

# Predicting Risk of Graft Rupture and Contralateral ACL Tears following Anterior Cruciate Ligament Rupture and Reconstruction: An Analysis Using Interpretable Machine Learning

Sara E Till<sup>1</sup>, Yining Lu<sup>1</sup>, Joshua Richard Labott<sup>1</sup>, Anna Reinholz<sup>1</sup>, Aaron John Krych<sup>1</sup>, Christopher L Camp<sup>1</sup>, Kelechi Okoroha

<sup>1</sup>Mayo Clinic

**INTRODUCTION:** Anterior cruciate ligament reconstruction (ACLR) can be a successful procedure in restoring knee stability. However, secondary ACL injury, either through graft failure or contralateral tear, are known complications. Revision ACLR can significantly impact patients' ability to successfully return to previous activities. Thus, the purpose of this investigation was to develop and internally validate an interpretable machine learning model to quantify the risk of graft re-rupture and contralateral ACL rupture in a longitudinal cohort treated with ACLR.

## METHODS:

An established geographic database of more than 600,000 patients was used to identify patients with a diagnosis of anterior cruciate ligament rupture between 1990 and 2016 with minimum 2-year follow-up. Medical records were reviewed for relevant patient information and four candidate machine learning algorithms were evaluated for prediction of graft re-rupture and contralateral ACL injury in patients following ACLR. Performance of the algorithms was assessed through discrimination, calibration, and decision curve analysis. Model interpretability was enhanced utilizing global variable importance plots and partial dependence curves.

## RESULTS:

A total of 1,517 patients met inclusion criteria. Among them, 142 (9.36%) had graft re-rupture and 132 (8.70%) had a contralateral ACL injury following index surgery. The best performing models achieved an area under the receiver operating characteristics (AUROC) curve of 0.70 for prediction of re-rupture and 0.67 for prediction of contralateral ACL rupture. Notable predictors for increased risk of graft re-rupture included younger age at injury, BMI>30, return to sport <250 days, initial time to surgery >75 days, utilization of allograft, femoral/tibial fixation with suspension/expansion devices, concomitant collateral ligament injury, and active or former smoking history. Predictors of contralateral ACLR injury included younger age at initial injury, BMI>25, active smoking history, initial time to surgery >75 days, history of contralateral knee arthroscopies, and involvement in contact sports.

## DISCUSSION AND CONCLUSION:

Less than 10% of all patients who undergo ACL reconstruction should be expected to sustain either a graft rupture or contralateral ACL injury. Machine learning models outperformed traditional prediction models and identified BMI>30, active or previous smoking history, and time to surgical intervention >75 days as common risk factors for both graft re-rupture as well as contralateral tear following ACL rupture. Following careful external validation, these models can be deployed in the clinical space to provide real-time quantifiable risk for counseling and timely intervention.

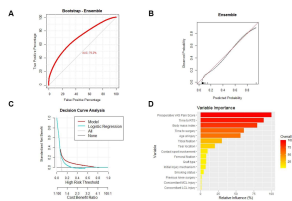


Figure 1 Performance of the best model for graft re-rupture. (A) Receiver operating characteristic (ROC) curve showing the area under the curve (AUC) of 0.70. (B) Calibration plot showing the observed vs predicted probabilities. (C) Decision curve analysis plot showing the net benefit of the model compared to no treatment or to the best alternative. (D) Global variable importance plot showing the relative importance of each variable in the model.

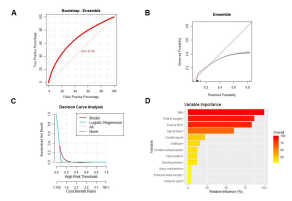


Figure 2 Performance of the best model for contralateral ACL injury. (A) Receiver operating characteristic (ROC) curve showing the area under the curve (AUC) of 0.67. (B) Calibration plot showing the observed vs predicted probabilities. (C) Decision curve analysis plot showing the net benefit of the model compared to no treatment or to the best alternative. (D) Global variable importance plot showing the relative importance of each variable in the model.

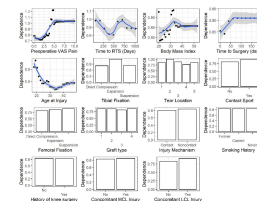


Figure 3 Partial dependence curves showing the predicted probability of graft re-rupture as a function of various variables. The variables are: (A) Age at Injury, (B) BMI, (C) Time to Surgery, (D) Return to Sport, (E) History of Knee Injury, (F) Concomitant ACL Injury, (G) Concomitant LCL Injury, (H) Concomitant PCL Injury, (I) Concomitant MCL Injury, (J) Concomitant Ligament Injury, (K) Concomitant Meniscus Injury, (L) Concomitant Cartilage Injury, (M) Concomitant Ligament and Cartilage Injury, (N) Concomitant Ligament, Cartilage and Meniscus Injury, (O) Concomitant Ligament, Cartilage, Meniscus and Ligament Injury, (P) Concomitant Ligament, Cartilage, Meniscus, Ligament and Ligament Injury.