EPiC Series in Health Sciences
Volume 6, 2024, Pages 45–49
Proceedings of The 22nd Annual Meeting of the International Society for Computer Assisted Orthopaedic Surgery

Improved Prediction of Postoperative Knee Function Using Preoperative Patient Factors and Intraoperative Measures of Bony Resection, Ligament Release, and Implant Alignment in Total Knee Arthroplasty: A Database Analysis of 363 Cases

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Abstract

Total knee arthroplasty (TKA) is a common approach to treating end-stage osteoarthritis of the knee while relieving pain and restoring joint function. However, the procedure has produced variations in postoperative outcomes, with up to 20% of patients left dissatisfied. Therefore, it is important to understand the preoperative and intraoperative factors that drive knee function post-TKA. Using intraoperative data acquired from a surgical navigation system and matched with patient pre- and postoperative data, this study aimed to identify preoperative and intraoperative predictors of PROMs measured using the Oxford Knee Score (OKS) at 1-year follow-up.

We analysed 363 cases of navigated TKA at our institution and matched them to preoperative and postoperative patient clinical records including age at index surgery, BMI, sex, presence of co-morbidities, EQ5D anxiety/depression score, and preoperative and postoperative OKS. Starting with a base model of 26 predictor variables, a linear regression model with backward elimination was used to identify predictors of postoperative OKS on a training set of 290 patients. 73 patients (20%) were randomly set aside to use as validation. We then used the remaining predictor variables to train two additional regression models: a Support Vector Machine (SVM) and a Boosted Decision

Tree then calculated the coefficient of determination (R2) and percent of patients that where the postoperative OKS was correctly identified within the minimally important clinical difference of 4.9 when the models were applied to the validation set.

Of the 26 predictor variables, 10 predictors remained in the final model following backwards elimination, including four that were directly under the control of the surgeon. The R2 of the linear regression, SVM, and XGBoost models were 0.37, 0.30, and 0.29 respectively within the validation set. Percentages of patients with correctly predicted OKS within the MICD ranged from 52% to 57% (linear regression to SVM).

In this study, we identified sets of preoperative and intraoperative factors which are partially predictive of postoperative OKS at 1-year follow-up. Post-operative prediction models such as the models presented here will help to guide continued research into which intraoperative variables, including bony resection depths, implant alignment, and whether to do ligament releases in surgery, most affect implant function post-TKA and to inform patients and clinicians of possible clinical outcomes.

1 Introduction

Total knee arthroplasty (TKA) is a common approach to treating end-stage osteoarthritis of the knee while relieving pain and restoring joint function. However, the procedure has produced variations in postoperative outcomes, with up to 20% of patients left dissatisfied [1]. Therefore, it is important for both patients and clinicians to understand both preoperative and intraoperative factors that drive knee function post-surgery. Patient-reported outcome measures (PROMs) are a commonly used tool to assess clinical outcomes from the perspective of the patient. A wide range of preoperative predictors of PROMs have been identified in the literature including age at index surgery, body mass index (BMI), sex, the presence of co-morbidities and preoperative mental health [2]. However, many studies do not include precise measurements of implant alignment and bony resection depths as predictors of knee function in addition to preoperative patient factors. Using intraoperative data acquired from a surgical navigation system and matched with patient pre- and postoperative data, this study aimed to identify preoperative and intraoperative predictors of PROMs measured using the Oxford Knee Score (OKS) at 1-year follow-up.

2 Methods

We analysed cases of navigated TKA completed between March 2007 and October 2022 at our institution and matched them to preoperative and postoperative patient clinical records including age at index surgery, BMI, sex, presence of co-morbidities, EQ5D anxiety/depression scores, and preoperative and postoperative OKS. We only included cases for which both preoperative and postoperative OKS records were available, resulting in a total of 363 cases. Starting with a base model of 26 predictor variables, a linear regression model was used to identify predictors of postoperative OKS on a training set of 290 patients. 73 patients (20%) were randomly set aside to use as a validation set. We then implemented a backwards elimination procedure where over each iteration, the predictor with the least predictive power (highest p-value) was removed from the model. The model was then trained again with the remaining variables. This process was repeated until there were no predictor variables remaining with p-values more than 0.05. However, we decided to force the inclusion of predictor variables such as age at index surgery and sex to make the prediction model as patient specific as possible. We then used the remaining predictor variables to train two additional regression models: a Support Vector Machine (SVM) and a Boosted Decision Tree (XGBoost). We then calculated the coefficient of determination (R2) when the models were applied to the validation set and the percent of patients that where the postoperative OKS was correctly identified within the minimally important clinical difference of 4.9 points [3]. Finally, we conducted a permutation-feature-importance process (measuring the decrease in model accuracy when a single feature value is randomly adjusted) to assess which factors were most predictive of postoperative OKS.

3 Results

Of the 26 predictor variables, 10 predictors remained in the final model following backwards elimination (Table 1), including four that directly under the control of the surgeon. The R2 of the linear regression, SVM, and XGBoost models were 0.37, 0.30, and 0.29 respectively (i.e., the models were able to explain 37%, 30% and 29% of the variance observed in postoperative OKS, respectively). Within the validation set, percentages of patients with correctly predicted OKS within the MICD ranged from 52% to 57% (linear regression to SVM) and ranged between 70% - 74% within 1.5 x MCID (XGBoost to linear regression) (Figure 1). For comparison, a prediction model that simply predicted the mean postoperative OKS would have predicted 32% and 54% of patients correctly within the MICD and 1.5 x MICD, respectively. In all cases, the patients with the lowest values of OKSs were systematically predicted to have much better outcomes (typically 20 points higher than they actually experienced).

4 Discussion

In this study, we identified sets of preoperative and intraoperative factors which are partially predictive of postoperative OKS at 1-year follow-up. There are several important limitations of this work. First, the use of predictive models built with data collected from one population may not be easily extrapolated to another. There are examples in the literature where models attempting to predict patient satisfaction post-TKA based on data from one population [4] were poorly predictive when applied to other populations [5, 6]. Furthermore, each model was trained on a relatively small number of patients and was not externally validated. Patient-specific factors such as age at operation (years) and preoperative OKS were positively correlated with post operative OKS while EQ5D anxiety/depression score and presence of co-morbidities were negatively correlated. For surgical variables, both medial and lateral bony resections on the tibia and lateral resections on the distal femur were positively correlated with post-operative OKS. However, the impact on OKS from these variables is likely to be small given the magnitude (ranging between 0.55 to 0.67 points/mm) of the regression coefficients and the small range of adjustments in these variables that a surgeon could reasonably make. Finally, any amount of lateral ligament release was negatively correlated with post-operative OKS.

Findings from this study are in overall agreement with several other postoperative PROM prediction models, though the R2 values we report are significantly higher. Jiang et al. used mixed-effects linear regression to create a model which identified patient-specific and socioeconomic predictors of OKS at 1-, 5-, and 10-years post-index, achieving R2 values of approximately 0.19 [7]. However, this study did not include intraoperative variables which may have contributed to postoperative OKS. Similarly, in addition to preoperative patient factors, Santos et al. included other clinical factors in their predictive model of 1-year OKS, including presence of fixed flexion deformity and other conditions affecting mobility, and achieved an R2 value of 0.19 [8]. Post-operative prediction models such as the models presented here will help to guide continued research into which intraoperative variables, including bony resection depths, implant alignment, and whether to do ligament releases in surgery, most affect implant function post TKA and to inform patients and clinicians of possible clinical outcomes.

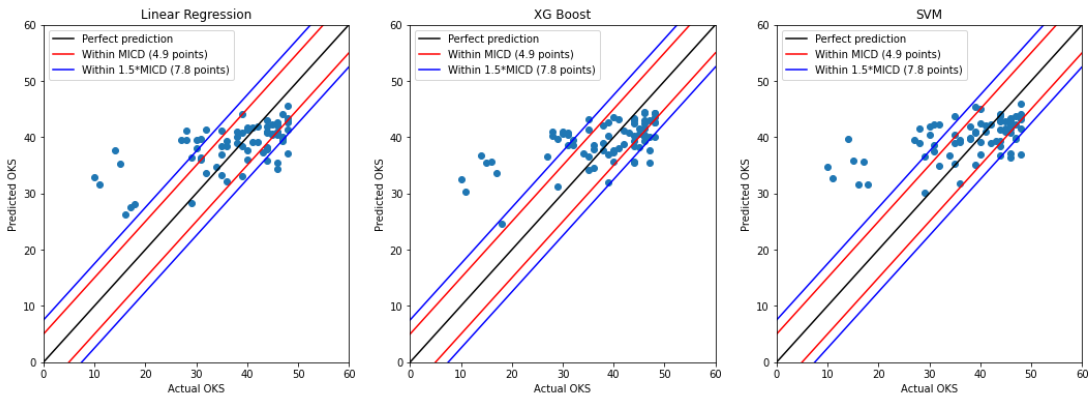

Figure 1: Calibration plots for different models trained to predict post operative Oxford Knee Score (OKS). Blue circles represent patients belong to the validation set of patients. The black line represents the one-to-one line indicating perfect agreement between the predicted and actual OKS. The red and blue lines represent the bounds showing plus/minus the MICD (4.9 points) and 1.5xMICD (7.8 points) associated with OKS.

*Predictor variable (units, if any)	Coefficients [95% CI] (units, if any)	p-value
EQ5D Anxiety/Depression (1 - 5)	-3.1 [-4.6 – -1.6]	$p < 0.05$
Preoperative OKS	0.20 [0.10 – 0.30]	$p < 0.05$
BMI (kg/m2)	0.14 [0 – 0.29] (points/(kg/m2))	$p < 0.05$
Distal Lateral Femoral Cut Depth (mm)	0.55 [0.1 – 1.0] (points/mm)	$p < 0.05$
Presence of Co-morbidities (binary)	-3.9 [-5.7 – -2.0]	$p < 0.05$
Medial Tibial Cut Depth (mm)	0.67 [0.20 – 1.1] (points/mm)	$p < 0.05$
Sex (Binary, Male = 1, Female = 0)	1.7 [-0.1 – 3.6]	$p = 0.06$
Presence Of Lateral Ligament Release (binary)	-4.9 [-9.1 – -0.75]	$p < 0.05$
Age At Operation (years)	0.30 [0.21 – 0.39] (points/year)	$p < 0.05$
Lateral Tibial Cut Depth (mm)	0.63 [0.17 – 1.1] (points/mm)	$p < 0.05$

Table 1: Summary of Preoperative and Intraoperative Factors used in the Prediction Model. *Predictor variables are ranked from those with the most to the least predictive power as measured using a permutation importance test. CI: confidence interval

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