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Endoscopic third ventriculostomy for treatment of adult hydrocephalus: long-term follow-up of 163 patients

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OBJECTIVE The efficacy of endoscopic third ventriculostomy (ETV) for the treatment of pediatric hydrocephalus has been extensively reported in the literature. However, ETV-related long-term outcome data are lacking for the adult hydrocephalus population. The objective of the present study was to assess the role of ETV as a primary or secondary treatment for hydrocephalus in adults.

METHODS The authors performed a retrospective chart review of all adult patients (age ≥ 18 years) with symptomatic hydrocephalus treated with ETV in Calgary, Canada, over a span of 20 years (1994–2014). Patients were dichotomized into a primary or secondary ETV cohort based on whether ETV was the initial treatment modality for the hydrocephalus or if other CSF diversion procedures had been previously attempted respectively. Primary outcomes were subjective patient-reported clinical improvement within 12 weeks of surgery and the need for any CSF diversion procedures after the initial ETV during the span of the study. Categorical and actuarial data analysis was done to compare the outcomes of the primary versus secondary ETV cohorts.

RESULTS A total of 163 adult patients with symptomatic hydrocephalus treated with ETV were identified and followed over an average of 98.6 months (range 0.1–230.4 months). All patients presented with signs of intracranial hypertension or other neurological symptoms. The primary ETV group consisted of 112 patients, and the secondary ETV consisted of 51 patients who presented with failed ventriculoperitoneal (VP) shunts. After the initial ETV procedure, clinical improvement was reported more frequently by patients in the primary cohort (87%) relative to those in the secondary ETV cohort (65%, $p = 0.001$). Additionally, patients in the primary ETV group required fewer reoperations ($p < 0.001$), with cumulative ETV survival time favoring this primary ETV cohort over the course of the follow-up period ($p < 0.001$). Fifteen patients required repeat ETV, with all but one experiencing successful relief of symptoms. Patients in the secondary ETV cohort also had a higher incidence of complications, with one occurring in 8 patients (16%) compared with 2 in the primary ETV group (2%; $p = 0.010$), although most complications were minor.

CONCLUSIONS ETV is an effective long-term treatment for selected adult patients with hydrocephalus. The overall ETV success rate when it was the primary treatment modality for adult hydrocephalus was approximately 87%, and 99% of patients experience symptomatic improvement after 2 ETVs. Patients in whom VP shunt surgery fails prior to an ETV have a 22% relative risk of ETV failure and an almost eightfold complication rate, although mostly minor, when compared with patients who undergo a primary ETV. Most ETV failures occur within the first 7 months of surgery in patients treated with primary ETV, but the time to failure is more prolonged in patients who present with failed previous shunts.

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KEY WORDS endoscopy; adult hydrocephalus; neuroendoscopy; ETV; endoscopic third ventriculostomy

ABBREVIATIONS APUCH = adults with previously untreated congenital hydrocephalus; ETV = endoscopic third ventriculostomy; iNPH = idiopathic normal pressure hydrocephalus; LOVA = longstanding overt ventriculomegaly in adults; VP = ventriculoperitoneal.

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The mainstay long-term treatment of hydrocephalus is cerebrospinal fluid (CSF) diversion either by the insertion of ventricular shunt or the creation of a ventriculocisternostomy.[20] Ventriculoperitoneal (VP) shunt insertion remains the most popular modality for treating hydrocephalus,[27] although up to 50% of VP shunts fail within the first 2 years after insertion.[3] Over the past 2 decades, a paradigm shift away from VP shunting and toward endoscopic third ventriculostomy (ETV) has occurred in the treatment of many forms of hydrocephalus.[14,15] There is now an abundance of literature on the long-term outcomes of ETV in the pediatric population, and some case-series have reported mixed pediatric and adult data.[4,8,19] Nevertheless, large population studies that have focused on the role of ETV in only adult hydrocephalus are comparatively lacking except for a few studies, which have only reported limited follow-up durations.[23,26,31,36] The objective of this article is to evaluate the long-term efficacy of ETV in the management of adult hydrocephalus in a large single-center population.

Methods

Patient Population

After obtaining University of Calgary's Institutional Review Board approval, a retrospective chart review was completed of all adult patients (age ≥ 18 years) who underwent ETV at Foothills Medical Centre from 1994 to 2014. Foothills Medical Centre is a tertiary care institution in Alberta, Canada, serving a population of approximately 2 million people residing in southern Alberta and parts of southwestern British Columbia. The choice to pursue an ETV rather than the insertion or revision of a VP shunt was based on the operating surgeon's clinical judgment, taking into consideration the etiology of the patient's hydrocephalus, technical aspects of each procedure, patient preference, and response to prior interventions. Patient information, such as demographics, symptomatology, imaging findings, and history of interventions for hydrocephalus, as well as occurrence of perioperative and delayed complications, was retrieved. The data were obtained from hospital and clinic registries, which included all archived hospital charts, imaging reports, operative reports, progress notes, multidisciplinary records, discharge summaries, and follow-up clinic notes. All surgeries were performed by two neurosurgeons with over 95% done by the corresponding author (M.G.H.).

Patient Selection Criteria and ETV Technique

Patients were identified as potential candidates for ETV if they presented with symptoms that were associated with an obstructive pattern of hydrocephalus. The typical hydrocephalus pattern was triventricular enlargement including a significant increase in the width of the third ventricle. Patients presenting without a history of treatment or with a failed shunt were offered the option of ETV at the discretion of the surgeon. While these patients were not part of a randomized trial or necessarily consecutive hydrocephalus patients, it has been the practice of the senior author to consider whether ETV was a possible option for all adult hydrocephalus patients at the time of initial assessment. The majority of the patients presenting with shunt malfunction (secondary ETV patients) had been previously treated by other neurosurgeons or at a very young age when ETV was not an available treatment option and did not have a shunt-related infection at the time of their initial presentation.

Endoscopic third ventriculostomy is performed via a standard, usually right-sided, precoronal incision with a 2-cm bur hole placed 3.0–3.5 cm from the midline, and either a rigid or flexible endoscope is used for all procedures. Our technique for creating the ventriculostomy involves perforation of the floor followed by expansion of the defect with either endoscopic forceps or the tip of the flexible endoscope. The goal, when possible, is to create a hole at least 2–3 times the scope diameter (> 10 mm). Any potentially obstructive membranes in the perimesencephalic cistern are also perforated. With respect to secondary ETVs, when we initially started doing these procedures, we undertook complete removal or ligation of the preexisting ventricular catheters and other shunt components. Nearly a decade ago, we evaluated our experience and determined that it was unnecessary as a routine part of the procedure, and stopped this practice. Today all preexisting shunts are left in situ unless there are obvious signs of a shunt-related infection. Following the ventriculostomy, the endoscope is withdrawn, and a small piece of cone-shaped Gelfoam is placed into the dural defect and secured with a small amount of Tisseel before standard wound closure.

Survey of the Preexisting Literature

A MEDLINE and EMBASE search for literature published over the past 10 years (2005–2015) was carried out to ascertain the extent of published data on adult ETV. The search was restricted to adults (age ≥ 18 years) and English-language articles only. Overall, 205 papers were retrieved, and these were then screened to select only those relevant to ETV. The abstracts of 70 shortlisted papers were further screened, eliminating any pediatric or combined pediatric-adult papers. Overall, only 18 papers met the described search algorithm (Fig. 1).

Statistical Analysis

IBM's SPSS (Statistical Package for the Social Sciences) Version 16.0 for Windows was used to tabulate and compute patient demographics and surgical outcomes and for all data analyses. The primary outcomes were patient-reported subjective clinical improvements within the immediate 6–12 weeks postoperatively and/or any subsequent need of a CSF diversion procedure, after patients had undergone their initial ETV. ETV success was defined as that which brought a resolution of clinical symptoms and that which lacked the need for a further CSF diversion procedure. Patient-reported outcomes were categorized as "improved," "no change," or "worsened" symptomatology. Each subject was assigned to one of two cohorts: a primary ETV group, which included all patients who underwent an ETV as the first treatment of their hydrocephalus, versus a secondary ETV group, which included any patient with a preexisting VP shunt. Independent-sample

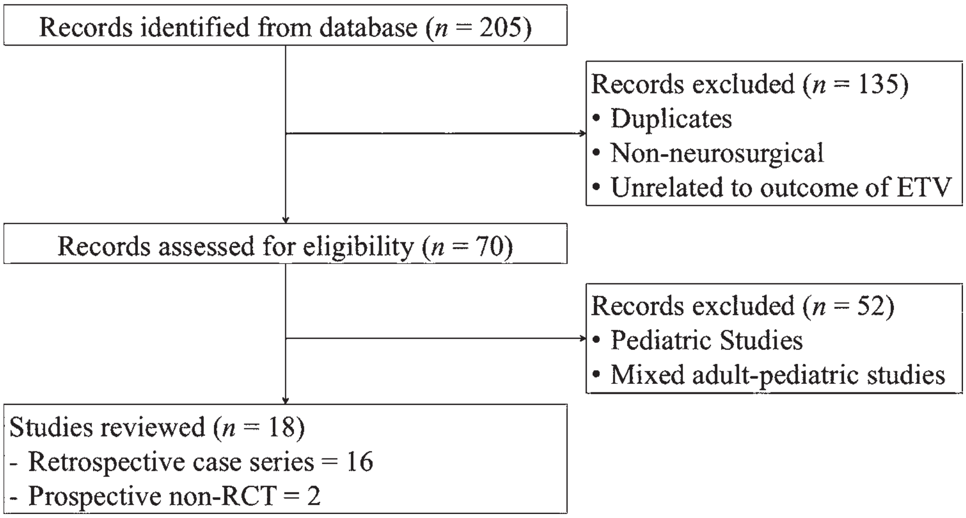

FIG. 1. Flow diagram depicting an ETV literature search. RCT = randomized controlled trial.

t-tests were used to compare groups with respect to scalar data, such as age at initial ETV. Fisher's exact tests were used to compare categorical data. For ordinal data, specifically patient-reported clinical outcomes, the Mann-Whitney U-test was used. Lastly, we used Kaplan-Meier survival analysis to compare time to ETV failure between the primary and secondary ETV groups, with significance being determined with the generalized Wilcoxon, Tarone-Ware, and Mantel-Cox tests. All tests were two tailed and results with $p \leq 0.05$ were considered to be statistically significant.

Results

Patient Characteristics

A total of 163 patients were identified (92 males and 71 females). Of these, 51 patients (31%) presented with shunt malfunctions, after a mean of 2 shunt revisions (range 0–26). The remaining 112 patients (69%) underwent ETV as an initial treatment for their hydrocephalus. The age of patients at the time of their initial ETV surgery was not normally distributed (Shapiro-Wilk test, $p = 0.006$), with an overall mean age of 46 ± 16 years (± SD; median 47 years, range 18–83 years). However, there was a difference between groups ($t = -3.903$, $p < 0.001$), with initial ETVs performed at 40 ± 14 years of age (median 37, range 20–67) in the secondary ETV cohort, and 50 ± 16 years of age (median 50 years, range 18–83 years) in the primary ETV cohort. All patients presented with symptomatic hydrocephalus with clinical findings consistent with either intracranial hypertension or other neurological symptoms, which were typically cognitive and gait difficulties.

The underlying origins (causes) and classification of the patterns of hydrocephalus across those etiologies are demonstrated in Table 1 and in Fig. 2. Classes of adult hydrocephalus were defined as follows: 1) acquired, 2) transitional (treatment initiated during childhood years), 3) longstanding overt ventriculomegaly in adults (LOVA) or adults with previously untreated congenital hydrocephalus (APUCH) (often also referred to as chronic congenital hydrocephalus, arrested hydrocephalus, or compensated hydrocephalus), and 4) idiopathic normal pressure hydrocephalus (iNPH).[12,24] Patients with congenital triventricular hydrocephalus were classified as having an "aqueductal pattern" to include those with triventricular hydrocephalus (enlargement of the lateral ventricles and the third ventricle) and either complete aqueductal obstruction or severe narrowing or the aqueduct with retained but reduced aqueductal CSF flow. An ETV was successfully completed in all patients. Twenty patients (12%) had an external ventricular drain placed before, during, or immediately after their ETV as a temporary adjunct in the management of acute intracranial hypertension.

One hundred twelve patients (69%) underwent primary ETV and 51 patients (31%) had secondary ETV as treatment for their hydrocephalus. Except for age and the type of hydrocephalus, there was no significant difference between the groups in terms of demographics, sex ($p = 0.610$), or etiology of hydrocephalus ($p = 0.104$). There was one case of iNPH in the secondary ETV group. The majority of patients in the primary ETV group presented with APUCH/LOVA (70%), while the secondary ETV group was predominated by transitional hydrocephalus (57%).

Outcome

The mean duration of follow-up was 8 years (98.6 ± 68 months; median 91.7 months, range 0.1–230.4 months). The duration of follow-up differed between the primary and secondary ETV groups, with the duration being somewhat longer (119.2 ± 69 months [range 0.1–225.2 months]) in the secondary ETV cohort than the primary ETV cohort (89.2 ± 66 months [range 0.3–230.4 months]). At the time of data analysis, 10 patients (8 from primary ETV group and 2 from the secondary ETV group) had died of causes unrelated to ETV.

At the first follow-up visit, within 6–12 weeks postoperatively, a total of 130 patients (80%) reported improve-

TABLE 1. Characteristics of 163 patients who underwent ETV*

Characteristic/Subcategory	Primary ETV	Secondary ETV	Total
Patients			
No.	112	51	163
Male	65 (58%)	27 (53%)	92 (56%)
Female	47 (42%)	24 (47%)	71 (44%)
No. of shunt revisions before 1st ETV			
0	—	11 (22%)	—
1	—	19 (37%)	—
2	—	7 (14%)	—
≥3	—	14 (27%)	—
Mean age (yrs) at 1st ETV	50 ± 16	40 ± 14	—
Management of shunt at time of 1st ETV			
Ligated	—	8 (16%)	—
Removed	—	16 (31%)	—
Unmodified	—	27 (53%)	—
Origin &/or pattern of hydrocephalus			
Aqueductal pattern†	75 (67%)	38 (75%)	113 (69%)
Tumor	19 (17%)	3 (6%)	22 (14%)
IVH	6 (5%)	3 (6%)	9 (6%)
Myelomeningocele	2 (2%)	5 (10%)	7 (4%)
Meningitis or TBI	3 (3%)	1 (1%)	4 (2%)
Cystic lesion	3 (3%)	1 (1%)	4 (2%)
Unspecified	4 (3%)	0 (0%)	4 (2%)
Classes of hydrocephalus			
Acquired	31 (28%)	2 (4%)	33 (20%)
Transitional	3 (3%)	29 (57%)	32 (20%)
APUCH/LOVA	78 (70%)	19 (37%)	97 (60%)
iNPH	0 (0%)	1 (2%)	1 (<1%)

IVH = intraventricular hemorrhage; TBI = traumatic brain injury; — = not applicable.

* Percentages are reported as proportions of corresponding cohorts in the same column.

† Aqueductal pattern refers to the congenital causes of aqueductal stenosis or aqueductal atresia associated with a pattern of triventricular hydrocephalus.

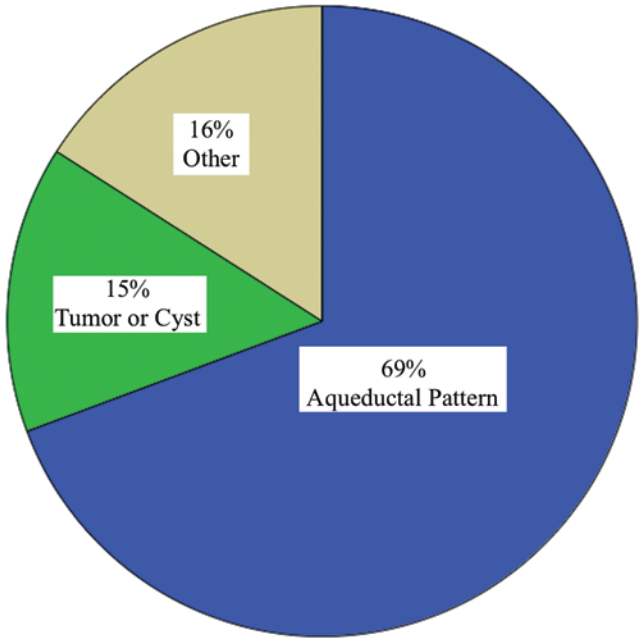

FIG. 2. Cause of hydrocephalus in 163 patients. "Aqueductal Pattern" refers to the congenital causes of aqueductal stenosis or aqueductal atresia associated with a pattern of triventricular hydrocephalus.

ment in their preoperative symptoms, 19 (12%) reported no change in their symptoms, and 14 (9%) reported a worsening of symptoms. When stratified by prior interventions for hydrocephalus, the primary ETV group exhibited better outcomes than the secondary ETV group (U = 2191.5, $p = 0.001$), with 97 patients (87%) reporting improvement and 4 (4%) describing a worsening in their symptoms, compared with 33 (65%) and 10 (20%) patients in the secondary ETV group, respectively. A logistic regression analysis was performed to examine the effects of primary versus secondary hydrocephalus, age at initial ETV, etiology of hydrocephalus, and sex on the likelihood of ETV failure. Failure of ETV was more commonly observed in patients with secondary hydrocephalus (OR 6.657, $p < 0.001$), while no significant association with age or sex was found. Figure 3 illustrates a detailed breakdown of symptomatic outcomes between the primary and secondary ETV groups.

An ETV was deemed to have failed if patients did not show improvement in symptoms within the first 12 weeks of their operation, had a recurrence of symptoms, or developed new symptoms consistent with hydrocephalus at any time postoperatively and had persistent or worsening hydrocephalus confirmed on postoperative imaging. The mean time to ETV failure was 3 months (range 0.2–6.9 months) versus 26 months (range 0.4–124.2 months) in the primary and secondary ETV groups, respectively. All ETV failures in the primary ETV group occurred within the first 2.5 years, but they were delayed up to 10 years in the secondary ETV group following the initial ETV procedure. Figure 4 demonstrates the time to ETV failure (in months) among the cohorts. Once ETV failure was established, the decision to revise the ETV or perform VP shunting was made by the surgeon on a case-by-case basis. Of the 33 patients who did not report improvement in their symptoms, 23 (70%) underwent a second operation. Of those 23 patients, 15 (65%) had another ETV procedure, 7 (30%) underwent revision of their previous VP shunt, and 1 had a new VP shunt inserted. The decision to reoperate was made more frequently in the secondary ETV group, with 16 patients (31%) undergoing a repeat operation compared with only 7 patients (6%) in the primary ETV group ($p < 0.001$). Cumulative survival time estimates in each cohort were assessed using a Kaplan-Meier curve (Fig. 4) and were found to significantly favor the primary ETV cohort (generalized Wilcoxon chi-square test = 13.489, $p < 0.001$). Survival estimates were 216 and 161 months for the primary and secondary ETV cohorts, respectively.

After undergoing a second procedure following the

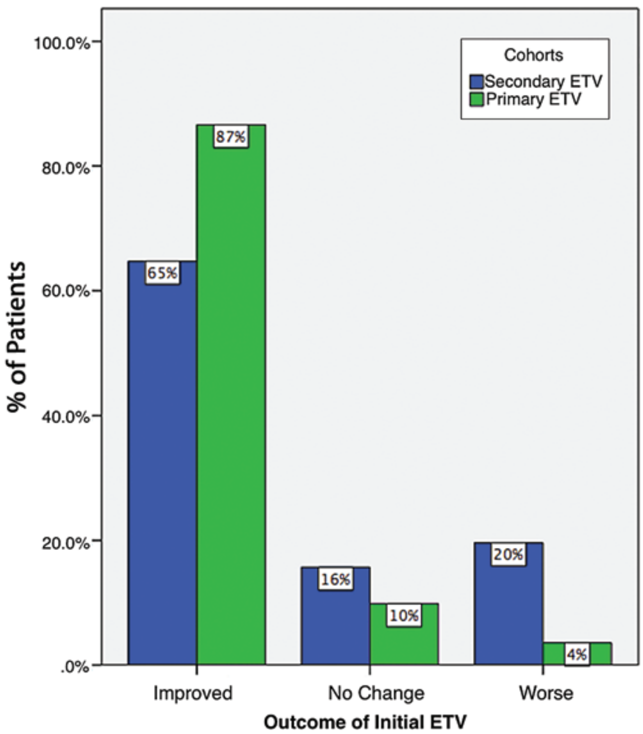

FIG. 3. Patient-reported symptom improvement after first ETV.

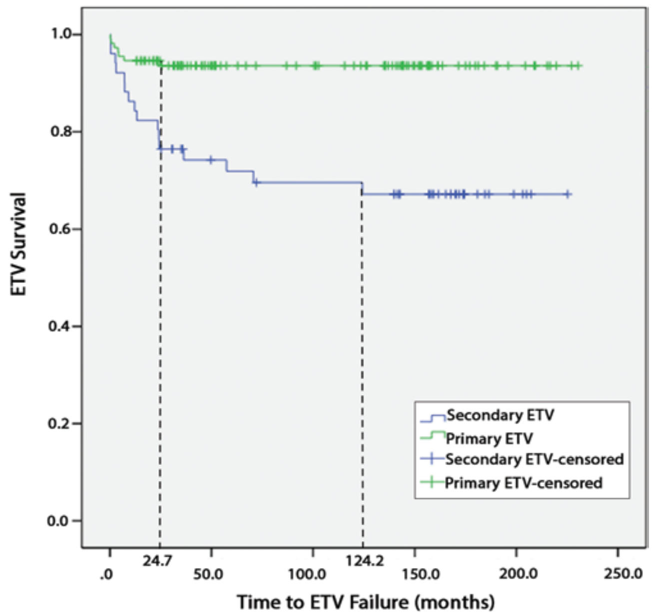

FIG. 4. Kaplan-Meier curves demonstrating time to ETV failure in primary and secondary ETV groups. The longest duration to initial ETV failure was 24.7 months and 124.2 months (*dotted lines*) among the primary and secondary ETV groups, respectively.

initial ETV, 111 of the 112 primary ETV patients (99%) had improvement of symptoms. Narrowing or complete closure of the third ventriculostomy site was identified in all but one of the primary ETV patients undergoing a second ETV. The remaining patient had a patent ostomy site and required a VP shunt before experiencing significant clinical improvement. Narrowing or complete closure of the third ventriculostomy site was identified in all but one of the secondary ETV patients undergoing a second ETV. The secondary ETV group, however, had 3 patients (2%) who remained symptomatic even after 3 procedures following their initial ETV and all had patent ostomy sites on MRI. Patients who underwent VP shunt revision or insertion after their initial ETV all had evidence of a patent ostomy site on MRI. Figure 5 is a graphic presentation of the trends in reoperation among cohorts.

Complications

Overall, 10 patients (6%) experienced complications related to their initial ETV procedure—2 patients (2%) and 8 patients (16%) in the primary and secondary ETV patient cohorts, respectively. Details of these complications are listed in Table 2. Radiographic images of some of these patient complications have been previously reported by Hader et al.[11] There were no cases of perioperative death.

A logistic regression analysis was done to examine the effect of various factors on the complication rates. Factors examined were primary versus secondary ETV, etiology of hydrocephalus, sex, and age at initial ETV. Complications were significantly more likely in patients with secondary than primary hydrocephalus (OR 5.023, $p = 0.011$). The average age of patients who sustained complications was 36.7 ± 12.5 years, which was younger than the overall average patient age, and was shown to be a significant predictor (OR 0.921, $p = 0.012$). Etiology of hydrocephalus and sex were not found to be significant factors. Fortunately, there were no complications that adversely affected long-term patient outcome.

Discussion

Most of the existing literature regarding the role for ETV in treating hydrocephalus deals with the pediatric population or includes mixed pediatric and adult patient populations. Studies that have presented specifically adult patients tend to have a small number of patients or short duration of post-ETV follow-up, often less than 3 years. The largest series published to date included 250 adult patients for whom the mean follow-up was 6 years.[9] The main indication for ETV in the adult population has been to manage diseases that create obstructive hydrocephalus. While there have been attempts to expand the scope of potential indications for ETV to include nonobstructive hydrocephalic diseases, such as iNPH,[5–7] conclusive data are still lacking.[32] The vast majority of reported experience with ETV in the adult population relates to patients presenting with a new diagnosis of an obstructive pattern of hydrocephalus. However, there is also an increasing experience with using ETV to treat patients presenting with shunt failure when there is an underlying diagnosis of obstructive hydrocephalus.[2,4,11] In this article we describe a population of 163 symptomatic adult patients with hydrocephalus who underwent ETV—112 patients treated primarily and 51 patients treated when they presented with VP shunt malfunction (secondary ETV); the mean and

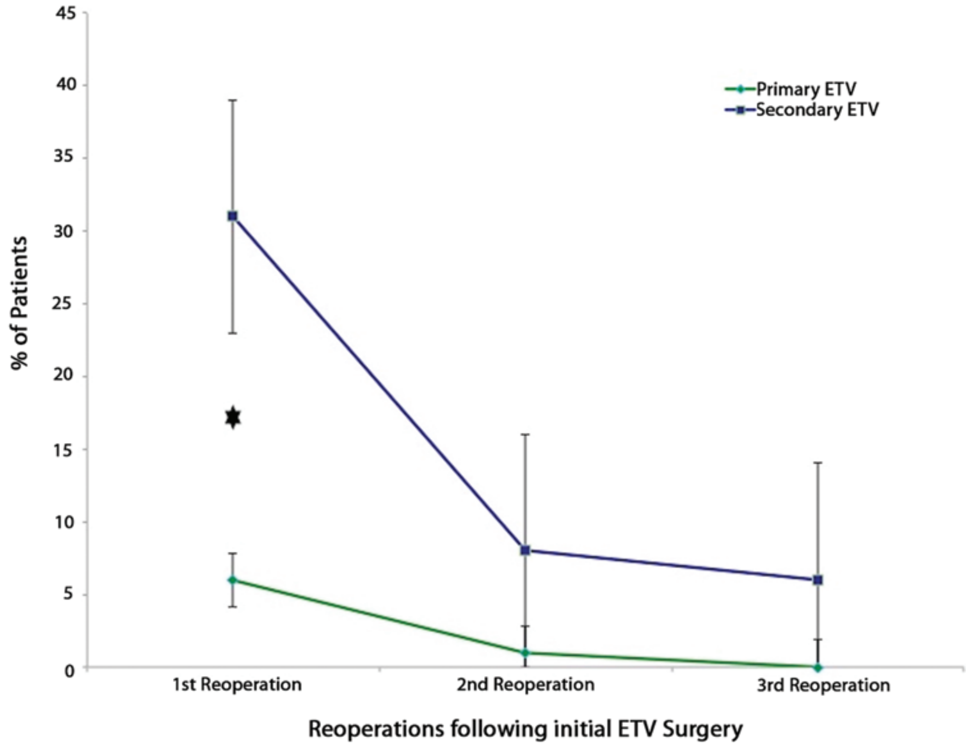

FIG. 5. Reoperations after initial ETV procedure.

median clinical follow-up duration was approximately 8 years. We also report the results associated with repeating ETVs in patients in whom the initial response was suboptimal or successful but subsequently failed.

Efficacy of ETV Treatment

In our population, the overall success rate of ETV as a primary modality for treating adult hydrocephalus was 87%, with 99% of patients obtaining subjective symptomatic improvement after 2 ETV procedures. Our ETV success outcomes fall within the range of outcomes that have been previously reported by other centers.[1,13,18,29,33,36] Some of the highest efficacy data were presented by Woodworth et al., who observed immediate improvements in 89% versus 71% of patients who underwent primary and secondary ETV, respectively.[35] In a larger cohort of 129 patients, Jenkinson et al. observed success rates of 83% and 67% in primary and secondary ETV groups, respectively.[13]

We have used ETV for treatment of symptomatic patients presenting with a failed VP shunt in both children and adult patients for 22 years.[11] Patients presenting with VP shunt failure initially had their shunts removed or ligated at the time of the ETV procedure. However, due to reported complications associated with the removal of nonfunctioning shunts, including injury to adherent brain tissue, intracranial hemorrhage, and prolonged operative time,[11,25,28,34] we now leave preexisting shunts in situ, except in cases of shunt infections. Thus far, we have not identified any adverse effects on secondary ETV outcomes in patients in whom nonfunctioning shunt have been left intact. Treatment-associated complications (Table 2) were low and did not have any long-term impact on patient outcome.

Long-Term ETV Treatment Outcomes

When discussing long-term outcomes for patients treated with ETV, it is important to compare these with the known results for VP shunts. Current VP shunt failure rates in adult patients still approach 15%–20% in the 1st year after treatment with first failure and repeat surgery occurring within 6–12 months.[21,22,30] In addition, long-term follow-up of shunt-treated patients demonstrated continued significant risk of shunt failure requiring repeat surgeries.[27]

Our results demonstrate that the long-term efficacy of ETV treatment in selected adult patients with hydrocephalus is significantly better than what can be currently achieved with VP shunts. Long-term follow-up in our population demonstrated a high probability of sustained ETV treatment efficacy with primary ETV patients rarely experiencing treatment failure after 7 months (Fig. 4). Even those patients who undergo secondary ETV do better in the long-term than shunt-treated patients, with over 60% of patients remaining shunt free at a mean follow-up of almost 10 years.

Issues Associated With ETV Treatment Failure

In our study, like many of the previous ones, we define ETV failure as the lack of symptomatic improvement requiring a revision surgery, whether it is a redo ventriculostomy or revision of an existing shunt or placement of

TABLE 2. Respective complications between groups and cumulative risks following ETV

Complication	Primary ETV*	Secondary ETV*	Cumulative Risk
Meningitis	0 (0%)	4 (8%)	2%
Epidural/subdural hematoma	1 (1%)	1 (2%)	1%
Weight gain	1 (1%)	1 (2%)	1%
Memory deficits	0 (0%)	1 (2%)	1%
Cranial nerve palsy	0 (0%)	1 (2%)	1%
Cumulative risk	2 (2%)	8 (16%)	6%

* Percentages are reported as proportions of corresponding cohorts in the same column.

a new shunt following the initial ETV procedure. Having a prior shunt to ETV portends a 22% relative risk of ETV failure, an outcome that has been reported in other studies.[13,35,36] As noted, the risk of ETV failure tends to occur at a much earlier stage in the primary ETV group, typically within the first 7 months postoperatively, and then plateau, whereas the risk of failure in the secondary group lingers on for a longer duration, as demonstrated on the Kaplan-Meier actuarial analysis (Fig. 4). One of the possible favorable factors for ETV success, especially in patients with chronic hydrocephalus undergoing a primary ETV, is that their tuber cinereum is usually very thin, which not only makes the ventriculostomy easier but also means the stoma will potentially remain open for longer. Patients who have preexisting shunts often do not have such a favorable third ventricle floor and may be at a higher risk for stoma closure.

Outcome Measures

The majority of reports, including ours, grade ETV success based on patient-reported subjective symptom changes and the avoidance of subsequent treatment with a VP shunt.[9,13,35] Documenting successful treatment of hydrocephalus in a patient with high intracranial pressure is easy to substantiate with this minimal standard, as the outcome of inadequate treatment should be sufficiently obvious because of the underlying life-threatening pathophysiology. It becomes more challenging when patients with chronic hydrocephalus are treated. These patients do not face the acute consequences of high intracranial pressure. They often present with longer-duration and progressive cognitive and gait/balance symptoms, which have both subjective and objective clinical features. Nevertheless, most clinical reports rely heavily on subjective measures of improvement when evaluating response to treatment. The same criticism can also be made for much of the shunt treatment literature.

It would be valuable to critically evaluate the cognitive outcomes in patients with chronic hydrocephalus undergoing ETV treatment. We reported the results of a small patient population of 13 patients in whom formal neuropsychology testing was used and demonstrated that ETV is capable of producing reliable improvements in cognitive dysfunction while treating hydrocephalus.[10] However, we also realized the challenges with doing this type of complex cognitive testing and have since instituted a protocol to assess cognitive function, activities of daily living, and quantitative gait assessment using video recording and gait velocity measurements. All of these can be accomplished within a relatively short time period during an outpatient clinic visit. This protocol is currently being used for all patients before and after treatment of hydrocephalus with ETV. We would encourage all future studies to incorporate objective testing of cognition and gait for this patient population.

Finally, our ultimate goal should be to develop quality of life measures for the adult patient, similar to what Kulkarni et al. accomplished for pediatric patients.[17] This will lead to a better understanding of the treatment outcome differences that are ultimately more relevant to our adult patients. In line with the need for quality-of-life measures, Kulkarni et al. also presented an ETV grading score to predict ETV success in pediatric patients. The ETV score has been validated on several occasions in the pediatric population and has proved itself as a versatile tool in guiding clinical decision making.[16] In 2015, Labidi et al.[18] applied Kulkarni's ETV Success Score to a mixed pediatric and adult population. Unfortunately, 50 of the 100 points in the Pediatric ETV Success Score are based on whether the patient is > 10 years of age, and half of the ETV Success Score value is automatically awarded when applied to adult patients. Thus, the ETV Success Score, in its current state, does not provide much capacity with regard to predicting ETV success in adult patients, and an alternative is required.

Limitations

Some of the limitations associated with the analysis of this patient population have been identified. Additional potential areas of concern relate to the nonrandomized nature of patient selection (i.e., selection bias). Further, while we defined clinical indications of ETV and shunt failure, we did not have specific measured criteria that define failure of ETV treatment. Finally, MRI was performed for almost all patients before and after ETV. However, except in more recently treated patients, we were unable to perform any sophisticated analysis of ventricular volume, flow through the third ventriculostomy site, or high-resolution evaluation to determine possible sites of obstructed CSF flow.

While these issues may be a limitation when attempting to compare the outcomes for treatment with ETV in all adult patients, this study nevertheless demonstrates very positive outcomes in this defined adult hydrocephalus patient population.

Conclusions

ETV is an effective long-term treatment for select adult patients with hydrocephalus. Overall ETV success rate as the primary treatment modality for adult hydrocephalus is approximately 87%, and 99% of patients obtain symptomatic improvement after 2 ETVs. Patients who fail VP shunt surgery prior to an ETV have a 22% relative risk of failure and an eightfold rate of complications, although mostly minor, when compared with patients who undergo a primary ETV. Most ETV failures occur within the first

7 months postoperation in primary ETV patients, but the time to failure is prolonged in patients who present with failed previous shunts. Future prospective studies should include objective measures of patient cognitive and gait function measure and quantified analysis of high resolution MRI, before and after ETV whenever possible, and objective criteria that specifically define treatment failure.

Acknowledgments

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Disclosures

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Author Contributions

Conception and design: all authors. Acquisition of data: all authors. 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. Approved the final version of the manuscript on behalf of all authors: Hamilton. Statistical analysis: Hamilton, Isaacs, Hader. Administrative/technical/material support: all authors. Study supervision: Hamilton, Isaacs, Hader.

Supplemental Information

Videos

Video Abstract. https://vimeo.com/177080581.

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