Machine Learning-Based Prediction of Arthrofibrosis Risk After Total Knee Arthroplasty

Dave T Huang[1,2], Andrew Nakla[2], Melodie F Meztger[1,2], Sean Rajaee[2]
[1] Orthopaedic Biomechanics Laboratory, Cedars Sinai Medical Center, Los Angeles, CA, USA
[2] Department of Orthopaedic Surgery, Cedars Sinai Medical Center, Los Angeles, CA, USA
Email: dave.huang@cshs.org

Summary

Arthrofibrosis occurs in 1–13% of total knee arthroplasty (TKA) patients. We retrospectively analyzed 1,558 TKA cases, including 293 arthrofibrosis cases, using an XGBoost model with a 70–30 train–test split, achieving 78% accuracy under 5-fold cross-validation. Class-specific F1 scores were 0.82 for non-arthrofibrosis and 0.71 for arthrofibrosis. Gain and SHAP analyses highlighted implant type (posterior stabilized vs. cruciate retaining) as one of the most influential predictors, with posterior-stabilized implants linked to lower arthrofibrosis risk. Higher preoperative knee flexion, older age, and female sex further reduced risk. These findings point to the value of proactive risk assessment to guide clinical decision-making.

Introduction

Total knee replacement (TKA) is performed over 800,000 times each year in the United States and is expected to exceed 1 million procedures by 2030. Although TKA yields a 90% success rate in relieving pain and improving mobility, roughly 1–13% of patients develop arthrofibrosis [1]—a pathologic stiffening of the knee caused by inflammation, infection, immobilization, or pre-existing conditions. Arthrofibrosis is typically diagnosed via range-of-motion assessments and imaging, and treated with physical therapy, bracing, manipulation under anesthesia, or surgery. By leveraging large datasets to identify risk patterns, ML-based models could help clinicians develop personalized pre-operative education, optimize surgical plans, and tailor postoperative care for patients most likely to develop arthrofibrosis.

Methods

A retrospective dataset of 1,558 total knee arthroplasty (TKA) cases from 2015 to 2020 was collected from a tertiary academic medical center, with 293 cases meeting arthrofibrosis criteria (≤100° postoperative flexion, ≥10° postoperative extension, or requiring manipulation under anesthesia within 100 days). Demographic and surgical data—such as patient sex, implant type, age, BMI, surgical details, and various comorbidities—were extracted from electronic health records using rule-based text mining and negation handling; a 25% sample was manually verified by a fellowship-trained orthopaedic surgeon. The machine learning pipeline employed Extreme Gradient Boosting (XGBoost) with a 70–30 stratified train–test split, augmented by Borderline SMOTE, sequential feature selection, and hyperparameter tuning via GridSearchCV. Model performance was evaluated with F1 score, while feature importance and interpretability were provided globally by Gain and locally by SHAP values, showing both the magnitude and direction of each feature's effect on predicting arthrofibrosis risk.

Results and Discussion

The XGBoost model yielded an overall accuracy of 0.78 under 5-fold cross-validation. Class-specific performance showed a strong F1 score of 0.82 for non-arthrofibrosis (precision 0.89, recall 0.76) and a lower F1 score of 0.71 for arthrofibrosis (precision 0.64, recall 0.81).

Gain and SHAP analysis revealed that implant type (posterior stabilized, PS vs. cruciate retaining, CR) was one of the most influential predictors, with posterior stabilized implants exhibiting a relatively lower risk of arthrofibrosis. A PS implant requires the removal of the posterior cruciate ligament in surgery, whereas a CR implant preserves it. Other factors such as greater preoperative knee flexion angle, older age, and male sex were also associated with a reduced likelihood of arthrofibrosis, which were consistent with previous studies [2,3], Figure 1.
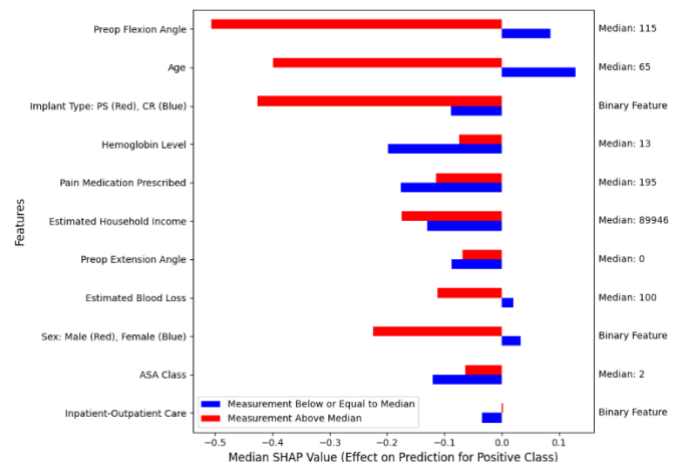

Figure 1. Simplified SHAP summary plot showing median SHAP values for features grouped by measurements.

Conclusions

Using a ML-based model, we were able to assess pre-operative risk factors and determined PS implants place patients at a lower risk for developing arthrofibrosis.

References

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