Predicting High-Value Care Outcomes After Surgery for Non–Skull Base Meningiomas

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■ OBJECTIVE: **A need exists to better understand the prognostic factors that influence high-value care outcomes after meningioma surgery. The goal of the present study was to develop predictive models to determine the patients at risk of experiencing an extended hospital length of stay (LOS), nonroutine discharge disposition, and/or a 90-day hospital readmission after non–skull base meningioma resection.**

■ METHODS: **In the present study, we analyzed the data from 396 patients who had undergone surgical resection of non–skull base meningiomas at a single institution between January 1, 2005 and December 31, 2020. The Mann-Whitney *U* test was used for bivariate analysis of the continuous variables and the Fisher exact test for bivariate analysis of the categorical variables. A multivariate analysis was conducted using logistic regression models.**

■ RESULTS: **Most patients had had a falcine or parasagittal meningioma (66.2%), with the remainder having convexity (31.8%) or intraventricular (2.0%) tumors. Nonelective surgery ($P < 0.0001$) and an increased tumor volume ($P = 0.0022$) were significantly associated with a LOS >4 days on multivariate analysis. The independent predictors of a nonroutine discharge disposition included male sex ($P = 0.0090$), nonmarried status ($P = 0.024$), nonelective surgery ($P = 0.0067$), tumor location within the parasagittal or intraventricular region ($P = 0.0084$), and an increased modified frailty index score ($P = 0.039$). Hospital readmission within 90 days was independently associated with nonprivate insurance ($P = 0.010$) and nonmarried status ($P = 0.0081$). Three models predicting for a prolonged LOS, nonroutine discharge disposition, and 90-day readmission were implemented in the form of an open-access, online calculator (available at: https://neurooncsurgery3.shinyapps.io/non_skull_base_meningiomas/).**

■ CONCLUSIONS: **After external validation, our open-access, online calculator could be useful for assessing the likelihood of adverse postoperative outcomes for patients undergoing surgery of non–skull base meningioma.**

INTRODUCTION

Meningiomas are the most common form of primary central nervous tumors, accounting for ∼10%–20% of all intracranial neoplasms.[1] Although these tumors will mostly be benign and rarely require emergent intervention, their proximity to important anatomic locations can necessitate surgical resection to prevent neurological decline.[2,3]

Because of differences in the presenting symptoms and the differences in suitability for surgery, skull base and non–skull base meningiomas have been largely dichotomized using the proposed definition by Al-Mefty.[3] Patients with non–skull base meningiomas, specifically, have an increased risk of cognitive decline after surgery, likely related to the intimate relationship between these tumors and the surrounding cortical brain parenchyma.[4,5] In addition, non–skull base meningiomas have been characterized by increased growth rates compared with the growth rates of skull base tumors.[6]

Key words
- Length of stay
- Meningioma
- Neuro-oncology
- Outcomes
- Readmission

Abbreviations and Acronyms
LOS: Length of stay
mFI-5: Five-factor modified frailty index
OR: Odds ratio
VIF: Variance inflation factor

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With an enlarging elderly patient population in the United States and abroad, the prevalence of meningiomas has been expected to steadily increase.[1,7] With this increasing prevalence, a necessity exists to optimize patient outcomes to eliminate inefficiencies and minimize costs in the healthcare system. Additionally, the recent COVID-19 (coronavirus disease 2019) pandemic has emphasized the importance of conserving scarce healthcare resources. Thus, improved predictive modeling of patient hospital courses could aid healthcare workers in more efficiently allocating resources and optimizing clinical workflows.[8,9] Thus, a need for a better understanding of the postoperative outcomes such as an extended length of stay (LOS), discharge disposition, and 90-day readmission exists, because these potentially modifiable outcomes all significantly result in increased healthcare costs after neurosurgery.[10-16]

The goal of the present study was to develop predictive algorithms to preoperatively estimate patients' risk of experiencing an extended LOS, requiring a nonroutine discharge disposition, or requiring readmission to the hospital within 90 days after discharge after surgical resection of a non—skull base meningioma. The predictive algorithms developed in the present study were implemented into an open-access, online calculator with the goal of integrating these models into future clinical workflows.

METHODS

Patient Selection and Recorded Variables

The present study used the demographic and clinical data from 396 patients who had undergone surgical resection of non—skull base meningiomas at a single institution between January 1, 2005 and December 31, 2020. The patient data were obtained by a manual review of the electronic medical records. The institutional review board, acting as a Health Insurance Portability and Accountability Act privacy board, reviewed and approved the waiver of written informed consent for our retrospective study (institutional review board approval no. 00181593). In addition, we found no applicable reporting guidelines that would have applied to our report. Using the EQUATOR (enhancing the quality and transparency of health research) reporting guidelines decision tree (available at: http://www.equatornetwork.org/wp-content/uploads/2013/11/20160226-RG-decision-tree-for-Wizard-CC-BY-26- February -2016.pdf), we found that none of the most popular checklists were appropriate for our study design.

The tumor size was determined using contrast-enhanced magnetic resonance imaging, with the tumor volume measured using the tumor dimensions in the axial (x), coronal (y), and sagittal (z) planes via the following formula, similar to previous studies: $\frac{x \cdot y \cdot z}{2}$.[17-19] For patients with >1 meningioma, the tumor volumes were summed to obtain the final volume measurement. To avoid small sample sizes and ensure stable model performance, a number of variables were dichotomized for bivariate and multivariate statistical analyses. Patient race was dichotomized as white and nonwhite, insurance was dichotomized as private and nonprivate insurance status, and surgery number was dichotomized as first or repeated (second or third) surgery. Patient frailty was quantified using the 5-factor modified frailty index (mFI-5). Using the mFI-5, a patient receives 1 point for the presence of each of the following comorbidities: a history of diabetes, a history of chronic obstructive pulmonary disease, congestive heart failure, hypertension requiring medication, and limited functional status requiring assistance with activities of daily living.[20] The total mFI-5 score (possible score range, 0—5 points) was then calculated. Non—skull base tumors were defined as convexity, parasagittal/falcine, and intraventricular meningiomas, using the Al-Mefty classification scheme.[3,5] Just as in prior studies, a symptomatic presentation was defined as a meningioma diagnosis prompted by any of the following symptoms: seizure, headache, nausea/vomiting, diplopia, decreased hearing, vertigo, dysarthria, dysphagia, confusion, bladder incontinence, motor deficit, sensory deficit, language deficit, visual deficit, cognitive deficit, and/or gait deficit.[19] In line with prior research, surgeon years of experience was defined as the number of years since a surgeon had completed residency training.[21,22]

For the present study, a prolonged LOS was defined as >4 days, which was the upper quartile of the LOS for all the patients in our study cohort. This method of defining a cutoff for a prolonged LOS using quartiles has been described previously.[15,23-26] A routine discharge disposition was defined as discharge to home (either with self-care or healthcare service assistance). A nonroutine discharge was defined as discharge to a rehabilitation facility, skilled nursing facility, or hospice facility, in accordance with the study by Brandel et al.[27] Ninety-day readmission was defined as readmission to a hospital within 90 days of the initial hospital discharge. After quantifying the association between the non—skull base meningioma location (parasagittal/falcine and intraventricular meningioma vs. convexity meningioma) and our 3 high-value care outcomes, we also analyzed the association between tumor location and postoperative complications to explore whether higher complication rates would lead to prolonged LOSs, nonroutine discharge, and/or 90-day readmissions. For the present study, a postoperative complication was defined as the occurrence of any one of the following: wound infection, hematoma, deep vein thrombosis or pulmonary embolism, cerebral venous thrombosis, myocardial infarction, meningitis, seizure, dysphagia, new language deficit, new motor deficit, new visual deficit, new sensory deficit, and/or new cognitive deficit.

Statistical Analysis

Data were collected using Microsoft Excel, version 2016 (Microsoft Corp., Redmond, Washington, USA), and analyzed using R statistical software, version 3.3.2 (The R Foundation, Vienna, Austria). The Shapiro-Wilk test was used to test for normality. The Mann-Whitney U test was used for bivariate analysis of continuous variables (owing to violation of the normality assumption), and the Fisher exact test was used for bivariate analysis of categorical variables. Multivariate analysis was conducted using logistic regression models, with variables achieving a significance level of $P < 0.05$ on bivariate analysis included as covariates in their respective models. Optimal logistic regression models were selected by removing covariates until the Akaike information criterion had been minimized to penalize overfitting.[28] For continuous variables, the odds ratios (ORs) in the multivariate logistic regression models should be interpreted as the increase in the odds per single unit increase of the variable of interest (e.g., an increase in the odds per 1-year increase in age, an increase in the odds per a 1-cm^3 increase in tumor size). Variance inflation factors (VIFs) were calculated for each covariate in our logistic regression models, with VIFs >5 indicating collinearity.[29] Model discrimination was assessed using the c-statistic, and 2000 bootstrapped samples were used to calculate the optimism-corrected c-statistics. In line with prior research, a model with clinically useful discrimination was defined as one having a c-statistic of ≥0.7.[30,31] The Hosmer-Lemeshow test was used to assess the goodness-of-fit and model calibration, with a test result of $P < 0.05$ indicating an inadequate model fit. Calibration plots were also created, with model calibration curves more closely approximating the 45° diagonal ideal line representing superiorly calibrated models. Three models predicting for a prolonged LOS, nonroutine discharge disposition, and 90-day readmission were implemented in the form of an open-access, online calculator. In the present study, P values <0.05 were considered statistically significant, and all P values were 2-sided.

RESULTS

Patient Demographic and Clinical Characteristics

The demographic and clinical characteristics of the 396 patients with non–skull base meningioma are listed in Table 1. Most patients were women (68.2%), white (73.5%), and of non-Hispanic/Latino origin (97.5%). Most patients had had private insurance (59.6%), were married (66.2%), and had undergone elective surgery (88.1%). The surgery was the first for most patients (89.9%), with 29 (7.3%) and 11 (2.8%) patients undergoing a second and third surgery, respectively. Of the 396 patients, 47 (11.9%) had undergone radiation therapy for their meningioma before surgical resection. Most of the patients had had parasagittal or falcine meningioma (66.2%), with the remainder having convexity (31.8%) or intraventricular (2.0%) tumors. Of the 396 patients, 62 (15.7%) had had multiple meningiomas. The average tumor size among our patient cohort was 22.35 ± 33.07 cm^3, and the mean mFI-5 score was 0.58 ± 0.81. Most of the patients had had a symptomatic presentation (84.8%). The presenting symptoms had included headache (47.7%), seizure (23.0%), motor deficit (16.9%), cognitive deficit (12.6%), sensory deficit (11.6%), vertigo (10.1%), visual deficit (10.1%), gait deficit (9.1%), decreased hearing (8.6%), confusion (7.3%), nausea/vomiting (7.1%), language deficit (4.3%), diplopia (2.5%), bladder incontinence (1.8%), and dysarthria (1.3%). The mean years of experience among the treating surgeons in our cohort was 20.49 ± 10.62 years. Most patients had had a hospital LOS of ≤4 days (75.8%), had been discharged to home (88.4%), and had not been readmitted to the hospital within 90 days after discharge (89.8%). A total of 118 patients (29.8%) had experienced ≥1 postoperative complication. Within our study cohort, 32 patients (8.1%) had had new-onset motor deficits, 22 (5.6%) had experienced postoperative seizures, 20 (5.1%) had had new-onset cognitive deficits, 20 (5.1%) had developed surgical site infections, 18 (4.5%) had experienced new-onset sensory deficits, 16 (4.0%) had had cerebral venous thrombosis, 11 (2.8%) had experienced new-onset visual deficits, 8 (2.0%) had experienced dysphagia, 8 (2.0%) had had new-onset language deficits, 5 (1.3%) had developed deep vein thrombosis or pulmonary embolus, 5 (1.3%) had had a hematoma, and 1 (0.3%) had had a myocardial infarction.

Bivariate Analyses

Our first stage of data analysis involved bivariate analyses between the patient characteristics and the odds of 1) a prolonged LOS, 2) a nonroutine discharge disposition, and 3) a 90-day readmission. The following variables demonstrated a statistically significant association with a prolonged LOS: older age ($P = 0.015$), male sex ($P = 0.012$), nonprivate insurance status ($P = 0.0041$), nonmarried status ($P = 0.0062$), nonelective surgery ($P < 0.0001$), prior radiation therapy ($P = 0.047$), a greater number of meningiomas at diagnosis ($P = 0.0056$), a greater tumor volume ($P < 0.0001$), and a higher mFI-5 score ($P = 0.0018$).

Regarding the discharge disposition, the following variables demonstrated a significant association with a nonroutine discharge: male sex ($P = 0.0011$), nonmarried status ($P = 0.0026$), nonelective surgery ($P < 0.001$), prior radiation therapy ($P = 0.047$), falcine/parasagittal or intraventricular tumor versus convexity tumor location ($P = 0.011$), a greater number of meningiomas at diagnosis ($P = 0.041$), a greater tumor volume ($P = 0.0045$), and a higher mFI-5 score ($P = 0.0045$). No significant difference was found in the postoperative complication rate between those with convexity meningiomas (23.8%) and those with falcine/parasagittal or intraventricular meningiomas (32.6%; $P = 0.078$).

Regarding hospital readmission, the following patient characteristics were significantly associated with 90-day hospital readmission: male sex ($P = 0.031$), nonprivate insurance status ($P = 0.0036$), and nonmarried status ($P = 0.0044$).

Multivariate Analyses

The results from the multivariate logistic regression model predicting for an extended LOS among non–skull base meningioma patients are listed in Table 2. The variables that were significantly and independently associated with an extended LOS included nonelective surgery (OR, 6.25; $P < 0.0001$) and greater tumor volume (OR, 1.01; $P = 0.0022$). The VIFs for all covariates in the logistic regression model predicting for an extended LOS were <5, suggesting a lack of collinearity. The model had a naive and optimism-corrected c-statistic of 0.755 and 0.738, respectively. A Hosmer-Lemeshow P value of 0.89 suggested adequate calibration. A calibration plot of the logistic regression model is depicted in Figure 1A.

The results of the multivariate logistic regression model predicting for a nonroutine discharge disposition are listed in Table 3. The variables that were significantly and independently associated with a nonroutine discharge include male sex (OR, 2.46; $P = 0.0090$), nonmarried status (OR, 2.17; $P = 0.024$), nonelective surgery (OR, 3.07; $P = 0.0067$), falcine/parasagittal or intraventricular versus convexity tumor location (OR, 3.37; $P = 0.0084$), and higher mFI-5 score (OR, 1.48; $P = 0.039$). Within our logistic regression model predicting for a nonroutine discharge, the VIFs for all covariates were <5, suggesting a lack of collinearity. Furthermore, the model had a naive and optimism-corrected c-statistic of 0.794 and 0.768, respectively. A Hosmer-Lemeshow P value of 0.26 indicated adequate model calibration. A calibration plot is displayed in Figure 1B.

The results of our multivariate logistic regression model predicting for 90-day hospital readmission are summarized in Table 4. The patient characteristics that were both significantly

Table 1. Patient Demographic and Clinical Characteristics ($n = 396$)

Characteristic	Mean ± SD or *n* (%)
Mean age (years)	58.72 ± 13.24
Sex	
Male	126 (31.8)
Female	270 (68.2)
Race	
White	291 (73.5)
African-American	55 (13.9)
Asian	21 (5.3)
Other	29 (7.3)
Ethnicity	
Hispanic/Latino	10 (2.5)
Not Hispanic/Latino	386 (97.5)
Insurance	
Private	236 (59.6)
Medicare	142 (35.9)
Medicaid	11 (2.8)
Uninsured	7 (1.8)
Marital status	
Married	262 (66.2)
Not married	134 (33.8)
Admission type	
Nonelective	47 (11.9)
Elective	349 (88.1)
Surgery	
First	356 (89.9)
Second	29 (7.3)
Third	11 (2.8)
History of radiation therapy	
Yes	47 (11.9)
No	349 (88.1)
Tumor location	
Parasagittal/falcine	262 (66.2)
Convexity	126 (31.8)
Intraventricular	8 (2.0)
Meningiomas (*n*)	
1	334 (84.3)
2	25 (6.3)
3	15 (3.8)
≥4	22 (5.6)

Continues

Table 1. Continued

Characteristic	Mean ± SD or *n* (%)
Tumor volume (cm^3)*	22.35 ± 33.07
mFI-5 score	0.58 ± 0.81
Components of mFI-5	
HTN requiring medication	136 (34.3)
Diabetes	50 (12.6)
COPD	21 (5.3)
Functional status†	13 (3.3)
Congestive heart failure	8 (2.0)
Symptomatic presentation	
Yes	336 (84.8)
No	60 (15.2)
Surgeon experience (years)	20.49 ± 10.62
Overall LOS (days)	4.53 ± 6.08
LOS >4 days	96 (24.2)
LOS ≤4 days	300 (75.8)
Discharge disposition	
Routine	350 (88.4)
Nonroutine	46 (11.6)
Readmitted within 90 days	
Yes	40 (10.1)
No	356 (89.9)
Postoperative complications	
Yes	118 (29.8)
No	278 (70.2)

SD, standard deviation; mFI-5, 5-factor modified frailty index score; HTN, hypertension; COPD, chronic obstructive pulmonary disease; LOS, length of stay.
*For patients with >1 meningioma, the tumor volumes were summed to obtain the final volume measurement.
†Functional status was defined as requiring assistance with activities of daily living.

and independently associated with an increased odds of 90-day readmission included nonprivate insurance status (OR, 2.46; $P = 0.010$) and nonmarried status (OR, 2.49; $P = 0.0081$). For the nonroutine discharge disposition model, the VIFs for all model covariates were <5, suggesting an absence of collinearity. Regarding discrimination, the model had a naive c-statistic of 0.687 and an optimism-corrected c-statistic of 0.668. Regarding calibration, the Hosmer-Lemeshow P value of 0.90 suggested adequate calibration. A calibration plot is depicted in Figure 1C.

The intercepts and β-coefficients of our Akaike information criterion–optimized, multivariate logistic regression models were subsequently used to derive equations to calculate the probability of an extended LOS, a nonroutine discharge, and 90-day hospital readmission. The equation for calculating the probability of extended LOS was as follows:

Table 2. Multivariate Logistic Regression Model Predicting for Length of Stay >4 Days ($n = 396$)

Characteristic	OR (95% CI)	*P* Value	VIF
Age (per 1-year increase)	1.02 (1.00–1.04)	0.053	1.01
Sex (male vs. female)	1.52 (0.89–2.58)	0.12	1.01
Marital status (not married vs. married)	1.65 (0.97–2.78)	0.062	1.01
Admission type (nonelective vs. elective)	6.25 (3.16–12.66)	<0.0001*	1.01
Prior radiation therapy (yes vs. no)	1.98 (0.97–3.97)	0.056	1.01
Greater tumor volume (per 1-cm^3 increase)	1.01 (1.01–1.02)	0.0022*	1.02

OR, odds ratio; CI, confidence interval; VIF, variance inflation factor.
*Statistically significant ($P < 0.05$).

$$Y = -3.33 + 0.019(Age) + 0.42(Male) + 0.50(Non-Married\ Status) + 1.83(Non-Elective\ Surgery) + 0.69(Prior\ Radiation) + 0.013(Tumor\ Volume)$$

The equation for calculating the probability for a nonroutine discharge disposition was as follows:

$$Y = -4.42 + 0.90(Male) + 0.77(Non-Married\ Status) + 1.12(Non-Elective\ Surgery) + 0.75(Prior\ Radiation) + 1.22(\ or\ Intraventricular\ Location) + 0.0060(Tumor\ Volume) + 0.39(mFI-5)$$

Finally, the equation for calculating the probability of 90-day hospital readmission was as follows:

$$Y = -3.28 + 0.66(Male) + 0.90(Medicare,\ Medicaid,\ or\ Uninsured) + 0.91(Non-Married\ Status)$$

For these 3 equations, a 1 is substituted into the equation in the presence of a categorical variable and a 0 is substituted in the absence of a categorical variable. The values for the continuous variables are entered directly into the equation. The probability of each outcome was given by $\frac{e^y}{1+e^y}$, where e is the base of the natural logarithm. All 3 predictive models were also incorporated into an open-access, online calculator, available at https://neurooncsurgery3.shinyapps.io/non_skull_base_meningiomas/.

DISCUSSION

In the present study, we developed 3 novel algorithms that predict the patient risk of an extended LOS, nonroutine discharge, and 90-day readmission after resection of non–skull base meningioma. On multivariate analysis, nonelective surgery and an increased tumor volume were associated with a LOS >4 days. The predictors for a nonroutine discharge disposition included male sex, nonmarried status, nonelective surgery, tumor location within the parasagittal/falcine or intraventricular regions, and higher mFI-5 score. Hospital readmission within 90 days was associated with nonprivate insurance status and nonmarried status.

Prior Research

Previous studies have investigated the predictors associated with an increased LOS, discharge disposition, and 90-day readmission for brain tumor patients. Jimenez et al.[17] had previously found that for patients undergoing parasagittal/falcine meningioma resection, higher preoperative frailty and an increased incidence of any postoperative complication was associated with an increased risk of a nonroutine discharge disposition. Huq et al.[11] further supported the importance of frailty as a predictor of high-value care outcomes, showing that an increased mFI-5 score predicted for an increased LOS in a large cohort of brain tumor patients. A 2020 study by Hauser et al.[32] analyzed a cohort of 9783 meningioma patients within the Nationwide Readmission Database from 2014 to 2015. They reported that Medicaid and Medicare insurance were associated with a greater likelihood of a 90-day readmission, with only Medicare significant for readmission within 30 days.[32] As more predictors of postoperative

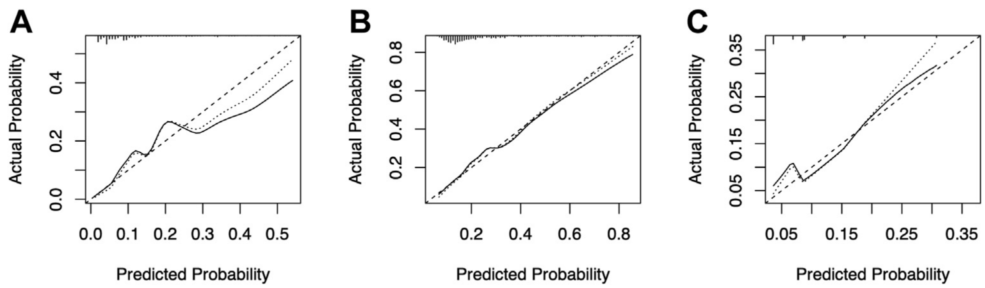

Figure 1. Calibration plot for logistic regression model predicting (**A**) length of stay >4 days, (**B**) nonroutine discharge disposition, and (**C**) hospital readmission within 90 days. The *dotted line* represents an apparent calibration curve calculated by fitting the model to the full dataset, and the *solid line* represents a bias-corrected calibration curve calculated by fitting the model to 2000 bootstrapped samples.

high-value care metrics have been identified, surgical investigators have begun to use these patient demographic and clinical characteristics to create statistical models capable of providing individualized risk assessments. Within neurosurgery, these calculators have more recently been developed for predicting the LOS, discharge disposition, and readmission rates for both brain and spine tumor patients.[10,11,33]

Prolonged LOS

A greater tumor volume was shown to be associated with a prolonged LOS in the present study. This finding is supported by several previous retrospective reviews, which found that the LOS increased with an increasing tumor volume for other neurosurgical tumor types, including vestibular schwannoma ($P = 0.003$) and anterior skull base meningiomas (linear regression β-coefficient, 0.12; $P < 0.001$), likely owing to increased intraoperative blood loss and other perioperative complications encountered in removing larger tumors in these series.[34,35] Nonelective surgery was also independently associated with an increased LOS in our study (OR, 6.25; $P < 0.0001$), in line with previous research findings for skull base meningioma patients (OR, 19.74; $P < 0.0001$).[19]

Nonroutine Discharge

For nonroutine discharge disposition, we found parasagittal/falcine and intraventricular meningioma locations were associated with greater odds of a nonroutine discharge compared with convexity tumors on both bivariate and multivariate analyses. Prior research has suggested that this finding might be driven by higher complication rates resulting from the proximity of these tumors to important draining veins and, subsequently, leading to more anatomically challenging surgical resections.[36,37] Such anatomical considerations could lead to more complex postoperative hospitalization trajectories and rehabilitation sequences, which could, in turn, increase the risk of a patient experiencing a nonroutine discharge. Our analysis demonstrated no statistically significant differences in the postoperative complication rates between the parasagittal/falcine or intraventricular meningioma patients and convexity meningioma patients ($P = 0.078$). A possible explanation for this association is that patients with parasagittal/falcine or intraventricular meningiomas simply require longer immediate postoperative medical management to recover from surgery and return to their baseline functional status relative to those with convexity meningioma, although the complication rates between the 2 groups were not significantly

Table 3. Multivariate Logistic Regression Model Predicting for Nonroutine Discharge Disposition ($n = 396$)

Characteristic	OR (95% CI)	*P* Value	VIF
Sex (male vs. female)	2.46 (1.25–4.85)	0.0090*	1.03
Marital status (not married vs. married)	2.17 (1.11–4.27)	0.024*	1.02
Admission type (nonelective vs. elective)	3.07 (1.34–6.84)	0.0067*	1.08
Prior radiation therapy (yes vs. no)	2.11 (0.88–4.75)	0.080	1.02
Tumor location (parasagittal/falcine or intraventricular vs. convexity)	3.37 (1.45–9.03)	0.0084*	1.06
Greater tumor volume (per 1-cm^3 increase)	1.01 (1.00–1.01)	0.13	1.02
Greater mFI-5 score (per 1-point increase)	1.48 (1.01–2.14)	0.039*	1.10

OR, odds ratio; CI, confidence interval; VIF, variance inflation factor; mFI-5, 5-factor modified frailty index score.
*Statistically significant ($P < 0.05$).

Table 4. Multivariate Logistic Regression Model Predicting for Hospital Readmission Within 90 Days ($n = 396$)

Characteristic	OR (95% CI)	*P* Value	VIF
Sex (male vs. female)	1.93 (0.97—3.81)	0.057	1.00
Insurance (Medicare, Medicaid, or uninsured vs. private)	2.46 (1.25—4.99)	0.010*	1.01
Marital status (not married vs. married)	2.49 (1.27—4.93)	0.0081*	1.00

OR, odds ratio; CI, confidence interval; VIF, variance inflation factor.
*Statistically significant ($P < 0.05$).

different. Further research with larger patient cohorts is necessary to establish the validity of our findings. However, given that work by Splavski et al.[38] have previously established the utility of the meningioma location in prognosticating the clinical outcomes, the findings from the present study have reaffirmed that tumor location remains an important factor in preoperative planning and risk stratification within this patient population.[38]

In addition to tumor location, we found that nonelective admission status was associated with nonroutine discharge disposition among non—skull base meningioma patients. This association was unique relative to previous findings from patients with skull base meningiomas, which had not found that nonelective surgery status predicted the disposition.[19] This might have resulted from the greater likelihood of non—skull base meningioma patients who require nonelective surgery to present with symptomatic brain/cortical involvement relative to patients with skull base meningioma, with secondarily greater rates of a nonroutine discharge.[39-41]

It has been previously shown that frailty increases the likelihood of a nonroutine discharge for patients intracranial metastases (OR, 1.61; $P = 0.035$). Our present findings mirror these results, with greater frailty predicting for nonroutine discharge among non—skull base meningioma patients (OR, 1.48; $P = 0.039$).

Ninety-Day Readmissions

Our study found that Medicare, Medicaid, and uninsured insurance status were significantly associated with 90-day readmission after non—skull base meningioma resection. This finding corroborates earlier findings that nonprivate insurance status is associated with 30- and 90-day readmission, regardless of meningioma type.[32] However, our model's optimism-corrected c-statistic was 0.668, just below the usual 0.7 cutoff that defines a predictive model with clinically useful discrimination.[30,31] These results suggest that further research is warranted to identify additional patient demographic and clinical variables that will be better able to prognosticate for 90-day hospital readmission after non—skull base meningioma surgery. Established predictors and models aimed at more effectively predicting for readmission could greatly improve postoperative monitoring both in and out of the hospital and should be more extensively studied to increase the provision of high-value care within neurosurgery. Additionally, married patients were more likely to not be readmitted to the hospital, in line with previous research demonstrating that married patients and individuals with larger social networks have decreased rates of readmission owing to a greater sense of interconnectedness and purpose at home.[42,43]

Comparison with Skull Base Meningiomas

Many of the high-value care outcomes analyzed in the present study have also been analyzed for skull base meningioma patients.[19] An increased LOS was significantly associated with a greater tumor volume among the non—skull base meningioma patients on multivariate analysis, although this relationship was not observed among skull base patients. Among skull base patients, older age was significantly and independently associated with a nonroutine discharge, a finding not replicated within our non—skull base patient cohort. Furthermore, although patient sex, marital status, and the mFI-5 score were all independently associated with a nonroutine discharge disposition for non—skull base patients, none of these variables were significantly associated with a nonroutine discharge for skull base patients on either bivariate or multivariate analysis. Many of the factors affecting the short-term postoperative outcomes relationships appear distinct between skull base and non—skull base meningioma patients, supporting the idea that these 2 tumor subtypes have distinct surgical considerations and should be analyzed separately in outcomes research.

Study Limitations

Because of the observational nature of the present retrospective study, we were unable to determine causal relationships among our analyzed parameters. The statistical models constructed in the present study predicted for nonroutine discharge disposition and an extended LOS with adequate calibration and discrimination. The model for 90-day readmission can predict which patients will have an elevated risk of this outcome. However, further improvements to the model discrimination in the form of additional predictors from larger patient cohorts are required. The present study cohort consisted only of patients from a single institution within a defined period. External validation with a larger, multi-institutional patient population would be ideal to better measure the discrimination and calibration metrics of our statistical models. After external validation, our predictive models have the potential to be incorporated into clinical workflows to aid in the delivery of cost-effective neurosurgical care. Because these models were constructed only for non—skull base meningioma patients undergoing resection, they are not valid to predict the outcomes for nonsurgical patients or patients with other types of intracranial tumors. Acknowledging these limitations, our study findings and predictive models have the potential to serve as a valuable resource for patients and clinicians by providing individualized predictors of the postoperative outcomes after non–skull base meningioma resection.

CONCLUSIONS

Nonelective surgery and an increased tumor volume were associated with a LOS >4 days. The independent predictors for a nonroutine discharge disposition included male sex, nonmarried status, nonelective surgery, tumor location within the parasagittal or intraventricular regions, and an increased mFI-5 score. Hospital readmission within 90 days was independently associated with nonprivate insurance and nonmarried status. Our findings can serve as a benchmark for future external validation efforts to develop multi-institutional algorithms for predicting the postoperative outcomes among non–skull base meningioma patients.

CRediT AUTHORSHIP CONTRIBUTION STATEMENT

Adrian E. Jimenez: Conceptualization, Formal analysis, Investigation, Methodology, Data curation, Writing – original draft, Writing – review & editing. **Sachiv Chakravarti:** Investigation, Methodology, Data curation, Writing – review & editing. **Sophie Liu:** Data curation, Writing – review & editing. **Esther Wu:** Data curation, Writing – review & editing. **Oren Wei:** Data curation, Writing – review & editing. **Pavan P. Shah:** Data curation, Writing – review & editing. **Sumil Nair:** Writing – original draft, Writing – review & editing. **Julian L. Gendreau:** Writing – original draft, Writing – review & editing. **Jose L. Porras:** Writing – review & editing. **Tej D. Azad:** Writing – review & editing. **Christopher M. Jackson:** Writing – review & editing. **Gary Gallia:** Writing – review & editing. **Chetan Bettegowda:** Writing – review & editing. **Jon Weingart:** Writing – review & editing. **Henry Brem:** Writing – review & editing. **Debraj Mukherjee:** Writing – review & editing.

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