Impact of preoperative endovascular embolization on immediate meningioma resection outcomes

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OBJECTIVE Preoperative embolization of meningiomas can facilitate their resection when they are difficult to remove. The optimal use and timing of such a procedure remains controversial given the risk of embolization-linked morbidity in select clinical settings. In this work, the authors used a large national database to study the impact of immediate preoperative embolization on the immediate outcomes of meningioma resection.

METHODS Meningioma patients who had undergone elective resection were identified in the National (Nationwide) Inpatient Sample (NIS) for the period 2002–2014. Patients who had undergone preoperative embolization were propensity score matched to those who had not, adjusting for patient and hospital characteristics. Associations between preoperative embolization and morbidity, mortality, and nonroutine discharge were investigated.

RESULTS Overall, 27,008 admissions met the inclusion criteria, and 633 patients (2.34%) had undergone preoperative embolization and 26,375 (97.66%) had not. The embolization group was younger (55.17 vs 57.69 years, $p < 0.001$) with a lower proportion of females (63.5% vs 69.1%, $p = 0.003$), higher Charlson Comorbidity Index ($p = 0.002$), and higher disease severity ($p < 0.001$). Propensity score matching retained 413 embolization and 413 nonembolization patients. In the matched cohort, preoperative embolization was associated with increased rates of cerebral edema (25.2% vs 17.7%, $p = 0.009$), posthemorrhagic anemia or transfusion (21.8% vs 13.8%, $p = 0.003$), and nonroutine discharge (42.8% vs 35.7%, $p = 0.039$). There was no difference in mortality ($\leq 2.4\%$ vs $\leq 2.4\%$, $p = 0.82$). Among the embolization patients, the mean interval from embolization to resection was 1.49 days. On multivariate analysis, a longer interval was significantly associated with nonroutine discharge (OR 1.33, $p = 0.004$) but not with complications or mortality.

CONCLUSIONS Relative to meningioma patients who do not undergo preoperative embolization in the same admission, those who do have higher rates of cerebral edema and nonroutine discharge but not higher rates of stroke or death. Thus, meningiomas requiring preoperative embolization represent a distinct clinical entity that requires prolonged, more complex care. Further, among embolization patients, the timing of resection did not affect the risk of in-hospital complications, suggesting that the timing of surgery can be determined according to surgeon discretion.

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KEY WORDS meningioma; embolization; resection; cerebral edema; timing; discharge disposition

MENINGIOMAS are frequently hypervascular, and preoperative embolization of dural feeding arteries, especially for large tumors or lesions with surgically inaccessible vascular supplies, can facilitate resection and decrease operative blood loss and surgical

complications.^{6,7,11,13,15,16,25,27,28} Nonetheless, the ideal use of preoperative meningioma embolization is controversial³⁴ as it can also lead to edema, hemorrhage, stroke, and cranial nerve palsies.^{20,23,30} Nonneurological complications related to endovascular therapy can occur as well and include

ABBREVIATIONS APR-DRG = All-Patient Refined Diagnosis-Related Group; CCI = Charlson Comorbidity Index; HCUP = Healthcare Cost and Utilization Project; NIS = National (Nationwide) Inpatient Sample.

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groin hematoma, femoral pseudoaneurysm, and arteriovenous fistula.²² Overall complication rates up to 8.3% have been reported in embolization for meningiomas.¹³

The optimal time interval between tumor embolization and resection is also unknown. Some studies have recommended a minimum of 24 hours if the goal is to simply maximize tumor devascularization and reduce operative blood loss and at least a week when trying to optimize tumor resectability and decrease edema.^{10,19,33} In contrast, other authors have suggested intervals of less than a week to reduce the opportunity for tumor revascularization.^{26,30} In the current work, using a large national database, we studied the impact of immediate preoperative embolization on the immediate outcomes of meningioma resection.

Methods

A retrospective observational study was performed using the National (Nationwide) Inpatient Sample (NIS) for the period between 2002 and 2014. The NIS is a database publicly available through the Healthcare Cost and Utilization Project (HCUP; <https://www.hcup-us.ahrq.gov/nisoverview.jsp>). It is the largest administrative all-payer database in the US, representing a 20% stratified sample of all US hospital discharges. Patient diagnoses and treatments are recorded using *International Classification of Diseases, Ninth Revision, Clinical Modification* (ICD-9-CM) codes.

Inclusion and Exclusion Criteria

The database was queried for all meningioma patients (diagnosis codes: 192.1, 225.2, 237.6) who had undergone craniotomy (procedure code: 01.51). Patients undergoing tumor embolization (procedure code: 39.72) in the same admission were identified. The NIS provides a “PRDAYn” variable that identifies on which day of hospitalization each procedure occurs. Therefore, patients with a PRDAYn missing for embolization or resection or patients who had an embolization day following the resection day were excluded in order to identify the preoperative embolization patients.

The primary exposure of interest was preoperative embolization for meningioma. Patient variables included tumor histology (benign or malignant), age, sex, race (white, black, Hispanic, Asian or Pacific Islander, or other), Charlson Comorbidity Index (CCI), insurance status (Medicare or private, Medicaid, or no coverage), and zip code income quartile. Admissions were categorized as elective or nonelective. The All-Patient Refined Diagnosis-Related Group (APR-DRG) index was used to represent disease severity.³ Hospital variables included region (Northeast, Midwest, South, West), location and teaching status (rural, urban nonteaching, urban teaching), and size (small, medium, or large).

Studied outcomes included morbidity, mortality, and discharge disposition. Complications were derived from previously defined adverse events of meningioma resection¹ and endovascular embolization, including hematoma complicating a procedure, cerebral infarction or hemorrhage, hydrocephalus, cerebral edema, cranial nerve palsy, meningitis or cerebral venous thrombosis, venous embolism, blood transfusion, and mechanical ventilation. Discharge disposition was categorized as routine, nonroutine (discharge to skilled nursing facility, acute rehabilitation facility, hospice, short-term hospital, or home health care), or in-hospital death.

Statistical Analysis

Statistical analysis was performed using Stata/MP version 14.1 (StataCorp LLC). Continuous variables are presented as the means $\pm$ standard deviations, and categorical variables are presented as counts with corresponding percentages. Independent samples t-tests and Wilcoxon rank-sum tests were used to detect group differences for normally and nonnormally distributed continuous variables, respectively. The chi-square test was used for categorical variables, and ordinal logistic regression was used for ordinal variables. Multivariate logistic regression analyses were completed to determine the impact of the interval between embolization and resection on these outcomes. Statistical significance was defined as $\alpha = 0.05$, and all tests were 2-sided. In accordance with the HCUP data use agreement, cells containing ≤ 10 patients are not reported as a patient privacy precaution.

Given significant differences between the embolization and nonembolization patient cohorts, we used propensity score matching to adjust for differences in patient and hospital characteristics. Multivariate logistic regression was used to estimate the propensity of preoperative embolization (compared with no preoperative embolization). Covariates were selected a priori and included age, sex, race, insurance status, zip code income quartile, CCI, APR-DRG index, elective status of the admission, hospital size, hospital region, hospital location, and hospital teaching status. Matched propensity score analysis was completed with a 1:1 nearest neighbor algorithm without replacement using the TEFFECTS and PSMATCH2 software modules in Stata.¹⁴ These matching methods were selected to minimize bias.² Patients who had undergone preoperative embolization were then matched to patients who had not, according to the propensity score. Following propensity score matching, rates of adverse outcomes were compared using chi-square tests.

Results

Overall, 27,008 meningioma admissions met the inclusion criteria, and 633 patients (2.34%) had undergone preoperative embolization and 26,375 (97.66%) had not. Baseline characteristics for both the overall and the propensity score-matched cohorts are shown in Tables 1 and 2. Several baseline differences were observed in the overall cohort, including a lower age (55.17 vs 57.69 years, $p < 0.001$) and a smaller proportion of females (63.5% vs 69.1%, $p = 0.003$) among the embolization patients. The embolization patients also had higher CCIs (OR 1.27, $p = 0.002$) and APR-DRG disease severity (OR 1.68, $p < 0.001$).

Unmatched Cohort

In the overall cohort, preoperative embolization was associated with significantly increased rates of hematoma

TABLE 1. Patient and hospital characteristics in the entire study cohort

Variable	No Embolization	Embolization	p Value
No. of patients	26,375	633	
Mean age in yrs	57.6872 ± 14.7214	55.1738 ± 14.2948	<0.001
Sex			0.003
Male	8,102 (30.9)*	231 (36.5)	
Female	18,127 (69.1)*	402 (63.5)	
Race			<0.001
White	15,970 (72.7)*	333 (62.9)*	
Black	2,458 (11.2)*	60 (11.3)*	
Hispanic	1,972 (9.0)*	60 (11.3)*	
Asian or Pacific Islander	782 (3.6)*	42 (7.9)*	
Other	790 (3.6)*	34 (6.4)*	
Insurance			0.001
Medicare or private	22,237 (87.6)*	500 (82.8)*	
Medicaid	2,252 (8.9)*	72 (11.9)*	
None	888 (3.5)*	32 (5.3)*	
Zip code income quartile			0.008
1	4,408 (22.3)*	122 (19.8)*	
2	4,889 (24.8)*	128 (20.8)*	
3	5,090 (25.8)*	168 (27.3)*	
4	5,340 (27.1)*	198 (32.1)*	
CCI			0.008
0	16,122 (61.1)	351 (55.5)	
1–2	8,230 (31.2)	219 (34.6)	
>2	2,023 (7.7)	63 (10.0)	
Severity of illness			<0.001
Minor loss of function	8,307 (38.8)*	179 (28.3)*	
Moderate loss of function	8,355 (39.1)*	242 (38.3)*	
Major loss of function	3,443 (16.1)*	151 (23.9)*	
Extreme loss of function	1,278 (6.0)*	60 (9.5)*	
Histology			0.88
Benign	25,028 (95.7)*	599 (95.5)*	
Malignant	1,137 (4.3)*	28 (4.5)*	
Admission type			<0.001
Nonelective	5,479 (25.4)*	285 (45.3)*	
Elective	16,055 (74.6)*	344 (54.7)*	
Hospital region			<0.001
Northeast	4,565 (18.7)*	91 (16.3)*	
Midwest	4,466 (18.3)*	81 (14.5)*	
South	9,162 (37.5)*	171 (30.7)*	
West	6,208 (25.4)*	214 (38.4)*	

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TABLE 1. Patient and hospital characteristics in the entire study cohort

Variable	No Embolization	Embolization	p Value
Location & teaching status of hospital			<0.001
Urban teaching	18,708 (77.1)*	501 (89.9)*	
Urban non-teaching	4,990 (20.6)*	56 (10.1)*	
Rural	557 (2.3)*	≤10 (≤1.8)*	
Bed size of hospital			<0.001
Large	18,684 (77.0)*	465 (83.5)*	
Medium	4,100 (16.9)*	51 (9.2)*	
Small	1,471 (6.1)*	41 (7.4)*	

Values expressed as the mean ± standard deviation or as number (%), unless indicated otherwise.

* Data missing for some cases; therefore, values do not reflect total study population.

complicating a procedure (3.6% vs 1.7%, $p < 0.001$), infarction or hemorrhage (7.6% vs 3.8%, $p < 0.001$), hydrocephalus (8.8% vs 4.1%, $p < 0.001$), cerebral edema (27.6% vs 11.8%, $p < 0.001$), meningitis or cerebral venous thrombosis ($\leq 1.6\%$ vs 0.6%, $p = 0.049$), and venous embolism (3.8% vs 1.8%, $p < 0.001$). Embolization patients also had higher rates of posthemorrhagic anemia or transfusion (21.8% vs 11.4%, $p < 0.001$), mechanical ventilation (9.0% vs 5.6%, $p < 0.001$), and nonroutine discharge (42.0% vs 33.3%, $p < 0.001$). There were no differences in the rates of cranial nerve palsy or death (Table 3).

Interval Analysis

Univariate and multivariate logistic regression analyses restricted to embolization patients were completed to determine the impact of the interval (days) before resection on adverse outcomes. The mean interval was 1.49 days (range 0–20 days). Covariates included the patient and hospital factors previously described. On univariate analysis, a longer interval was significantly associated with an increased risk for infarction or hemorrhage (OR 1.14, $p = 0.022$) and nonroutine discharge (OR 1.31, $p < 0.001$). On adjusted analysis, only the association with nonroutine discharge remained significant (OR 1.33, $p = 0.004$).

Matched Cohort

After 1:1 propensity score matching, 413 embolization patients and 413 nonembolization patients were retained for comparison (Table 2). In this matched cohort, preoperative embolization was associated with increased rates of cerebral edema (25.2% vs 17.7%, $p = 0.009$), posthemorrhagic anemia or transfusion (21.8% vs 13.8%, $p = 0.003$), and nonroutine discharge (42.8% vs 35.7%, $p = 0.039$). There were no other significant associations (Table 4).

Discussion

Using the NIS database, we completed a retrospec-

TABLE 2. Patient and hospital characteristics in the propensity score–matched sample

Variable	No Embolization	Embolization	p Value
No. of patients	413	413	
Mean age in yrs	54.5036 ± 15.1125	55.7554 ± 13.934	0.22
Sex			0.83
Male	149 (36.1)	152 (36.8)	
Female	264 (63.9)	261 (63.2)	
Race			0.26
White	265 (64.2)	260 (63.0)	
Black	52 (12.6)	53 (12.8)	
Hispanic	56 (13.6)	46 (11.1)	
Asian or Pacific Islander	19 (4.6)	34 (8.2)	
Other	21 (5.1)	20 (4.8)	
Insurance			0.90
Medicare or private	342 (82.8)	344 (83.3)	
Medicaid	47 (11.4)	48 (11.6)	
None	24 (5.8)	21 (5.1)	
Zip code income quartile			0.85
1	93 (22.5)	83 (20.1)	
2	93 (22.5)	95 (23.0)	
3	104 (25.2)	105 (25.4)	
4	123 (29.8)	130 (31.5)	
CCI			0.18
0	249 (60.3)	238 (57.6)	
1–2	135 (32.7)	131 (31.7)	
>2	29 (7.0)	44 (10.7)	
Severity of illness			0.71
Minor loss of function	109 (26.4)	114 (27.6)	
Moderate loss of function	177 (42.9)	161 (39.0)	
Major loss of function	91 (22.0)	97 (23.5)	
Extreme loss of function	36 (8.7)	41 (9.9)	
Histology			0.51
Benign	396 (95.9)	392 (94.9)	
Malignant	17 (4.1)	21 (5.1)	
Admission type			0.57
Nonelective	185 (44.8)	177 (42.9)	
Elective	228 (55.2)	236 (57.1)	
Hospital region			0.006
Northeast	62 (15.0)	79 (19.1)	
Midwest	53 (12.8)	31 (7.5)	
South	160 (38.7)	136 (32.9)	
West	138 (33.4)	167 (40.4)	

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TABLE 2. Patient and hospital characteristics in the propensity score–matched sample

Variable	No Embolization	Embolization	p Value
Location & teaching status of hospital			1.00
Urban teaching	365 (88.4)	365 (88.4)	
Urban non-teaching	48 (11.6)	48 (11.6)	
Bed size of hospital			0.50
Large	340 (82.3)	342 (82.8)	
Medium	49 (11.9)	41 (9.9)	
Small	24 (5.8)	30 (7.3)	

Values expressed as the mean ± standard deviation or as number (%), unless indicated otherwise.

tive analysis of meningioma patients who had undergone resection with or without immediate preoperative embolization. Consistent with its goal of decreasing surgical complexity, preoperative embolization was more likely to be performed in patients with comorbid conditions and higher disease severity indices. When adjusting for hospital and patient factors (excluding tumor-specific information not in the NIS database, such as size, location, and arterial feeders), we found that patients who had undergone preoperative embolization had a 47% increased risk of cerebral edema, 92% increased risk of posthemorrhagic anemia or transfusion, and 7% increased risk for nonroutine discharge. In contrast, there were no differences for other complications, such as cranial nerve palsy, cerebral infarction or hemorrhage, and death.

Because preoperative embolization is more likely to be performed for large,²⁹ vascular meningiomas with difficult-to-access feeding arteries,¹² the increased risks for cerebral edema, blood loss, and adverse discharge are not necessarily surprising. Nonetheless, such tumor characteristics represent a confounding variable by indication, where a variable is associated with both the exposure and the outcome.^{31,32} While our use of propensity score matching minimized confounding of the measured variables available in the NIS database, it did not preclude confounding by unmeasured variables, such as individual surgeon preferences or tumor characteristics. Given this limitation, our data suggest that complex meningiomas thought to require preoperative embolization represent a clinical entity distinct from those meningiomas that appear resectable without preoperative treatment. Nonetheless, preoperative embolization and resection of such complex meningiomas can be safely performed in the majority of cases.

The higher rate of cerebral edema we observed in the embolization patients (25.2% vs 17.7% in the matched cohort) is consistent with rates in prior studies^{8,21,36,37} and likely results from a combination of the increased complexity of tumors selected for embolization and an effect of the embolization itself.³⁴ Pretreatment edema exists in up to two-thirds of meningioma patients and varies with tumor location, tumor size, and extent of cortical dam-

TABLE 3. Outcomes in the full patient sample

Variable	No Embolization	Embolization	p Value
No. of patients	26,375	633	
Hematoma complicating a procedure	447 (1.7)	23 (3.6)	<0.001
Cerebral infarction or hemorrhage	1,009 (3.8)	48 (7.6)	<0.001
Hydrocephalus or performance of ventriculostomy	1,082 (4.1)	56 (8.8)	<0.001
Cerebral edema	3,121 (11.8)	175 (27.6)	<0.001
Cranial nerve palsy	621 (2.4)	21 (3.3)	0.12
Posthemorrhagic anemia or transfusion	3,001 (11.4)	138 (21.8)	<0.001
Meningitis or cerebral venous thrombosis	166 (0.6)	≤10 (≤1.6)	0.049
Venous embolism or placement of IVC filter	483 (1.8)	24 (3.8)	<0.001
Mechanical ventilation	1,472 (5.6)	57 (9.0)	<0.001
Nonroutine discharge	8,649 (33.3)*	260 (42.0)*	<0.001
Death during hospitalization	366 (1.4)	12 (1.9%)	0.28

IVC = inferior vena cava.

Values expressed as number (%), unless indicated otherwise.

* Data missing for some cases; therefore, values do not reflect total study population.

age.^{8,17,18,24} Larger meningiomas and those located in the frontal convexity or middle third falx have been shown to have significantly greater edema.²⁴ Therefore, while embolization is known to be associated with cerebral edema,³⁴ many of the patients in our study probably had baseline edema before embolization or resection. Unfortunately, the timing and cause of this edema cannot be directly ascertained from our data set. However, abnormal imaging results (such as cerebral edema) are only coded for billing and only appear in the NIS database with documented clinical significance,⁹ and those patients with baseline symptomatic edema not reflected in the CCI and APR-DRG index were almost certainly more likely to have had deeper or larger tumors that would be selected for preoperative embolization.

To our knowledge, this is the first report of a greater incidence of nonroutine discharge disposition among meningioma patients who underwent preoperative emboliza-

tion than that among nonembolized patients. Because this finding persisted on adjusted analysis—unlike complications of embolization, such as stroke or hemorrhage—it probably represents a meaningful clinical impact of the increased complexity of tumors selected for embolization. Therefore, further care of cerebral edema in complex meningioma patients may be required for clinical manifestations such as nausea and vomiting, altered mental status, or decreased respiratory drive. Prolonged care following hospital discharge also probably increases costs for both patients and health care systems and should be considered when planning treatment.

Together, our data suggest that meningiomas selected for preoperative embolization represent a subset of high-risk tumors and that patients with these tumors have extra clinical needs. Surgical and postoperative care for these patients should be planned accordingly and the costs perhaps reimbursed differently than those for simple menin-

TABLE 4. Outcomes in the propensity score–matched patient sample

Variable	No Embolization	Embolization	p Value
No. of patients	413	413	
Hematoma complicating a procedure	≤10 (≤2.4)	16 (3.9)	0.057
Cerebral infarction or hemorrhage	24 (5.8)	24 (5.8)	1.00
Hydrocephalus or performance of ventriculostomy	31 (7.5)	37 (9.0)	0.45
Cerebral edema	73 (17.7)	104 (25.2)	0.009
Cranial nerve palsy	13 (3.1)	14 (3.4)	0.84
Posthemorrhagic anemia or transfusion	57 (13.8)	90 (21.8)	0.003
Meningitis or cerebral venous thrombosis	≤10 (≤2.4)	≤10 (≤2.4)	0.31
Venous embolism or placement of IVC filter	11 (2.7)	15 (3.6)	0.43
Mechanical ventilation	41 (9.9)	38 (9.2)	0.72
Nonroutine discharge	144 (35.7)*	173 (42.8)*	0.039
Death during hospitalization	≤10 (≤2.4)	≤10 (≤2.4)	0.82

Values expressed as number (%), unless indicated otherwise.

* Data missing for some cases; therefore, values do not reflect total study population.

giomas. Future longitudinal studies are needed to determine if there are associations between preoperative embolization and long-term outcomes for meningioma patients.

The interval between embolization and craniotomy is also a controversial topic, with mixed recommendations and evidence for impact on efficacy or patient outcomes.^{4,5,10,12,19,30,35} However, embolization and resection are usually completed within 72 hours of each other and within the same hospital stay.¹¹ In the current analysis, we identified delayed resection as a risk factor for cerebral infarction or hemorrhage, although this relation did not persist on multivariate analysis. However, there was a significant association between a longer interval and nonroutine discharge on both unadjusted and adjusted analyses. Given that delayed resection does not appear to be associated with an increased risk of in-hospital complications, the timing of surgery following embolization can be largely determined according to surgeon discretion.

There are several limitations to retrospective analyses utilizing a large administrative database as well as the risk of confounding by indication, as discussed above. Specifically, the NIS does not contain information about a patient's baseline neurological status and long-term outcome or about procedural details, such as the particle size and type of embolic agent. However, the object of this study was to assess the overall risk of adverse in-hospital outcomes for preoperative embolization patients relative to that for nonembolization patients, and therefore we did not require this information. An additional limitation related to our study design is our assessment of preoperative embolizations only performed in the same admission as the craniotomy. In some cases, patients undergo embolization and are discharged for variable lengths of time before being readmitted for resection. Although this was probably true for only a minority of cases, these types of patients may have been misclassified as nonembolization patients, likely biasing comparisons between groups toward the null. Large database analyses of meningioma patients would be improved by the availability of longitudinal data on post-discharge complications and tumor recurrence. Furthermore, data on tumor characteristics such as size, feeding arteries, and location would enable more precise matching of embolization and nonembolization patients for analysis.

Conclusions

Meningiomas requiring preoperative embolization likely represent a distinct clinical entity with greater treatment complexity and higher risks. These findings have important implications for the management of and reimbursement structure for these complex tumors.

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References

1. Ambekar S, Sharma M, Madhugiri VS, Nanda A: Trends in intracranial meningioma surgery and outcome: a Nationwide

- Inpatient Sample database analysis from 2001 to 2010. *J Neurooncol* **114**:299–307, 2013
2. Austin PC: Statistical criteria for selecting the optimal number of untreated subjects matched to each treated subject when using many-to-one matching on the propensity score. *Am J Epidemiol* **172**:1092–1097, 2010
3. Averill RF, Goldfield NI, Muldoon J, Steinbeck BA, Grant TM: A closer look at all-patient refined DRGs. *J AHIMA* **73**:46–50, 2002
4. Bendszus M, Klein R, Burger R, Warmuth-Metz M, Hofmann E, Solymosi L: Efficacy of trisacryl gelatin microspheres versus polyvinyl alcohol particles in the preoperative embolization of meningiomas. *AJNR Am J Neuroradiol* **21**:255–261, 2000
5. Bendszus M, Martin-Schrader I, Warmuth-Metz M, Hofmann E, Solymosi L: MR imaging- and MR spectroscopy-revealed changes in meningiomas for which embolization was performed without subsequent surgery. *AJNR Am J Neuroradiol* **21**:666–669, 2000
6. Bendszus M, Rao G, Burger R, Schaller C, Scheinemann K, Warmuth-Metz M, et al: Is there a benefit of preoperative meningioma embolization? *Neurosurgery* **47**:1306–1312, 2000
7. Borg A, Ekanayake J, Mair R, Smedley T, Brew S, Kitchen N, et al: Preoperative particle and glue embolization of meningiomas: indications, results, and lessons learned from 117 consecutive patients. *Neurosurgery* **73** (2 Suppl **Operative**):ons244–ons252, 2013
8. Carli DF, Sluzewski M, Beute GN, van Rooij WJ: Complications of particle embolization of meningiomas: frequency, risk factors, and outcome. *AJNR Am J Neuroradiol* **31**:152–154, 2010
9. Centers for Medicare and Medicaid Services, National Center for Health Statistics: **ICD-9-CM Official Guidelines for Coding and Reporting**. (https://www.cdc.gov/nchs/data/icd/icd9cm_guidelines_2011.pdf) [Accessed February 13, 2018]
10. Chun JY, McDermott MW, Lamborn KR, Wilson CB, Hingashida R, Berger MS: Delayed surgical resection reduces intraoperative blood loss for embolized meningiomas. *Neurosurgery* **50**:1231–1237, 2002
11. Dean BL, Flom RA, Wallace RC, Khayata MH, Obuchowski NA, Hodak JA, et al: Efficacy of endovascular treatment of meningiomas: evaluation with matched samples. *AJNR Am J Neuroradiol* **15**:1675–1680, 1994
12. Djindjian R, Cophignon J, Théron J, Merland JJ, Houdart R: Embolization by superselective arteriography from the femoral route in neuroradiology. Review of 60 cases. 1. Technique, indications, complications. *Neuroradiology* **6**:20–26, 1973
13. Dubel GJ, Ahn SH, Soares GM: Contemporary endovascular embolotherapy for meningioma. *Semin Intervent Radiol* **30**:263–277, 2013
14. Garrido MM, Kelley AS, Paris J, Roza K, Meier DE, Morrison RS, et al: Methods for constructing and assessing propensity scores. *Health Serv Res* **49**:1701–1720, 2014
15. Gruber A, Killer M, Mazal P, Bavinszki G, Richling B: Preoperative embolization of intracranial meningiomas: a 17-years single center experience. *Minim Invasive Neurosurg* **43**:18–29, 2000
16. Haider AS, Rana H, Lee LK, Shail MS, Leonard D, Khan U, et al: Large transcalvarial meningioma: surgical resection aided by preoperative embolization. *Cureus* **9**:e1229, 2017
17. Hou J, Kshetry VR, Selman WR, Bambakidis NC: Peritumoral brain edema in intracranial meningiomas: the emergence of vascular endothelial growth factor-directed therapy. *Neurosurg Focus* **35**(6):E2, 2013
18. Ide M, Jimbo M, Kubo O, Yamamoto M, Takeyama E, Imanaga H: Peritumoral brain edema and cortical damage by meningioma. *Acta Neurochir Suppl (Wien)* **60**:369–372, 1994

19. Kai Y, Hamada J, Morioka M, Yano S, Todaka T, Ushio Y: Appropriate interval between embolization and surgery in patients with meningioma. **AJNR Am J Neuroradiol** **23**:139–142, 2002
20. Kallmes DF, Evans AJ, Kaptain GJ, Mathis JM, Jensen ME, Jane JA, et al: Hemorrhagic complications in embolization of a meningioma: case report and review of the literature. **Neuroradiology** **39**:877–880, 1997
21. Kasuya H, Shimizu T, Sasahara A, Takakura K: Phenytoin as a liquid material for embolisation of tumours. **Neuroradiology** **41**:320–323, 1999
22. Kominami S, Watanabe A, Suzuki M, Mizunari T, Kobayashi S, Teramoto A: Preoperative embolization of meningiomas with N-butyl cyanoacrylate. **Interv Neuroradiol** **18**:133–139, 2012
23. Lefkowitz M, Giannotta SL, Hieshima G, Higashida R, Halbach V, Dowd C, et al: Embolization of neurosurgical lesions involving the ophthalmic artery. **Neurosurgery** **43**:1298–1303, 1998
24. Lobato RD, Alday R, Gómez PA, Rivas JJ, Domínguez J, Cabrera A, et al: Brain oedema in patients with intracranial meningioma. Correlation between clinical, radiological, and histological factors and the presence and intensity of oedema. **Acta Neurochir (Wien)** **138**:485–494, 1996
25. Macpherson P: The value of pre-operative embolisation of meningioma estimated subjectively and objectively. **Neuroradiology** **33**:334–337, 1991
26. Manelfe C, Lasjaunias P, Ruscalleda J: Preoperative embolization of intracranial meningiomas. **AJNR Am J Neuroradiol** **7**:963–972, 1986
27. Oka H, Kurata A, Kawano N, Saegusa H, Kobayashi I, Ohmomo T, et al: Preoperative superselective embolization of skull-base meningiomas: indications and limitations. **J Neurooncol** **40**:67–71, 1998
28. Quiñones-Hinojosa A, Kaprelian T, Chaichana KL, Sanai N, Parsa AT, Berger MS, et al: Pre-operative factors affecting resectability of giant intracranial meningiomas. **Can J Neurol Sci** **36**:623–630, 2009
29. Raper DM, Starke RM, Henderson F Jr, Ding D, Simon S, Evans AJ, et al: Preoperative embolization of intracranial meningiomas: efficacy, technical considerations, and complications. **AJNR Am J Neuroradiol** **35**:1798–1804, 2014
30. Richter HP, Schachenmayr W: Preoperative embolization of intracranial meningiomas. **Neurosurgery** **13**:261–268, 1983
31. Rush B, Rousseau J, Sekhon MS, Griesdale DE: Craniotomy versus craniectomy for acute traumatic subdural hematoma in the United States: a national retrospective cohort analysis. **World Neurosurg** **88**:25–31, 2016
32. Salas M, Hofman A, Stricker BH: Confounding by indication: an example of variation in the use of epidemiologic terminology. **Am J Epidemiol** **149**:981–983, 1999
33. Shi ZS, Feng L, Jiang XB, Huang Q, Yang Z, Huang ZS: Therapeutic embolization of meningiomas with Onyx for delayed surgical resection. **Surg Neurol** **70**:478–481, 2008
34. Singla A, Deshaies EM, Melnyk V, Toshkezi G, Swarnkar A, Choi H, et al: Controversies in the role of preoperative embolization in meningioma management. **Neurosurg Focus** **35**(6):E17, 2013
35. Teasdale E, Patterson J, McLellan D, Macpherson P: Sub-selective preoperative embolization for meningiomas. A radiological and pathological assessment. **J Neurosurg** **60**:506–511, 1984
36. Wakhloo AK, Juengling FD, Van Velthoven V, Schumacher M, Hennig J, Schwechheimer K: Extended preoperative polyvinyl alcohol microembolization of intracranial meningiomas: assessment of two embolization techniques. **AJNR Am J Neuroradiol** **14**:571–582, 1993
37. Yasui K, Shoda Y, Suyama T, Numa Y, Amanouchi YY, Kawamoto K: Preoperative embolization for meningioma using lipiodol. **Interv Neuroradiol** **4** (Suppl 1):63–66, 1998

Disclosures

Dr. Pannell has been a consultant for Stryker.

Author Contributions

Conception and design: all authors. Acquisition of data: Brandel, Lopez Ramos. Analysis and interpretation of data: Brandel, Lopez Ramos. Drafting the article: Brandel, Rennert. Critically revising the article: all authors. Reviewed submitted version of manuscript: all authors. Approved the final version of the manuscript on behalf of all authors: Khalessi. Statistical analysis: Brandel. Administrative/technical/material support: Wali, Santiago-Dieppa, Steinberg, Abraham. Study supervision: Khalessi, Rennert, Santiago-Dieppa, Pannell.

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