1 (53.7 - 70.0)	60.0 (55.4 - 69.6)	61.8 (52.1 - 69.5)	0.923
BMI (kg/m^2)	26.0 (23.5 - 28.5)	26.4 (23.8 - 28.5)	25.4 (22.8 - 28.5)	0.193
Involved side of KES (Nm/kg)	0.76 (0.59 - 0.98)	0.72 (0.52 - 0.83)	0.84 (0.69 - 1.14)	0.002
Uninvolved side of KES (Nm/kg)	0.95 (0.75 - 1.18)	0.82 (0.64 - 1.07)	1.12 (0.91 - 1.35)	< 0.001
Involved side of HAS (Nm/kg)	0.51 (0.41 - 0.70)	0.44 (0.30 - 0.60)	0.61 (0.44 - 0.82)	< 0.001
Uninvolved side of HAS	0.57 (0.43 - 0.78)	0.46 (0.34 - 0.60)	0.70 (0.50 - 0.85)	< 0.001
Preoperative TUG (seconds)	10.5 (8.5 - 13.3)	12.4 (10.4 - 16.4)	8.8 (7.3 - 10.5)	< 0.001
TUG at 6 months (seconds)	9.4 (7.6 - 11.8)	11.8 (10.7 - 14.4)	7.6 (7.1 - 8.3)	< 0.001
Side of operation, n (%)				
Right/Left	55 (52%)/50 (48%)	27 (50%)/27 (50%)	28 (55%)/23 (45%)	0.759
Type of implant, n (%)				
Kyocera (BS5)	34 (32%)	17 (31.5%)	17 (33.3%)	
Kyocera (Initia)	18 (17%)	10 (18.5%)	8 (15.7%)	
Stryker (Triathlon)	21 (20%)	10 (18.5%)	11 (21.6%)	0.972
Depuy (ATTUNE)	20 (19%)	10 (18.5%)	10 (19.6%)	
Smith & nephew (JOURNEY II)	12 (11%)	7 (13.0%)	5 (9.8%)	
Surgical time (minutes)	151.1 ± 27.1	149.1 ± 28.2	153.3 ± 25.9	0.432

Tourniquet usage, n (%)	72 (68.6%)	36 (66.7%)	36 (70.6%)	0.824
Incision length (cm)	14.0 (13.0 - 15.0)	14.0 (14.0 - 15.0)	14 (12.0 - 15.0)	0.908
Uninvolved side of TKA, n (%)	35 (33%)	14 (26%)	21 (41%)	0.147
Previous THA, n (%)	16 (15%)	11 (20%)	5 (10%)	0.217
Discharge destinations, n (%)				
Rehabilitation hospital	99 (94%)	51 (94.4%)	48 (94.1%)	1.000
Home	6 (6%)	3 (5.6%)	3 (5.9%)	

Data were presented as mean (SD) or median (IQR).
BMI, body mass index; KES, knee extensor strength; HAS, hip abductor strength; TKA, total knee arthroplasty; THA, total hip arthroplasty; SD, standard deviation; IQR, Interquartile range

Table. 2 Multiple linear regression model for predicting the TUG at 6 months after TKA

Independent Variable	B	SE	β	*P*-value
Model 1				
Age	0.182	0.048	0.021	< 0.001
Sex	-0.921	0.822	-1.740	0.265
BMI	0.121	0.083	0.129	0.147
Involved side of KES	-3.378	1.004	-0.312	0.001
Model 2				
Age	0.174	0.048	0.334	< 0.001
Sex	-0.615	0.799	-0.071	0.444
BMI	0.095	0.085	0.103	0.265
Involved side of HAS	-3.904	1.307	-0.279	0.004
Model 3				
Age	0.185	0.047	0.019	< 0.001
Sex	-0.975	0.812	-1.036	0.233
BMI	0.067	0.085	0.127	0.807
Uninvolved side of KES	-3.437	0.932	-0.393	< 0.001
Model 4				
Age	0.168	0.047	0.013	< 0.001
Sex	-0.925	0.786	-0.999	0.242
BMI	0.060	0.084	0.114	0.479
Uninvolved side of HAS	-4.832	1.226	-0.560	< 0.001

B, partial regression coefficient; SE, standard error; β, standardized partial regression coefficient; BMI, body mass index; KES, knee extensor strength; HAS, hip abductor strength; TUG, timed up and go test