Outcome Prediction After Anterior Cervical Discectomy and Fusion with Machine Learning

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Introduction: Anterior cervical discectomy and fusion (ACDF) is one of the most commonly performed spine procedures, offering excellent outcomes for patients with cervical radiculopathy or myelopathy. Despite its routine use, certain patients remain at elevated risk for short-term complications, readmission, or non-home discharge. Traditional risk calculators often lack the sensitivity to account for individual patient complexity in this context. This study applied multiple machine learning (ML) models to predict short-term postoperative outcomes after ACDF and to identify the most influential preoperative factors contributing to each outcome. The broader aim was to develop a clinically interpretable risk prediction tool tailored to the ACDF population.

Methods: Patients undergoing ACDF between 2019 and 2023 were identified from the National Surgical Quality Improvement Program (NSQIP) database using CPT code 22551. After applying standard exclusion criteria, 47,415 cases were included for analysis. Four supervised ML algorithms—XGBoost, LightGBM, Random Forest, and Elastic Net Logistic Regression—were trained to predict four 30-day postoperative outcomes: readmission, major complications, prolonged length of stay (LOS ≥3 days), and non-home discharge. A stacked ensemble model was created by integrating the outputs of the individual models. The data were split 75% for training and 25% for testing. Model performance was evaluated using area under the receiver operating characteristic curve (AUROC). Feature importance was assessed using mean SHapley Additive exPlanations (SHAP) values from the best-performing model for each outcome. For major complications, SHAP dependence plots were used to further explore the top four predictors.

Results: The ensemble model consistently outperformed individual algorithms across all four outcomes, achieving AUROC values of 0.78 for 30-day readmission, 0.76 for major complications, 0.74 for prolonged LOS, and 0.85 for non-home discharge. Feature importance varied by outcome. For readmission, ASA classification, sex, platelet count, and age were the most predictive variables. Prolonged LOS was primarily influenced by race, ASA classification, hematocrit, and age. Non-home discharge was most closely associated with age, ASA status, hematocrit, and race.

The most influential predictors for major complications were ASA classification, platelet count, age, and sex. SHAP analysis revealed that ASA class III was associated with increased complication risk relative to lower classes. Platelet levels below 180,000 were linked to elevated risk based on positive SHAP values. Complication risk also rose steadily in patients over age 50. Lastly, female patients demonstrated slightly higher model-predicted risk compared to males.

Conclusion: Ensemble machine learning models demonstrated strong predictive performance for short-term outcomes following ACDF, with highest accuracy observed for non-home discharge and readmission. Feature importance analysis revealed distinct predictors for each outcome, reinforcing the value of outcome-specific modeling in surgical risk stratification. Key risk factors such as ASA classification, platelet count, age, and hematocrit consistently influenced model performance. SHAP-based interpretation provided clinically actionable insights—such as higher complication risk in older patients, thrombocytopenia, and ASA class III status—that can inform surgical planning. A clinical risk calculator was developed from the ensemble model to deliver personalized risk estimates, supporting preoperative counseling and optimization in patients undergoing ACDF.

Significance/Clinical Relevance: ACDF is a widely performed spine procedure, yet identifying patients at risk for complications or prolonged recovery remains a clinical challenge. This study applies predictive modeling to improve risk communication and optimize preoperative planning.