Permanent Cerebrospinal Fluid Diversion in Adults With Posterior Fossa Tumors: Incidence and Predictors

Hassan Saad, MD [*]
David P. Bray, MD [*]
J. Tanner McMahon, MD [‡]
Brandon D. Philbrick, MD [‡]
Reem A. Dawoud, BS [‡]
J. Miller Douglas, BS [‡]
Segun Adeagbo, BS [‡]
Steven K. Yarmoska, PhD [‡]
Matthew Agam, MD [*]
Jocelyn Chow [*]
Gustavo Pradilla, MD [*]
Jeffrey J. Olson, MD [*]
Ali Alawieh, MD, PhD [*]
Kimberly Hoang, MD [*]

[*]Department of Neurosurgery, School of Medicine, Emory University, Atlanta, Georgia, USA; [‡]School of Medicine, Emory University, Atlanta, Georgia, USA

Correspondence:
Kimberly Hoang, MD,
Department of Neurosurgery,
Emory University Hospital,
1365 Clifton Rd,
Atlanta, GA 30322, USA.
Email:
kimberly.bojanowski.hoang@emory.edu

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BACKGROUND: Posterior fossa tumors (PFTs) can cause hydrocephalus. Hydrocephalus can persist despite resection of PFTs in a subset of patients requiring permanent cerebrospinal fluid (CSF) diversion. Characteristics of this patient subset are not well defined.

OBJECTIVE: To define preoperative and postoperative variables that predict the need for postoperative CSF diversion in adult patients with PFTs.

METHODS: We surveyed the CNS (Central Nervous System) Tumor Outcomes Registry at Emory (CTORE) for patients who underwent PFT resection at 3 tertiary-care centers between 2006 and 2019. Demographic, radiographic, perioperative, and dispositional data were analyzed using univariate and multivariate models.

RESULTS: We included 617 patients undergoing PFT resection for intra-axial (57%) or extra-axial (43%) lesions. Gross total resection was achieved in 62% of resections. Approximately 13% of patients required permanent CSF diversion/shunting. Only 31.5% of patients who required pre- or intraop external ventricular drain (EVD) placement needed permanent CSF diversion. On logistic regression, size, transependymal flow, use of perioperative EVD, postoperative intraventricular hemorrhage (IVH), and surgical complications were predictors of permanent CSF diversion. Preoperative tumor size was only independent predictor of postoperative shunting in patients with subtotal resection. In patients with intra-axial tumors, transependymal flow ($P = .014$), postoperative IVH ($P = .001$), surgical complications ($P = .013$), and extent of resection ($P = .03$) predicted need for shunting. In extra-axial tumors, surgical complications were the major predictor ($P = .022$).

CONCLUSION: Our study demonstrates that presence of preoperative hydrocephalus in patients with PFT does not necessarily entail the need for permanent CSF diversion. We report the major predictive factors for needing permanent CSF diversion.

KEY WORDS: Posterior fossa tumor, Shunt, Hydrocephalus, Intra-axial, Extra-axial, Ventriculoperitoneal shunt

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Hydrocephalus (HCP) is a cardinal clinical presentation of patients with posterior fossa tumors (PFTs). PFTs can cause both obstructive and communicating HCP.[1] HCP can also develop after PFT surgery secondary to subtotally resected tumors, increased cerebral edema, or intraventricular hemorrhage (IVH).[2]

Although the majority of HCP resolves after resection of PFTs,[2,3] prior studies have reported a rate of HCP after PFT surgery to be 2% to 7% and up to 40% in adult and pediatric patients, respectively.[2,4] Other manuscripts have suggested that only a subset of patients with PFTs will need cerebrospinal fluid (CSF) diversion postoperatively.[2,4,5] Identifying patients who are at high risk of developing HCP may avoid unnecessary invasive procedures, readmissions,

ABBREVIATIONS: aOR, adjusted odds ratio; **EOR,** extent of resection; **ETV,** endoscopic ventriculostomy; **EVD,** external ventricular drain; **GTR,** gross total resection; **HCP,** hydrocephalus; **PFT,** posterior fossa tumor; **STR,** subtotal resection; **TEF,** transependymal flow; **VPS,** ventriculoperitoneal shunt

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complications, and drain-weaning protocols that prolong hospitalization. In this work, we describe the incidence of preoperative, persistent, and new-onset HCP after posterior fossa surgery in high-volume tertiary-care centers. We also analyze the predictors of HCP after resection of PFTs in different patient subpopulations.

METHODS

Study Design

This is a multisite retrospective study of adult (≥18 yr) patients undergoing craniotomy for PFTs at Emory University between January 2006 and December 2019. Data were collected from the CNS (Central Nervous System) Tumor Outcomes Registry at Emory (CTORE) database, a prospectively maintained database of patient outcomes for CNS tumors treated at the participating sites. The study was approved by the institutional review board at Emory, and an informed consent waiver was obtained.

Patient Selection

We included consecutive adult patients who underwent PFT resection within the study period. Patients with concurrent posterior fossa and supratentorial lesions were included provided the posterior fossa lesion was the target of surgical intervention.

Data Collection

Patient charts were reviewed for patient demographics, procedures, surgical complications, pathology, need for permanent CSF diversion, length of stay, and patient disposition. Preoperative imaging was performed within 1 wk of surgical intervention, and postoperative magnetic resonance (MR) imaging was performed within 72 h of surgery. Transependymal flow (TEF) was defined as periventricular hyperintense signal on T2-weighted MR images or low attenuation periventricular changes seen on computed tomography scan. Mass effect on the fourth ventricle was categorized into "no mass effect," "partial effacement," or "full effacement." Location of lesions was dichotomized into extra-axial or intra-axial lesions. Gross total resection (GTR) was defined as complete resection noted on the postoperative imaging. Surgical complications were defined as ischemic stroke, postoperative hematoma, postoperative edema requiring decompression, infection, CSF leak, and wound complications.

CSF Diversion

The need for ventriculoperitoneal shunt (VPS) placement was the primary outcome in this study. In a subset of patients, an external ventricular drain (EVD) was placed pre- or intraoperatively for HCP at the surgeon's preference. Criteria for VPS placement included failure to wean the EVD because of high intracranial pressures, symptomatic (worsening mental status), or radiographic failure (ventriculomegaly) or for patients with new postoperative HCP.

Statistical Analysis

Statistical analysis was done using SPSS 24 (IBM Corporation) and GraphPad Prism 8 (GraphPad). Univariate analyses were performed using Student's *t*-test for Gaussian distributed parametric variables, Mann-Whitney test for non-parametric variables, and Chi-squared or Fisher's exact test for categorical variables. Multivariate analysis was performed using logistic regression analysis for predictors of VPS requirement while adjusting for variables with $P < .1$ on univariate analysis in addition to preset variables (age, gender, body mass index, and lesion size). An $\alpha < 0.05$ was considered for statistical significance.

RESULTS

Patient Population

During the studied period, a total of 672 patients underwent surgical resection for PFTs. A total of 55 (8%) patients were excluded because of inaccessible preoperative imaging or age (<18 yr) at the time of surgery (**Supplemental Figure**). Therefore, 617 patients were included in this study with the mean age of 51 yr, 57% female, and 60% white race. Approximately 57% of the lesions were intra-axial. The majority of patients had primary brain tumors (68%). GTR was achieved in 62% of patients. The majority of patients were discharged home postoperatively (72%) (Table 1).

Incidence and Characteristics of Patients Requiring a VPS

Among the studied cohort, 30% of patients presented with ventriculomegaly, and 12% had associated evidence of HCP with TEF on preoperative imaging. HCP was defined as ventriculomegaly associated with clinical manifestations such as headache, nausea, or vomiting. A preoperative EVD was placed in 6% of patients, whereas an intraoperative EVD was placed in an additional 13%. All patients with EVD placement had an attempted EVD wean prior to conversion to VPS. The rate of VPS requirement in our cohort was 13% (Table 1).

Patients requiring a VPS were more likely to have intra-axial lesions, larger tumor size, and a higher number of infratentorial lesions on pre-admission variables ($P < .05$). In patients with ventriculomegaly on presentation, only 22% (40/178) required postoperative VPS and 34% (23/67) of patients with preop TEF required a VPS. In patients requiring preoperative EVD placement, 31.5% (37/117) required VPS postoperatively.

Regarding postoperative variables, there was a significantly higher rate of postoperative IVH, complications, or re-operation in the VPS group. The rate of GTR was significantly lower in shunted patients (49% vs 64%, $P = .011$). Patients who required a VPS required a longer hospital stay (21 vs 7 d, $P < .001$) and were less likely to be discharged home (55% vs 75%, $P = .001$). The highest rates of VPS requirement were found in patients with choroid plexus papilloma (30%), ependymoma (23.8%), low-grade glioma (23.5%), and medulloblastoma (20%) (Figure 1A). Patients with intraventricular tumors had a comparable rate of VPS (12.3%) compared to those with intra-axial tumors (14.8%), and both groups showed significantly lower rates of VPS than patients with extra-axial tumors (27.2%, $P < .05$) (Figure 1B).

Predictors of VPS Requirement

We performed multivariate logistic regression using preoperative variables alone (Figure 2). Both tumor size (adjusted odds

TABLE 1. Patient Demographic, Radiological and Outcome Variables Dichotomized Based on Need for Shunt

	Full cohort		No shunt		Shunt			
Variable	**N**	**Mean (SD) N (%)**	**N**	**Mean (SD) N (%)**	**N**	**Mean (SD) N (%)**	**Test**	**P-value**
Female gender	617	353 (57%)	536	313 (58%)	81	40 (49%)	Chi-sqr	.148
White race	617	369 (60%)	536	316 (59%)	81	53 (65%)	Chi-sqr	.351
Age	617	51 (16)	536	51 (16)	81	47 (16)	*T*-test	.325
BMI	584	28 (8)	508	28 (8)	76	30 (11)	*T*-test	.057
Location	**617**		**536**		**81**		**Chi-sqr**	**.041**
Intra-axial		**353 (57%)**		**298 (56%)**		**55 (68%)**		
Extra-axial		**264 (43%)**		**238 (44%)**		**26 (32%)**		
Lesion size	**562**	**34 (37)**	**489**	**32 (35)**	**73**	**47 (48)**	***T*-test**	**<.001**
Number of infratentorial lesions	**617**	**1 [0]**	**536**	**1 [0]**	**81**	**1 [1]**	***T*-test**	**<.001**
Number of supratentorial lesions	617	0 (1)	536	0 (1)	81	0 (1)	*T*-test	.927
Preop ventriculomegaly	**587**	**178 (30%)**	**508**	**138 (27%)**	**79**	**40 (51%)**	**Chi-sqr**	**<.001**
Preop transependymal flow	**573**	**67 (12%)**	**497**	**44 (9%)**	**76**	**23 (30%)**	**Chi-sqr**	**<.001**
Preop EVD placement	**617**	**36 (6%)**	**536**	**23 (4%)**	**81**	**13 (16%)**	**Chi-sqr**	**<.001**
Pre- or intraop EVD	**617**	**117 (19%)**	**536**	**80 (15%)**	**81**	**37 (48%)**	**Chi-sqr**	**<.001**
Mass effect on fourth ventricle	617		536		81		Chi-sqr	.175
No mass effect		165 (27%)		147 (28%)		18 (22%)		
Partial effacement		331 (54%)		292 (54%)		39 (48%)		
Full effacement		66 (11%)		49 (9%)		17 (21%)		
Intraventricular mass		17 (3%)		15 (3%)		2 (3%)		
Not available		38 (6%)		33 (6%)		5 (6%)		
Mass effect: any extent	617	452 (73%)	536	389 (73%)	81	63 (78%)	Chi-sqr	.198
Postop-IVH	**617**	**85 (14%)**	**536**	**59 (11%)**	**81**	**26 (32%)**	**Chi-sqr**	**<.001**
Surgical complication	**617**	**175 (28%)**	**536**	**130 (24%)**	**81**	**45 (56%)**	**Chi-sqr**	**<.001**
Need for re-operation	**617**	**68 (11%)**	**536**	**45 (8%)**	**81**	**23 (28%)**	**Chi-sqr**	**<.001**
Benign pathology	617	227 (45%)	536	243 (45%)	81	34 (42%)	Chi-sqr	.632
Metastatic (vs primary)	**617**	**200 (32%)**	**536**	**182 (34%)**	**81**	**18 (22%)**	**Chi-sqr**	**.041**
EOR: GTR (vs STR)	**590**	**367 (62%)**	**514**	**330 (64%)**	**76**	**37 (49%)**	**Chi-sqr**	**.011**
LOS	**611**	**9 (12)**	**531**	**7 (6)**	**80**	**21 (28)**	***T*-test**	**<.001**
Disposition	**609**		**529**		**80**		**Chi-sqr**	**.001**
Home		**438 (72%)**		**394 (75%)**		**44 (55%)**		
Home health		**3 (0.5%)**		**3 (0.6%)**		**0 (0.0)**		
Acute rehab		**103 (17%)**		**85 (16%)**		**18 (23%)**		
Subacute rehab		**28 (5%)**		**23 (4%)**		**5 (6%)**		
Hospice		**28 (5%)**		**16 (3%)**		**12 (15%)**		
Death		**9 (1.5%)**		**8 (1.5%)**		**1 (1%)**		

STR, subtotal resection.Bold values are statistically significant ($P < .05$).

ratio [aOR] = 2.7, $P = .03$) and presence of TEF (aOR = 2.5, $P = .02$) on preoperative imaging are the 2 independent predictors of needing a VPS.

An independent logistic regression of pre- and postoperative variables (Figure 3) revealed that presence of preoperative TEF (aOR = 2.8, $P = .02$), requirement of pre- or intraoperative EVD (aOR = 2.3, $P = .01$), presence of postoperative IVH (aOR = 2.6, $P = .007$), and surgical complications (aOR = 2.7, $P = .001$) independently predicted VPS need. Variables that predicted lower odds of shunt requirement were GTR and extra-axial location of tumor.

Of 55 patients in which an EVD wean was attempted, only 11 patients (21%) failed their wean and required VPS placement. The rate of VPS was comparable among patients whose EVD was weaned over 5, 10, or 15 d (15%, $P > .1$) and was higher in patients with prolonged wean exceeding 15 d (50%; Figure 4).

Effect of Tumor Size on Need for VPS

Tumor size was an independent predictor for VPS following PFT resection when only preoperative variables were included, but not when including postoperative variables (Figures 1 and 2). In the regression model predicting need for VPS shunt, there was significant interaction between tumor size and extent of resection when predicting postoperative need for VPS. To validate this interaction, we split the patient cohort into those with subtotal resection (STR) vs GTR and performed independent regression models for the same variables (Figure 3). Tumor size was an independent predictor of need for VPS in patients with STR (aOR (size in cm^3) = 2.0, 95% CI: 1.04-4.1, $P = .038$), but not those with GTR (aOR (size in cm^3) = 0.73, 95% CI: 0.17-3.2, $P = .672$). Therefore, PFT residual rather than preoperative PFT size portends a risk for VPS requirement.

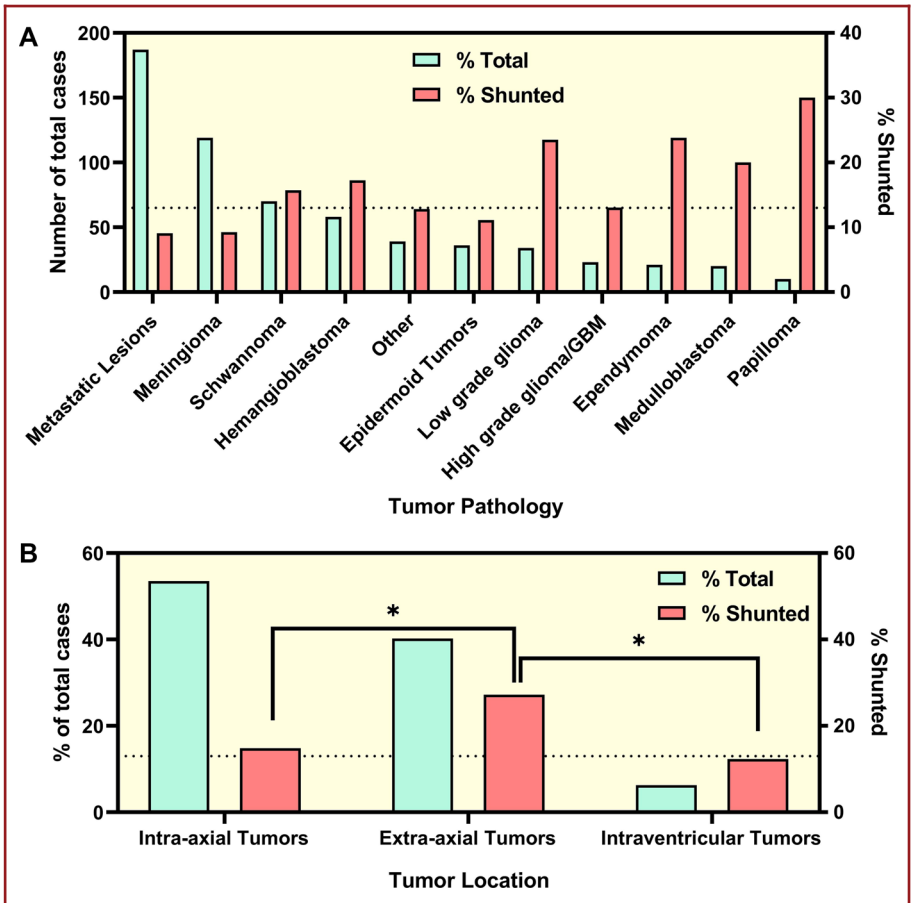

FIGURE 1. **A**, *Distribution of cases across different tumor pathology and the associated rate of VPS requirement per pathology. Left axis (blue bars) represented the total number of cases for each pathology. Right axis (red bars) represents the rate of VPS requirement per pathology. The dashed line marks the average rate of VPS requirement in the full cohort.* **B**, *Distribution of cases across different location groups and the associated rate of VPS requirement per pathology. Left axis (blue bars) represents the percentage of cases for each location. Right axis (red bars) represents the rate of VPS requirement per pathology. The dashed line marks the average rate of VPS requirement in the full cohort. Chi-squared test was used for comparison. *P < .05.*

Notably, when the cohort was dichotomized by extra-axial vs intra-axial location of lesion, there was a positive linear association between size and rate of VPS requirement in patients with extra-axial PFTs ($R^2 = 0.7$, $P = .012$) with a 3% increase in rate of VPS requirement with every 5000 mm^3 increase in tumor size preop (Figure 4). There was no association between size and rates of VPS requirement in patients with intra-axial lesions ($R^2 = 0.05$, $P = .6$) (Figure 5).

Predictors in Extra-Axial vs Intra-Axial Lesions

In patients requiring VPS after PFT surgery, those who had extra-axial PFT had significantly larger tumor size, whereas patients with intra-axial PFT did not have significantly larger tumor size preoperatively (Tables 2 and 3).

Independent predictors for VPS requirement in patients with intra-axial lesions included presence of preoperative TEF, postoperative IVH, surgical complications, and extent of resection (Figure 6A). In patients with extra-axial lesions, surgical complications were the only independent predictor of need for VPS (Figure 6B).

DISCUSSION

Key Results

We report upon the largest cohort investigating the incidence and predictors of the need for permanent CSF diversion in adult patients with PFTs to date. We studied 617 adult patients with intra-axial and extra-axial PFTs. Although 30% of patients presented with ventriculomegaly, only 13% of all patients required a VPS. Tumor features associated with VPS requirement included intra-axial location, larger size, and presence of multiple

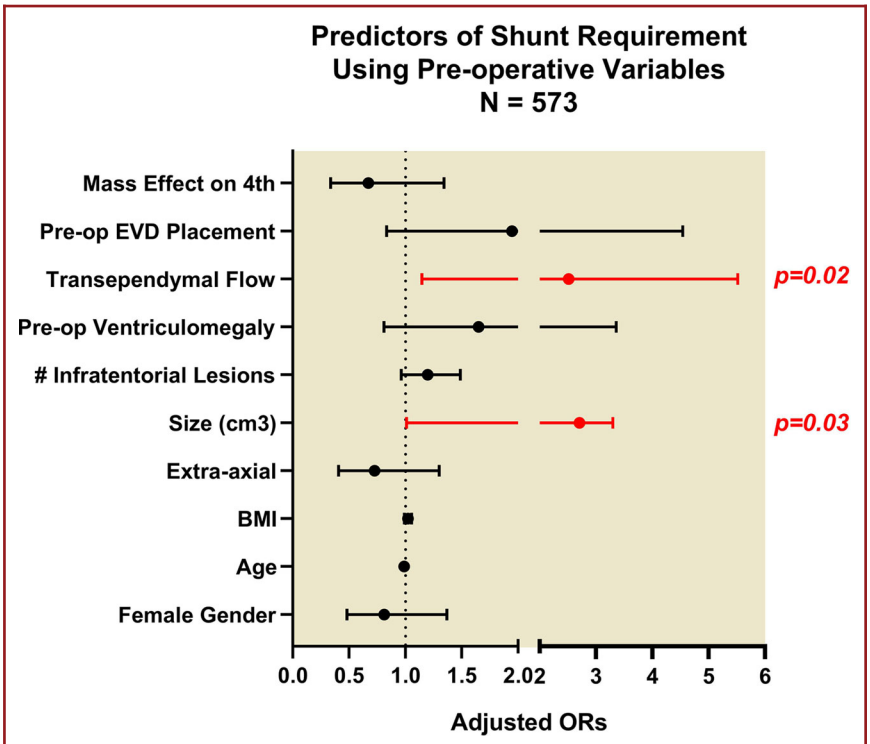

FIGURE 2. *Predictors of VPS requirement in patients with PFT based on preoperative variables. Graph represents the adjusted odds ratio (aOR) for multivariate logistic regression for predictors of VPS requirement in our cohort. Marks represent the aOR, and error bars span the 95% CI. P-values are provided for significant results (P < .05) and highlighted in red color.*

infratentorial lesions. Additionally, patients requiring VPS were more likely to have preoperative ventriculomegaly, TEF, and needed preoperative or intraoperative EVD placement than those who did not require VPS. Only 22% of patients presenting with HCP required permanent CSF diversion. On multivariate analysis, independent predictors of VPS requirement included STR, intra-axial location, presence of TEF on preoperative imaging, and presence of postoperative complications including postoperative IVH. In the subpopulation of patients with extra-axial tumors, there was a stronger association between preoperative tumor size and need for VPS, and the presence of postoperative complications was the only independent predictor of need for VPS.

Interpretation

In our cohort, 30% of adults with PFTs presented with ventriculomegaly and associated symptoms of HCP. Prior series have reported that PFTs can present with HCP in up to 80% in pediatric patients and up to 21.4% in adults.[2,6] Acute HCP was present in 12% of our cohort, and 19% of presenting patients required either preoperative or intraoperative CSF diversion. Temporary CSF diversion in patients with PFTs can be a life-saving procedure and a temporizing bridge to surgery.[6]

HCP may also persist, even after PFT resection. Some neurosurgeons advocate for permanent CSF diversion prior to resection of PFTs.[7-11] Advantages of such an approach include reducing postoperative complications, mortality, and postoperative HCP.[9,10,12] However, preoperative CSF diversion procedures can be rife with complications such as upward herniation, device malfunction, procedural hemorrhage, and metastasis via the shunt system.[5,13,14] Additionally, HCP can resolve after PFT resection, so preoperative CSF diversion may subject patients to unnecessary invasive procedures.[5,13,14] In our study, only 22% of patients presenting with HCP required permanent CSF diversion via VPS (Table 1). Even in patients who required preoperative EVD placement, only 31% required a VPS postoperatively. In a study of 234 adult patients with PFTs who underwent resection with or without endoscopic ventriculostomy (ETV), only 3/52 (6%) of patients who were previously diagnosed with preoperative HCP had persistent HCP that required permanent CSF diversion. Notably, in this study, 21% of patients had ETV during resection resulting in a comparable overall rate of requirement for CSF diversion as in our study.[2] In a smaller series, only 2 patients of 33 (6%) who had an EVD placed before surgery for PFTs were shunted postoperatively. Our data suggest a clear discordance between preoperative HCP and postoperative HCP

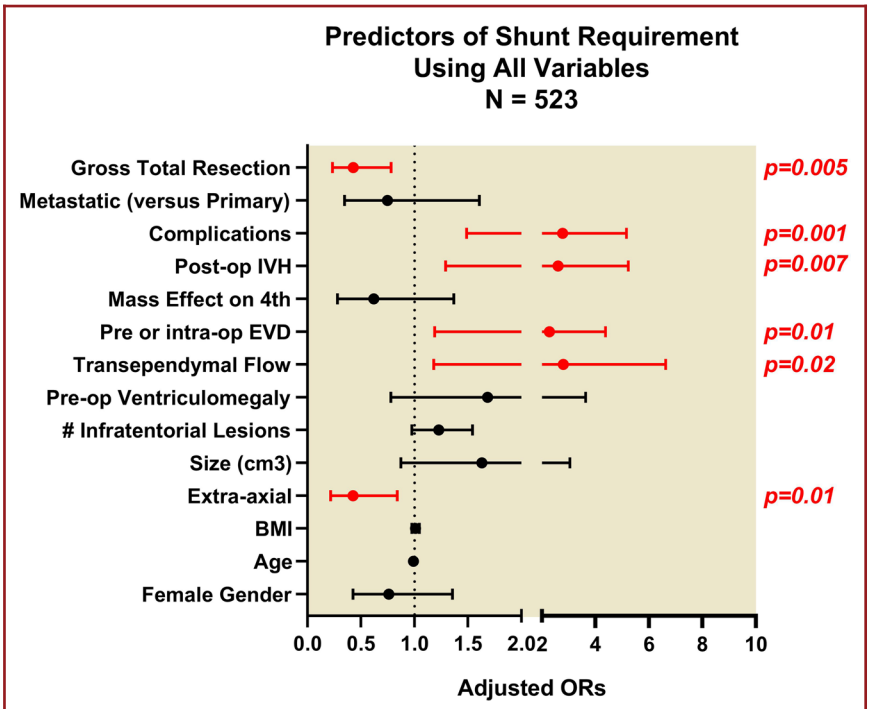

FIGURE 3. *Predictors of VPS requirement in patients with PFT based on preoperative and postoperative variables. Graph represents the adjusted odds ratio (aOR) for multivariate logistic regression for all predictors of VPS requirement in our cohort. Marks represent the aOR, and error bars span the 95% CI. P-values are provided for significant results (P < .05) and highlighted in red color.*

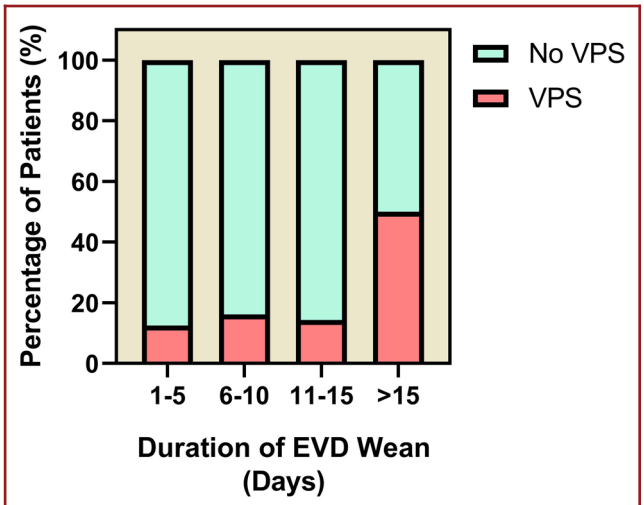

FIGURE 4. *Effect of EVD wean on rate of VPS requirement. Distribution of patients dichotomized by whether a VPS is needed over different durations of EVD wean in days.*

requiring permanent CSF diversion and show that less than a third of patients with preoperative HCP will need permanent CSF diversion (Figure 7).

Preoperative placement of an EVD did not influence the need for postoperative VPS. Given the low risk of EVD placement, and the ability of EVD to temporize acute HCP, preoperative EVD placement should be considered in patients suspected to have HCP from their PFT. Furthermore, length of EVD wean did not affect shunt placement, indicating that after surgery, a long wean or repeated weans are not likely to lessen the chances of VPS dependency. This has significant implication for practice patterns and lengths of hospital stay.

When considering both preoperative and postoperative variables, we found an increased number of predictors of postoperative VPS. STR, postoperative complications, postoperative IVH, perioperative EVD placement, and intra-axial tumor all predicted postoperative VPS. These predictors dovetail with previously published studies. Our subanalysis of the interaction of tumor size and extent of resection (EOR) provides additional information. When controlling for EOR (dichotomizing STR and GTR), tumor size predicted the need for VPS if GTR was not achieved. Most neurosurgeons attempt maximal safe resection in PFT surgery, but often because of relation to critical neurovascular structures, GTR is not feasible. When

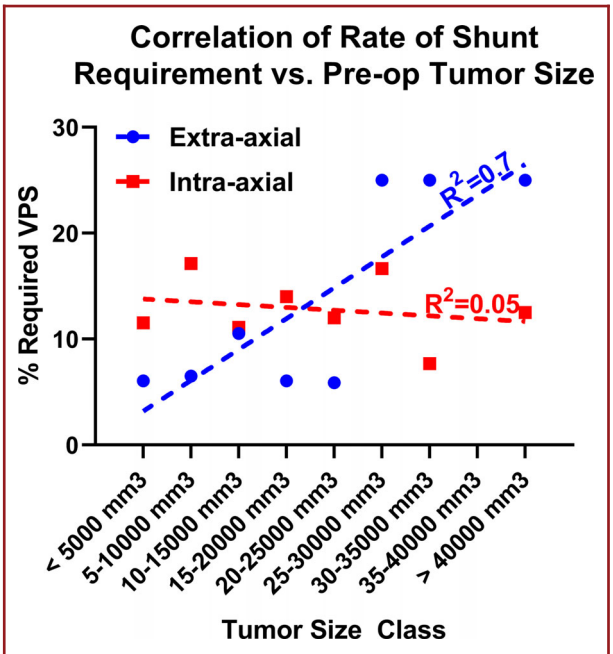

FIGURE 5. *Correlation between preoperative tumor size and rate of VPS requirement in patients with intra-axial vs extra-axial PFTs. Tumor size was classified into classes of 5000 mm³ increments. Correlation was tested using the Pearson's correlation coefficient and best fit lines are shown as dashed lines on the graph with associated R^2 value for the correlation.*

STR is expected preoperative by the neurosurgeon, patients and families can be counseled regarding the increased risk of VPS postoperatively.

We analyzed predictors of postoperative VPS dichotomized amongst those who had intra-axial and extra-axial PFTs. In patients with intra-axial PFT, GTR portended a lower chance of postoperative VPS, whereas complications, IVH, and TEF were related with increased risk of postoperative VPS. Meanwhile, in patients with extra-axial PFTs, only tumor size predicted postoperative VPS. This suggests that extra-axial PFTs tend to cause HCP by obstructing CSF pathways, and resection of the PFT restores normal CSF flow and treats HCP. Patients with intra-axial PFTs had similar rates of postoperative IVH when compared with patients with extra-axial PFTs (14% vs 12%). Postoperative IVH had a significant influence upon postoperative VPS rate in intra-axial PFTs, and positive trend in extra-axial PFTs ($P < .1$). This observation is likely to the larger sample size in the intra-axial cohort.

We favor placing a perioperative EVD in patients presenting with symptoms of HCP as a bridge to surgery. This explains why perioperative EVD placement was an independent predictor of the need for CSF diversion, given that it is a surrogate of decompensated HCP rather than being the reason for postop shunting. This is not the case in the study population scrutinized by Won et al,[4,5] in which approximately 60% of patients who had EVD placement did not have preop HCP or periventricular CSF capping. This is an important distinction in that our patient

TABLE 2. Univariate Analysis for Predictors of Shunting in Patients With Intra-Axial Lesions

	No shunt		Shunt			
Variable	**N**	**Mean (SD) N (%)**	**N**	**Mean (SD) N (%)**	**Test**	***P*-value**
Female gender	298	154 (52%)	55	22 (40%)	Chi-sqr	.142
White race	298	168 (56%)	55	36 (66%)	Chi-sqr	.207
Age	298	52 (16)	55	48 (16)	*T*-test	.74
BMI	**281**	**28 (8)**	**51**	**30 (13)**	***T*-test**	**.046**
Lesion size	268	33 (37)	49	42 (36)	*T*-test	.096
Number of infratentorial lesions	298	1 (1)	55	1 (1)	T-test	.063
Number of supratentorial lesions	298	1 (1)	55	1 (1)	*T*-test	.452
Preop ventriculomegaly	**280**	**96 (34%)**	**54**	**29 (54%)**	**Chi-sqr**	**.009**
Preop transependymal flow	**272**	**31 (11%)**	**51**	**17 (33%)**	**Chi-sqr**	**<.001**
Preop EVD placement	**298**	**19 (6%)**	**55**	**11 (20%)**	**Chi-sqr**	**.003**
Pre- or intraop EVD	**298**	**55 (19%)**	**55**	**25 (46%)**	**Chi-sqr**	**<.001**
Mass effect on fourth ventricle	298		55		Chi-sqr	.187
No mass effect		45 (15%)		9 (16%)		
Partial effacement		195 (65%)		27 (49%)		
Full effacement		32 (11%)		13 (24%)		
Intraventricular mass		7 (2%)		1 (2%)		
Not available		19 (6%)		5 (9%)		
Postop-IVH	**298**	**31 (10%)**	**55**	**20 (36%)**	**Chi-sqr**	**<.001**
Surgical complication	**298**	**58 (20%)**	**55**	**25 (46%)**	**Chi-sqr**	**<.001**
Need for re-operation	**298**	**23 (8%)**	**55**	**13 (24%)**	**Chi-sqr**	**<.001**
Benign pathology	**298**	**199 (76%)**	**55**	**27 (50%)**	**Chi-sqr**	**.014**
Metastatic (vs primary)	**298**	**160 (90%)**	**55**	**18 (32%)**	**Chi-sqr**	**.005**
EOR: GTR (vs STR)	**287**	**204 (71%)**	**52**	**28 (54%)**	**Chi-sqr**	**.022**

STR, subtotal resection. Bold values are statistically significant ($P < .05$).

TABLE 3. Univariate Analysis for Predictors of Shunting in Patients With Extra-Axial Lesions

	No shunt		Shunt			
Variable	**N**	**Mean (SD) N (%)**	**N**	**Mean (SD) N (%)**	**Test**	***P*-value**
Female gender	238	159 (67%)	26	18 (69%)	Chi-sqr	.802
White race	238	148 (62%)	26	17 (65%)	Chi-sqr	.391
Age	238	51 (15)	26	45 (17)	*T*-test	.343
BMI	227	29 (7)	25	29 (6)	*T*-test	.987
Lesion size	**221**	**30 (32)**	**24**	**57 (67)**	***T*-test**	**<.001**
Number of infratentorial lesions	**238**	**1 (0)**	**26**	**1 (1)**	***T*-test**	**<.001**
Number of supratentorial lesions	238	0 (1)	26	0 (1)	*T*-test	.449
Preop ventriculomegaly	**228**	**42 (18%)**	**25**	**11 (44%)**	**Chi-sqr**	**.007**
Preop transependymal flow	**225**	**13 (6%)**	**25**	**6 (24%)**	**Chi-sqr**	**.006**
Preop EVD placement	238	4 (2%)	26	2 (8%)	Chi-sqr	.051
Pre- or intraop EVD	**238**	**25 (11%)**	**26**	**12 (46%)**	**Chi-sqr**	**<.001**
Mass effect on fourth ventricle	238		26		Chi-sqr	.278
No mass effect		102 (43%)		9 (35%)		
Partial effacement		97 (41%)		12 (46%)		
Full effacement		17 (7%)		4 (15%)		
Intraventricular mass		8 (3%)		1 (4%)		
Not available		14 (6%)		0 (0.0%)		
Postop-IVH	238	28 (12%)	26	6 (23%)	Chi-sqr	.12
Surgical complication	**238**	**72 (30%)**	**26**	**20 (77%)**	**Chi-sqr**	**<.001**
Need for re-operation	**238**	**22 (9%)**	**26**	**10 (36%)**	**Chi-sqr**	**<.001**
Benign pathology	238	194 (82%)	26	19 (73%)	Chi-sqr	.301
Metastatic (vs primary)	238	22 (9%)	26	0 (0.0%)	Chi-sqr	.143
EOR: GTR (vs STR)	238	126 (56%)	26	9 (36%)	Chi-sqr	.071

STR, subtotal resection. Bold values are statistically significant ($P < .05$).

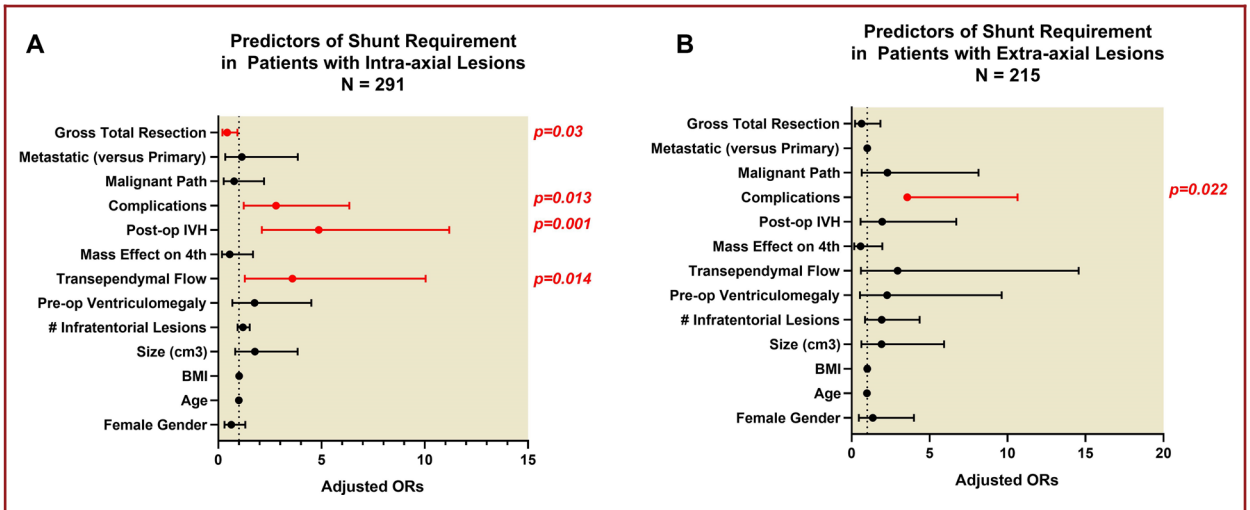

FIGURE 6. A, *Predictors of VPS requirement in patients with PFT based on preoperative and postoperative variables in patients with intra-axial PFTs. Graphs represent the adjusted odds ratio (aOR) for multivariate logistic regression for all predictors of VPS requirement in patients with intra-axial lesions. Marks represent the aOR, and error bars span the 95% CI. P-values are provided for significant results ($P < .05$) and highlighted in red color.* B, *Predictors of VPS requirement in patients with PFT based on preoperative and postoperative variables in patients with extra-axial PFTs. Graphs represent the aOR for multivariate logistic regression for all predictors of VPS requirement in patients with extra-axial lesions. Marks represent the aOR, and error bars span the 95% CI. P-values are provided for significant results ($P < .05$) and highlighted in red color.*

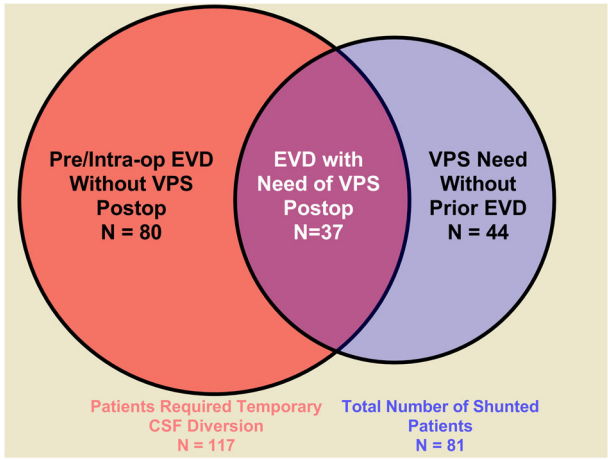

FIGURE 7. *Venn diagram illustrating the overlap between perioperative CSF diversion and need of permanent VPS placement.*

population received perioperative drainage for both symptoms and radiographic findings, rather than based on imaging criteria alone.

Generalizability

Our cohort represents the largest database of PFTs resected at a single institution to date. The overall postoperative VPS rate in our cohort was 13% (n = 81). This is comparable to what was observed in similar studies. We believe our cohort is representative of high-volume, tertiary-care, and neurosurgical centers. Therefore, the results of our study are generalizable to PFTs encountered in most neurosurgeons' practices.

Limitations

Conclusions of this work are limited by the retrospective nature of the study conducted at a single healthcare system, albeit at multiple hospital sites. Additionally, there was no standard criteria to select which patients received a preoperative EVD, which could have influenced the chance of requiring VPS. However, we believe that this is not a major detraction to our analysis as it mirrors what is encountered in clinical practice. We attempted to control these selection biases with our nuanced analyses that included factors involved in the decision making in our regression models.

Our definition of ventriculomegaly was subjective. We relied upon neuroradiology reports when extracting data from electronic charts, and then confirmed the presence of ventriculomegaly. This may add a selection bias to our results.

Lastly, we have included a heterogeneous set of patients; we included both intra-axial and extra-axial lesions, benign and malignant pathologies, and cases requiring extensive surgery (ie, skull base approaches), and more straightforward cases. Although there are inherent weaknesses secondary to incorporating lesions with such diverse pathology, surgical technique, and anatomy, we believe the generalizability and statistical power of the analysis support the inclusion of this heterogeneous patient population.

CONCLUSION

Describing which patients with PFTs who will most likely need postoperative permanent CSF diversion will not only help avoid unnecessary procedures, but it will also decrease length of stay (with its associated costs and complications) with expedient shunting practices. We defined preoperative and postoperative variables that predicted the odds of postoperative VPS shunting. In the future, we and other groups will need to develop an accurate grading system validated in a prospective cohort that can predict postoperative VPS rates in patients undergoing resection of PFTs.

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Supplemental Figure. Flowchart illustrating patient selection process and excluded patients.