Machine Learning Models Forecast Outcomes in Cervical Disc Replacement

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Introduction: Cervical disk replacement (CDR) has emerged as a motion-preserving alternative to anterior cervical discectomy and fusion (ACDF) for the treatment of cervical radiculopathy and myelopathy. While early outcomes have been favorable, patient-specific risk for adverse short-term events remains difficult to predict. Traditional surgical risk calculators often lack precision when applied to CDR populations due to its distinct patient profile and complication profile. This study evaluates the performance of several machine learning (ML) models in predicting short-term postoperative outcomes after CDR and identifies key preoperative factors that influence each risk domain. The broader objective is to create a clinically interpretable model for individualized perioperative risk assessment.

Methods: Patients undergoing CDR between 2019 and 2023 were identified using CPT code 22856 within the National Surgical Quality Improvement Program (NSQIP) database. After applying standard exclusions, 5,683 patients were included. Four supervised ML algorithms—XGBoost, LightGBM, Random Forest, and Elastic Net Logistic Regression—were trained to predict four 30-day outcomes: readmission, major complications, prolonged length of stay (LOS ≥3 days), and non-home discharge. A stacked ensemble model was developed by integrating predictions from the base models. Data were split 75:25 into training and testing sets. Model performance was evaluated using area under the receiver operating characteristic curve (AUROC). SHapley Additive exPlanations (SHAP) values were used to determine feature importance for each outcome based on the most accurate model. For major complications, SHAP dependence plots were generated for the top four predictors.

Results: The ensemble model achieved the highest performance across all outcomes, with AUROC values of 0.69 for readmission, 0.70 for major complications, 0.86 for prolonged LOS, and 0.88 for non-home discharge. Feature importance varied by outcome. For readmission, the top contributors were sodium, platelet count, hematocrit, blood urea nitrogen (BUN), and age. Prolonged LOS was influenced primarily by race, ASA classification, BUN, ethnicity, and age. Predictors of non-home discharge included platelet count, white blood cell count (WBC), hematocrit, and body mass index (BMI).

For major complications, the four most influential features were race, platelet count, hematocrit, and age. SHAP analysis revealed that Asian and Black/African American patients had higher predicted risk (positive SHAP values), while other racial groups had lower risk. Platelet counts below 160,000 were associated with elevated predicted risk. Hematocrit levels below 40% increased model-predicted risk, while levels ≥44% reduced it. Age over 50 was linked to increasing complication risk, with risk escalating in older age brackets.

Conclusion: Machine learning models demonstrated strong predictive performance for short-term outcomes following cervical disk replacement, with the ensemble model outperforming all individual algorithms across all endpoints. Notably, the ensemble achieved its highest accuracy for prolonged length of stay and non-home discharge. Feature importance analysis revealed that predictors varied by outcome, with hematologic markers, BMI, race, and age among the most influential factors. SHAP analysis offered interpretable insights into major complication risk, highlighting increased risk in older patients, those with low hematocrit and platelet levels, and certain racial subgroups. These findings support the integration of ensemble ML models into clinical decision-making for CDR. A user-friendly risk calculator was developed from the ensemble model to deliver individualized risk estimates and support preoperative optimization.

Significance/Clinical Relevance: Cervical disc replacement is a motion-preserving alternative to spinal fusion with generally favorable outcomes, but risk prediction remains underdeveloped. This study introduces a predictive framework to support personalized care pathways.