

ORIGINAL RESEARCH

Interactive Combinations Between Gait Speed and Physical Function at Acute Phase Can Predict the Physical Activity at 2 Years After Total Knee Arthroplasty Using Classification and Regression Tree Analysis



Gakuto Kitamura, PT, MSc,^a Manabu Nankaku, PT, PhD,^a Takuma Yuri, OT, PhD,^a Shinichi Kuriyama, MD, PhD,^b Shinichiro Nakamura, MD, PhD,^b Kohei Nishitani, MD, PhD,^b Ryosuke Ikeguchi, MD, PhD,^{a,b} Shuichi Matsuda, MD, PhD^{a,b}

From the ^aRehabilitation Unit, Kyoto University Hospital, Kyoto, Japan; and ^bDepartment of Orthopaedic Surgery, Kyoto University Graduate School of Medicine, Kyoto, Japan.

Abstract

Objective: To clarify the interactive combinations of various clinical factors associated with physical activity (PA) at 2 years after total knee arthroplasty (TKA) using classification and regression tree (CART) analysis.

Design: A retrospective cohort study.

Setting: A single university hospital.

Participants: 286 patients who underwent TKA (N=286).

Main Outcome Measures: PA was assessed preoperatively, 3 weeks, and 2 years after TKA. Physical functions, namely, 10 m walking test (10MWT), timed Up and Go test, 1-leg standing time, isometric knee extension and flexion strength, knee joint stability, knee pain, femora-tibial angle, and the passive knee extension and flexion angle, were measured before surgery as a baseline and 3 weeks after TKA as acute phase. CART analysis was conducted to clarify the interactive combinations that accurately predict the PA at 2 years after TKA.

Results: The results of CART analysis indicated that gait speed (≥ 1.05 m/s) at the acute phase after TKA was the primal predictor for the postoperative PA at 2 years. The highest postoperative PA at 2 years was determined by gait speed (≥ 1.05 m/s) and PA (>74.5) at the acute phase. The PA at baseline and at acute phase, as well as the body mass index were also selected as predictors of postoperative PA at 2 years.

Conclusion: The present study suggested that acquiring gait speed (≥ 1.05 m/s) and PA (>74.5) in the postoperative acute phase is the predictive of a high PA at 2 years after TKA.

Archives of Physical Medicine and Rehabilitation 2023;104:902–8

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Total knee arthroplasty (TKA) is commonly performed to improve knee pain or knee function. In the clinical setting, patients with TKA would like to return to their daily life and recover to the level of physical activity (PA) before the onset of disease¹ as soon as possible. Some patients expect the TKA to reduce the pain and achieve the ability to perform normal and recreational activities.² Previous studies reported that PA is associated with fear of falls,

quality of life (QOL),³ and mortality.⁴ PA after TKA has been reported to improve over time, reaching a maximum of 2 years postoperatively.^{5,6} Significant improvements in PA and QOL have been reported after TKA.^{7,8} However, the PA of patients who underwent TKA is less compared with age-matched control subjects and not many patients can reach the PA level recommended in the health-enhancing guideline.^{7,9} Therefore, the postoperative PA could be 1 of the most important outcomes for patients with TKA.

Disclosures: Some authors (S.M., S.K., K.N.) have a financial relation with Kyocera unrelated to this study. The other authors have nothing to disclose.

Predicting the postoperative PA before surgery and at the early phase after TKA is important to set feasible goals and perform an optimized physical therapy. Previous studies reported that PA after TKA is related to sex, body mass index (BMI), renal failure, PA before surgery, and disease-specific QOL.^{5,10,11} However, a previous study reported that only patient characteristics and preoperative patient-reported outcome measures were not reliable predictors for long-term postoperative outcomes.¹² We also reported that physical functions such as muscle strength and functional mobility during the acute phase would be important to consider in predicting outcomes after total hip arthroplasty.¹³ Therefore, to estimate the postoperative PA more accurately, it may be necessary to determine the best interactive combination from the assessment of various outcomes including physical functions at both timing of baseline and the recovery process after TKA.

Multiple logistic/linear regression has often been used in previous reports on prognostic prediction in the medical field. Recently, the classification and regression tree (CART) analysis has been considered as a useful analysis to determine the prognostic factors.¹⁴ The main advantages of CART over multiple regression analysis are that; it can consider the interactions among independent variables and determine the best interactive combination that predicts the dependent variable; it can be used regardless of data normality; cutoff values are calculated; a large number of independent values can be included in the analysis. However, there have been no studies to examine the interactive combinations to predict the PA after TKA using CART analysis.

The purpose of the present study was to clarify the interactive combinations of various clinical factors associated with the PA at 2 years after TKA using CART analysis.

Methods

Study design and participants

The present study was a retrospective cohort study. This study was conducted on 350 patients presenting for rehabilitation after TKA at the Kyoto University Hospital between February 2012 and August 2018. The inclusion and exclusion criteria are shown in figure 1 and finally, 286 patients were included in this study. Before assessment, patients were informed about this study and gave written consent for prospective data collection and retrospective data analysis based on the Declaration of Helsinki. The process of informed consent was described in our previous study.¹⁵ This study was conducted with the approval of the Kyoto University Medical Ethics Committee.

Surgery and rehabilitation program

TKA was performed by 5 orthopedic surgeons at the Kyoto University Hospital. TKA implant was used Bi-Surface knee

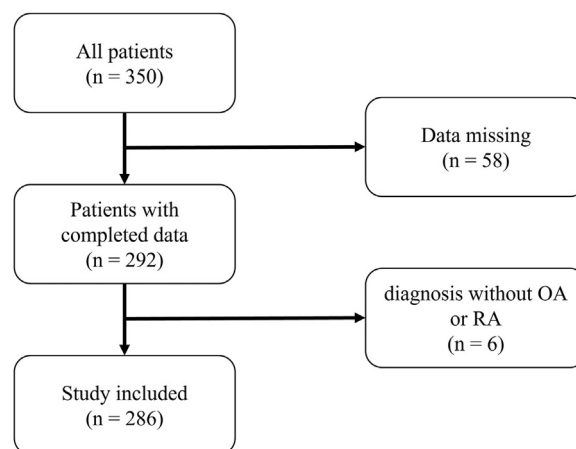


Fig 1 Flow chart of participants. OA, osteoarthritis; RA, rheumatoid arthritis.

prosthesis (Japan Medical Material, Kyoto, Japan) or Nex-Gen (Zimmer Biomet, Warsaw, IN, USA). All TKA procedures were performed using the medial parapatellar approach with the mechanical alignment method. The rotation of the femoral component was set to be parallel to the surgical epicondylar axis. The tibial component was positioned perpendicular to the postoperative mechanical axis of the tibia in the coronal plane. Patella resurfacing was performed in all patients. All implants were fixed by cement. Postoperative rehabilitation was started on the day after surgery with full weight-bearing of the operative leg. The rehabilitation goal was to obtain an independent gait with a cane by 3 weeks postoperatively. The rehabilitation programs were exercise to improve knee flexion and extension angle, strength training of leg, gait training, and exercise to achieve activity of daily living motion.

Outcome measurements

Participant's characteristics, such as diagnosis and history of TKA, were obtained from our clinical note and shown in table 1.

PA was measured preoperatively, 3 weeks, and 2 years after TKA by using the item number 4 (PA) of the Japanese version of the 2011 knee society scoring system (2011 KSS) from 0 to 100-point scale (100 being the highest amount of PA).¹⁶ This scoring system is a 4-item assessment of TKA patients' symptoms, expectations, satisfaction, and PA. The reliability and validity of all of the 4 items of the 2011 KSS have been reported.¹⁷

Physical functions were assessed preoperatively and 3 weeks postoperatively. The postoperative assessment in the acute phase

List of abbreviations:

BMI	body mass index
CART	classification and regression tree
FTA	femora-tibial angle
PA	physical activity
QOL	quality of life
R²	coefficient of determination
TKA	total knee arthroplasty
TUG	timed Up and Go test
10MWT	10 m walking test

Table 1 Characteristics of participants

Variables	Values
Sex, men/women	49/237
Age (y)	73.5 (7.8)
Height (cm)	152.9 (8.0)
Weight (kg)	61.3 (12.5)
BMI (kg/m ²)	26.2 (4.6)
Diagnosis, OA/RA	241/45
Primary or revision TKA, primary/revision	283/3
History of contralateral TKA, yes/no	92/194

Abbreviations: OA, osteoarthritis; RA, rheumatoid arthritis.

was conducted at 3 weeks after TKA, in consideration of the fact that each assessment can be conducted safely in the acute stage. The 10 m walking test (10MWT), timed Up and Go test (TUG), 1-leg standing time, knee extension and flexion strength, knee joint stability, knee pain, femora-tibial angle (FTA), and the passive knee extension and flexion angle were measured as assessments for physical function. The 10MWT was performed on a marked 14 m walkway with 2 m at the start and end that allowed for acceleration and deceleration. For the TUG, participants were instructed to stand from the armless chair (seat height of 45 cm), walk 3 m, and turn to the sitting position in the same chair. 10MWT and TUG were performed for the fastest speed of participants. The maximum isometric knee extension and flexion strength were measured for 3 seconds using by IsoForce GT-330 (OG Giken Co, Ltd, Okayama, Japan). These measurements were conducted with a chair sitting position with the hips at angles of 90° and knees at angles of 60°. The force sensor was placed 5 cm above the lateral malleolus. The torque was calculated by multiplying force by lever arm (distance between the force sensor and the level of the tibial plateau for knee extensor strength) and expressed as a percentage of body weight (Nm/kg) as described previously.¹⁸ The reliability of this method was reported in a previous study.¹⁹ Knee joint stability was assessed with the passively moving of the tibia in the anterior-posterior direction (sagittal plane) or in the adduction-abduction direction (coronal plane) with the knee flexion at angles of 30°. Stability in the sagittal plane was scored based on the distance that the tibia was moved as follows: less than 5 mm: 10 points, 5-10 mm: 5 points, more than 10 mm: 0 points. Stability in the coronal plane was scored based on the angle that the tibia was moved as follows: 5° or less: 3 points, 6-9°: 2 points, 10-14°: 1 point, 15° or more: 0 points. Knee stability was assessed manually and visually. The pain was scored based on the intensity and frequency of knee pain as follows: 6 points; mild or occasional pain: 5 points; mild pain only when climbing stairs: 4 points; mild pain when walking and climbing stairs: 3 points; moderate and occasional pain even when doing nothing: 2 points; moderate and constant pain: 1 point; severe pain: 0 points. FTA was measured in the standing position and scored as follows: FTA=170°-175°: 0 points, less than 170° or greater than 175°: add 3 points for each degree, greater than 181° or less than 164°: 20 points. Knee society score²⁰ was used for assessment basis of knee joint stability, pain, and FTA.

Statistical analysis

For assessments of 10MWT, TUG, 1-leg standing time, and muscle strength, the better score between the 2 trials was used for analyses. Paired *t* test or Wilcoxon's signed-rank test was conducted to compare physical functions between preoperative and postoperative acute phases. For the PA, repeated measures 1-way analysis of variance with the Bonferroni post hoc comparisons were performed to compare the outcome among 3 time points, namely, preoperatively, postoperative acute phase, and 2 years after surgery.

CART analysis was used to examine the factors predicting PA at 2 years after TKA. CART analysis is a kind of decision tree analysis that recursively partitions the root node into 2 child nodes by selecting the numeric value of the independent variable that reduces the impurity of the dependent variable the most after branching.²¹ Both qualitative and quantitative variables can be used as dependent and independent variables in CART analysis. Only independent variables which predict dependent variable are automatically selected in CART tree model. PA at 2 years after

TKA was entered as the dependent variable, and participants' characteristics (age, sex, height, weight, BMI, diagnosis, primary or revision, contralateral TKA history), and physical functions were entered as independent variables. The minimum number of participants included in the terminal node, which is the final node with no further splitting, was set on 5 % of the whole sample size because the sample size of the present study was relatively small.²² The 10-fold cross-validation was conducted for the created decision tree to confirm the generalization of the tree. Ten-fold cross-validation means that all samples are randomly split into 10 groups of the same sample size and each group verify the generalization of the CART tree, for a total of 10 verifications. The coefficient of determination (R^2) was calculated for the created decision tree and cross-validation. Statistical analysis was conducted by using SPSS v 28 (IBM Corp, New York, NY, USA). Statistical significance was set at $P < .05$.

Results

Physical functions

Table 2 shows the results of each preoperative and acute phase physical function. Bilateral knee extension flexion angle and knee pain were significantly improved at the acute phase after TKA. On the operative side, knee extension and flexion strength were significantly decreased at the acute phase after TKA, and knee stability of sagittal and coronal plane and FTA were significantly improved at the acute phase after TKA.

Physical activities

Table 3 shows a comparison of PA between each measurement period. Repeated measures 1-way analysis of variance demonstrated that there was a significant main effect of measurement timing on the PA. The post hoc multiple comparisons revealed a significant increase in PA over time (fig 2).

CART analysis

The decision tree created by CART analysis is shown in figure 3. The analysis generated 7 terminal nodes (in order of increasing PA at 2 years after TKA surgery, rank 1-rank 7). The range of each rank PA average was 39.3-93.2. The R^2 were 0.69 for created decision tree and 0.61 for cross-validation. The first partitioning was determined by 10MWT time at the acute phase, and the cutoff value was 9.48 seconds, namely, gait speed of 1.05 m/s. If 10MWT was 1.05 m/s or faster, PA at the acute phase was selected for the next independent variable with cutoff values of 50.5 and 74.5. The next partitioning of the node 7 with PA at the acute phase of ≤ 74.5 was BMI with cutoff values of 27.7. If 10MWT at the acute phase was slower than 1.05 m/s, they were split by preoperative PA with cutoff values of 39.5. The node 5 with preoperative PA of ≤ 39.5 was split by PA at the acute phase with cutoff values of 34.5.

Discussion

In this study, CART analysis demonstrated that splitting the participants firstly by 10MWT (with a cutoff value of 1.05 m/s) at the

Table 2 Physical functions before and after TKA

Variables	Preoperation	Postoperation	95% CI	P Value
10 m gait time (s)	10.6 (7.3)	10.5 (4.5)	-0.8, 0.9	.913
TUG (s)	11.9 (8.6)	11.8 (5.4)	-0.9, 1.1	.795
Operative side				
One leg standing time (s)	11.2 (11.2)	12.4 (10.9)	-2.6, 0.2	.089
Knee extension strength (Nm/kg)	0.94 (0.46)	0.68 (0.3)	0.21, 0.31	<.001
Knee flexion strength (Nm/kg)	0.47 (0.46)	0.35 (0.21)	0.02, 0.09	<.001
Knee extension angle (°)	-8.4 (7.2)	-5.6 (9.9)	-4.0, -1.5	<.001
Knee flexion angle (°)	119.5 (17.9)	116.3 (14.0)	0.8, 5.5	.008
Knee stability sagittal	1.88 (0.34)	1.93 (0.26)	-0.46, -0.06	.011
Knee stability coronal	2.60 (0.58)	2.80 (0.44)	-1.37, -0.66	<.001
Knee pain	2.16 (1.42)	3.90 (1.44)	-1.97, -1.51	<.001
FTA	12.66 (8.64)	1.31 (4.42)	10.2, 12.1	<.001
Non-operative side				
One-leg standing time (s)	12.8 (11.6)	14.3 (11.2)	-2.8, -0.2	.026
Knee extension strength (Nm/kg)	1.13 (0.51)	1.17 (0.47)	-0.09, 0.01	.096
Knee flexion strength (Nm/kg)	0.51 (0.26)	0.54 (0.22)	-0.05, 0.00	.079
Knee extension angle (°)	-4.9 (6.2)	-3.4 (9.7)	-2.6, -0.4	.009
Knee flexion angle (°)	124.9 (17.3)	127.8 (16.3)	-5.1, -0.8	.008
Knee stability sagittal	1.92 (0.27)	1.92 (0.28)	-0.03, 0.04	.847
Knee stability coronal	2.76 (0.46)	2.74 (0.53)	-0.20, 0.41	.604
Knee pain	4.15 (1.79)	5.02 (1.34)	-1.07, -0.67	<.001
FTA	7.36 (8.91)	6.55 (8.70)	-0.03, 0.04	.052

NOTE. Data are expressed as mean $\pm$ SD.

Abbreviation: CI, confidence interval.

acute phase predict more accurately than by other independent variables (preoperative PA, PA at acute phase, and BMI) selected after seconds partitioning. To our knowledge, this was the first study that revealed the predictors and their cutoff values of PA after TKA by means of considering the interaction among independent variables. Previous studies have reported that gait speed is associated with life-space mobility in older age.^{23,24} Fast gait speed enables patients to widen their life-space area. In this way, gait speed may have affected the PA in the current study. Moreover, the result of this study suggests that acquiring gait speed (1.05 m/s or faster) in the postoperative acute phase is the prioritized goal to obtain high PA after TKA. The mean gait speed in previous studies was slightly slower than our cutoff value of 1.05 m/s in 10MWT.^{25,26} However, our cutoff value divided our patient's cohort (n=286) into 149 (52.1%; node 1) and 137 (47.9%; node 2) patients, respectively. Therefore, the 10MWT (with a cutoff value of 1.05 m/s) can be considered as a feasible criterion.

CART analysis indicated that if postoperative 10MWT was 1.05 m/s or faster, the second variable selected was PA at 3 weeks after TKA with cutoff values of 50.5 and 74.5 (rank 1-3, rank 5). This result indicates that interactive combination between 10MWT and PA at the acute phase was promising predictor of PA

at 2 years after TKA. A higher level of PA at the acute phase may promote the restoration of muscle functions and gait ability, resulting in increased PA at 2 years after TKA. However, few researchers have investigated the effect of PA in the acute phase on postoperative outcomes. Therefore, it is desirable to conduct a more detailed analysis of these relations.

A previous study reported that BMI is the independent predictor of PA at 1 year after TKA.⁷ Singh et al²⁷ also described that BMI of 30 or higher is more likely to be restricted the postoperative activities. Similarly, CART analysis in the present study selected BMI at surgery as a factor for discriminating PA levels after TKA. However, the predictive value of BMI appears to be uncertain because BMI was selected as the predictor of dependent variables only at the partitioning of node 7.

In the result of our analysis, if postoperative 10MWT was slower than 1.05 m/s, preoperative PA was selected as the next predictor with a cutoff value of 39.5. It was reported that preoperative PA is the independent predictor of PA after TKA²⁸ and preoperative step count positively correlated with step count at 1 year postoperatively.⁹ The results of the present study partially supported these reports. In view of the findings in CART analysis, patients in rank 7 cannot expect an increase in PA even 2 years after surgery because it is difficult to obtain an improvement in

Table 3 Results of repeated measures of 1-way analysis of variance

	Preoperation	Postoperation	2 years	F-Value	95% CI of Mean Difference			P Value
					Preoperation vs Postoperation	Postoperation vs 2 Years	2 Years vs Preoperation	
PA	40.8 (18.0)	51.2 (18.8)	65.8 (20.1)	125.1	6.6, 14.2	10.8, 18.4	21.2, 28.8	<.001

NOTE. Data are expressed as mean $\pm$ SD.

Abbreviation: CI, confidence interval.

neuromuscular electrical stimulation, high-intensity rehabilitation) in the acute phase was effective in improving function after TKA.^{37,38} In contrast, a systematic review indicated that the effects of intervention before surgery on postoperative improvement were inconclusive.³⁹ Therefore, further study will be needed to investigate effective rehabilitation to obtain 10MWT $\geq$ 1.05 m/s at acute phase after TKA and to determine whether improving 10MWT by postoperative training will affect long-term PA after TKA.

Limitations

The present study has several limitations. First, PA in the present study was based solely on subjective assessment, namely, the 2011 KSS.¹⁷ It should be noted that PA in the present study was different from that measured using objective PA measures, such as a 3-axis accelerometer and a pedometer. However, sufficient reliability and validity of the 2011 KSS has been reported.¹⁷ Therefore, we believe that the 2011 KSS is reasonable measurement to assess and easily monitor the PA in patients with TKA in clinical settings. Second, knee pain and knee joint stability were assessed by using an ordinal scale. This may have influenced why knee pain or knee joint stability was not selected in the CART analysis. Third, the patients in this study were older and mostly women compared with other study.^{26,27} Therefore, these characteristics should be considered in generalizing the results of this study. Finally, other possible factors remain to be evaluated, such as comorbidity profile, hip muscle functions, and the type of TKA prosthesis.

Conclusions

The results of CART analysis indicated that gait speed ($\geq$ 1.05 m/s) at the acute phase after TKA was the primal predictor for the postoperative PA at 2 years. The highest postoperative PA at 2 years was determined by gait speed ($\geq$ 1.05 m/s) and PA ($>$ 74.5) at the acute phase after TKA. The preoperative PA ($>$ 39.5) and BMI ($\leq$ 27.7) were selected as predictors of postoperative PA at 2 years.

Keywords

Knee arthroplasty; Physical activity; Rehabilitation; Walking speed

Corresponding author

Gakuto Kitamura, PT, MSc, Rehabilitation Unit, Kyoto University Hospital, 54 Shogoin-Kawahara-cho, Sakyo-ku, Kyoto 606-8507, Japan. *E-mail address:* k_gakuto@kuhp.kyoto-u.ac.jp.

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