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Endoscopic third ventriculostomy for pediatric tumor-associated hydrocephalus

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OBJECTIVE Surgical options for managing hydrocephalus secondary to CNS tumors have traditionally included ventriculoperitoneal shunting (VPS) when tumor resection or medical management alone are ineffective. Endoscopic third ventriculostomy (ETV) has emerged as an attractive treatment strategy for tumor-associated hydrocephalus because it offers a lower risk of infection and hardware-related complications; however, relatively little has been written on the topic of ETV specifically for the treatment of tumor-associated hydrocephalus. Here, the authors reviewed the existing literature on the use of ETV in the treatment of tumor-associated hydrocephalus, focusing on the frequency of ETV use and the failure rates in patients with hydrocephalus secondary to CNS tumor.

METHODS The authors queried PubMed for the following terms: "endoscopic third ventriculostomy," "tumor," and "pediatric." Papers with only adult populations, case reports, and papers published before the year 2000 were excluded. The authors analyzed the etiology of hydrocephalus and failure rates after ETV, and they compared failure rates of ETV with those of VPS where reported.

RESULTS Thirty-two studies with data on pediatric patients undergoing ETV for tumor-related hydrocephalus were analyzed. Tumors, particularly in the posterior fossa, were reported as the etiology of hydrocephalus in 38.6% of all ETVs performed (984 of 2547 ETVs, range 29%–55%). The ETV failure rate in tumor-related hydrocephalus ranged from 6% to 38.6%, and in the largest studies analyzed (> 100 patients), the ETV failure rate ranged from 10% to 38.6%. The pooled ETV failure rate was 18.3% (199 failures after 1087 procedures). The mean or median follow-up for ETV failure assessment ranged from 6 months to 8 years in these studies. Only 5 studies directly compared ETV with VPS for tumor-associated hydrocephalus, and they reported mixed results in regard to failure rate and time to failure. Overall failure rates appear similar for ETV and VPS over time, and the risk of infection appears to be lower in those patients undergoing ETV. The literature is mixed regarding the need for routine ETV before resection for posterior fossa tumors with associated hydrocephalus.

CONCLUSIONS Treatment of tumor-related hydrocephalus with ETV is common and is warranted in select pediatric patient populations. Failure rates are overall similar to those of VPS for tumor-associated hydrocephalus.

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KEYWORDS tumor-associated hydrocephalus; endoscopic third ventriculostomy; pediatric

Hydrocephalus is one of the most common pathologies requiring neurosurgical intervention in children. Managing hydrocephalus due to pediatric CNS tumors presents a complex and challenging problem.[39] Postresection hydrocephalus occurs in approximately 30% of children with posterior fossa tumors, and obstructive hydrocephalus is present in approximately 80% of pediatric patients with posterior fossa tumors.[9,26] Surgical options for addressing hydrocephalus have traditionally included ventriculoperitoneal shunting (VPS) when tumor resection and/or medical management alone are ineffective. Endoscopic third ventriculostomy (ETV) was initially described in 1923 by William Mixter[25] as a treatment strategy for hydrocephalus and has appeal as a method to reduce the risk of introducing hardware-related infectious complications in children who need surgical treatment for hydrocephalus. Numerous studies have compared ETV and VPS in regard to efficacy and infection rates in treatment of pediatric hydrocephalus in general, with the consensus being that ETV reduces procedural

ABBREVIATIONS ETV = endoscopic third ventriculostomy; ETVSS = ETV Success Score; VPS = ventriculoperitoneal shunting.

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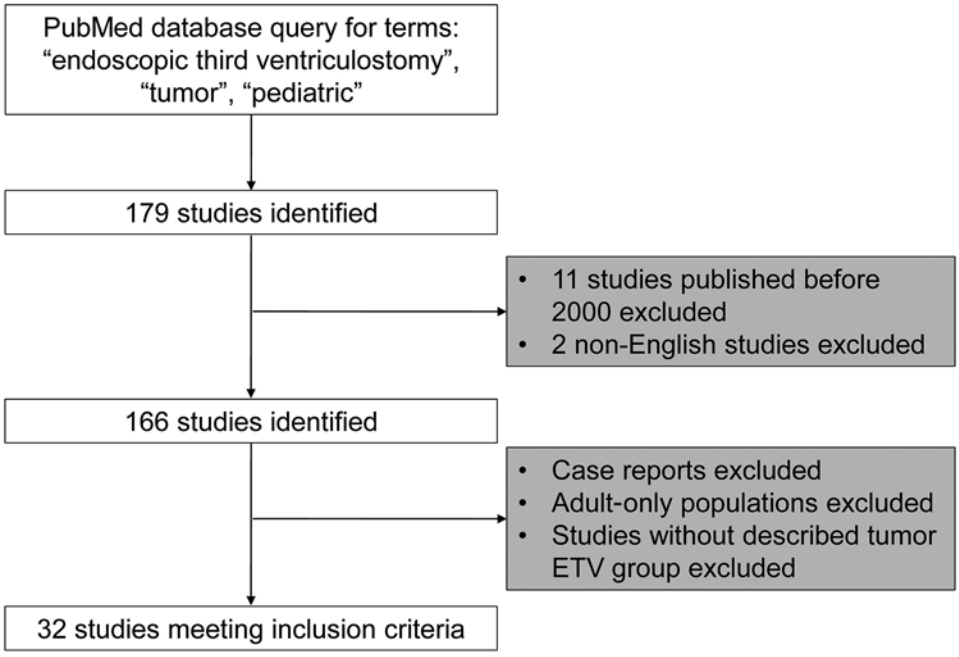

FIG. 1. PRISMA diagram of the literature search and selection process.

infection risk, but the overall reoperation rates for recurrent hydrocephalus are equivalent between ETV and VPS.[15,21,38] However, relatively little has been written specifically about the use of ETV in the pediatric CNS tumor population.

Here, we review the existing literature on ETV in the treatment of tumor-associated hydrocephalus, paying specific attention to the frequency of ETV use in this clinical scenario and the failure rates of preresection ETV in patients with hydrocephalus secondary to CNS tumors.

Methods

We queried PubMed in August 2019 for the following terms: "endoscopic third ventriculostomy," "tumor," and "pediatric." We excluded papers that evaluated only adult (age 18 years and older) populations, but we included mixed adult and pediatric population studies if analysis of the pediatric population was reported separately. We also excluded papers published before 2000 and case reports. Results were filtered for English-language literature. Even if the primary aim of the study in question was not tumor-related hydrocephalus, we analyzed subpopulations in papers that reported tumor as a cause for hydrocephalus.

Data were collected on hydrocephalus etiology or indication for ETV, study type (prospective cohort, retrospective cohort, or systematic review/meta-analysis), year of data collection, ETV failure rates, mean postoperative follow-up, and comparison of outcomes between ETV and VPS, if reported. Linear regression was used to analyze the effect of study publication year on ETV failure rate. Pooled calculations for frequency of ETV for tumor-associated hydrocephalus etiology and for ETV failure rates over multiple studies (excluding systemic reviews and meta-analyses) were performed.

Results

The initial search query yielded 179 study results. Of the initial 179 results, only 168 studies were published in 2000 or later. Of these, 166 were studies written in the English language, 32 of which met the inclusion criteria (Fig. 1).

Thirty-two studies with data on pediatric patients undergoing ETV for tumor-related hydrocephalus were analyzed,[1–4,6–10,12,13,15–24,26–31,34–38] including 3 systematic literature reviews, 3 international prospective cohort studies, 2 multiinstitutional prospective cohort studies, and 24 retrospective or prospective single-institution studies.

Frequency of ETV for Hydrocephalus Secondary to CNS Tumors

Table 1 displays a summary of the literature on frequency of ETV use for tumor-associated hydrocephalus. The cause of hydrocephalus was neoplasia in 29% to 55% of ETV cases analyzed. In the largest studies (> 1000 patients), the cause of hydrocephalus was neoplasia in approximately 35% of ETV cases. The overall pooled frequency from all primary studies (excluding review articles) was 38.6%, whereas the mean (± SD) frequency was 39.5% ± 9.0%. Few studies reported the percentage of tumor by subtypes, but in the studies that did so, posterior fossa tumors and midbrain/tectal tumors were the most common subtype.

ETV Failure Rates in Tumor-Related Hydrocephalus

Table 2 displays a summary of the literature that reported ETV failure rates for tumor-related hydrocephalus. In the largest studies analyzed (> 100 patients undergoing ETV for tumor-related hydrocephalus), the failure rate of ETV ranged from 10% to 38.6%. Overall, failure rates

TABLE 1. Frequency of ETV use for tumor-associated hydrocephalus

Authors & Year	Design, Level of Evidence	Pt Population	Frequency	Tumor Subtype/Location
Madsen et al., 2018	Systematic literature review (130 studies), level III*	11,952 ETVs in children w/ any-cause hydrocephalus	Pooled mean: 34.1% (SD 17.2%)	NR
Bouras & Sgouros, 2011	Systematic literature review (34 studies), level III*	2985 ETVs in 2884 adult & pediatric pts for any-cause hydrocephalus	37.6%	NR
Kulkarni et al., 2016	International prospective cohort, level II	336 pts who had ETV for any-cause hydrocephalus	137 (41.0%)	21.2% midbrain; 14.4% posterior fossa; 5.4% supratentorial
Lam et al., 2014	National database retrospective review, level III	501 pts who had ETV for any cause	209 (41.7%)	NR
Kulkarni et al., 2010[15]	International prospective cohort, level II	1209 pts who had ETV (n = 489) or VPS (n = 720) for any-cause hydrocephalus	175 (35.8% of all ETVs)	NR
Naftel et al., 2011	Single-institution consecutive case series, level IV	151 pts who had ETVs btwn 1995 & 2009	72 (47.7%)	5 (6.9%) supratentorial; 46 (63.9%) midbrain; 21 (29.2%) posterior fossa
Kulkarni et al., 2009	International cohort from 12 institutions, level II	618 pts who had ETV for any cause	182 (29.4%)	62 (34.1%) midbrain tectal; 120 (65.9%) nontectal
Beuriat et al., 2017	Single-institution retrospective review, level III	975 pts treated for hydrocephalus; 280 pts who had ETV	155 (55.4%)	NR
Feng et al., 2004	Single-institution retrospective review, level III	58 pts who had ETV for any-cause hydrocephalus	21 (36.2%)	NR
Furlanetti et al., 2012	Consecutive case series, level IV	114 pediatric pts who had ETV for any-cause hydrocephalus	33 (28.9%)	NR

NR = not reported; pt = patient.

* Data presented from systemic reviews were not included in the overall calculations of pooled/mean frequencies of ETV for tumor-associated hydrocephalus. The overall pooled/mean frequency calculations are derived from primary studies only.

ranged from 6% to 38.6%. The overall pooled failure rate from all primary studies (excluding review articles) was 18.3%, whereas the mean (± SD) failure rate was 17.4% ± 8.6%. Postoperative follow-up ranged from 6 months to 8 years. Timing of ETV (pre- vs postresection ETV) and tumor subtype by study are shown.

Figure 2 displays failure rates by publication year of each study. No difference in failure rate by study year was seen on linear regression analysis ($R^2 = 0.016$, $p = 0.61$).

Comparison of ETV and VPS Failure Rates for Tumor-Associated Hydrocephalus

Table 3 compares failure rates and time to failure for ETV versus VPS in pediatric patients with tumor-associated hydrocephalus. There were only 5 studies with direct comparison of ETV versus VPS specifically for tumor-associated hydrocephalus. Two studies (those by El-Ghandour[7] and Beuriat et al.[1]) reported a significantly lower failure rate with ETV than with VPS, whereas 3 studies (those by Dewan et al.,[4] Sainte-Rose et al.,[35] and Ruggiero et al.[34]) did not report significantly lower ETV failure rates compared with VPS. Regarding time to failure, Dewan et al.[4] reported a significantly shorter time to failure for ETV than for VPS ($p = 0.03$), whereas El-Ghandour[7] did not find a significant difference in time to failure.

Discussion

As enthusiasm for the use of ETV in the treatment of hydrocephalus as a whole has grown, understanding the benefits of ETV in tumor-associated hydrocephalus may improve overall outcomes. Here, we have reviewed the literature on ETV in tumor-related hydrocephalus, including the relative frequency of ETV use in patients with this disorder and the failure rates of ETV in this population. Tumors, particularly in the posterior fossa, were reported as the etiology of hydrocephalus in 29% to 55% of all ETVs performed. The ETV failure rate ranged from 10% to 38.6% in the largest studies analyzed. No differences were observed for failure rate by study year. Only 5 studies directly compared ETV with VPS for tumor-associated hydrocephalus, and they reported mixed results regarding superiority in regard to failure rate and time to failure.

Frequency of ETV for Tumor-Related Hydrocephalus

Tumor was the etiology of hydrocephalus in 29%–55% of ETV cases in the studies reported. Two systematic literature reviews, one by Bouras and Sgouros[3] and the other by Madsen et al.,[23] demonstrated that 34.1% ± 17.2% (pooled mean ± SD) and 37.6% of pediatric ETVs, respectively, were performed for tumor-associated hydrocephalus. These findings are similar to those that Kulkarni et al.[15] found in an international prospective cohort (35.8% of all ETVs were for tumor-related hydrocephalus). Slightly higher rates were reported by Lam et al.[19] (41.7% of patients in the cohort), Beuriat et al.[1] (55.4%), and Naftel et al.[28] (47.7%). Generally, the rates of ETV use for tumor-related hydrocephalus have not increased over time. The

TABLE 2. Failure rates of ETV for tumor-related hydrocephalus

Authors & Year	Design, Level of Evidence	Pt Population	ETV Failure Rate & Follow-Up Duration	Pre- or Post-Resection ETV	Tumor Subtype/Location
Lam et al., 2014	National database retrospective review, level III	501 pts who had ETV for any etiology; 209 pts w/ tumor	24.9% (52/209), 1 yr; 38.6%, 5 yrs	NR	NR
Kulkarni et al., 2009	International cohort from 12 institutions, level II	618 pts who had ETV for any etiology; 133 pts w/ tumor	27.8% (37/133), 6 mos	NR	88 nontectal tumors; 45 tectal tumors
Beuriat et al., 2017	Single-institution retrospective review, level III	975 pts treated for hydrocephalus; 280 pts treated w/ ETV; 155 pts w/ tumor	10.3% (16/155), 1 yr	NR	NR
Sainte-Rose et al., 2001	Single-institution consecutive series, level IV	206 pts who had surgery for posterior fossa tumor; 67 pts treated w/ ETV	7.5% (5/67), mean 2.2 yrs	Pre	46% medulloblastoma; 24% ependymoma; 21% astrocytoma; 3% ganglioglioma; 3% PNET; 3% other
Dewan et al., 2017	Time-to-failure analysis via a systematic review & single-institution retrospective review, level III*	408 pts who had ETV &/or VPS for posterior fossa tumor–related hydrocephalus	21% cumulative ETV failure for tumor, median 26 mos	NR	49.5% medulloblastoma; 24.7% astrocytoma; 23.3% ependymoma; 2.6% other
Morelli et al., 2005	Single-institution retrospective review, level III	160 pts w/ posterior fossa tumors; 22 pts treated w/ ETV for hydrocephalus	18% (4/22), 12 mos	Mixed pre & post	26% pilocytic astrocytoma; 19% ependymoma; 17% medulloblastoma; 14% WHO II astrocytoma; 5% WHO III astrocytoma; 19% other
Frisoli et al., 2019	Single-institution retrospective review, level III	74 pts w/ hydrocephalus who had posterior fossa tumor resection; 38 pts treated w/ ETV	16% (6/38), mean 5 yrs	Pre	44.7% medulloblastoma; 39.5% WHO I astrocytoma; 7.9% ependymoma; 5.3% ATRT
O'Brien et al., 2006	Single-institution series, level III	42 pts w/ hydrocephalus & midline tumors	32% (13/41; 1 pt excluded from follow-up), mean 32 mos	Intra-resection	24 pineal tumors; 9 tectal tumors; 3 midbrain tumors; 3 thalamic tumors; 1 pontine tumor; 1 3rd ventricular tumor
El Beltagy et al., 2010	Single-institution retrospective review, level III	40 pts w/ hydrocephalus who had posterior fossa tumor resection & preresection ETV	35.0% (14/40), mean 13 mos	Pre	21 medulloblastoma; 9 WHO I astrocytoma; 4 WHO II astrocytoma; 6 ependymoma
Bhatia et al., 2009	Single-institution retrospective review, level III	37 pts w/ hydrocephalus secondary to posterior fossa tumors who had preresection ETV	13.5% (5/37), mean 56 mos	Pre	42% medulloblastoma; 41% WHO I astrocytoma; 7% ependymoma; 10% other
El-Ghandour, 2011	Single-institution retrospective review, level III	53 pts w/ obstructive hydrocephalus due to posterior fossa midline tumors; 32 pts who had ETV	6.2% (2/32), mean 27 mos	NR	62.5% medulloblastoma; 37.5% ependymoma
Feng et al., 2004	Single-institution retrospective review, level III	58 pts who had ETV for any-cause hydrocephalus; 21 pts w/ tumor	19% (4/21); w/in 9 mos	NR	8 pineocytoma; 4 hemangioblastoma; 3 thalamic astrocytoma; 2 ependymoma; 2 medulloblastoma; 2 other
Tamburrini et al., 2008	Prospective single-institution cohort, level II	30 w/ persistent postresection hydrocephalus who had ETV; 104 pts treated w/ posterior fossa tumor resection	10.0% (3/30), NR	Post	12 WHO I astrocytoma; 10 medulloblastoma; 8 ependymoma
Furlanetti et al., 2012	Consecutive single-institution case series, level IV	114 pediatric pts who had ETV for any-cause hydrocephalus; 33 pts w/ posterior fossa tumors	9.1% (3/33), mean 65 mos	NR	NR

CONTINUED ON PAGE 5 »

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TABLE 2. Failure rates of ETV for tumor-related hydrocephalus

Authors & Year	Design, Level of Evidence	Pt Population	ETV Failure Rate & Follow-Up Duration	Pre- or Post-Resection ETV	Tumor Subtype/Location
Ray et al., 2005	Single-institution retrospective review, level III	43 pediatric pts who had ETV for tumor-related hydrocephalus	26% (11/43), mean 24 mos	NR	14 brainstem; 9 posterior fossa; 6 thalamic; 4 midbrain; 3 pineal; 2 3rd ventricular; 5 other
Ruggiero et al., 2004	Single-institution retrospective review, level III	63 children w/ posterior fossa tumors; 20 w/ hydrocephalus & ETV	20% (4/20), mean 21 mos	Pre	7 medulloblastoma; 5 astrocytoma; 3 PNET; 2 ependymoma; 3 other
Li et al., 2005	Consecutive single-institution case series, level IV	31 pts w/ tectal glioma w/ hydrocephalus; 18 treated w/ ETV	11% (2/18), median 8 yrs	NR	Tectal glioma
Miwa et al., 2015	Multiinstitutional pt registry in Japan, level III	221 pediatric pts w/ CNS tumor; 177 pts w/ hydrocephalus; 101 treated w/ ETV	9.9% (10/101), mean 23.8 mos	Intra-resection/biopsy	42% germ cell tumor; 24% astrocytic tumor; 16% cystic lesions; 6% pineal tumor; 12% other
Macarthur et al., 2001	Consecutive single-institution case series, level IV	47 pediatric pts w/ tumor-related hydrocephalus treated w/ ETV	17.0% (8/47), median 12 mos	Intra-resection/biopsy	42% WHO I astrocytoma; 25% PNET; 6% ependymoma; 6% craniopharyngioma; 6% germinoma; 15% other

ATRT = atypical teratoid rhabdoid tumor; PNET = primitive neuroectodermal tumor.
* Data presented from systemic reviews were not included in the overall calculations of pooled/mean failure rates of ETV for tumor-associated hydrocephalus. The overall pooled/mean failure rate calculations are derived from primary studies only.

FIG. 2. ETV failure rate for tumor-associated hydrocephalus by publication year of each study (excludes data from meta-analyses/systemic reviews). Linear regression analysis demonstrated no significant difference in failure rate by year ($p = 0.61$).

rates of ETV reported in these studies for various locations or tumor subtypes varied substantially.

ETV Failure in Tumor-Related Hydrocephalus

In the largest studies analyzed (> 100 patients undergoing ETV for tumor-related hydrocephalus), the failure rate of ETV ranged from 10% to 38.6%.[4,17,19] Overall, failure rates ranged from 6% to 35%. ETV failure generally occurs quickly (within the first 3 months) but then the failure rate plateaus.[4] These failure rates are overall unsurprising and provide a frame of reference with which to counsel patients and families regarding the expected outcomes of ETV surgery.

Lam et al.[19] analyzed the national MarketScan database from 2003 to 2011 and determined that of the 209 patients with tumor-associated hydrocephalus who underwent ETV, 157 (75.1%) of the procedures were successful at 1 year. Furthermore, the 5-year success rate for ETV in this population of patients was 61.4%. The 5-year success rate for ETV in children with tumor-associated hydrocephalus was also found to be similar to that for other causes of hydrocephalus (65.5% with myelomeningocele, 52.3% with congenital etiologies).

Kulkarni et al.[17] reported data from an international cohort from 12 institutions. The authors included 618 patients who underwent ETV for any cause, 29.4% of whom (182 patients of 618 total) underwent ETV for tumor-related hydrocephalus. Ninety-six (72.2%) of 133 patients who underwent ETV for tumor-related hydrocephalus had treatment success at 6 months. Tectal tumors were associated with a higher ETV success rate at 6 months than nontectal tumors (82.2% vs 67.0%). Sainte-Rose et al.[35] reported a single-institution consecutive series of 206 patients, of whom 196 underwent surgery for treatment of hydrocephalus due to posterior fossa tumors. The authors stratified their population into 3 groups: 67 patients who underwent preresection ETV because hydrocephalus was present on admission (group A); 82 patients who had

TABLE 3. Comparison of failure rates of ETV and VPS for tumor-associated hydrocephalus

Authors & Year	Design, Level of Evidence	Pt Population	Length of Follow-Up	Failure Rate			Time to Failure (mos)		
				ETV	VPS	p Value	ETV	VPS	p Value
Dewan et al., 2017	Systematic review & single-institution retrospective review, level III	408 pts undergoing ETV &/or VPS for posterior fossa tumor–related hydrocephalus	Median 26 mos	21%	29%	0.105	Median 0.82	Median 4.7	0.03
Beuriat et al., 2017	Retrospective review of single-institution cohort, level III	975 pts treated for hydrocephalus; 280 pts treated w/ ETV (155 for tumor-related hydrocephalus); 695 pts treated w/ VPS (160 for tumor-related hydrocephalus)	1 yr	10.3% (16/155)	38.8% (62/160)	<0.001	NR	NR	NR
El-Ghandour, 2011	Single-institution retrospective review, level III	53 pts w/ obstructive hydrocephalus due to posterior fossa midline tumors	ETV: mean 27 mos; VPS: mean 25 mos	6.2% (2/32)	38% (8/21)	0.003	Mean 10.3	Mean 5.6	0.2
Sainte-Rose et al., 2001	Single-institution consecutive series, level IV	206 pts who had posterior fossa tumor resection; 67 undergoing ETV; 16 undergoing VPS	Mean 2.2 yrs	7.5% (5/67)	12.5% (2/16)	0.61	NR	NR	NR
Ruggiero et al., 2004	Single-institution retrospective review, level III	63 children w/ posterior fossa tumors; 20 undergoing ETV; 4 undergoing VPS	Mean 21 mos	20% (4/20)	0% (0/4)	NR	Mean 0.9	NR	NR

hydrocephalus present on admission but did not undergo ETV before resection (group B); and 47 patients who did not have evidence of preresection hydrocephalus (group C). In group A, 4 patients (6.0%) required VPS postresection and 1 patient required repeat ETV. In group B, 16 (19.5%) required VPS postresection ($p < 0.02$ compared with group A). No VP shunts were inserted in the group C population. Importantly, there were significant differences between groups A, B, and C with regard to anatomical tumor location and subtype (e.g., group A had more midline tumors and medulloblastomas compared with groups B and C).

Frisoli et al.[10] performed a retrospective review of 74 patients presenting with hydrocephalus who underwent posterior fossa tumor resection between 2005 and 2016. Pineal and tectal tumors were excluded. The most common tumor subtype was medulloblastoma (48.6%) followed by low-grade astrocytoma (35.1%). The 38 patients who underwent preresection ETV were compared with 36 historical control patients who underwent tumor resection but no preoperative or perioperative ETV. The rate of postoperative VPS was 31% in the non-ETV group compared with 16% in the ETV group ($p = 0.131$).

ETV Versus VPS in Tumor-Related Hydrocephalus

Numerous studies have compared ETV and VPS for treatment of pediatric hydrocephalus generally,[15,16,38] but few have specifically compared the two treatments for tumor-related hydrocephalus specifically. Dewan et al.[4] conducted time-to-failure analysis of ETV and VPS for hydrocephalus secondary to posterior fossa tumors via a systematic review and single-institution retrospective review. The study included 408 patients, 284 of whom were from the authors' institution. The cumulative failure rates were statistically similar for ETV and VPS, but the median time to failure was earlier for ETV than for VPS (0.82 [IQR 0.2–1.8] months vs 4.7 [IQR 0.3–5.7] months, $p = 0.03$). In the time-to-failure analysis, the ETV survival curve dropped sharply and then plateaued about 2 months postoperatively, whereas the VPS survival curve fell gradually but then crossed below the ETV curve at 5.7 months postoperatively ($p = 0.21$, log-rank test). The authors concluded that ETV failure occurred before VPS failure, but long-term success may be similar or higher for ETV. El-Ghandour[7] also compared ETV and VPS for posterior fossa tumor–related hydrocephalus in 53 pediatric patients, finding ETV to be superior to VPS because of the shorter length of surgery (15 minutes vs 35 minutes), lower morbidity (9.3% vs 38%), reduced mortality (0% vs 4.7%), and lower incidence of failure (6.2% vs 38%). The ETV failure rate at a 27-month mean follow-up was 6.2% versus a VPS failure rate of 38% at a 25-month mean follow-up ($p = 0.003$). Sainte-Rose et al.[35] reported an ETV failure rate of 7.5% at follow-up of 2.2 years versus a VPS failure rate of 12.5% at the same follow-up duration ($p = 0.61$) in patients with hydrocephalus secondary to posterior fossa tumor. Given the dearth of literature in this subpopulation of patients undergoing ETV, future prospective studies investigating efficacy and safety of ETV versus VPS in patients with tumor-related hydrocephalus are warranted.[14]

Although Riva-Cambrin et al.[32] did not analyze patients undergoing ETV, in 2016 the authors did analyze cause of VPS failure in the largest prospective study to date in 1036 children undergoing VPS placement. The rates of VPS failure were 29.3% in the posterior fossa tumor group and 30.1% in the "other" tumor group at a median follow-

up of 264 days. The failure rates they observed in children undergoing VPS for tumor-associated hydrocephalus are relatively similar to the ETV failure rates for children undergoing ETV for tumor hydrocephalus reported in the largest studies found in our current review (10%–38.6%).

Predictors of Good Outcome After Preresection ETV

In 2009, Riva-Cambrin et al.[31] published a scoring system to predict those pediatric patients who would require CSF diversion after posterior fossa tumor resection. The score consisted of 10 points: 3 points for age < 2 years, 3 points for cerebral metastases, 2 points for moderate or severe hydrocephalus, 1 point for papilledema, and 1 point for preoperative radiographic features consistent with an ependymoma, dorsally exophytic brainstem glioma, or medulloblastoma. High-risk patients were those with scores > 4 points, and low-risk patients were those with scores of 0–2. The rate of postoperative CSF diversion was 73% for high-risk patients and 25% for low-risk patients. Foreman et al.[9] published a modified version of the success score published by Riva-Cambrin et al.[31] in a cohort of 76 patients, finding that 4 variables were significant in predicting postresection hydrocephalus: age < 2 years, moderate/severe hydrocephalus, preoperative tumor diagnosis, and transependymal edema.

The original ETV Success Score (ETVSS) published by Kulkarni et al.[17] was developed to predict which pediatric patients would have the highest chance of hydrocephalus treatment success with ETV and was later validated in a multicenter cohort of 489 patients who underwent ETV.[16] The ETVSS is an estimate of the percentage probability of ETV success, ranging from 0% to 90% probability. There are 3 primary components: age, etiology, and history of previous shunt. Tumors are considered within the etiology component, with nontectal tumors adding 20% to the ETVSS, and tectal tumors adding 30% to the ETVSS. Overall, tumors portend a favorable increase in the ETVSS compared with other etiologies.

Complications of ETV

In the meta-analysis by Madsen and colleagues,[23] complications related to ETV were reported, although those specifically related to tumor-associated hydrocephalus were not analyzed. Overall perioperative mortality was 0.2% ± 0.1%, and the mean ETV failure rate was 34.7% ± 18.0%.

Texakalidis et al.[38] performed a meta-analysis comparing ETV and VPS for pediatric hydrocephalus including 8419 patients (not specifically for tumor-associated hydrocephalus), finding that infection was significantly lower in the ETV group (OR 0.19, 95% CI 0.07–0.53) but that mortality, postoperative CSF leakage, and reoperation rates were similar between groups.

Bouras and Sgouros[3] performed a systematic literature review including 2985 ETVs performed in 2884 patients from 34 studies. Importantly, the population included for this review was mixed (adult and pediatric). The early postoperative mortality rate was 0.21%. The overall complication rate was 8.5%. The rate of intraoperative hemorrhage was 3.7%, and the rate of severe intraoperative hemorrhage was 0.6% (including a 0.21% rate of basilar rupture).

Macarthur et al.[22] published a detailed report of complications encountered in 61 neuroendoscopic procedures for pediatric CNS tumors, 47 of which were ETVs for tumor-associated hydrocephalus. Only 1 death, 6 intraoperative hemorrhages, 4 CSF fistulas, and 1 deep infection occurred, and 9 extraventricular drains were required for temporary CSF diversion postoperatively.

El-Ghandour[7] analyzed complications related to ETV in a posterior fossa tumor cohort, reporting no mortality in 32 patients who underwent ETV, 1 case (3.1%) of CSF leak, and 2 cases (6.2%) of bleeding. Ray et al.[30] also analyzed ETV complications in a pediatric tumor-related hydrocephalus cohort, finding a total complication rate of 20.9% in 43 ETVs, including 1 infection and 3 cases of venous bleeding.

Patient Selection for ETV in Tumor-Related Hydrocephalus

Controversy exists regarding the necessity of default preresection ETV in posterior fossa tumor–related hydrocephalus.[5] Fritsch et al.[11] reported that in a single-institution series of 58 patients with posterior fossa tumors, 52 presented with hydrocephalus, but only 6 patients (11.5%) required permanent treatment for hydrocephalus at a mean follow-up of 25 months. Of those 6, 4 patients received a VP shunt and 2 patients underwent ETV. Morelli et al.[26] posed a similar question of the necessity of ETV in posterior fossa tumor–related hydrocephalus, finding that routine postoperative ETV may be beneficial in the treatment of persistent hydrocephalus, but not prophylactically, given that only 22 (13.8%) of 160 patients with posterior fossa tumors required treatment for hydrocephalus (ultimately with ETV) in the cohort.

In some populations of patients with CNS tumors, the overall survival prognosis brings into question the ethics of hydrocephalus treatment. For instance, Roujeau et al.[33] reported that in patients with hydrocephalus secondary to brainstem gliomas, the overall 1-year survival rate was 33%, and the survival rate of patients with obstructive hydrocephalus was not significantly different from that of patients who did not develop hydrocephalus despite treatment. Given the overall poor prognosis in these patients, the need for CSF diversion as a whole must be counterbalanced with overall patient outcome and quality of life.

ETV in Non–Posterior Fossa Tumors

Most of the studies analyzed in this review investigated patients who underwent ETV for posterior fossa tumors; however, several studies reported results from ETV for those with lesions outside the posterior fossa. For example, Macarthur et al.[22] reported a consecutive series of 61 neuroendoscopic procedures in 53 children with tumors, 47 of which were ETV for tumor-related hydrocephalus. Sixteen of the 53 tumors were cerebellar (30.2%), whereas 13 were brainstem (24.5%), 12 were third ventricular (22.6%), 5 were thalamic or hypothalamic (9.4%), 4 were pineal (7.5%), and 3 were classified as "other" location. Morgenstern et al.[27] determined that none of the 15 patients who underwent ETV for pineal region tumors in their study required repeat CSF diversion procedures at the 6-month follow-up. Hayhurst et al.[13] reported a small series of 11 patients who underwent ETV for hydrocephalus second-

ary to cerebellopontine angle tumors, with 7 (63.6%) of the patients remaining shunt-free at follow-up. Li et al.[20] published a consecutive case series of 31 patients with tectal glioma and hydrocephalus (cohort age range 6 weeks–20 years), 18 of whom were treated with ETV, and 2 (11%) of those 18 experienced ETV failure at long-term follow-up (median 8 years).

Molecular Diagnostics and Tumor-Related Hydrocephalus

New tools of molecular analysis have shed light on how different tumor subgroups may be more susceptible to developing hydrocephalus. For instance, Schneider et al.[36] reported that in a cohort of 143 medulloblastoma pediatric patients, no patient with the Wnt tumor subtype required CSF diversion procedures (ETV or VPS), whereas 29% of Shh, 29% of group 3, and 43% of group 4 patients required CSF diversion. Therefore, molecular diagnostic techniques may aid in stratifying the need for CSF diversionary procedures for patients with tumors harboring a variety of molecular signatures.

Limitations

This study has several limitations. We only searched the PubMed database and may have excluded contributory literature contained in other sources. Most of the studies reported herein are single-center retrospective studies, which limits the generalizability of results and also implies significant heterogeneity in patient management and surgical decision-making. We did not perform a meta-analysis, which limits how the data presented can be quantified or interpreted with any statistical significance. Furthermore, we did not assess patient characteristics (e.g., age differences, tumor subtype), hospital size/case volume, or technical differences in ETV operations between studies (e.g., use of Fogarty balloons for wider fenestration), which may affect failure rates.

Conclusions

The use of ETV in tumor-associated hydrocephalus is largely heterogeneous with regard to indications, timing, and tumor subtypes. The failure rate of ETV for tumor-associated hydrocephalus in the studies with the largest patient populations ranges from 10% to 38.6%. Although ETV has been reported to fail more than VPS in tumor-associated hydrocephalus in the short term, overall rates of success/failure may be similar over time, and the risk of infection appears to be lower in those patients undergoing ETV. Molecular tumor profiles may help predict those patients at higher risk of a CSF diversionary requirement associated with tumor resection. Nonetheless, treatment of tumor-associated hydrocephalus with ETV is relatively common (approximately 30% to 55% of all ETVs performed), and future studies are warranted to elucidate the role of ETV in this complex patient population.

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Disclosures

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Author Contributions

Conception and design: Sherrod. Acquisition of data: Sherrod. Analysis and interpretation of data: all authors. Drafting the article: all authors. Critically revising the article: all authors. Reviewed submitted version of manuscript: all authors.

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