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Development of a Machine-Learning Model for Anterior Knee Pain After Total Knee Arthroplasty With Patellar Preservation Using Radiological Variables

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A B S T R A C T

Background: Anterior knee pain (AKP) following total knee arthroplasty (TKA) with patellar preservation is a common complication that significantly affects patients' quality of life. This study aimed to develop a machine-learning model to predict the likelihood of developing AKP after TKA using radiological variables.
Methods: A cohort of 131 anterior stabilized TKA cases (105 patients) without patellar resurfacing was included. Patients underwent a follow-up evaluation with a minimum 1-year follow-up. The primary outcome was AKP, and radiological measurements were used as predictor variables. There were 2 observers who made the radiological measurement, which included lower limb dysmetria, joint space, and coronal, sagittal, and axial alignment. Machine-learning models were applied to predict AKP. The best-performing model was selected based on accuracy, precision, sensitivity, specificity, and Kappa statistics. Python 3.11 with Pandas and PyCaret libraries were used for analysis.
Results: A total of 35 TKA had AKP (26.7%). Patient-reported outcomes were significantly better in the patients who did not have AKP. The Gradient Boosting Classifier performed best for both observers, achieving an area under the curve of 0.9261 and 0.9164, respectively. The mechanical tibial slope was the most important variable for predicting AKP. The Shapley test indicated that high/low mechanical tibial slope, a shorter operated leg, a valgus coronal alignment, and excessive patellar tilt increased AKP risk.
Conclusions: The results suggest that global alignment, including sagittal, coronal, and axial alignment, is relevant in predicting AKP after TKA. These findings provide valuable insights for optimizing TKA outcomes and reducing the incidence of AKP.

Total knee arthroplasty (TKA) is a surgical procedure used to treat severe knee osteoarthritis [1]. The primary goals of this procedure are to improve function, reduce pain, and enhance the quality of life. While historical reports indicated an 80% satisfaction rate after TKA, a recent meta-analysis has reported an increase in satisfaction of up to 90% [2].

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Availability of Data: The datasets used or analyzed during the present study are available from the corresponding author on reasonable request and approval from the ethical board committee of our institution.
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Anterior knee pain (AKP) following TKA is a complication that significantly affects patients' quality of life [3,4]. The estimated prevalence of AKP is around 30% [5]. It manifests as pain around or behind the patella, making activities such as standing up after prolonged sitting, descending stairs, and kneeling on any surface challenging [5]. The management of the patella during TKA, either by arthroplasty or retention, has been associated with AKP. Furthermore, no difference has been found in the quality of life of patients after TKA who did and did not have a patellar arthroplasty [6].

Several factors may contribute to AKP, like preoperative pain, sex [5], psychiatric background [7], the manner in which the infrapatellar fat pad is managed during the surgical procedure [8], damage to neurovascular structures [9], sizing of the components [10], and trochlea design [11]. Additionally, the alignment of the TKA plays a crucial role, although the ideal alignment remains controversial.

The study of coronal alignment, employing various methods such as mechanical, kinematic, and functional alignment, has undergone extensive analysis [12]. Despite this, these approaches have not shown notable improvements in functional outcomes, especially concerning issues related to AKP [13] or patellofemoral kinematics [14]. Some studies have suggested that the sagittal alignment plays an important role. Aliyev et al. found that an increased anterior femoral offset was associated with AKP, but they did not control the axial or coronal planes [15].

Assessing the axial alignment typically requires the use of computed tomography (CT) scans. However, Savin et al. [16] described the "seated view of the knee" on radiography, which enables the identification, on a radiograph, of the epicondylar axis relative to the posterior aspect of the component axis, showing a good correlation with femoral rotation measured on CT. This measurement has been replicated by other authors [17,18]. Proper assessment of axial alignment, along with the evaluation of other planes, is essential to assessing malalignment in patients dissatisfied with their TKA outcomes [19].

Recently, we conducted a cohort study on patients who underwent TKA without patellar resurfacing, using an anterior stabilized insert [20]. The primary outcome was to measure satisfaction and self-perceived improvement in the quality of life at a minimum of 1 year after surgery, using the scale published by Goodman et al. [21]. This scale comprises a Likert-type questionnaire with 4 questions for satisfaction and 1 for quality of life. Using the Goodman scale, these patients reported a 90% satisfaction rate and an 86% improvement in their quality of life after TKA. The presence of AKP was identified as the most important risk factor for dissatisfaction. Additionally, we published a set of radiographs along with their respective measurements and agreement [22], which included various variables related to lower limb dysmetria, joint space, and coronal sagittal and axial alignment.

In this context, machine-learning techniques can aid in identifying patterns and relationships in radiological data, which may be valuable in predicting the likelihood of developing AKP after TKA with patellar preservation. The objective of this study was to estimate the predictive value of radiological variables in the incidence of AKP after TKA using machine-learning techniques. Specifically, we aimed to identify the radiological variables most strongly associated with the development of AKP and establish a hierarchy of importance among these variables.

Methods

This study received approval from our ethics committee and included 131 cases (105 patients) of primary TKA using the Vanguard Cruciate-Retaining Anterior Stabilized Knee System (Zimmer Biomet, Warsaw, IN) without patellar resurfacing between January 11, 2018 and March 21, 2021. In 2022, patients were invited to participate in a follow-up evaluation of their TKA, which included an in-person assessment by a physiotherapist and control radiographs at no cost. Prior to the evaluation and radiographs, all patients received information about the study and provided signed informed consent.

The primary outcome of this study was the presence of AKP during the 2022 follow-up. Patients were asked if they experienced AKP during their daily activities regardless of intensity and frequency (daily or weekly). The response was recorded as either yes (AKP [+]) or no (AKP [−]). For patients who underwent surgery on both knees, they were asked about the presence of AKP in each knee separately. Also, evaluation included the following patient-reported functional scales: Western Ontario and MacMaster Universities Arthritis Index (WOMAC)—pain, WOMAC-stiffness, WOMAC-function, Kujala, Knee injury and Osteoarthritis outcome score—quality of life, and Goodman (satisfaction and self-reported improvement in quality of life).

The set of control radiographs included antero-posterior and lateral full-limb-length standing views, weight-bearing antero-posterior and lateral knee views, a patellar axial view at 30°, and a seated knee view. There were 2 observers, a musculoskeletal radiologist (observer 1) and an orthopedic specialist focused on knee surgery (observer 2), who performed the measurements. A concordance study was conducted prior to this study, and 17 of 32 measurements showed at least moderate concordance and were selected as candidate predictor variables for this study [22]. These 17 measurements included lower limb dysmetria, hip-knee-ankle angle, distal lateral femoral mechanical angle, and proximal medial tibial mechanical angle from the full-limb-length standing antero-posterior radiograph; tibial mechanical and anatomical slope from the full-limb-length standing lateral radiograph; lateral and medial joint space in extension from the antero-posterior standing knee view; lateral and medial joint space in flexion and femoral rotation from the seated view [16]; distal anatomical sagittal femoral alignment, tibial proximal anatomical slope, and 2 measures for patellar height (Caton-Deschamps index and tibia-patella angle) from the lateral knee view; and patellar lateralization and patellar tilt from the axial patellar view. Figure 1 summarizes the knee views and measurements carried out in this study. By considering measurements from all radiological acquisitions taken in these patients, we were able to obtain a comprehensive assessment of the knee.

For statistical analyses, a descriptive analysis was conducted first. Age and patient-reported outcomes were summarized using the median and range. Radiological measurements were summarized using the mean and standard deviation. Categorical variables were presented as absolute and percent frequencies. The Wilcoxon rank test was employed to compare continuous variables, while the Fisher's exact test was used for categorical variables when comparing between the AKP (+) and AKP (−) groups.

The data were divided into a training and test set using a 70:30 ratio. There were 13 machine-learning models tested, including Quadratic Discriminant Analysis, Extra Trees Classifier, Random Forest Classifier, Light Gradient Boosting Machine, Gradient Boosting Classifier, Decision Tree Classifier, Ada Boost Classifier, K Neighbors Classifier, Ridge Classifier, Logistic Regression, Linear Discriminant Analysis, Support Vector Machine with a Linear Kernel, and Naive Bayes. After developing the optimal model for each algorithm using the training set, their performance was evaluated using the test set. A 10-fold cross-validation was applied to validate these models, with the train and test sets alternated to reduce the risk of overfitting.

Discrimination, which represents the model's accuracy in predicting the presence of AKP, was assessed using the area under the

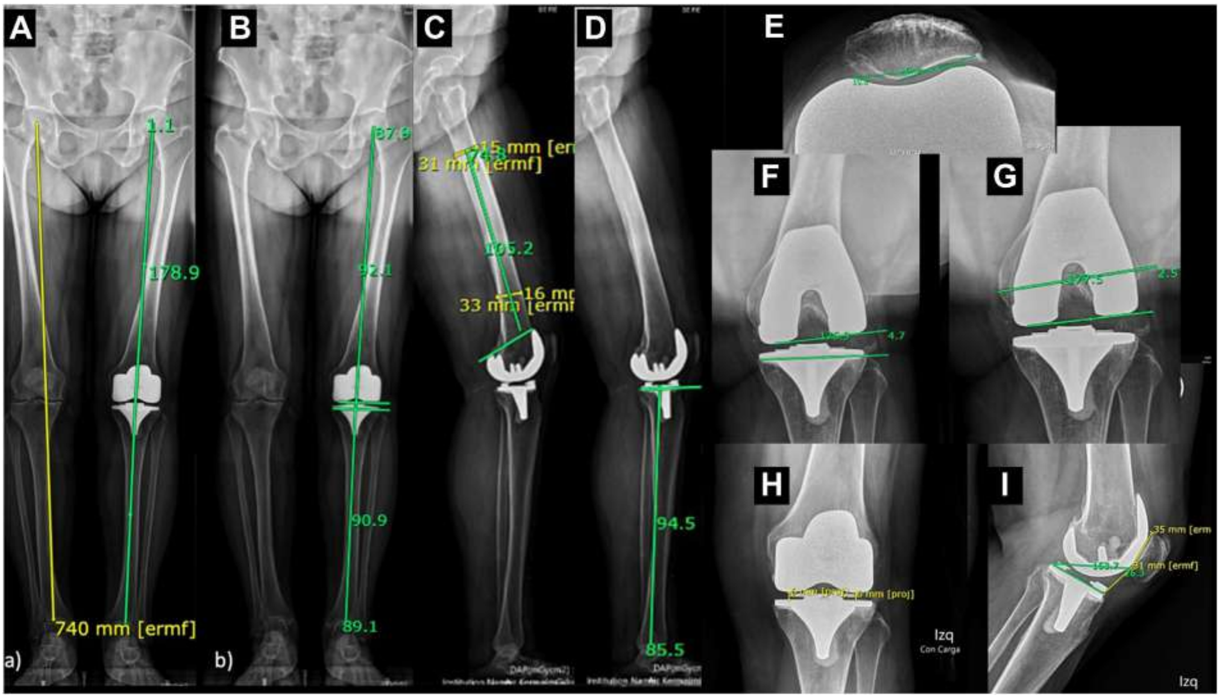

Fig. 1. Radiographic measurements used in the study. (A) Full-limb-length standing antero-posterior radiograph of the right lower limb, illustrating measurements of limb length on the right side and hip-knee-ankle (HKA) angle on the left. (B) Full-limb-length standing antero-posterior radiograph with measurements of distal lateral femoral mechanical angle (DLFAm) and proximal medial tibial mechanical angle (PMTAm). (C and D) Full-limb-length standing lateral radiograph depicting the anatomical inclination of the femoral component and the tibial mechanical slope, respectively. (E) Axial knee view with measurement of patellar tilt. (F and G) Seated view with measurement of joint angle in flexion and rotation of the femoral component, respectively. (H) Anteroposterior knee view with measurements of the medial and lateral femorotibial joint space in extension. (I) Lateral knee view with measurement of patellar height using 2 methods (Caton-Deschamps index and tibia-patella angle).

curve (AUC). Additional metrics such as accuracy, precision, and sensitivity (recall) were used to evaluate the machine-learning models. Accuracy represents the ratio of correct predictions and is calculated by summing the true positives and true negatives divided by the total number. Precision reflects the model's accuracy in identifying positive classes and is calculated by dividing the true positives by the sum of true positives and false positives. Sensitivity (recall) measures the ratio of correctly predicted positive classes and is calculated by dividing the true positives by the sum of true positives and false negatives. The best-performing model was selected based on a thorough analysis of these metrics, with the initial comparison parameter being the AUC. Models were estimated for both observers to reduce the risk of bias.

After analyzing the metrics of the 13 machine-learning models, the best-performing model was selected. Grid search was used for model tuning to maximize performance without overfitting. If the model allowed for straightforward interpretation of variable importance, that information was included. Shapley additive explanations (SHAP) testing was also conducted, if possible, to assess the impact of variables on prediction. Python 3.11 (Python Software Foundation, Wilmington, DE) with the Panda and PyCaret libraries was used for all analyses.

Results

A total of 131 TKA in 105 patients were included. AKP was found in 35 of the total TKAs, representing 26.7%. Among these cases, 33 patients (31.4%) were affected: 20 had undergone unilateral TKA, 11 experienced AKP in only one knee despite undergoing bilateral TKA, and 2 patients reported AKP in both knees.

No statistically significant differences were found between the AKP groups in terms of age at surgery, gender, or affected side (Table 1). All patient-reported outcomes were significantly better in the AKP (−) group (Table 1). The measurements of both observers are summarized in Table 2.

The best performance model for each observer was achieved by the Gradient Boosting Classifier, reaching an AUC of 0.9164, accuracy of 0.8154, precision of 0.8098, and sensitivity of 0.8768 for observer 1. For observer 2, the AUC was 0.9261, accuracy was 0.7989, precision was 0.7825, and sensitivity was 0.8732. The metrics for all machine-learning models tested are summarized in Table 3 for observer 1 and Table 4 for observer 2. After tuning, the AUC settled at 0.91 for observer 1 and 0.86 for observer 2.

The most important variable for each observer was the tibial mechanical slope (Figures 2 and 3), accounting for 0.17 to 0.22. Both observers identified the same top 10 variables to predict AKP after TKA, which were obtained from the full-limb-length standing antero-posterior and lateral radiographs, the lateral knee radiograph, the axial view, and the seated view. Limb dysmetria ranked as the third most important variable for both observers, while distal anatomical sagittal femoral alignment was the most controversial variable, being the fourth most important for observer 1 and the eighth for observer 2.

The SHAP test was conducted for the Gradient Boosting Classifier model. According to the model developed with measurements made by observer 1, high or low values of tibial mechanical slope, a shorter operated leg, valgus coronal alignment, and excessive patellar tilt increased the risk of AKP. Conversely, intermediate values of mechanical slope and femoral rotation close to 0° in relation to the posterior condyles increased the likelihood of not experiencing AKP after TKA (Figure 4). The SHAP test applied to the model estimated for observer 2 showed a similar trend, but with less intensity, except for the excessive shortening of the operated limb, which posed a major risk of anterior pain (Figure 5).

Table 1
Comparison of Median Age at Surgery, Sex, and Side Frequency Between Patients With and Without Anterior Knee Pain (AKP) .

Variables	Anterior Knee Pain Present	Anterior Knee Pain Absent	*P* Values
Age at surgery	64 y (48 to 86)	66 y (47 to 88)	.2958 (Wilcoxon test)
Women (%)	22 (30.14)	51 (69.90)	.427 (Fisher's exact test)
Men (%)	13 (22.41)	45 (77.6)	
Left Knee (%)	17 (32.08)	36 (67.92)	.315 (Fisher's exact test)
Right Knee (%)	18 (23.08)	60 (76.92)	
WOMAC-pain	6 (2 to 14)	1 (0 to 10)	<.0001 (Wilcoxon test)
WOMAC-stiffness	2 (0 to 6)	1 (0 to 8)	.0014 (Wilcoxon test)
WOMAC-Function	7 (0 to 55)	17 (1 to 50)	.0001 (Wilcoxon test)
KOOS-QL	50 (13 to 94)	69 (5 to 100)	.0669 (Wilcoxon test)
Kujala	64 (32 to 90)	77 (29 to 100)	.0001 (Wilcoxon test)
Goodman A (satisfaction)	88 (0 to 100)	100 (38 to 100)	.0027 (Wilcoxon test)
Goodman B (quality of life)	5 (1 to 6)	5 (2 to 6)	.0001 (Wilcoxon test)

WOMAC, Western Ontario and MacMaster Universities Arthritis Index; KOOS-QL, knee injury and osteoarthritis outcome score—quality of life.

Discussion

The results of the present study support the utility of the machine-learning model in predicting AKP after TKA with patellar preservation. According to the algorithm, no radiological measurement by itself has an importance more than 20%. This implies that the association between anterior pain and radiological measurements does not depend on a single parameter, and the global alignment—coronal, sagittal, and axial—are relevant for this adverse outcome. The resulting hierarchy from the algorithms is as follows: sagittal alignment (tibial and femoral), limb length discrepancy, coronal alignment, and axial alignment.

A cadaveric study demonstrated that retro-patellar pressure increased after TKA compared to the native state [23]. Finding ways to reduce this pressure may be crucial in diminishing the incidence of AKP. Similar to our results, a study using a validated knee finite element model showed that the tibial slope, particularly in Cruciate-Retaining Anterior Stabilized TKA, was the most important factor in knee kinematics [24]. Moreover, an in vivo navigated study by Keshmiri et al. [25] demonstrated that excessive tibial slope or flexion of the femoral component significantly alters patellofemoral kinematics, especially at 90° of knee flexion. Although they did not correlate it to clinical outcomes, Antinolfi et al. [26] showed a lower KSS and Kujala score based on the position of the femoral flange, which is partly determined by the sagittal alignment of the femoral component, and concluded that it was correlated with AKP. Furthermore, clinical studies with longer follow-up have shown a strong association between the sagittal position of the femoral component and the development of AKP 10 years after TKA [27]. The main explanation for this lies in the tibiofemoral contact point described by Jong et al. [28]. Changes in femoral or tibial sagittal alignment result in more anterior or posterior tibiofemoral contact, which in turn affects retro-patellar pressure, leading to a kinematic overstuffing of the patellofemoral joint. Xi-Qing Pan et al. [29] demonstrated that a slight increase in tibial slope of 3° compared to the native state leads to more anterior tibio-femoral contact, resulting in less pain and better reported outcomes. Also, Farooq et al. using machine-learning techniques reported that adequate tibial slope restoration and femoral flexion predict good outcomes [30].

The patellar height was not found to be associated with AKP in the present study. Many different ways to assess these parameters have been described, but we only used 2 validated methods in this study: Caton-Deschamps and patellar-tibial angle [31,32]. Patella baja has been associated with a lower degree of flexion and patella alta with patella instability, but there is no association with AKP, according to a recent review [33].

Coronal alignment also plays a role in patellofemoral kinematics. Valgus alignment has shown to increase the pressure in the lateral facet of the patella after TKA [34], which is similar to our findings in which the Shapley test shows that valgus increases the likelihood of AKP. On the contrary, in the varus knee, varus alignment after TKA has not been associated with an alteration of the patellofemoral kinematics [35]. In both models estimated in this

Table 2
Summary of Radiological Measurements by Each Observer for Patients With and Without Anterior Knee Pain.

Radiological Measurement	Observer 1		Observer 2	
	Anterior Knee Pain Present	Anterior Knee Pain Absent	Anterior Knee Pain Present	Anterior Knee Pain Absent
Dysmetria	1.5 (±5.9)	1.1 (±8.86)	1.3 (±5.25)	−0.2 (±6.9)
Hip-knee-ankle angle	2.7 (±3.43)	2.1 (±3.71)	2.6 (±3.38)	1.7 (±3.72)
Distal lateral femoral mechanical angle	91.9 (±2.55)	91.5 (±2.53)	92.0 (±2.38)	91.7 (±2.44)
Proximal medial tibial mechanical angle	89.6 (±2.16)	89.7 (±2.29)	89.3 (±2.00)	89.9 (±2.18)
Mechanical tibial slope	86.4 (±2.98)	85.6 (±3.07)	86.6 (±2.66)	85.6 (±3.08)
Anatomical tibial slope	87.7 (±2.74)	86.4 (±2.94)	86.2 (±2.27)	86.1 (±2.56)
Medial joint space in extension	5.6 (±1.59)	5.8 (±1.90)	5.7 (±1.66)	5.9 (±1.92)
Lateral joint space in extension	5.8 (±1.60)	5.8 (±1.89)	5.9 (±1.68)	6.1 (±1.76)
Medial joint space in flexion	5.4 (±2.17)	5.4 (±2.63)	5.6 (±2.06)	5.6 (±2.52)
Lateral joint space in flexion	6.7 (±2.81)	6.5 (±2.97)	7.0 (±2.78)	6.6 (±2.90)
Femoral rotation	−0.4 (±2.97)	0.3 (±2.66)	0.4 (±2.31)	0.2 (±2.13)
Distal anatomical sagittal femoral alignment	3.4 (±2.94)	3.6 (±2.85)	3.5 (±3.13)	3.5 (±3.02)
Tibial proximal anatomical slope	86.3 (±9.60)	85.8 (±6.19)	84.9 (±9.26)	85.6 (±6.00)
Caton-Deschamps index	0.93 (±0.17)	0.93 (±0.16)	0.96 (±0.15)	0.96 (±0.14)
Patella-Tibial angle	30.6 (±3.22)	30.4 (±3.45)	29.5 (±2.89)	29.6 (±3.29)
Patella lateralization	−1.3 (±3.12)	−1.3 (±2.95)	−1.0 (±2.85)	−0.7 (±2.30)
Patellar tilt	7.2 (±3.40)	7.8 (±3.30)	6.6 (±4.73)	7.0 (±3.29)

Table 3
Summary of Metrics for all 13 Machine-Learning Algorithms Attempted to Predict Anterior Knee Pain (AKP) Using Measurements Made by Observer 1.

Machine Learning Algorithms	Area Under the Curve	Accuracy	Precision	Sensitivity
Quadratic Discriminant Analysis	0.9435	0.8753	0.8775	0.9054
Extra Trees Classifier	0.9510	0.8747	0.9140	0.8625
Random Forest Classifier	0.9210	0.8659	1.000	0.7500
Light Gradient Boosting Machine	0.8158	0.8236	0.7948	0.9196
Gradient Boosting Classifier	0.9164	0.8154	0.8098	0.8768
Decision Tree Classifier	0.8629	0.7912	0.7765	0.9036
Ada Boost Classifier	0.7968	0.7538	0.7304	0.8893
K Neighbors Classifier	0.7065	0.7236	0.7476	0.7893
Ridge Classifier	0.0000	0.6714	0.7067	0.7482
Logistic Regression	0.6780	0.6714	0.7067	0.7482
Linear Discriminant Analysis	0.6655	0.6560	0.6949	0.7036
SVM - Linear Kernel	0.0000	0.6187	0.6760	0.6625
Naive Bayes	0.5709	0.5396	0.5973	0.5304
Gradient Boosting Classifier - Tuned	0.9130	0.8214	0.8058	0.9018

Also, the last row includes the metrics of the tuned Gradient Boosting Classifier (GBC) model.

study, the coronal alignment of the femoral component was more important than the tibial side. An explanation is that the distal femoral cut determines the orientation of the trochlear groove, which can lead to patellar maltracking [33]. Regarding the patellofemoral joint, it seems that varus alignment is more tolerable than valgus alignment, which is important to consider when performing kinematic or functional alignment.

Previous studies have established a correlation between limb dysmetria and unfavorable outcomes [36–38]. However, this study is the first to establish a direct link between limb dysmetria and AKP. The Shapley test results indicate a strong association between a shorter limb length and the presence of AKP. It is important to note that the occurrence of this issue is less common than after total hip arthroplasty, and a greater degree of varus or valgus deformity before TKA is associated with a more important lengthening of the limb [39].

Axial alignment has been related to patellofemoral disorders, including AKP; nevertheless, its importance was less than 10% in predicting AKP for both observers in this study. Like Keshmiri et al. [25], we expected a greater influence of axial alignment; nevertheless, the importance of sagittal alignment was found to be greater. Nevertheless, the position of the patella in axial view, named patellar lateralization in this study, is related to the femoral component rotation as well [40]. The same accounts for patellar tilt, which has been found to be strongly correlated with femoral component rotation [41]. So indirectly, the influence of the femoral component rotation was higher. Excessive patellar tilt in this study increased the incidence of AKP; similarly, previous studies had found that excessive tilt diminished KSS outcomes as well [42]. Unfortunately, tibial rotation was not assessed in this study, as no radiologically validated measurement was found in the literature. Tibial rotation may play a significant role in knee kinematics. This measure could impact the importance of axial rotation in the genesis of AKP [43].

The findings of this study have important clinical implications. Early identification of patients at higher risk of developing AKP after TKA would allow for more precise and personalized preventive intervention. Additionally, knowledge of the radiological variables associated with AKP can guide surgical decision-making, especially now in the era of robotic-assisted surgery [44]. Robotic assistance allows for a more precise customization of the sagittal alignment than conventional instrumentation, especially in the tibial slope, according to a recent randomized controlled trial [45] and in the axial alignment [46], which, according to the results of this study, could prevent AKP.

It is important to note that this study has some potential limitations. The sample of patients was low and limited to a single center, and these results cannot be extrapolated to TKA with patellar resurfacing or a posterior stabilized insert. Furthermore, the radiological variables analyzed may be subject to some measurement variability due to the involvement of 2 observers. Despite these limitations, the results suggest that the machine-learning model can be a promising tool for predicting AKP after TKA with patellar preservation using radiological measurements.

Table 4
Summary of Metrics for all 13 Machine-Learning Algorithms Attempted to Predict Anterior Knee Pain (AKP) Using Measurements Made by Observer 2.

Machine Learning Algorithms	Area Under the Curve	Accuracy	Precision	Sensitivity
Quadratic Discriminant Analysis	0.8832	0.8951	0.9750	0.8304
Extra Trees Classifier	0.9459	0.8654	0.8875	0.8589
Random Forest Classifier	0.9495	0.8280	0.7970	0.9161
Light Gradient Boosting Machine	0.9205	0.8209	0.7762	0.9429
Gradient Boosting Classifier	0.9261	0.7989	0.7825	0.8732
Decision Tree Classifier	0.7929	0.7978	0.7767	0.9000
Ada Boost Classifier	0.8324	0.7764	0.7556	0.8732
K Neighbors Classifier	0.6580	0.6780	0.6719	0.7732
Ridge Classifier	0.0000	0.6643	0.6815	0.7179
Logistic Regression	0.6735	0.6582	0.6681	0.7304
Linear Discriminant Analysis	0.6782	0.6423	0.6562	0.6893
SVM - Linear Kernel	0.0000	0.6363	0.6393	0.7321
Naive Bayes	0.6678	0.5995	0.5847	0.8018
Gradient Boosting Classifier – Tuned	0.8605	0.7918	0.7611	0.8786

Also, the last row includes the metrics of the tuned Gradient Boosting Classifier (GBC) model.

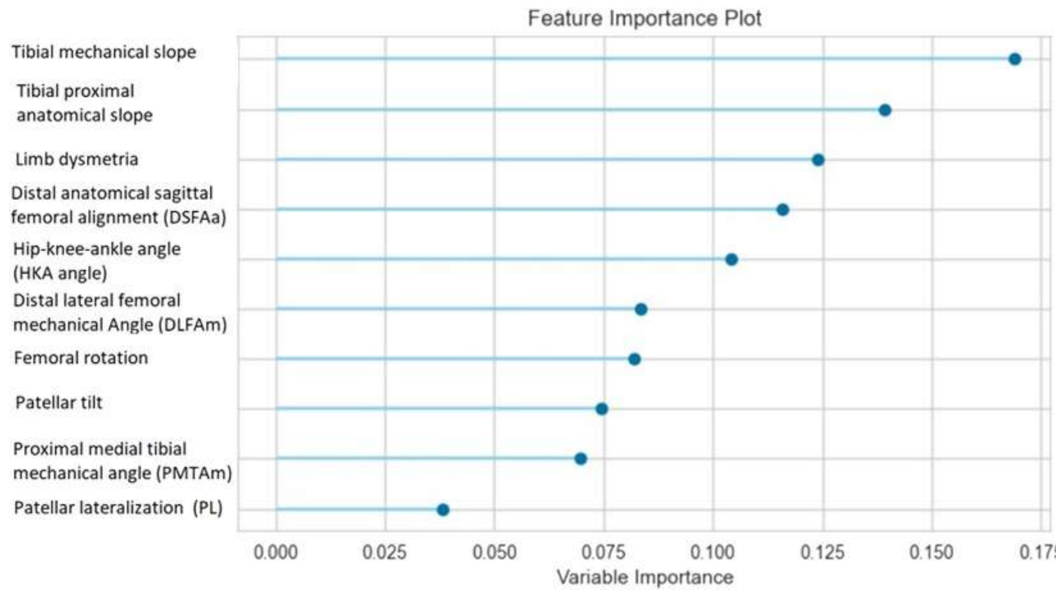

Fig. 2. Importance plot for observer 1.

Conclusions

A machine-learning algorithm effectively predicts AKP by using radiological measurements obtained from a set of postoperative radiographs that assess global alignment. Our findings indicate that excessive or steep mechanical tibial slope, shorter limb length, valgus coronal alignment, and excessive patellar tilt are predictive variables for AKP following cruciate-retaining anterior stabilized TKA without patellar resurfacing. However, it is important to note that further studies with a larger sample size are required to validate these findings.

CRediT authorship contribution statement

Maximiliano Barahona: Writing – original draft, Project administration, Methodology, Funding acquisition, Data curation, Conceptualization, Writing – review & editing, Resources, Methodology, Data curation. **Mauricio A. Guzmán:** Writing – review & editing, Validation, Resources. **Sebastian Cartes:** Validation, Supervision, Formal analysis. **Andres E. Arancibia:** Writing – review & editing, Visualization, Validation, Supervision, Formal analysis. **Javier E. Mora:** Writing – review & editing,

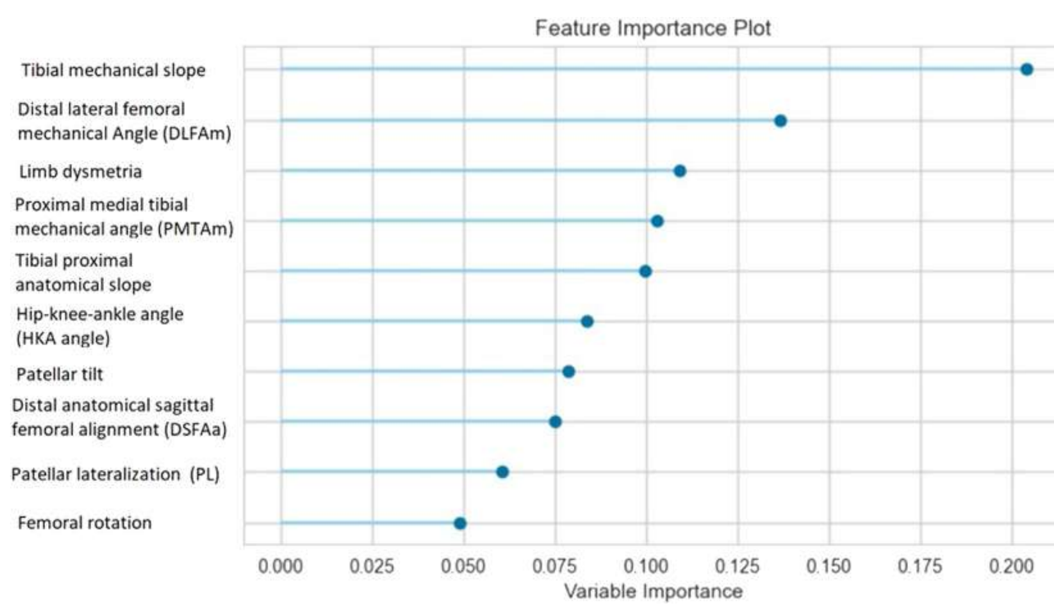

Fig. 3. Importance plot for observer 2.

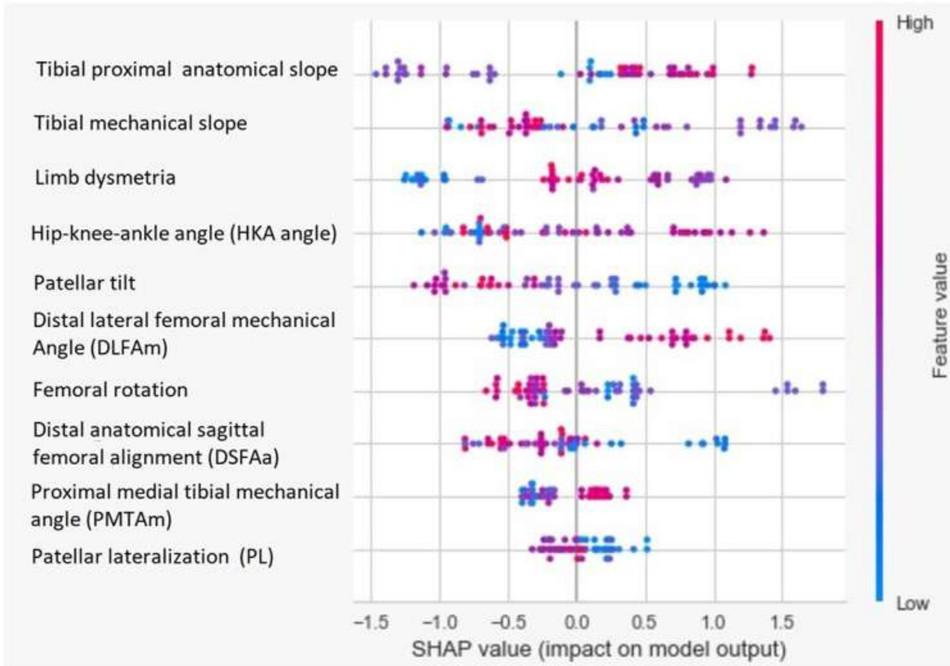

Fig. 4. Shapley additive explanations (SHAP) test applied to Gradient Boosting Classifier model by observer 1 for anterior knee pain prediction after total knee arthroplasty. A negative SHAP value indicates a greater probability of having anterior knee pain.

Validation, Resources, Formal analysis, Data curation. **Macarena A. Barahona:** Writing – original draft, Resources, Investigation. **Daniel Palma:** Writing – review & editing, Resources, Investigation. **Jaime R. Hinzpeter:** Writing – review & editing, Validation, Supervision, Investigation. **Carlos A. Infante:** Writing – review & editing, Visualization, Validation, Supervision, Project administration.

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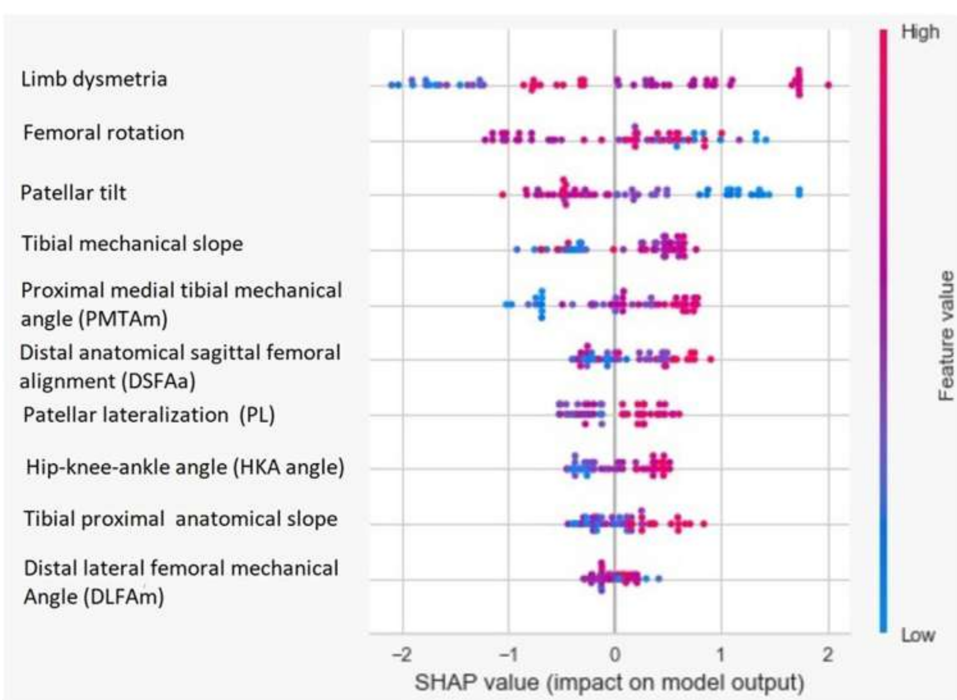

Fig. 5. Shapley additive explanations (SHAP) test applied to Gradient Boosting Classifier model by observer 2 for anterior knee pain prediction after total knee arthroplasty. A positive SHAP value indicates a greater probability of not experiencing anterior knee pain.

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