Retrospective Cohort Study

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Prediction of early functional outcomes in patients after robotic-assisted total knee arthroplasty: a nomogram prediction model

Xudong Duan, MD, Yiwei Zhao, MD, Jiewen Zhang, MD, Ning Kong, MD, Ruomu Cao, PhD, Huanshuai Guan, MD, Yiyang Li, MD, Kunzheng Wang, MD, Pei Yang, PhD*, Run Tian, MD*

Background: Robotic-assisted total knee arthroplasty (RA-TKA) is becoming more and more popular as a treatment option for advanced knee diseases due to its potential to reduce operator-induced errors. However, the development of accurate prediction models for postoperative outcomes is challenging. This study aimed to develop a nomogram model to predict the likelihood of achieving a beneficial functional outcome. The beneficial outcome is defined as a postoperative improvement of the functional Knee Society Score (fKSS) of more than 10 points, 3 months after RA-TKA by early collection and analysis of possible predictors.

Methods: This is a retrospective study on 171 patients who underwent unilateral RA-TKA at our hospital. The collected data included demographic information, preoperative imaging data, surgical data, and preoperative and postoperative scale scores. Participants were randomly divided into a training set ($N = 120$) and a test set ($N = 51$). Univariate and multivariate logistic regression analyses were employed to screen for relevant factors. Variance inflation factor was used to investigate for variable collinearity. The accuracy and stability of the models were evaluated using calibration curves with the Hosmer–Lemeshow goodness-of-fit test, consistency index and receiver operating characteristic curves.

Results: Predictors of the nomogram included preoperative hip-knee-ankle angle deviation, preoperative 10-cm Visual Analogue Scale score, preoperative fKSS score and preoperative range of motion. Collinearity analysis with demonstrated no collinearity among the variables. The consistency index values for the training and test sets were 0.908 and 0.902, respectively. Finally, the area under the receiver operating characteristic curve was 0.908 (95% CI 0.846–0.971) in the training set and 0.902 (95% CI 0.806–0.998) in the test set.

Conclusion: A nomogram model was designed hereby aiming to predict the functional outcome 3 months after RA-TKA in patients. Rigorous validation showed that the model is robust and reliable. The identified key predictors include preoperative hip-knee-ankle angle deviation, preoperative visual analogue scale score, preoperative fKSS score, and preoperative range of motion. These findings have major implications for improving therapeutic interventions and informing clinical decision-making in patients undergoing RA-TKA.

Keywords: clinical prediction model, functional outcome, nomogram, robotic-assisted total knee arthroplasty

Introduction

As the age of the population increases, immune and degenerative diseases of the knee joint pose significant health risks[1]. Osteoarthritis (OA) is a leading cause of disability and affects more people than any other joint disease. It most frequently afflicts the knee joint[2]. Conservative treatments and arthroscopic surgery have been used as graded treatment methods with some success for these types of diseases[3,4]. However, total knee arthroplasty (TKA) is regarded as a tried-and-true treatment option for patients with end-stage knee joint disease[1]. The improvement of surgical techniques and prosthetic designs has led to continued worldwide application of TKA, with good clinical benefits to patients[5,6]. However, 14–36% of patients present suboptimal outcomes postoperatively[7], primarily due to persistent pain, limited knee function, postoperative complications, and

HIGHLIGHTS

- We developed a novel nomogram model to predict the early functional outcomes of patients 3 months after robotic-assisted total knee arthroplasty.
- We discussed the factors affecting the outcomes at 3 months postoperatively, which was considered as the key predictors.
- We performed a retrospective study of patients undergoing total knee arthroplasty helped by robotic-assissted system developed in China to fill the gaps in the research field.

Department of Bone and Joint Surgery, The Second Affiliated Hospital of Xi'an Jiaotong University, Xi'an, China

X.D. and Y.Z. contributed equally to this work, and both of them were first authors.

Sponsorships or competing interests that may be relevant to content are disclosed at the end of this article.

*Corresponding author. Address: No.157, Xiwu Rd, Xincheng District, Xi'an, Shaanxi, 710004, China. Tel.: + 862 987 679 869; fax: + 862 987 679 000. E-mail: yangpei@xjtu.edu.cn (P. Yang); and Tel.: + 862 987 679 870; fax: + 862 987 679 000. E-mail: ortianrun@163.com (R. Tian).

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failure to achieve the intended improvement[8,9]. Although expert surgical teams are able to assess the potential benefits and risks to patients preoperatively, it is often hard to predict when the expected benefit will not occur.

Robotic-assisted total knee arthroplasty (RA-TKA) has been clinically employed as a newly developed surgical technique. Several studies have reported that RA-TKA can achieve superior surgical outcomes compared with manual TKA. Its superiority is reflected in more precise prosthesis placement, alignment of the lower limb, less postoperative pain, shorter hospital stays[10–12] and higher the homogeneity. In other words, differences in surgical outcomes due to differences in experience between operators, or the same operator operating at different times, are considerably minimized. These advantages promote the comprehensives and wide applicability of RA-TKA. However, despite the increasing application of RA-TKA, there is evidence which suggests that the complication rate is not significantly different between RA-TKA and manual TKA[13], and questions the difference in long-term postoperative functional scores[14]. Meanwhile, many patients are dissatisfied with the results of knee replacement surgery. Given the additional cost of RA-TKA surgery, this ambiguity about clinical benefits creates concerns for both doctors and patients. Therefore, it is critical to predict accurately which patients may benefit or fail to respond well following RA-TKA. An accurate prediction can improve the efficiency of medical decision-making and enhance surgical benefits, leading to more beneficial clinical outcomes for patients. Factors such as age, sex, body mass index, social support, mental health, preoperative knee pain and functional status, number of comorbidities, and different operational processes have been reported to potentially be associated with different TKA treatment outcomes[15–19]. However, the association of these factors with outcomes has not been consistently reported in the literature, raising uncertainty about the accuracy of outcome prediction.

The nomogram is a reliable graphical tool that can perform complex statistical calculations. It works by assigning a specific score to each sub-variable, which is then matched to the scale of the outcomes to obtain predicted probabilities, which are visually presented[20]. Due to its competence in performing multivariate analysis and visually displaying the impact of each factor on the outcome, nomogram models have been increasingly gaining popularity in recent years for prediction studies for various diseases[21,22]. However, the nomogram prediction model has not yet been applied to the RA-TKA field, and current research has primarily focused on robotic surgical assistance systems developed in Europe and the United States[12,23,24]. To the knowledge of the authors, there have been no studies on prediction models for short-term functional outcomes after TKA or RA-TKA. Furthermore, studies predicting postoperative functional outcomes in patients undergoing TKA aided by robotic-assisted systems developed in China are also lacking. In this study, clinical data were retrospectively collected from patients who underwent TKA assisted by a new seven-axis robotic-assisted system (Jianjia, Hangzhou Jianjia Robot Co., Ltd). The data included demographic data, preoperative imaging data, surgical data, preoperative and postoperative scale scores. A nomogram prediction model was designed and efficacy tests to predict more accurately whether different patients can achieve satisfactory functional outcomes 3 months after RA-TKA.

Materials and methods

Exclusion and inclusion criteria

This is a retrospective study that was conducted at a single centre. Inclusion criteria included: (1) Patients aged 18–85 years with knee osteoarthritis, rheumatoid arthritis, or traumatic arthritis; (2) Patients who underwent primary unilateral RA-TKA; (3) Patients who had follow-ups for more than 3 months, with complete preoperative and postoperative imaging data available. Exclusion criteria included: (1) complications related to RA-TKA within 3 months postoperatively; (2) Readmission related to RA-TKA complications or other surgeries, such as periprosthetic infection, delayed wound healing, wound nonunion, periprosthetic fracture, or any other procedure performed within 3 months; (3) Comorbidities that can affect functional recovery, such as lower limb neuromuscular diseases.

The Ethics Committee of our hospital approved this retrospective cohort study, and all patients signed informed consent. The study enroled 204 patients who underwent unilateral RA-TKA at our hospital from January 2021 to March 2022. After excluding 33 patients due to unsuccessful follow-up or missing imaging data, a total of 171 patients were included in the study. All patients were randomly assigned to either the training group ($N=120$) or the test group ($N=51$) for the final analysis. This study was registered with https://www.chictr.org.cn/index.html. The Strengthening the Reporting of Cohort Studies in Surgery (STROCSS, Supplemental Digital Content 2, https://links.lww.com/JS9/A27) guidelines were followed during writing of this report[25].

Surgical technique

The surgical procedures were performed by an experienced surgeon, proficient in the application of RA-TKA. Using computed tomography data obtained before TKA, a computer-assisted navigation system was used to create a three-dimensional model of the lower limb. The osteotomy angle and volume were calculated based on the model, and the same type of knee prosthesis (Zimmer-Biomet LPS) was used for all implants. An anterior midline approach was employed in this study. The received signal was stabilized and a positioning pin with a reflective sphere was used to complete the registration of the spatial position. The cut guide plate attached to the robotic arm was aligned with the predesigned cut line once the accuracy of the registration was confirmed. Once the cut volume was confirmed to match the preoperative plan, the plate was inserted under the guidance of the navigation system to complete the distal femur and anterior-posterior osteotomy. A similar approach was used to complete the tibia cut. Finally, soft tissue balance was performed separately in knee extension and flexion, respectively. Quantitative evaluation was performed using robotic navigation systems. The model test was confirmed to be correct and the alignment of the leg was verified. Following surgery, all patients followed the same rehabilitation program and analgesia pattern.

Potential predictive factors

Potential preoperative and intraoperative predictors were collected for all patients, including age, sex, BMI, surgical side, hip-knee-ankle (HKA) angle, HKA angle deviation (the difference between the HKA angle and 180°), preoperative 10-cm Visual Analogue Score (VAS), preoperative Functional Knee Society

Score (fKSS), preoperative Range of Motion (ROM) and operation time. A full-length weight-bearing anteroposterior X-ray of the lower limbs was taken to obtain the HKA angle, which was the angle formed by the mechanical axis of the femur and tibia.

Outcome measures

The outcome of the model was assessed using fKSS, which evaluates the walking and stair climbing function of patients with scores ranging from 0 to 100, with higher scores representing better knee function[26]. The fKSS was assessed by the surgeon before surgery and at a 3-month follow-up. The Minimal Clinically Important Difference (MCID) is the least differential change in scores that is considered detrimental or beneficial to the patient[27]. Results reported from the literature have shown that MCIDs were distributed between 6.1 and 34.5 in patients undergoing primary TKA[28–30]. Verbeek *et al.*[22] defined a beneficial outcome as an improvement in fKSS score of greater than or equal to 20 5 years after revision knee arthroplasty. Based on previous literature, an improvement of more than 10 points in fKSS score at 3 months after primary RA-TKA was hereby defined as a beneficial outcome.

Statistical analysis

The data were analyzed using SPSS (Version 25.0; IBM) and R 4.1.2 (R Foundation for Statistical Computing). Categorical variables were analyzed with the χ^2 test, and continuous variables were analyzed with the independent samples *t*-test or rank sum test. A significance level of *P* less than 0.05 was considered statistically significant. Univariate logistic regression analysis was performed on the demographic data and imaging parameters of patients in the training set. The dependent variable was an improvement of the postoperative fKSS score by greater than or equal to 10 at a test level of 0.05. In univariate logistic regression analysis, an independent variable was included in the multiple logistic regression model if *P* less than 0.1. Variance inflation factors (VIFs) and tolerances were calculated to assess the collinearity assumption, with VIF less than 5 and tolerance greater than 0.1 considered to indicate no significant collinearity. The reliability of internal validation was assessed using the bootstrap method with 1000 replicates. The discrimination of the nomogram model was evaluated by the consistency index (C-index) and receiver operating characteristic curve (ROC) analysis. Furthermore, calibration curves were drawn to evaluate the prediction model with the Hosmer–Lemeshow goodness-of-fit test, and a *P* value of the Hosmer–Lemeshow test greater than 0.05 indicates that a model has high goodness of fit.

The detailed steps of the study design and methodology are illustrated in Fig. 1.

Results

There were no significant differences between the training and test sets in preoperative demographic data or imaging parameters, including fKSS score, operation time, ROM, sex ratio, proportion of operated sides, age, BMI value, HKA angle, HKA angle deviation, and VAS score (Table 1). A beneficial outcome, as defined by a greater than 10 points improvement in fKSS score at 3 months postoperatively, was observed in 118 patients overall. Of these, 85 (70.8%) belonged in the training set and 33 (64.7%) in the test set, with no significant difference detected between the two groups ($P > 0.05$).

Factors affecting the beneficial fKSS score results at 3 months postoperatively

Demographic data (i.e. age, preoperative fKSS score, sex, side of operation, BMI, ROM, VAS), radiographic parameters (i.e. preoperative HKA angle, preoperative HKA angle deviation) and operation time were investigated using univariate logistic regression analysis to determine their effects on the beneficial fKSS score results at 3 months postoperatively. The statistically significant predictors were revealed to be age ($P = 0.015$), preoperative HKA angle ($P = 0.046$), preoperative HKA angle deviation ($P < 0.001$), preoperative fKSS score ($P < 0.001$), preoperative VAS score ($P < 0.001$), and preoperative ROM ($P < 0.001$) (Table 2).

As a result, the significant predictors included in the multiple logistic regression analysis. Results showed that preoperative HKA angle deviation, preoperative VAS score, preoperative fKSS score, and preoperative ROM were statistically significant predictors of beneficial fKSS score at 3 months postoperatively (Table 3). The multiple logistic regression analysis also revealed that an increase in preoperative HKA angle deviation 1° resulted in a 19.4% reduction in the probability of a beneficial fKSS score result at 3 months postoperatively (EXP (B) = 0.806, 95% CI 0.673–0.965, $P = 0.019$). An increase in preoperative VAS score by one point, resulted in a decrease of the probability of achieving a beneficial outcome by 36.2% (EXP (B) = 0.638, 95% CI 0.448–0.910, $P = 0.013$). Conversely, an increase in preoperative ROM by 1° led to an increase in the probability of achieving a beneficial outcome by 3.8% (EXP (B) = 1.038, 95% CI 1.006–1.070, $P = 0.020$). Finally, an increase in preoperative fKSS score by one point resulted in a decrease of 3.7%in the probability of achieving a beneficial outcome (EXP (B) = 0.963, 95% CI 0.929–0.999, $P = 0.041$) (Table 3). The collinearity diagnostic analysis showed that the VIFs of those risk factors were less than 5, suggesting that there is no strong indication of multicollinearity among variables. Thus, four variables were included in the final multivariable prediction model as predictors.

Development and validation of the prediction model

Statistically significant results from the multivariate logistic regression analysis were included into the prediction model and displayed as nomograms. The integral value of each included variable can be assessed from Fig. 2, and the integral value of all variables can be combined to calculate the total score and corresponding probability. Furthermore, C-index values from the calibration curves were 0.908 for the training set and 0.902 for the test set, respectively, indicating excellent predictive ability (Fig. 3A and B). The findings of the Hosmer–Lemeshow goodness-of-fit test also was not significant in the training and test sets ($\chi^2 = 11.588$, 7.107, $P = 0.171$, 0.525, respectively). The area under the ROC curve was 0.908 (95% CI 0.846–0.971) for the training set and 0.902 (95% CI 0.806–0.998) for the test set (Fig. 4). All the above findings show that the performance of the proposed model is outstanding.

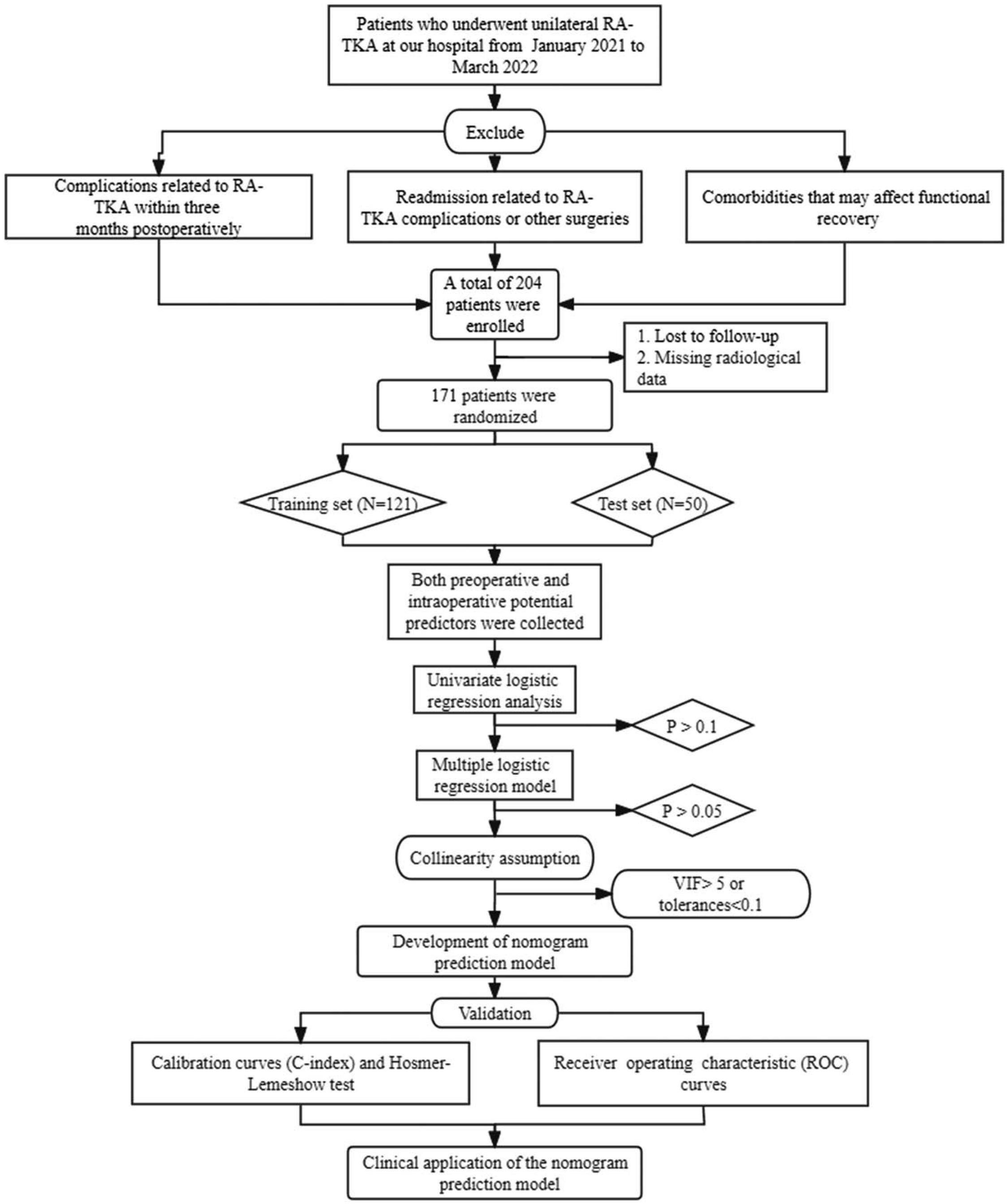

Figure 1. Flow chart of patient selection and study design. RA-TKA, robotic-assisted total knee arthroplasty; VIF, variance inflation factor.

A clinical illustration of the Nomogram

To demonstrate applicability of the proposed model, two patients who underwent RA-TKA in clinical practice were evaluated. The patient presented with a preoperative HKA angle deviation of 20° (score 7.3), a preoperative knee ROM of 100° (score 54.2), a preoperative VAS score of 4 (score 66.7), and a preoperative fKSS score of 30 (score 53.4). The total score of the nomogram model was 181.6 points, indicating a probability greater than 75% of achieving a beneficial outcome at 3 months postoperatively. The second patient had a preoperative VAS score of 7 (score 33.3), a preoperative HKA angle deviation of 18 (score 14.7), a preoperative knee ROM of 70 (score 30.9), a preoperative fKSS score of 50 (score 35.6), and a total calculated nomogram model score of 114.5. This patient had less than a 10% chance of obtaining a beneficial outcome at 3 months postoperatively.

Discussion

The continuous development of medical technology has led to the expectation for doctors to provide personalized treatment plans

Table 1

Demographic and clinical characteristics of the study population in the training and test cohorts ($n=171$).

	Training	Test	Statistic	P
N	120	51		
Age	66.01 ± 9.03	64.61 ± 10.77	$t=0.875$	0.383
BMI (kg/m^2)	25.50 ± 3.41	25.75 ± 3.56	$t=-0.439$	0.661
Operation time	93.91 ± 14.50	94.57 ± 15.37	$t=-0.268$	0.789
Preoperative HKA angle	174.47 ± 7.25	173.87 ± 8.53	$t=0.473$	0.637
Preoperative HKA angle deviation	7.72 ± 4.82	8.64 ± 5.92	$t=-0.982$	0.329
Sex				
Male	55	26		
Female	65	25	$\chi^2=0.380$	0.537
Surgical side				
Left	62	28		
Right	58	23	$\chi^2=0.150$	0.698
Beneficial outcome	85(70.8%)	33(64.7%)	$\chi^2=0.628$	0.428
Preoperative fKSS	42.33 ± 18.00	40.02 ± 9.51	$t=1.094$	0.275
Preoperative VAS	5.98 ± 2.34	6.36 ± 2.34	$t=-0.990$	0.323
Preoperative ROM	104.41 ± 18.91	100.10 ± 22.46	$t=1.201$	0.233

fKSS, functional Knee Society Score; HKA, hip-knee-ankle; ROM, range of motion; VAS, Visual Analogue Score.

for individual patients while optimizing surgical results. The RA-TKA approach allows for personalized preoperative planning and its precise execution to truly personalize knee replacement surgery. Nomogram models are used in clinical decision-making by acting accessible analysis and prediction tools. In this study, a nomogram model was constructed to predict the likelihood of patients achieving short-term beneficial outcomes with RA-TKA. The enroled patients were randomly divided into a training set ($N=120$) and a test set ($N=51$). There was no significant difference between the two groups in preoperative demographic data and imaging parameters ($P>0.05$). Of these patients, 118 (69.01%) presented beneficial outcomes at 3 months postoperatively, which is comparable to the results of recent study[7]. The present study supported that preoperative HKA angle deviation, preoperative VAS score, preoperative fKSS score, and preoperative ROM had a statistically significant impact on beneficial functional outcomes at 3 months postoperatively ($P<0.05$).

Previous literature has explored prediction models for TKA and RA-TKA. Muertizha *et al.*[21] used a nomogram to predict

Table 2

Results of single logistic regression analysis in the training set.

Variables	EXP (B)	95% CI	P
Age	1.057	1.011–1.106	0.015*
BMI	1.008	0.898–1.133	0.889
Sex	0.993	0.451–2.189	0.987
Surgical side	0.840	0.382–1.846	0.663
Preoperative HKA angle	1.064	1.001–1.130	0.046*
Preoperative HKA angle deviation	0.744	0.664–0.833	0.000*
Operation time	0.986	0.959–1.014	0.317
Preoperative VAS	0.471	0.356–0.625	0.000*
Preoperative fKSS	0.955	0.931–0.980	0.000*
Preoperative ROM	1.049	1.021–1.087	0.000*

*statistically significant difference ($P<0.05$).
fKSS, functional Knee Society Score; HKA, hip-knee-ankle; ROM, range of motion; VAS, Visual Analogue Score.

Table 3

Results of multiple logistic regression analysis in the training set.

Variables	EXP (B)	95% CI	P
Age	1.028	0.966–1.094	0.386
Preoperative HKA angle	0.958	0.875–1.049	0.354
Preoperative HKA angle deviation	0.806	0.673–0.965	0.019*
Preoperative VAS	0.638	0.448–0.910	0.013*
Preoperative fKSS	0.963	0.929–0.999	0.041*
Preoperative ROM	1.038	1.006–1.070	0.020*

*statistically significant difference ($P<0.05$).
fKSS, functional Knee Society Score; HKA, hip-knee-ankle; ROM, range of motion; VAS, Visual Analogue Score.

factors contributing to 1-year dissatisfaction after TKA. Motesharei *et al.*[31] developed a model to predict the operation time of RA-TKA and obtained satisfactory results. In contrast to previous studies, a nomogram model was hereby developed to predict functional outcomes for early patient benefit following RA-TKA to direct early clinical intervention and address patient and physician concerns regarding RA-TKA surgery. According to earlier findings of minimal clinical differences[30], an improvement in fKSS score of greater than or equal to 10 points at 3 months after primary RA-TKA was defined in this study as a beneficial outcome. The reasoning for selecting this criterion has been explained in the methods section of this paper. The integration of subjective and objective evaluation indicators in tandem facilitates the comprehensive evaluation of clinical differences[32]. In this study, comprehensive potential predictors were selected, including age, sex, surgical side, BMI, HKA angle, HKA angle deviation, preoperative VAS score, preoperative fKSS score, preoperative knee ROM, and operation time. Furthermore, the present study focused on patients undergoing RA-TKA, which will effectively reduce the uncertainty introduced by the surgeon. Moreover, patients with relevant complications, readmissions, and concomitant neuromuscular disease of the lower extremities or conditions that could affect functional recovery within 3 months after surgery were excluded. The exclusion of such patients enabled the study to obtain a more accurate predictive model for routine TKA.

Our previous RA-TKA study showed that the preoperative HKA angle had an impact on the success rate of the procedure[33]. Similarly, the findings of this study revealed that preoperative HKA angle deviation has a detrimental influence on patients' short-term benefits after surgery. HKA can serve as an important indicator for measuring the lower limb force line after TKA[34,35]. Cohort studies have reported a wider distribution of HKA in patients undergoing TKA compared with patients with early diagnosis or risk factor of OA[36]. Additionally, significant changes in HKA after TKA leading to adverse experiences in patients have been highlighted in the literature[21]. These findings suggest a potential correlation between preoperative HKA and the outcome of RA-TKA surgery. The significant changes in the HKA angle before and after surgery are a potential explanation for the negative association reported here. In RA-TKA, it is always desirable to restore the neutral mechanical alignment of the patient's lower limb and ensure their equal length. However, for patients with a considerable preoperative HKA deviation, reaching such a result may require more soft tissue damage, which could have unfavourable effects on postoperative recovery and joint function.

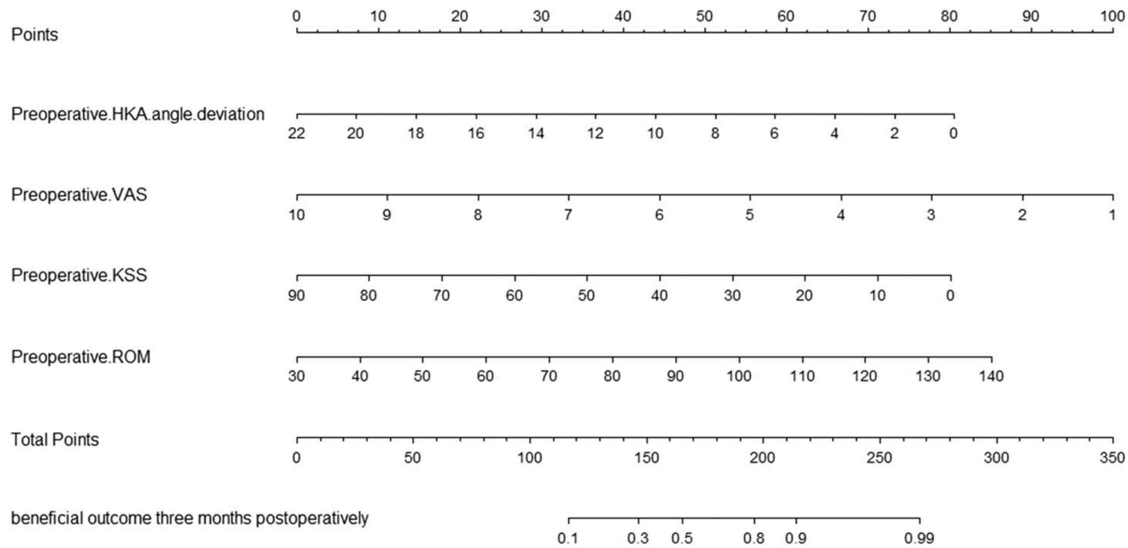

Figure 2. Nomogram for predicting the probability of beneficial outcome three months postoperatively. Construction: The variable axis of each predictor was established separately and the patient's information was positioned on each axis. The localization value of each variable axis was positioned vertically upward to the scoring axis to obtain a single score. The scores for each variable were summed to give a total score and a vertical line was drawn at the corresponding point of the total score to determine the probability of a beneficial outcome three months after RA-TKA. HKA, hip-knee-ankle; KSS, Knee Society Score; RA-TKA, robotic-assisted total knee arthroplasty; ROM, range of motion; VAS, Visual Analogue Score.

In this study, preoperative ROM was also associated with favourable results. Preoperative ROM has been previously proposed as a strong predictor of ROM after TKA[37,38]. Similarly, the results of this study show that patients with better preoperative ROM are more likely to achieve satisfactory clinical benefits with RA-TKA. Low ROM can lead to limitations in squatting, leg raising, and other movement behaviours, causing inconvenience to daily activities. The negative impact of low preoperative ROM on outcome may be due to long-standing low ROM which can lead to extensor stiffness, fibrotic changes around soft tissue joints, and changes in mechanical structure. All these changes in motor structure caused by long-term limitations may not be completely corrected during RA-TKA[39].

The present study found that preoperative VAS scores influenced the achievement of beneficial outcomes. In fact, preoperative knee pain was identified as a significant contributor to poor outcomes after TKA and increased the risk of postoperative dissatisfaction by 2.49-fold[9,40]. The VAS for pain is a common method for evaluating arthritis pain and is a highly sensitive metric[41]. The results reported hereby show the significant effect of the changes in VAS score on the probability of achieving a beneficial outcome. This effect of preoperative pain on the clinical outcome scores may be related to cognitive factors such as pain-induced sleep disorders, anxiety, depression and motor dysfunction[42,43].

The KSS has been a well-established metric for evaluating knee function and is also a postoperative-focused evaluation index for manual TKA and RA-TKA[26]. Preoperative fKSS was found to be a strong factor in early postoperative function scores. Specifically, an increase in fKSS scores has been associated with a decreased probability of achieving a beneficial outcome. Similar reports of negative correlation of preoperative fKSS with postoperative fKSS scores are consistent with the present study conclusions[22]. Van Laarhoven *et al.*[44] obtained similar results from an analysis of 5-year functional outcome after revision TKA and proposed an association between ceiling effects and this negative correlation. Higher baseline preoperative fKSS scores may indicate relatively appreciable knee function, which could lead to higher psychological expectations and less room for improvement in knee function. We hypothesize that this negative effect is associated with a smaller scope for improvement in knee function and higher psychological expectations in patients with higher preoperative fKSS scores. In addition, earlier observation cycles may result in nonsignificant fKSS improvement and clinical benefit.

Furthermore, BMI is a key influencing factor in knee joint diseases and various literature studies have confirmed its impact on postoperative outcomes of joint replacement[45,46]. However, in our study, the effect of BMI on outcomes in the present study did not show significant statistical differences, which may be attributed to the characteristics of the population investigated. Previous research has concluded that high BMI (≥ 30 kg/m^2) is associated with poor functional outcomes and an increased risk of complications following joint replacement surgery[46,47]. In contrast, the average BMI of the population enroled in the present study was 25.50 ± 3.41 (training group) and 25.75 ± 3.56 (test group), indicating a relatively concentrated BMI distribution with no significantly overweight participants. This may explain the difference between our study results and previous research findings.

Personalized risk prediction models aim to accurately predict outcomes, making nomogram testing crucial. The C-index is commonly used to assess the concordance between predicted and actual results of nomograms[48]. A nomogram model for preoperative prediction was developed in this study based on one training cohort and successfully validated in another independent cohort. Collinearity diagnosis of the covariates was used to avoid overfitting and unstable predictive results. The C-index of the

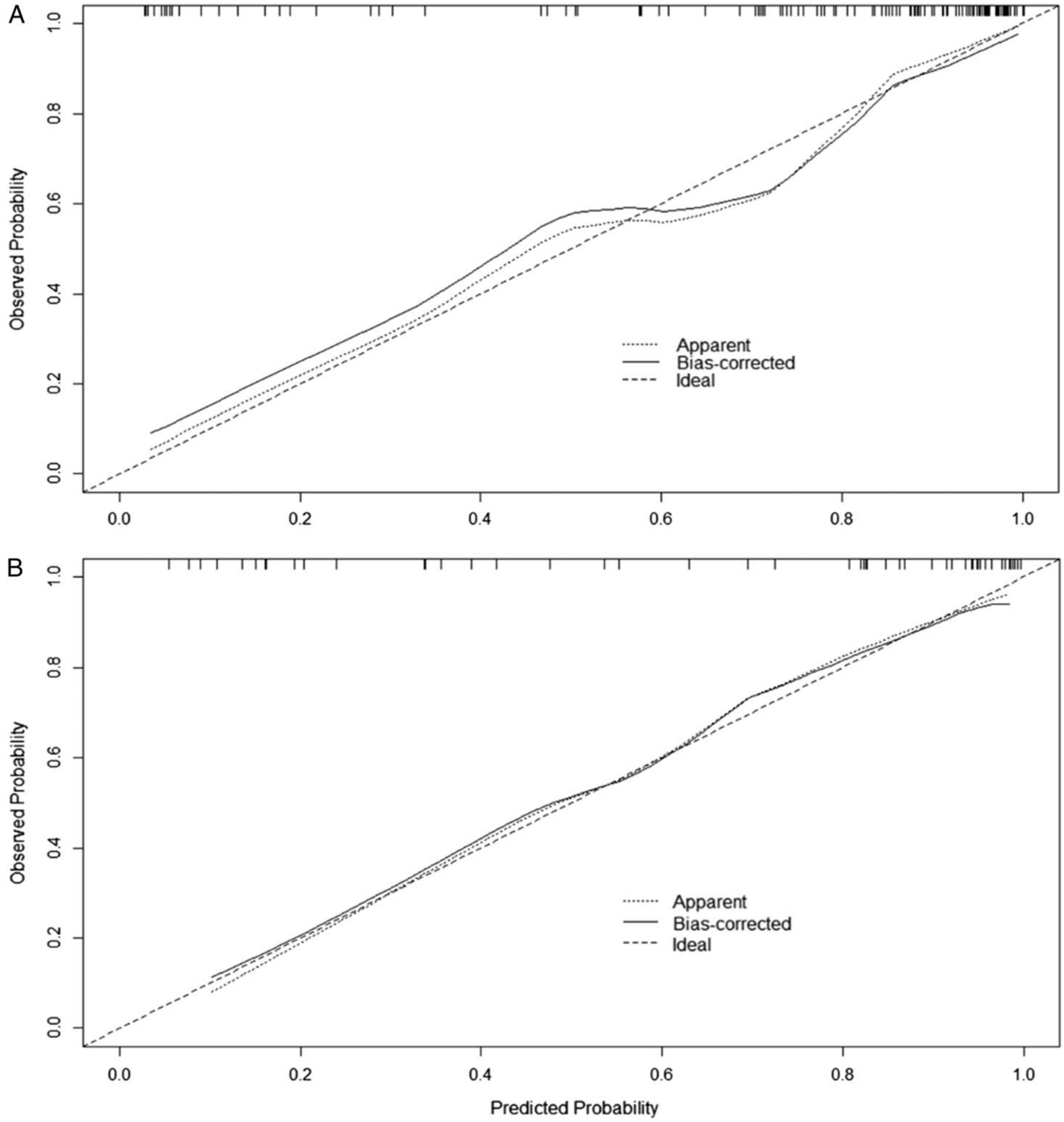

Figure 3. Calibration curves of the nomogram in the training and test cohort. (A). Calibration curve of training cohort nomogram (C-index =0.908); (B). Calibration curve of validation cohort nomogram (C-index =0.902). The dashed line indicates the calibrated curve, the solid line indicates the original curve, the diagonal line indicates the prediction model in an ideal state. The closer the curve shape is to the diagonal line indicates better prediction performance. (*x*-axis: the predicted probability of a patient achieving a beneficial outcome; *y*-axis: the probability of an actual observed patient achieving a beneficial outcome). C-indes, consistency index.

calibration curve demonstrates good repeatability and reliability of the model (Fig. 3A and B). In addition, the proposed model demonstrated good discriminatory ability, with an area under the ROC curve larger than 0.9. Furthermore, RA-TKA had better operation reproducibility and result homogeneity than manual TKA[14,49]. The model was constructed based on patient the data of patients before and after RA-TKA treatment, which supported the stability and reliability of the model prediction results to some extent. All above points demonstrate the satisfactory predictive ability of the proposed model.

To the knowledge of the authors, one literature a study has predicted the long-term functional outcomes after TKA[22]. However, there are no predictive studies on the outcomes of RA-TKA, especially ones investigating the outcomes-prediction of robotic-assisted TKA developed in China. This study fills the gap in the prediction of short-term clinical outcomes after RA-TKA. The developed predictive model allows for the calculation of four critical variables and enables the estimation of the probability of achieving beneficial short-term clinical impact after surgery. Consequently, medical personnel can identify patients who are at risk of having poor surgical outcomes, thus allowing them to adjust the objective risk through early clinical intervention. Furthermore, the prediction results of this model also guide patient expectations of the surgical outcome. These features contribute to achieving more satisfactory treatment results and more cost-effective medical practices.

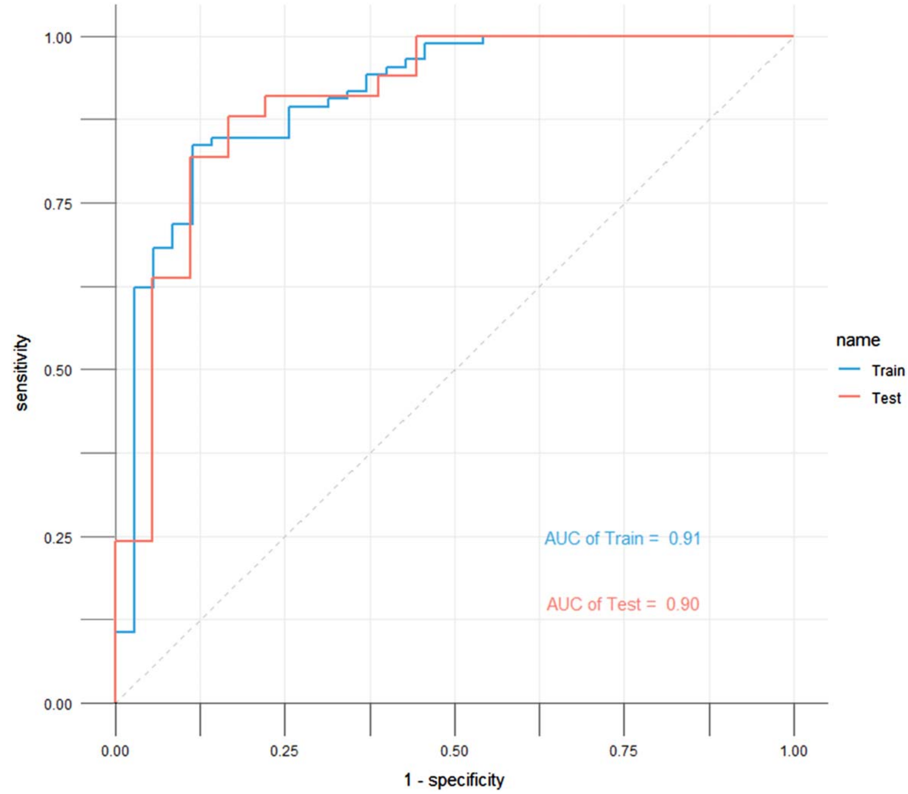

Figure 4. ROC curve of the nomogram in the training and validation cohort. The area under the ROC curve (AUC) indicates the discriminatory ability of the model for individuals. AUC = 0.5 indicates that the model is indistinguishable from individuals and AUC = 1 indicates that the model is ideally discriminative from individuals. (*x*-axis: 1-specificity; *y*-axis: sensitivity). ROC, receiver operating characteristic.

This study still has some limitations. First, the small sample size used in the study may result in bias, which is difficult to avoid. Future experiments will focus on expanding the sample size to produce a more reliable and stable model, we intend to expand the sample size in future experiments. Second, due to the 3-month postoperative follow-up period, this study focused only on short-term outcomes. The predictive performance of the model for long-term postoperative outcomes was not assessed. Last, this study was conducted with patients from a single medical institution, it is challenging to eliminate selection bias and information bias associated with single-centre samples. Therefore, to improve the diagnostic efficacy of the model, it needs to be further prospectively studied using samples from multiple centres.

Conclusion

This study successfully developed a novel nomogram model to predict the functional outcome of patients 3 months after RA-TKA. The clinical efficacy of this model was verified to be both satisfactory and reliable, with promising potential for practical application. The implementation of this model will enable better early therapeutic intervention and more informed clinical decision-making, leading to better treatment outcomes and reduced healthcare costs. The results of the present study have contributed to the improvement of predictive modelling in the field of RA-TKA and will have major consequences in the improvement of patient outcomes in the future.

Ethical approval

This study was approved by the ethics committee of the second affiliated Hospital of Xi'an Jiaotong University (Permit Number: XJTU 2021-015).

Consent

Written informed consent was obtained from the patient for publication of this case report and accompanying images. A copy of the written consent is available for review by the Editor-in-Chief of this journal on request.

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Author contribution

X.D., Y.Z., J.Z., K.W., P.Y., R.T. completed patient recruitment and surgery; R.C., H.G. measured the patient's imaging data; N.K.,Y.L.collected research data; X.D. analyzed the clinical trial data; X.D. and Y.Z. authored the manuscript.

Conflicts of interest disclosure

There are no conflicts of interest.

Research registration unique identifying number (UIN)

1. Name of the registry: A clinical trial on the effectiveness and safety of robotic-assisted surgery system for total knee arthroplasty.
2. Unique Identifying number or registration ID: ChiCTR 2200065786.
3. Hyperlink to your specific registration (must be publicly accessible and will be checked): (http://www.chictr.org.cn/showproj.aspx?proj=168010.

Guarantor

Run Tian.

Data statement

The data are not publicly available, as participants in this study need their data for further analysis.

Provenance and peer review

Not commissioned, externally peer-reviewed.

References

[1] Price AJ, Alvand A, Troelsen A, *et al*. Knee replacement. Lancet 2018; 392:1672–82.

[2] Smith WB II, Steinberg J, Scholtes S, *et al*. Medial compartment knee osteoarthritis: age-stratified cost-effectiveness of total knee arthroplasty, unicompartmental knee arthroplasty, and high tibial osteotomy. Knee Surg Sports Traumatol Arthrosc 2017;25:924–33.

[3] Mao B, Pan Y, Zhang Z, *et al*. Efficacy and safety of hyaluronic acid intra-articular injection after arthroscopic knee surgery: a systematic review and meta-analysis. Orthop Surg 2023;15:16–27.

[4] McAlindon TE, Bannuru RR, Sullivan MC, *et al*. OARSI guidelines for the non-surgical management of knee osteoarthritis. Osteoarthritis Cartilage 2014;22:363–88.

[5] Kurtz S, Ong K, Lau E, *et al*. Projections of primary and revision hip and knee arthroplasty in the United States from 2005 to 2030. J Bone Joint Surg Am 2007;89:780–5.

[6] Abdelaal MS, Restrepo C, Sharkey PF. Global perspectives on arthroplasty of hip and knee joints. Orthop Clin North Am 2020;51:169–76.

[7] Beswick AD, Wylde V, Gooberman-Hill R, *et al*. What proportion of patients report long-term pain after total hip or knee replacement for osteoarthritis? A systematic review of prospective studies in unselected patients. BMJ Open 2012;2:e000435.

[8] Kim TK, Chang CB, Kang YG, *et al*. Causes and predictors of patient's dissatisfaction after uncomplicated total knee arthroplasty. J Arthroplasty 2009;24:263–71.

[9] Bourne RB, Chesworth BM, Davis AM, *et al*. Patient satisfaction after total knee arthroplasty: who is satisfied and who is not? Clin Orthop Relat Res 2010;468:57–63.

[10] Kayani B, Konan S, Tahmassebi J, *et al*. Robotic-arm assisted total knee arthroplasty is associated with improved early functional recovery and reduced time to hospital discharge compared with conventional jig-based total knee arthroplasty: a prospective cohort study. Bone Joint J 2018; 100-B:930–7.

[11] Hampp EL, Chughtai M, Scholl LY, *et al*. Robotic-arm assisted total knee arthroplasty demonstrated greater accuracy and precision to plan compared with manual techniques. J Knee Surg 2019;32:239–50.

[12] Batailler C, Fernandez A, Swan J, *et al*. MAKO CT-based robotic arm-assisted system is a reliable procedure for total knee arthroplasty: a systematic review. Knee Surg Sports Traumatol Arthrosc 2021;29:3585–98.

[13] Zhang J, Ndou WS, Ng N, *et al*. Robotic-arm assisted total knee arthroplasty is associated with improved accuracy and patient reported outcomes: a systematic review and meta-analysis. Knee Surg Sports Traumatol Arthrosc 2022;30:2677–95.

[14] Kim YH, Yoon SH, Park JW. Does robotic-assisted TKA result in better outcome scores or long-term survivorship than conventional TKA? A randomized, controlled trial. Clin Orthop Relat Res 2020; 478:266–75.

[15] Parsley BS, Bertolusso R, Harrington M, *et al*. Influence of gender on age of treatment with TKA and functional outcome. Clin Orthop Relat Res 2010;468:1759–64.

[16] Wylde V, Hewlett S, Learmonth ID, *et al*. Persistent pain after joint replacement: prevalence, sensory qualities, and postoperative determinants. Pain 2011;152:566–72.

[17] Escobar A, Quintana JM, Bilbao A, *et al*. Effect of patient characteristics on reported outcomes after total knee replacement. Rheumatology (Oxford) 2007;46:112–9.

[18] Andreozzi V, Conteduca F, Iorio R, *et al*. Comorbidities rather than age affect medium-term outcome in octogenarian patients after total knee arthroplasty. Knee Surg Sports Traumatol Arthrosc 2020;28:3142–8.

[19] King LK, Waugh EJ, Jones CA, *et al*. Comorbidities do not limit improvement in pain and physical function after total knee arthroplasty in patients with knee osteoarthritis: the BEST-Knee prospective cohort study. BMJ Open 2021;11:e047061.

[20] Park SY. Nomogram: an analogue tool to deliver digital knowledge. J Thorac Cardiovasc Surg 2018;155:1793.

[21] Muertizha M, Cai X, Ji B, *et al*. Factors contributing to 1-year dissatisfaction after total knee arthroplasty: a nomogram prediction model. J Orthop Surg Res 2022;17:367.

[22] Verbeek JFM, Hannink G, Defoort KC, *et al*. Age, gender, functional KSS, reason for revision and type of bone defect predict functional outcome 5 years after revision total knee arthroplasty: a multivariable prediction model. Knee Surg Sports Traumatol Arthrosc 2019;27:2289–96.

[23] Fu J, Wang Y, Li X, *et al*. Robot-assisted vs. conventional unicompartmental knee arthroplasty: systematic review and meta-analysis. Orthopade 2018;47:1009–17.

[24] Lee G-C, Wakelin E, Randall A, *et al*. Can a robot help a surgeon to predict a good total knee arthroplasty? Bone Joint J 2021;103-B:67–73.

[25] Mathew G, Agha R. Group Strocss, STROCSS 2021: Strengthening the reporting of cohort, cross-sectional and case-control studies in surgery. Ann Med Surg (Lond) 2021;72:103026.

[26] Insall JN, Fau DLd, Scott RD, *et al*. Rationale of the Knee Society clinical rating system, Clin Orthop Relat Res 1989;13–4.

[27] Clement ND, MacDonald D, Simpson AH. The minimal clinically important difference in the Oxford knee score and Short Form 12 score after total knee arthroplasty. Knee Surg Sports Traumatol Arthrosc 2014; 22:1933–9.

[28] Jacobs CA, Christensen CP. Correlations between knee society function scores and functional force measures. Clin Orthop Relat Res 2009;467: 2414–9.

[29] Giesinger JM, Hamilton DF, Jost B, *et al*. WOMAC, EQ-5D and knee society score thresholds for treatment success after total knee arthroplasty. J Arthroplasty 2015;30:2154–8.

[30] Lee WC, Kwan YH, Chong HC, *et al*. The minimal clinically important difference for Knee Society Clinical Rating System after total knee arthroplasty for primary osteoarthritis. Knee Surg Sports Traumatol Arthrosc 2017;25:3354–9.

[31] Motesharei A, Batailler C, De Massari D, *et al*. Predicting robotic-assisted total knee arthroplasty operating time : benefits of machine-learning and 3D patient-specific data. Bone Jt Open 2022;3:383–9.

[32] Revicki D, Hays RD, Cella D, *et al*. Recommended methods for determining responsiveness and minimally important differences for patient-reported outcomes. J Clin Epidemiol 2008;61:102–9.

[33] Tian R, Duan X, Kong N, *et al*. Robotic-assisted total knee arthroplasty is more advantageous for knees with severe deformity: a randomized controlled trial study design. Int J Surg (Lond, Engl) 2023;109:287–96.

[34] Heyse TJ, Decking R, Davis J, *et al*. Varus gonarthrosis predisposes to varus malalignment in TKA. HSS J 2009;5:143–8.

[35] Kato M, Warashina H, Kataoka A, *et al*. Calcaneal insufficiency fractures following ipsilateral total knee arthroplasty. Injury 2021;52:1978–84.

[36] Ramazanian T, Yan S, Rouzrokh P, *et al*. Distribution and correlates of hip-knee-ankle angle in early osteoarthritis and preoperative total knee arthroplasty patients. J Arthroplasty 2022;37:S170–5.
[37] Bin Abd Razak HR, Han XA, Chong HC, *et al*. Total knee arthroplasty in Asian subjects: preoperative range of motion determines postoperative range of motion? Orthop Surg 2014;6:33–7.
[38] Kotani A, Yonekura A, Bourne RB. Factors influencing range of motion after contemporary total knee arthroplasty. J Arthroplasty 2005;20:850–6.
[39] Kurosaka M, Yoshiya S, Mizuno K, *et al*. Maximizing flexion after total knee arthroplasty: the need and the pitfalls. J Arthroplasty 2002;17:59–62.
[40] Chodor P, Kruczynski J. Preoperative risk factors of persistent pain following total knee arthroplasty. Biomed Res Int 2022;2022:4958089.
[41] da Costa BR, Saadat P, Basciani R, *et al*. Visual Analogue Scale has higher assay sensitivity than WOMAC pain in detecting between-group differences in treatment effects: a meta-epidemiological study. Osteoarthritis Cartilage 2021;29:304–12.
[42] Theunissen M, Fau PMl, Bruce J, *et al*. Preoperative anxiety and catastrophizing: a systematic review and meta-analysis of the association with chronic postsurgical pain. Clin J Pain 2012;28:819–41.
[43] Boye Larsen D, Laursen M, Simonsen O, *et al*. The association between sleep quality, preoperative risk factors for chronic postoperative pain and postoperative pain intensity 12 months after knee and hip arthroplasty. Br J Pain 2021;15:486–96.
[44] van Laarhoven SN, Heesterbeek PJC, Teerenstra S, *et al*. Revision for coronal malalignment will improve functional outcome up to 5 years postoperatively. Knee Surg Sports Traumatol Arthrosc 2022;30:2731–7.
[45] DeMik DE, Muffly SA, Carender CN, *et al*. What is the impact of body mass index cutoffs on total knee arthroplasty complications? J Arthroplasty 2022; 37:683–87.e1.
[46] Sun K, Li H. Body mass index as a predictor of outcome in total knee replace: A systemic review and meta-analysis. Knee 2017;24:917–24.
[47] Si HB, Zeng Y, Shen B, *et al*. The influence of body mass index on the outcomes of primary total knee arthroplasty. Knee Surg Sports Traumatol Arthrosc 2015;23:1824–32.
[48] Iasonos A, Schrag D, Raj GV, *et al*. How to build and interpret a nomogram for cancer prognosis. J Clin Oncol 2008;26:1364–70.
[49] Kayani B, Konan S, Ayuob A, *et al*. Robotic technology in total knee arthroplasty: a systematic review. EFORT Open Rev 2019;4:611–7.