

# Risk of Developing Postoperative Deficits Based on Tumor Location after Surgical Resection of an Intracranial Meningioma

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## Abstract

**Object** Meningiomas occur in various intracranial locations. Each location is associated with a unique set of surgical nuances and risk profiles. The incidence and risk factors that predispose patients to certain deficits based on tumor locations are unclear. This study aimed to determine which preoperative factors increase the risk of patients having new deficits after surgery based on tumor location for patients undergoing intracranial meningioma surgery.

**Methods** Adult patients who underwent primary, nonbiopsy resection of a meningioma at a tertiary care institution between 2007 and 2015 were retrospectively reviewed. Stepwise multivariate logistic regression analyses were used to identify associations with postoperative deficits based on tumor location.

**Results** Postoperatively, from the 761 included patients, there were 39 motor deficits (5.1%), 23 vision deficits (3.0%), 19 language deficits (2.5%), 27 seizures (3.5%), and 26 cognitive deficits (3.4%). The factors independently associated with any postoperative deficits were preoperative radiation (hazard ratio [HR] [95% confidence interval, CI] 3.000 [1.346–6.338],  $p = 0.008$ ), cerebellopontine angle tumors (HR [95% CI] 2.126 [1.094–3.947],  $p = 0.03$ ), Simpson grade 4 resections (HR [95% CI] 2.000 [1.271–3.127],  $p = 0.003$ ), preoperative motor deficits (HR [95% CI] 1.738 [1.005–2.923],  $p = 0.048$ ), preoperative cognitive deficits (HR [95% CI] 2.033 [1.144–3.504],  $p = 0.02$ ), and perioperative pulmonary embolisms (HR [95% CI] 11.741 [2.803–59.314],  $p = 0.0009$ ).

**Conclusion** Consideration of the factors associated with postoperative deficits in this study may help guide treatment strategies for patients with meningiomas.

## Keywords

- complications
- meningioma
- postoperative deficits
- risk factors
- surgical resection
- tumor location

## Introduction

### Background

Surgical resection has long been the preferred treatment of meningiomas when treatment is pursued. This is usually the case for those tumors that are symptomatic, growing, or

causing mass effect.<sup>1</sup> These tumors are often erroneously considered easier to remove than other intracranial tumors because most have the perception of meningiomas in convexity locations.<sup>2</sup> However, these surgeries, even those along the convexity, can still lead to complications and deficits.<sup>3</sup>

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Previous studies that have evaluated postoperative complications and deficits following meningioma surgery have only focused on a single location or a type of surgical complication.<sup>4–20</sup> It therefore remains unclear how meningiomas in different locations differ in terms of postoperative complications and the factors that predispose to these complications. This is especially important as the incidence of meningiomas is rising as a result of widespread availability of neuroimaging.<sup>21</sup>

## Objectives

The goals of this study were to: (1) determine how postoperative deficits vary with tumor location, and (2) determine the factors that are independently associated with higher rates of different postoperative deficits. An understanding of these objectives could allow for better guidance in providing informed consent to patients and their families, as well as developing techniques aimed at decreasing deficits during the surgical resection of meningiomas.

## Methods

### Participants

Institutional Review Board approval (72892) was obtained prior to the start of this study and all included patients gave their consent. All adult patients who underwent surgical resection of an intracranial meningioma at a single, tertiary care institution between 2007 and 2015 were recorded and reviewed.

### Recorded Variables

Of the 852 patients who underwent surgery during the reviewed period, 90 were excluded. The exclusion criteria included those with multiple meningiomas, neurofibromatosis type 2, radiation-induced meningiomas, or patients with tumors in locations not analyzed in this study. The locations analyzed were convexity, anterior skull base, parasagittal/parafalcine, sphenoid wing, tentorial, cerebellopontine angle (CPA), and foramen magnum. Patients with meningiomas who did not undergo surgical resection or underwent needle biopsy were also excluded. This was done to create as uniform a population as possible to evaluate postoperative deficits for the most common meningioma locations. The clinical, operative, and hospital records of the remaining 761 patients were retrospectively reviewed. Recorded information included patient demographics, comorbidities, presenting symptoms, magnetic resonance imaging (MRI) findings, tumor pathology/grade, and use of adjuvant therapy. Tumor pathology and grade were determined by a senior neuropathologist in all cases according to the 2007 World Health Organization (WHO) grading system.<sup>22</sup> Patients were assigned a preoperative Karnofsky Performance Scale (KPS) by the chart reviewer based on preoperative symptoms. A motor deficit was defined as any decrease in strength. Vision deficits were divided into diplopia and visual field deficits. Patients with visual field deficits underwent Humphrey visual field testing by an ophthalmologist. A cognitive deficit was recorded if the patient had any signs of decreased mental ability, and possible deficits were

formally evaluated by speech and language pathology.<sup>23</sup> Postoperative seizures included any seizure within 48 hours after surgery.

All MRI images were obtained and reviewed. The characteristics that were recorded included the lesions' volume and longest dimension. Tumor appearance included location, sinus invasion, midline shift, and the presence of edema or cysts. Tumor locations were both analyzed separately and grouped with others based on similar characteristics.<sup>24</sup> Extent of resection was recorded as Simpson grade 1 through 4 by postoperative neuroimaging obtained within 48 hours of surgery and operative reports.<sup>25</sup> The primary outcome evaluated for each patient was the presence of new or worsened postoperative deficits that were persistent (present at last follow-up). The following postoperative outcomes were assessed: new motor deficits, new vision deficits, seizures, and new cognitive deficits.

### Statistical Methods

Stepwise multivariate logistic regression analyses were performed to identify factors independently associated with different postoperative deficits. In these analyses, univariate analysis was first performed to identify potential associations between radiographic, preoperative, operative, perioperative, and pathologic variables with postoperative deficits. All variables associated with postoperative deficits in univariate analysis ( $p < 0.10$ ) were then analyzed in a stepwise multivariate logistic regression model.<sup>26</sup> Values with  $p < 0.05$  in these analyses were considered statistically significant. Intergroup analyses were also performed using Student's *t*-test and Fisher's exact test for continuous and categorical data, respectively. JMP Pro 12 (SAS, Cary, North Carolina, United States) was used unless otherwise specified. Authors adhered to the Strengthening the Reporting of Observational Studies in Epidemiology guidelines in this study.

## Results

### Preoperative Patient Characteristics, Outcomes, and Differences between Tumor Locations

The preoperative characteristics and outcomes of the 761 patients who underwent surgical resection of an intracranial meningioma are summarized in ►Table 1. The average age ( $\pm$  standard deviation) was 55.7 ( $\pm 12.8$ ) years, and 202 (26.5%) were male. The median (interquartile range) KPS score was 80 (80–90). Note that 682 of the 761 meningiomas were WHO grade 1 (91.5%), 57 (7.7%) were WHO grade 2, and 6 (0.8%) were WHO grade 3. After performing intergroup comparisons between meningiomas in different locations, white patients had a lower incidence of anterior skull base meningiomas compared with other locations ( $p = 0.05$ ). African American patients had a higher incidence of anterior skull base tumors compared with other locations ( $p = 0.01$ ). ►Fig. 1 illustrates the total percentage of postoperative deficits in each intracranial location. Convexity tumor resections had the lowest incidence of postoperative motor deficits ( $p = 0.006$ ). Tumors located in the CPA were associated with the highest rate of postoperative diplopia ( $p = 0.0002$ ). Tumors located in the

**Table 1** Demographic table

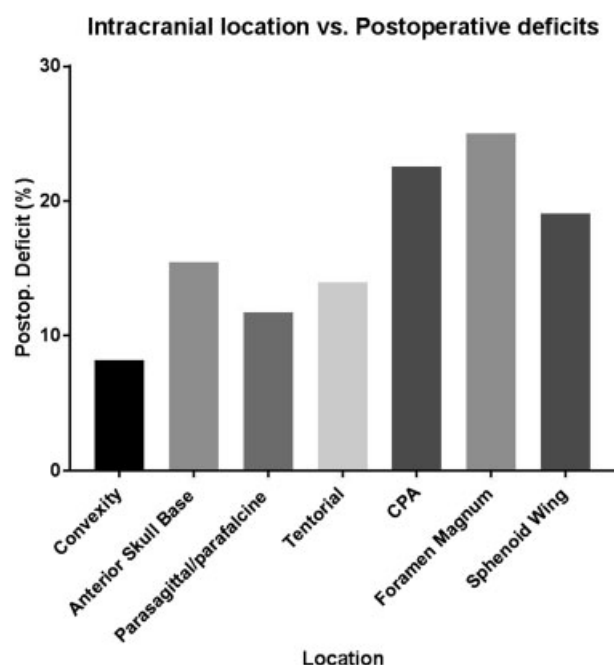
	Convexity	Anterior skull-base	Parasagittal + Parafalcine	Tentorial	CPA	Foramen magnum	Sphenoid wing	Total
	n = 208	n = 97	n = 204	n = 43	n = 71	n = 12	n = 126	N = 761
Age (avg)	55.7	56.5	55.7	55.7	54.3	52.5	56.0	55.7
Male	63 (30.3%)	27 (27.8%)	63 (30.9%)	5 (11.6%)	13 (18.1%)	3 (23.1%)	28 (22.0%)	202 (26.5%)
KPS > 70	176 (84.6%)	81 (83.5%)	168 (82.3%)	35 (81.4%)	59 (81.9%)	10 (76.9%)	98 (77.2%)	625 (82.0%)
White	154 (74.4%)	<b>59 (60.8%)</b>	156 (76.5%)	31 (72.1%)	52 (72.2%)	9 (69.2%)	86 (67.7%)	545 (71.6%)
African American	27 (13.0%)	<b>26 (26.8%)</b>	27 (13.2%)	7 (16.3%)	8 (11.1%)	2 (15.4%)	27 (21.2%)	124 (16.3%)
Hispanic	1 (0.5%)	1 (1.0%)	3 (1.5%)	0	1 (1.4%)	0	2 (1.6%)	8 (1.1%)
Asian	5 (2.4%)	4 (4.1%)	7 (3.4%)	2 (4.7%)	3 (4.2%)	0	3 (2.4%)	24 (3.2%)
<b>Postop complications</b>								
Motor deficit	<b>3 (1.4%)</b>	2 (2.1%)	12 (5.9%)	5 (11.6%)	8 (11.1%)	2 (15.4%)	7 (5.5%)	39 (5.1%)
Diplopia	1 (0.5%)	2 (2.1%)	0	1 (0.1%)	<b>6 (8.5%)</b>	0	2 (1.6%)	10 (1.3%)
Visual field deficit	1 (0.5%)	<b>7 (7.2%)</b>	1 (0.5%)	0	0	0	3 (2.4%)	10 (1.3%)
Language deficit	4 (1.9%)	1 (1.0%)	7 (3.4%)	0	2 (2.8%)	1 (7.7%)	4 (3.2%)	19 (2.5%)
Postop seizure	9 (4.3%)	3 (3.1%)	5 (2.5%)	2 (4.7%)	1 (1.4%)	0	7 (5.5%)	27 (3.5%)
Cognitive deficit	4 (1.9%)	7 (7.2%)	4 (2.0%)	1 (2.3%)	3 (4.2%)	0	7 (5.5%)	26 (3.4%)
<b>WHO grade</b>								
I	<b>179 (87.3%)</b>	90 (94.7%)	<b>176 (88.9%)</b>	40 (93.0%)	69 (97.2%)	11 (91.7%)	119 (96.7%)	682 (91.5%)
II	21 (10.2%)	5 (5.3%)	21 (10.6%)	3 (7.0%)	2 (2.8%)	1 (8.3%)	4 (3.3%)	57 (7.7%)
III	5 (2.4%)	0	1 (0.5%)	0	0	0	0	6 (0.8%)
<b>Simpson grade</b>								
I	<b>111 (53.4%)</b>	<b>3 (3.1%)</b>	<b>41 (20.1%)</b>	4 (9.3%)	4 (5.6%)	2 (15.4%)	13 (10.2%)	178 (23.4%)
II	<b>47 (22.6%)</b>	38 (39.2%)	<b>88 (43.1%)</b>	14 (32.6%)	28 (38.9%)	4 (30.8%)	37 (29.1%)	256 (33.6%)
III	32 (15.4%)	16 (16.5%)	25 (12.3%)	7 (16.3%)	7 (9.7%)	1 (7.7%)	<b>30 (23.6%)</b>	118 (15.5%)
IV	<b>18 (8.7%)</b>	40 (41.2%)	<b>50 (24.5%)</b>	18 (41.9%)	<b>33 (45.8%)</b>	6 (46.2%)	47 (37.0%)	210 (26.6%)
<b>Outcomes</b>								
Recurring	24 (11.7%)	10 (10.3%)	<b>35 (17.2%)</b>	3 (7.0%)	5 (6.9%)	2 (15.4%)	<b>25 (19.8%)</b>	102 (13.5%)
Mortality	9 (4.3%)	3 (3.1%)	12 (5.9%)	3 (7.0%)	0	2 (15.4%)	12 (9.4%)	41 (5.4%)

Abbreviations: CPA, cerebellopontine angle; KPS, Karnofsky Performance Scale; WHO, World Health Organization.

Note: Bolded values are statistically different from other tumor locations.

anterior skull base were associated with the highest rate of decreased visual fields after surgery ( $p = 0.0003$ ). WHO grade 1 tumors were less likely to be located in the convexity or parasagittal/parafalcine than other locations ( $p = 0.009$  and  $p = 0.05$ , respectively). Simpson grade 1 resections were performed significantly more with convexity and parasagittal/parafalcine tumors ( $p \leq 0.0001$  and  $p = 0.02$ , respectively), and significantly less with anterior skull base tumors ( $p = 0.004$ ). Simpson grade 2 resections were performed sig-

nificantly more with parasagittal/parafalcine tumors ( $p = 0.02$ ) and significantly less with convexity tumors ( $p = 0.002$ ). Simpson grade 3 resections were performed to a significantly higher degree with sphenoid wing meningiomas ( $p = 0.01$ ). Simpson grade 4 resections were performed significantly more often with CPA meningiomas ( $p = 0.02$ ), and significantly less in convexity and parasagittal/parafalcine tumors ( $p \leq 0.0001$  and  $p = 0.04$ , respectively). Parasagittal/parafalcine and sphenoid wing meningiomas were found to recur at a higher rate than



**Fig. 1** Mean number of all postoperative deficits according to intracranial location.

other meningiomas ( $p = 0.02$  and  $p = 0.01$ , respectively). We found no other pre-, peri-, or postoperative differences between the different tumor locations analyzed in the study.

### Factors Associated with Any Postoperative Deficits

The factors associated with any postoperative deficits after surgical resections are summarized in ►Table 2. In univariate analysis, the factors associated with any postoperative deficit were sphenoid wing tumors, CPA tumors, Simpson grade 1 and 4 resections, age, prior anticoagulation, coronary artery disease, previous coronary artery bypass graft (CABG)/stents, KPS < 70, preoperative motor and cognitive deficits, previously recurring meningioma, postoperative pulmonary embolism, intraoperative ventricle entry, tumor volume, preoperative radiation, and postoperative prophylactic radiation. In stepwise multivariate analysis, the factors independently associated with any postoperative deficits were preoperative radiation (hazard ratio [HR] [95% confidence interval, CI] 3.000 [1.346–6.338],  $p = 0.008$ ), CPA tumors (HR [95% CI] 2.126 [1.094–3.947],  $p = 0.03$ ), Simpson grade 4 resections (HR [95% CI] 2.000 [1.271–3.127],  $p = 0.003$ ), preoperative motor deficits (HR [95% CI] 1.738 [1.005–2.923],  $p = 0.048$ ), preoperative cognitive deficits (HR [95% CI] 2.033 [1.144–3.504],  $p = 0.02$ ), and postoperative pulmonary embolisms (HR [95% CI] 11.741 [2.803–59.314],  $p = 0.0009$ ).

### Factors Associated with Postoperative Motor Deficits

The factors associated with higher risk for postoperative motor deficits are summarized in ►Table 3. In univariate analysis, the factors associated with postoperative motor deficits were tentorial tumors, CPA tumors, Simpson grade 1 and 4 resections, and postoperative pulmonary embolisms. In stepwise multivariate analysis, the factors independently

**Table 2** Independent factors associated with any deficits after surgical resection for intracranial meningiomas

Multivariate stepwise logistic regression for any new deficits		
Risk factors	p-Value	OR [95% CI]
Preoperative radiation	0.008	3.000 [1.346–6.338]
Cerebellopontine angle location	0.027	2.126 [1.094–3.947]
Simpson grade 4 resection	0.003	2.000 [1.271–3.127]
Preop motor deficit	0.048	1.738 [1.005–2.923]
Preop cognitive deficit	0.017	2.033 [1.144–3.504]
Periop pulmonary embolism	0.0009	11.741 [2.803–59.314]

Abbreviations: CI, confidence interval; OR, odds ratio.

**Table 3** Independent factors associated with motor deficits after surgical resection for intracranial meningiomas

Multivariate stepwise logistic regression for new motor deficit		
Risk factors	p-Value	OR [95% CI]
Periop pulmonary embolism	0.0005	17.255 [3.949–71.336]
Simpson grade 4 resection	0.001	3.011 [1.545–5.900]

Abbreviations: CI, confidence interval; OR, odds ratio.

associated with postoperative motor deficits were perioperative pulmonary embolisms (HR [95% CI] 17.255 [3.949–71.336],  $p = 0.0005$ ) and Simpson grade 4 resections (HR [95% CI] 3.011 [1.545–5.900],  $p = 0.001$ ).

### Factors Associated with Postoperative Diplopia or Visual Field Deficits

The factors associated with higher risk for postoperative diplopia and visual deficits are summarized in ►Tables 4 and 5, respectively. In univariate analysis, the only factor associated with postoperative diplopia was the CPA location (HR [95% CI] 10.538 [3.213–34.592],  $p = 0.0003$ ). The factor significantly associated with decreased visual fields postoperatively was the anterior skull-base location (HR [95% CI] 10.267 [3.211–35.331],  $p = 0.0002$ ).

**Table 4** Independent factors associated with diplopia after surgical resection for intracranial meningioma

Multivariate stepwise logistic regression for new diplopia		
Risk factors	p-Value	OR [95% CI]
Cerebellopontine angle location	0.0003	10.538 [3.213–34.592]

Abbreviations: CI, confidence interval; OR, odds ratio.

**Table 5** Independent factors associated with visual field deficits after surgical resection for intracranial meningioma

Multivariate stepwise logistic regression for new visual field deficit		
Risk factors	p-Value	OR [95% CI]
Anterior skull base location	0.0002	10.267 [3.211–35.331]

**Table 6** Independent factors associated with seizures after surgical resection for intracranial meningioma

Multivariate stepwise logistic regression for postoperative seizure		
Risk factor	p-Value	OR [95% CI]
Extent of midline shift	0.0083	1.143 [1.038–1.248]
Recurrent meningioma	0.0056	4.146 [1.544–10.673]
Preop motor deficits	0.0049	3.693 [1.509–8.817]
Preop seizures	0.0348	2.975 [1.086–7.592]
Periop pulmonary embolism	< 0.0001	45.781 [10.006–222.398]

**Factors Associated with Postoperative Seizures**

The factors associated with higher risk for postoperative seizures are summarized in ►Table 6. In univariate analysis, the factors associated with postoperative seizures were previously recurring meningiomas, coronary artery disease, diabetes mellitus, KPS < 70, intraoperative ventricle entry, preoperative motor deficits and seizures, pulmonary embolism, tumor volume, extent of midline shift, and preoperative radiation. In stepwise multivariate analysis, the factors independently associated with seizures were increasing midline shift (HR [95% CI] 1.143 [1.038–1.248],  $p = 0.008$ ), previously recurring meningiomas (HR [95% CI] 4.146 [1.544–10.673],  $p = 0.006$ ), preoperative motor deficits (HR [95% CI] 3.693 [1.509–8.817],  $p = 0.005$ ), preoperative seizures (HR [95% CI] 2.975 [1.086–7.592],  $p = 0.03$ ), and perioperative pulmonary embolism (HR [95% CI] 45.781 [10.006–222.398],  $p < 0.0001$ ).

**Factors Associated with Postoperative Cognitive Deficits**

The factors associated with higher risk for postoperative cognitive deficits are summarized in ►Table 7. In univariate analysis, the factors associated with postoperative cognitive deficits were male, age, coronary artery disease, previous CABG/stents, hypertension, prior anticoagulation, KPS score < 70, and preoperative cognitive deficits. In stepwise multivariate analysis, the factors independently associated with cognitive deficits were older age (HR [95% CI] 1.038 [1.002–1.075],  $p = 0.04$ ), CABG/stents (HR [95% CI] 1.038 [1.002–1.075],  $p = 0.04$ ), and preoperative KPS < 70 (HR [95% CI] 2.805 [1.184–6.417],  $p = 0.02$ ).

**Table 7** Independent factors associated with cognitive deficits after surgical resection for intracranial meningioma

Multivariate stepwise logistic regression for new cognitive deficits		
Risk factor	p-Value	OR [95% CI]
Older age	0.0378	1.038 [1.002–1.075]
Previous CABG/stents	0.0014	6.274 [2.137–17.070]
Preop KPS < 70	0.0201	2.805 [1.184–6.417]

Abbreviations: CABG, coronary artery bypass graft; CI, confidence interval; KPS, Karnofsky Performance Scale; OR, odds ratio.

**Discussion****Key Results**

In this study, we observed 134 postoperative deficits in 761 patients. Independent risk factors for postoperative deficits were preoperative radiation, tumors outside of the convexity, CPA tumors, subtotal resections, coronary artery disease, and preoperative motor or cognitive deficits. Independent risk factors for postoperative motor deficits were pulmonary embolisms, nonconvexity tumors, subtotal resections, and intraoperative ventricle entry. Independent risk factors for postoperative vision deficits were tumors outside of the convexity, parasagittal, or parafalcine areas. Independent risk factors for seizures within 48 hours of surgery were extent of midline shift, previously recurring meningioma, preoperative motor deficits, preoperative seizures, and pulmonary embolisms. Independent risk factors for postoperative cognitive deficits were age, previous CABG/stents, and KPS scores below 70.

**Prior Studies on Postoperative Deficits after Meningioma Resection**

Surgical resection of meningiomas are widely performed and are often associated with good outcomes.<sup>27</sup> As a result, many surgeons and patients erroneously perceive that these tumors are straightforward and without complications.<sup>27</sup> However, the surgical difficulty and risk profiles for meningiomas in different locations is distinct. A comparison between meningiomas in different locations as it relates to postoperative complications has yet to be done in a large modern patient population. Li et al analyzed 199 patients with petroclival meningiomas for risk factors associated with poor postoperative KPS score, hemiparesis, and cranial nerve deficits, and found that these included surgery history, age, tumor size, tumor consistency, vital artery encasement, peritumoral edema, and absence of tumor–brainstem interface.<sup>10</sup> The largest study on postoperative outcomes was performed by Wirsching et al looking specifically at postoperative epilepsy.<sup>20</sup> They found that independent risk factors of seizures include preoperative epilepsy, surgical complications, hydrocephalus, recurrent surgery, symptomatic intracranial hemorrhage, age, and tumor progression.<sup>20</sup> Therefore, the factors associated with postoperative deficits as it relates to tumor location for patients undergoing intracranial meningioma surgery would



help inform surgeons and their patients about the potential risks of deficits, as well as potentially develop ways to minimize these risks.

### Factors Independently Associated with Postoperative Deficits

#### Any Postoperative Deficits

This study observed 134 postoperative deficits (18%) after meningioma resections in 761 patients. CPA tumors had the largest incidence of postoperative deficits (27.8%). The factors independently associated with any postoperative deficits were preoperative radiation, CPA tumors, Simpson grade 4 resections, preoperative motor and cognitive deficits, and perioperative pulmonary embolisms. Preoperative radiation is more often performed on meningiomas that appear most aggressive, so it is likely that this factor led to more difficult surgeries with more postoperative deficits.<sup>28</sup> Subtotal resections may lead to excessive swelling of residual tumor, leading to the postoperative deficits we observed in these cases. Also, these meningiomas were likely located in complex areas, making them more difficult to resect while also carrying greater chances of causing neurological dysfunctions. While a subtotal resection is often chosen due to the high risk of a gross total resection during a case, it is important to note that there may be also be some innate postoperative risk of leaving tumor behind. Tumors near the CPA often involve complex surgical fields, leading to more subtotal resections. It has been demonstrated that a lower preoperative functional status can increase risk for worse functional outcomes after meningioma resection.<sup>25</sup> This supports our finding that preoperative motor and cognitive deficits can lead to more postoperative deficits. Lastly, pulmonary embolisms have been found to lead to potentially devastating surgical complications, even involving death in the worst cases.<sup>29,30</sup>

#### Postoperative Motor Deficits

In this study, 39 patients (5.1%) had postoperative motor deficits after surgery. Tumors removed from the tentorium and the foramen magnum had the highest rates of motor deficits (11.6% and 15.4%, respectively). The factors independently associated with postoperative motor deficits were incomplete resection (Simpson grade 4) and perioperative pulmonary embolisms. Oyama et al analyzed postoperative motor deficits in 16 cases with parasagittal/parafalcine tumors and found these deficits to be caused by either an intracerebral hematoma or newly developed brain edema.<sup>14</sup> Batra et al performed a similar study with CPA tumors and found tumor size and preoperative facial nerve paresis to have the highest associations with postoperative motor deficits.<sup>4</sup> We did not find tumor size or edema to be associated with these deficits. In addition, the association between incomplete resections and motor deficits may be a result of intraoperative decision making caused by decreased intraoperative signals and/or difficulty in resecting tumor. Tumors that are incompletely resected may also predispose the brain to significant edema leading

to neurological deficits. Lastly, perioperative pulmonary embolisms are known to cause a large range of deficits, one of which being motor function.<sup>29,30</sup>

#### Postoperative Vision Deficits

In total, 22 patients (2.9%) had postoperative vision deficits. Twelve patients (1.5%) had diplopia, and 12 patients (1.5%) had worsened visual fields (two patients had both vision deficits). Postoperative diplopia was significantly associated with CPA location, and decreased visual fields were significantly associated with anterior skull base location. Cosetti et al also found postoperative diplopia to be significantly associated with tumors in the CPA.<sup>31</sup> They found this result to be due to acute vestibular deafferentation leading to skew deviation; however, this mechanism was not investigated in this study.<sup>31</sup> Schick and Hassler also found visual field deficits to be associated with tumors in the anterior skull.<sup>16</sup> One study analyzed 65 patients with medial sphenoid wing meningiomas and found that factors leading to postoperative vision deficits were preoperative visual decline, subtotal resection, and repeat surgery.<sup>7</sup> Any compression to the optic chiasm or optic nerves is able to cause field deficits, so this association with tumors in the proximity was not surprising.

#### Postoperative Seizures

Our study observed that 27 patients (3.5%) had seizures after surgical resections. The factors independently associated with postoperative seizures were extent of midline shift, revision resections, preoperative motor deficits, preoperative seizures, and perioperative pulmonary embolisms. Wirsching et al analyzed 779 patients and found that 104 (19.4%) suffered from postoperative epileptic seizures.<sup>20</sup> Of these patients, they found risk factors to include preoperative seizures, major surgical complications, hydrocephalus, revision surgery, intracranial hemorrhage, younger age, and tumor progression.<sup>20</sup> Zheng et al analyzed 97 patients and found that the only risk factor to postoperative seizures was the co-occurrence of new permanent neurological deficits.<sup>32</sup> Our findings that increased midline shift leads to higher risk for seizures is in line with one study that found mass effect from meningiomas led to generalized seizures.<sup>33</sup> Our study was also similar to that of Wirsching et al in finding that resections and preoperative seizures were independently associated with postoperative seizures.<sup>20</sup> Patients with preoperative seizures are at risk of postoperative seizures as has been seen with other tumors including metastatic brain tumors and malignant gliomas.<sup>34,35</sup> In addition, the motor cortex is known to be susceptible to initiation of seizures; therefore, patients with preoperative motor deficits may be especially at risk as the tumor has likely already affected these regions.<sup>36</sup> In addition, perioperative pulmonary embolisms were independently found to be associated with postoperative seizures. The presence of these thrombotic events can affect intracranial pressure, cerebral blood flow, and cerebral autoregulation, thus predisposing to seizures.<sup>29</sup> Furthermore, pulmonary embolisms may actually be a consequence of postoperative deficits, due to increased hospital stays and decreased mobilization.

### Postoperative Cognitive Deficits

We found 26 patients (3.4%) to have new cognitive deficits after meningioma resections. Comparing intracranial locations, removal of tumors from anterior skull base led to the highest proportion of cognitive deficits after surgery (7.2%). The factors independently associated with postoperative cognitive decline were age and previous CABG/stents. Dijkstra et al analyzed 89 patients who underwent treatment for meningiomas and found that lower executive functioning was associated with a greater preoperative epilepsy burden.<sup>37</sup> However, there were no presurgical assessments of cognitive function in this study.<sup>37</sup> Krupp et al examined the outcomes for 91 patients after surgical resection of their meningiomas and found increasing age to be the most significant risk factor for postoperative neuropsychological problems, which was supported as an independent risk factor in our study.<sup>9</sup> Although the pathophysiological mechanism for this link is unknown, studies have shown that patients undergoing CABG surgery are inclined to have postoperative deficits after their cardiac surgery.<sup>28,38</sup> While a direct link cannot be made in our study, our results may give evidence that this post-CABG cognitive decline was exacerbated by meningioma resection.

### Strengths and Limitations

We believe this study provides valuable information for patients and their neurosurgical care teams. This is the first study to analyze the risk factors for all postoperative deficits in the common meningioma tumor locations. We were able to use our relatively large patient sample size to determine what predisposing factors should be considered when aiming to minimize risk of these deficits. Other studies have largely focused on specific deficits or tumor locations, leading to small sample sizes with less generalizable results.<sup>5–20,28</sup> Our study concludes that there are preoperative factors that can predispose patients to higher risks of postoperative deficits, allowing providers to consider these when planning for surgery and postoperative care.

While we believe this study provides the most relevant information concerning postoperative deficits from meningioma removal, the study is not without limitations. One limitation is that we limited our study to the most common meningioma locations. Our aim for this study was to be a comprehensive analysis of general groupings, while differentiating between olfactory groove and planum, for example, would likely require much higher multi-institutional studies to give clinically relevant conclusions. We also decided to combine locations that were close in proximity including planum and olfactory groove lesions, sagittal and parafalcine lesions, and medial/middle/lateral sphenoid wing lesions. We did this to increase the generalizability of our study; however, we understand that there are likely different risk factors between these locations that were not focused on in this study. Moreover, we also analyzed cognitive deficits based on neurological exam and patients and their families' perception of their recovery. Not all patients underwent neurocognitive testing, which would provide more objective information about postoperative cognitive function. Another limitation

includes findings that we were unable to explain. For example, we did not have an explanation why African Americans were more likely to have meningiomas in anterior skull base compared with other locations. Lastly, our study includes the limitations present in a retrospective review, including inherent bias in patient or treatment selection. Therefore, prospective studies are necessary to confirm that knowledge of the risk factors we discovered can decrease postoperative patient deficits, with it ideally being done across multiple institutions with varying patient populations.

### Conclusion

While surgical resection remains the gold standard for the treatment of a significant number of meningiomas, the risk for postoperative deficits is unclear. Based on tumor locations, we found that meningiomas in the convexity are much safer to resect in terms of postoperative deficits. The factors that were independently associated with different types of postoperative deficits were distinct. By accounting for these risk factors, surgeons may be able to better inform patients about the risk of deficits, as well as attempting to adjust their strategies to minimize the risk of postoperative neurological deficits.

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