A Machine Learning Model to Predict Length of Hospitalization Following Head and Neck Microvascular Free Tissue Transfer

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Abstract

The average length of hospitalization varies widely for patients receiving microvascular free tissue transfer for head and neck defects[4-7]. While past studies have examined predictive factors for increased length of stay (LOS)[4–7,11–13], causal machine learning (ML) models predicting LOS are extremely limited in head and neck surgery. This study analyzed patients who underwent head and neck free flap reconstruction from 2022 to 2025 at our institution, using mutual information (MI) analysis for ML and a Peter Clark (PC) algorithm for causal relationships. ML analysis determined Charlson Comorbidity Index, preoperative albumin, and hypertension as important predictors of length of stay. Causal inference analysis determined Peripheral Vascular Disease (PVD) as significantly positively associated with length of stay, while other variables were not statistically significant. Causal ML remains a promising tool for predicting clinical outcomes in free tissue transfer, with potential for enhanced accuracy through multi-institutional studies incorporating larger, more diverse patient populations.

Introduction

Microvascular free tissue transfer is a primary method for reconstruction in patients with large or complex defects of the head and neck, with success rates of 95-99%[1–3]. Average length of hospitalization following these procedures has been reported between 8-26 days[4–7]. Many free flap patients have significant medical comorbidities, socioeconomic factors, or postoperative complications leading to increased length of hospitalization[3,8–10]. Studies have reported various factors predictive of increased length of hospitalization, including increased operative time, flap takeback, wound breakdown, surgical site infection, and postoperative pneumonia[4–7,11–13]. The vast majority of previous studies have relied on traditional statistical analysis, and true predictive models using these methods are limited[14]. Machine learning (ML) is a type of artificial intelligence that uses patterns and associations between variables to predict outcomes. Studies exploring ML models to predict outcomes for patients undergoing head and neck free flap reconstruction are extremely limited, and studies that do exist have explored the utility of supervised ML and decision tree analysis[14–17]. Causal ML incorporates causal relationships into the machine learning algorithm, allowing the model to be more predictive and generalizable[18]. To our knowledge, no literature exists that explores a ML model which causally predicts length of stay for these patients. The present study aims to expand on the currently limited ML techniques in the context of head and neck surgery, including the first AI model to include a causal analysis for prediction of head and neck microvascular surgery length of hospitalization.

Demographics	Mean
Length of Stay	11.25 (days)
Age	62 (years)
BMI	24.63
Distance from Hospital	50.73 (miles)
Charlson Comorbidity Index	4.90

Methods and Materials

A retrospective chart review was conducted for patients who underwent free flap reconstruction for head and neck defects from 2022 to 2025 at a single institution. Several variables were extracted for each subject, including those related to demographic data, medical and social history, Charlson comorbidity index (a verified comorbidity aggregate calculator [19]), defect and flap type, pathology, preoperative laboratory values, intraoperative details, and postoperative course. The data were de-identified and processed. An MI analysis with feature importance was employed for traditional machine learning analysis. For causal inference, a PC algorithm was used for initial causal relationship suggestions. This was then augmented using a domain expert knowledge causality chart provided by the physician investigators as well as a large language model (LLM) which searched existing literature for potential causal links. The set of edges inferred by the PC algorithm was compared against the sets derived from domain experts and LLM sets to create a final merged graph structure.

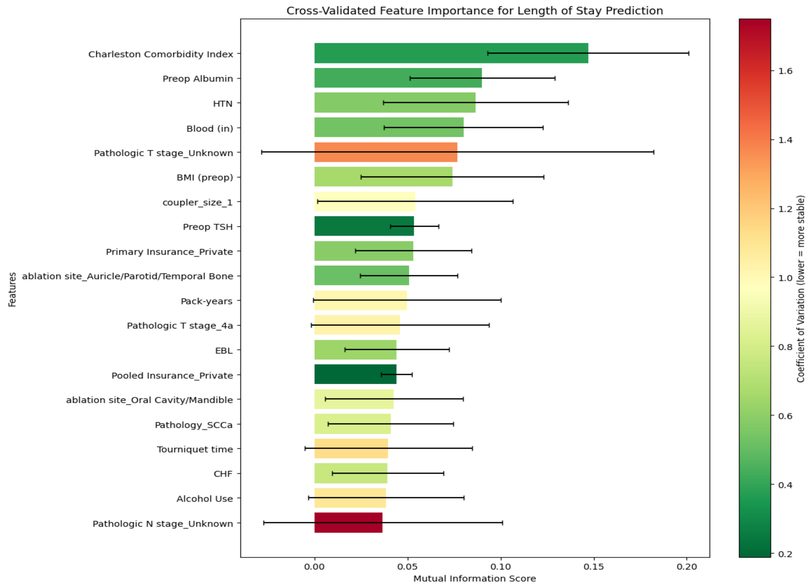
Results

Mean length of stay was 11.18 days (median 9 days, range 5-74 days).

Cross-validated MI analysis for length of stay highlighted ‘Charlson Comorbidity Index’ (mean MI: 0.147 ± 0.054, CV: 0.366), 'Preop Albumin' (mean MI: 0.090 ± 0.039, CV: 0.431), and 'HTN' (Hypertension; mean MI: 0.087 ± 0.050, CV: 0.574) as consistently important. Among four regression models tested, a Random Forest Regressor yielded the best performance on the test set for log-transformed length of hospitalization.

The causal inference analysis identified Peripheral Vascular Disease (PVD) as having a significant direct positive association with length of stay (β = 0.237, p = 0.01). Other factors, including preoperative albumin (β = -0.107, p = 0.20), age at surgery (β = 0.070, p = 0.50), Congestive Heart Failure (β = 0.120, p = 0.15), Charlson Comorbidity Index (β = -0.014, p = 0.90), did not demonstrate statistically significant direct relationships with length of hospitalization within this model.

Demographics	Count	Percentage
Gender		
Male	118	76.1%
Female	37	23.9%
Race		
White	107	69.0%
African American	44	28.4%
Other	4	2.6%
Primary Insurance		
Medicaid	37	23.9%
Medicare	66	42.6%
Other	52	33.5%



Discussion

This study represents the first application of causal ML to predict length of hospitalization in head and neck free flap reconstruction, offering a novel approach going past traditional correlation-based statistical methods. Interestingly, while traditional MI analysis identified Charlson Comorbidity Index, preoperative albumin, and hypertension as important predictors, these factors did not demonstrate casual relationships with length of hospitalization in the causal relationship model. The causal ML approach may reveal that these common risk factors influence LOS through indirect pathways or confounding variables, rather than a direct causal mechanism.

In the present study, there are several limitations that warrant consideration. Patients of a single institution may limit the generalizability across different systems and patient populations. Additionally, a larger sample size would train a more accurate and reliable ML model.

Future directions should focus on larger validation studies to expand the model’s prediction accuracy. Multi-institutional studies could also be employed to increase patient population diversity. Utilization of this model in clinical decision-making will inform preoperative counseling, planning, and resource use in patients undergoing head and neck free flap reconstruction.

Conclusions

Causal ML analysis is a powerful tool that can assist in prediction of length of stay for patients undergoing head and neck free flap reconstruction. Causal inference analysis determined Peripheral Vascular Disease (PVD) as significantly positively associated with length of stay, while other variables were not statistically significant. Identifying preoperative factors that place patients at risk of increased length of hospitalization aids in counseling patients more thoroughly, thus providing more accurate risk assessments in those undergoing head and neck microvascular free tissue transfer.

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