Endoscopic Third Ventriculostomy in 250 Adults With Hydrocephalus: Patient Selection, Outcomes, and Complications

**BACKGROUND:** Endoscopic third ventriculostomy (ETV) has been used predominantly in the pediatric population in the past. Application in the adult population has been less extensive, even in large neurosurgical centers. To our knowledge, this report is one of the largest adult ETV series reported and has the consistency of being performed at 1 center.

**OBJECTIVE:** To determine the efficacy, safety, and outcome of ETV in a large adult hydrocephalus patient series at a single neurosurgical center. In addition, to analyze patient selection criteria and clinical subgroups (including those with ventriculoperitoneal [VPS] malfunction or obstruction and neurointensive care unit patients with extended ventricular drainage before ETV) to optimize surgical results in the future.

**METHODS:** We conducted a retrospective review of adult ETV procedures performed at our center between 2000 and 2014.

**RESULTS:** The overall rate of success (no further cerebrospinal fluid diversion procedure performed plus clinical improvement) of 243 completed ETVs was 72.8%. Following is the number of procedures with the success rate in parentheses: aqueduct stenosis, 56 (91%); communicating hydrocephalus including normal pressure hydrocephalus, nonnormal pressure hydrocephalus, and remote head trauma, 57 (43.8%); communicating hydrocephalus in postoperative posterior fossa tumor without residual tumor, 14 (85.7%); communicating hydrocephalus in subarachnoid hemorrhage without intraventricular hemorrhage, 23 (69.6%); obstruction from tumor/cyst, 42 (85.7%); VPS obstruction (diagnosis unknown), 23 (65.2%); intraventricular hemorrhage, 20 (90%); and miscellaneous (obstructive), 8 (50%). There were 9 complications in 250 intended procedures (3.6%); 5 (2%) were serious.

**CONCLUSION:** Use of ETV in adult hydrocephalus has broad application with a low complication rate and reasonably good efficacy in selected patients.

**KEY WORDS:** Adults, Endoscopic third ventriculostomy, Hydrocephalus

**ABBRVIEATIONS:** ETV, endoscopic third ventriculostomy; EVD, external ventricular drain; ICP, intracranial pressure; IVH, intraventricular hemorrhage; NICU, neurointensive care unit; NPH, normal pressure hydrocephalus; SAH, subarachnoid hemorrhage; VPS, ventriculoperitoneal shunt

Ventriculoperitoneal shunt (VPS) placement continues to be the most widely utilized procedure for the treatment of hydrocephalus. Nevertheless, it is accompanied by frequent complications and malfunctions. Some studies have shown an overall shunt failure rate as high as 59%, with the majority of failures occurring within the first 6 months after shunt placement.1 In addition, the rate of long-term shunt failure in an individual going from childhood through adulthood over a 20-year period is in the range of 80%.2-3 Against this background, endoscopic third ventriculostomy (ETV) continues to capture clinical interest as an alternative to traditional VPS placement, more recently so in light of new concepts in cerebrospinal fluid (CSF) flow dynamics.4-10

Large series of patients with hydrocephalus treated by ETV have been published; however, these series were predominantly on pediatric
populations11-15 or combined pediatric and adult populations.16-21 Studies evaluating the utility of ETV in the treatment of all causes of adult hydrocephalus are less frequent.22,23 This report reviews the experience with 250 ETV procedures performed by a single neurosurgical service over a 14.5-year period for the management of a variety of conditions causing hydrocephalus in adults.

**METHODS**

**Study Design**

Institutional review board approval was obtained to conduct a retrospective review of all cases of adult patients (>17 years of age) with hydrocephalus in whom an ETV procedure was performed at our center between January 2000 and June 2014 (14.5 years). The categories consisted of aqueduct stenosis, intraventricular hemorrhage (IVH), communicating hydrocephalus, obstruction from tumor or cyst, VPS obstruction (diagnosis unknown), and miscellaneous (Table 1). Patients were classified as having communicating hydrocephalus if there was no obstruction (whether by an intra-axial or extra-axial mass, intraventricular blood, or periventricular edema or hemorrhagic mass) of CSF outflow from the ventricular system. The communicating hydrocephalus group was subdivided into patients with: (1) normal pressure hydrocephalus (NPH), non-NPH, and remote head trauma; (2) postcraniotomy for posterior fossa tumor without residual tumor; and (3) subarachnoid hemorrhage (SAH) without IVH (Table 1). The patients with communicating hydrocephalus postcraniotomy for posterior fossa tumor without residual tumor (Table 1) developed symptomatic hydrocephalus either years or months after total resection; in each case, there was no obvious persistent obstruction or recurrent tumor.

The diagnosis of hydrocephalus and categories were determined on the basis of computed tomographic (CT) imaging and/or magnetic resonance (MR) imaging obtained before the performance of an ETV and clinical history. Not all ETV patients had preoperative MR imaging of the brain. This was particularly true of patients in the neurointensive care unit (NICU) who had an ETV for removal of an external ventricular drain (EVD) and only had CT scans of the head. Another small group of patients had cardiac pacemakers, which precluded obtaining an MR scan.

Outcome following ETV was determined by chart review of hospital stay and postoperative clinic revisit records.

**Procedure**

Details of the standard preferred technique for the performance of ETV have been previously described (Figures 1 and 2).24,25 In brief, the burr hole is placed 3 cm from the midline and 1 cm in front of the coronal suture. The lateral ventricle is tapped with a soft ventricular catheter (Integra LifeSciences, Plainsboro, New Jersey), which is left in place during the procedure for continuous intracranial pressure (ICP) monitoring. A rigid 0-degree endoscope in a 4.6-mm double irrigating sheath (Minop, Aesculap, Tuttinglen, Germany) is introduced into the lateral ventricle by following the catheter25 under video guidance. The ventricular catheter is generally removed at the end of the procedure. Normal saline at a temperature of 90°F is used for irrigation. The volume of irrigation is monitored during the procedure. The endoscopic apparatus itself is used to pierce the floor of the third ventricle midway between the mammillary bodies and the infundibular recess (Figure 1). The floor of the third ventricle is classified as neural (opaque), translucent, or transparent. If there is a neural floor, the previously described “cookie cut”24 is made in the tuber cinereum by the endoscope apparatus to expose the membranous floor and membrane of Liliequist. This allows direct visualization of the location of the basilar complex before penetration (Figure 2). After piercing the exposed membranous floor, the endoscope is introduced into the prepontine cistern to confirm continuity with the third ventricle and visualize the basilar artery. A Gelfoam plug (Pfizer Inc., New York, New York) is inserted into the cortical tract at the end of the procedure. On occasion, if there is a tough fibrous floor, balloon dilatation of the stoma to approximately 5 mm after instrument perforation of the floor is used as an alternative technique. Electrocoagulation was never used on the floor of the third ventricle or on the edges of the stoma. VPSs were removed at the time of ETV only in cases of shunt infection.

![TABLE 1. Success Rate of Endoscopic Third Ventriculostomy According to Diagnostic Categories of Hydrocephalus in 243 Completed Procedures](https://www.neurosurgery-online.com)

<table>
<thead>
<tr>
<th>Category</th>
<th>Average Age, y</th>
<th>Female: Male</th>
<th>No. (%) of 243</th>
<th>Success per Category No. Pts. (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aqueduct stenosis</td>
<td>50</td>
<td>29:27</td>
<td>56 (23)</td>
<td>51 (91)</td>
</tr>
<tr>
<td>IVH</td>
<td>64</td>
<td>8:12</td>
<td>20 (8.2)</td>
<td>18 (90)</td>
</tr>
<tr>
<td>Communicating hydrocephalus</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Includes NPH, non-NPH, remote head trauma</td>
<td>65</td>
<td>17:40</td>
<td>57 (23.5)</td>
<td>25 (43.8)</td>
</tr>
<tr>
<td>Hydrocephalus postcraniotomy for posterior fossa tumor without residual tumor</td>
<td>55</td>
<td>8:6</td>
<td>14 (5.8)</td>
<td>12 (85.7)</td>
</tr>
<tr>
<td>SAH without intraventricular hemorrhage</td>
<td>61</td>
<td>13:10</td>
<td>23 (9.5)</td>
<td>16 (69.6)</td>
</tr>
<tr>
<td>Obstruction from tumor or cysta</td>
<td>53</td>
<td>22:20</td>
<td>42 (17.3)</td>
<td>36 (85.7)</td>
</tr>
<tr>
<td>VPS obstruction, diagnosis unknown</td>
<td>41</td>
<td>7:16</td>
<td>23 (9.5)</td>
<td>15 (65.2)</td>
</tr>
<tr>
<td>Miscellaneous cause (obstructive)</td>
<td>46</td>
<td>6:2</td>
<td>8 (3.3)</td>
<td>4 (50)</td>
</tr>
<tr>
<td>Overall success rate</td>
<td></td>
<td></td>
<td></td>
<td>72.8%</td>
</tr>
</tbody>
</table>

IVH, intraventricular hemorrhage; NPH, normal pressure hydrocephalus; Pts., patients; SAH, subarachnoid hemorrhage; VPS, ventriculoperitoneal shunt.

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Data Sources and Variables

Available medical records, operative reports, imaging studies, and follow-up visit reports were reviewed. Comparison of ventricular size before and after ETV was not documented consistently and was not included in the analysis. Any case requiring a further CSF diversion procedure after ETV (including insertion or reinsertion of an EVD) was considered a failure. However, there were other cases that were considered a failure, even though no further CSF diversion procedure was performed. In such cases, the patient’s condition either failed to improve or deteriorated after ETV; however, VPS placement was not performed because of patient refusal, family refusal, and/or comorbidities. Therefore, in this study, success of ETV was defined by no further CSF diversion procedure, as well as clinical improvement. Particular attention was drawn to the subgroups of ETV for communicating hydrocephalus, obstructed VPS, and extended external ventricular drainage in the NICU. Successful EVD removal was determined by an ICP reading below 20 cm H2O without opening for drainage, as well as relief of preoperative symptoms and signs. If the ICP remained below 20 cm H2O for 24 hours post-ETV and no clinical deterioration was observed, the EVD was removed.

RESULTS

Descriptive and Outcome Data

Our review identified 250 adult patients who were selected for ETV procedures during the study period. During the same time frame, there were 392 primary VPS procedures performed at our institution (57% communicating hydrocephalus; 43% obstructive hydrocephalus) that were not part of the ETV series reported here. Of the individual patients who had MR images of the brain, there were no patients rejected preoperatively for the ETV procedure because of the anatomic contour on MR imaging of the third ventricle, the basilar artery configuration, or the size of the prepontine cistern. We did not find the MR interpretation of the prepontine cistern or floor of the third ventricle particularly predictive of what we saw under direct vision while performing the ETV.

In 243 patients the ETV was completed. Seven of 250 cases (2.8%) were aborted after introducing the endoscope into the

FIGURE 1. Endoscope apparatus entering the prepontine cistern. A, the shaft and the tip of the 0-degree endoscope in the metal sheath with the 2 irrigating ports but no working channel. B, close-up drawing of the perforating end of the endoscope apparatus. Note the anterior sharp edge formed by the protruding 0-degree endoscope from the metal sheath. C, a lateral view depicting the endoscope in B penetrating the membrane of Liliequist into the prepontine cistern. Notice that the smooth posterior portion of the endoscope apparatus slides over the basilar complex. All is performed under direct vision with video guidance.
lateral or third ventricle. Reasons for aborting the ETV procedure were bradycardia (n = 1), lack of anatomic landmarks on the floor of the third ventricle (n = 2), abnormal head shape (n = 1), small foramen of Monro (n = 2), and no prepontine cistern with a posterior cerebral artery (P1) herniation into the field (n = 1). There were no complications in the aborted procedures. Our standard technique was abandoned for balloon dilatation in 19 of 243 (7.8%) completed ETV procedures but in only 3 of the last 140 procedures. Fifteen of 250 (6%) procedures were performed after left-sided burr-hole entry. Among the completed procedures, there were 3 redo/revision procedures.

Navigation was used to enter the lateral ventricles in 6.4% of the 250 ETV procedures and only when the ventricles were small or there was a shift in the midline structures or an anomaly of the cerebral hemisphere. We did not find any benefit in navigation helping to determine the point of entry into the floor of the third ventricle. When the prepontine cistern was narrow, we relied on direct vision with the endoscope to maneuver around the basilar complex and dorsum sella. The frequency of the need for navigation remained the same during the entire series.

The characteristics and success rate of the 243 completed ETV procedures according to the category of hydrocephalus are illustrated in Table 1. The age range of the patients was 17 to 88 years (mean, 51 years), with 128 men (52.7%), and a mean follow-up of 6 years (7 months to 14.5 years). The overall ETV success rate was 72.8% (Table 1).

Forty-six patients underwent ETV for malfunction of a preexisting VPS, with 35 (76%) successful ETV procedures in this subgroup (Table 2). Because of apparent critical dependence on the previous VPS, 5 of these patients had EVD placement at the time of ETV for postoperative ICP monitoring. Four of these EVD placements were in patients with VPS infection; only 1 of the 4 had a successful ETV. The single patient without VPS infection who underwent postoperative EVD placement had a successful ETV. Eight of our patients had the shunts placed before the age of 17 years and were in the pediatric-to-adult...
transition group as described by Reddy et al.³ Four of the 8 had successful ETVs. The duration between the initial VPS to subsequent ETV in this entire group of 46 patients averaged 25 years (mean 20 years). Of the 46 VPS patients, there were no NPH patients with a malfunctioning or obstructed VPS in whom an ETV conversion was attempted.

In the current total series of 250 patients, 41 patients in the NICU had an ETV to relieve dependence on an EVD (Table 3). The interval between EVD placement and ETV performance ranged from 10 to 18 days. The EVD was successfully removed 24 hours after ETV in 32 of 41 (78%) EVD-dependent patients.

Of the 66 ETV failures among 243 completed procedures, 28 patients subsequently underwent primary VPS, and 5 of those patients did not improve. Another 8 patients in whom ETV was a failure underwent VPS revision. The remaining 30 patients did not undergo subsequent VPS placement or any other CSF diversion procedure for reasons that included family refusal, patient refusal, and/or comorbidities. Nevertheless, these cases were counted as failures according to our definitions for procedural outcome. The 30 patients who did not undergo VPS or any other CSF diversion procedure after failed ETV included 3 deaths within 30 days post-ETV; 3 EVD-to-ETV failures in the NICU; 6 refusals of the patient (average age 71 years) and/or family in the communicating hydrocephalus group; 2 others in the communicating group (NPH) with strokes in the interim after ETV; 3 patients in the communicating group lost to follow-up; 3 patients with obstructive hydrocephalus in whom severe cardiac and medical problems prevented clearance for surgery; and 9 other patient and/or family refusals for VPS that included a supratentorial tumor, remote intraventricular tumor surgery, head trauma, postoperative arteriovenous fistula, postoperative posterior fossa arachnoid cyst, postoperative remote aneurysm surgery, aqueduct stenosis with persistent severe headache, a preoptic cyst, and SAH. One patient with communicating hydrocephalus (NPH) and a failed ETV had a VPS inserted without clinical improvement that shortly thereafter became infected. The VPS was removed, and the patient and family refused replacement.

In the current series of 243 ETVs, with the exception of the 3 late failures, all failures were evident within the first 6 to 8 weeks after ETV. The 3 early ETV redos were all done within the first 6 weeks after the initial ETV and 2 were successful. There were 2 other cases in the success group in which endoscopic reexploration was performed for recurrent headache as the only concern 5 and 8 years post-ETV, respectively. Both patients had open ETV stomas under direct view, and their ICP was monitored with an EVD for 3 days postoperatively. The prevailing ICP remained below 10 cm H₂O. Neither of the 2 patients had a VPS inserted and the headaches are minimal 7 and 2 years, respectively, later.

The ETV success rate in the first division of the communicating hydrocephalus group (includes NPH, non-NPH, remote head trauma; Table 1) was 43.8%. Four of the 10 patients in this division who had triventricular dilatation with a normal fourth ventricle had successful ETVs. This division of communicating hydrocephalus included 8 patients with remote significant head trauma, of whom 6 (75%) had successful ETVs. The higher rate of success of ETV procedures in posttraumatic hydrocephalus has been reported by others.²⁷,²⁸ In another 8 of 57 (14%) patients without head trauma in this category, headache was a significant concern. Six of those 8 patients had successful ETVs. Twenty-one of the 57 patients (37%) in this communicating hydrocephalus division had moderate to severe dementia, and only 6 of these 21 had a successful ETV. ETV was successful in 7 of 9 patients who had only gait disturbance. In the second division of the communicating group, the 14 patients with communicating hydrocephalus who underwent a craniotomy for posterior fossa tumor (Table 1) developed symptomatic hydrocephalus either years or months after total resection of a posterior fossa tumor. In each case, there was no obvious persistent obstruction or recurrent tumor. Five of the 14 patients already had a VPS and presented with shunt malfunction. Four of these 5 underwent successful ETV. ETV was successful in 12 of 14 patients (85.7%) in this group overall. Our experience with successful ETVs in the postoperative posterior fossa group is similar to that reported by others.²⁹,³⁰ The last division of the communicating hydrocephalus group was SAH without

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### TABLE 2. Endoscopic Third Ventriculostomy for Ventriculoperitoneal Shunt Malfunction in 46 Cases

<table>
<thead>
<tr>
<th>Reason for VPS, No. Patients</th>
<th>Average Age, y</th>
<th>Average Years Post-VPS</th>
<th>Successful ETV (No.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aqueduct stenosis, 11</td>
<td>51</td>
<td>21.5</td>
<td>11</td>
</tr>
<tr>
<td>Cause of hydrocephalus</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>unknown, 23</td>
<td>43</td>
<td>18.6</td>
<td>15</td>
</tr>
<tr>
<td>Obstruction from tumor, 5</td>
<td>60</td>
<td>22.3</td>
<td>5</td>
</tr>
<tr>
<td>Miscellaneous, 5</td>
<td>39</td>
<td>17</td>
<td>2</td>
</tr>
<tr>
<td>Trauma, 2</td>
<td>48</td>
<td>6.5</td>
<td>2</td>
</tr>
<tr>
<td>Overall success of ETV, 35</td>
<td></td>
<td></td>
<td>35/46 (76%)</td>
</tr>
</tbody>
</table>

*ETV, endoscopic third ventriculostomy; VPS, ventriculoperitoneal shunt.

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### TABLE 3. Patients With Extended External Ventricular Drainage in the Neurointensive Care Unit

<table>
<thead>
<tr>
<th>Factor</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age range in years (average)</td>
<td>28-83 (58.7)</td>
</tr>
<tr>
<td>Female, No.</td>
<td>20</td>
</tr>
<tr>
<td>Reason for EVD, No. of patients</td>
<td></td>
</tr>
<tr>
<td>Aqueduct stenosis</td>
<td>2</td>
</tr>
<tr>
<td>Hemorrhage</td>
<td>30</td>
</tr>
<tr>
<td>Tumor</td>
<td>5</td>
</tr>
<tr>
<td>Other</td>
<td>4</td>
</tr>
<tr>
<td>Day range EVD in place (average)</td>
<td>10-61 (14)</td>
</tr>
<tr>
<td>Successful removal of EVD after ETV</td>
<td>78% (32/41)</td>
</tr>
</tbody>
</table>

*EVD, external ventricular drain; ETV, endoscopic third ventriculostomy.*
in intraventricular obstruction or hemorrhage, in which the success rate was 69.6% (Table 1).

There were 9 complications in 250 intended ETV procedures (3.6%). Five complications (2%) were considered serious and included 1 case of subcortical brain abscess, 1 status epilepticus, 1 Terson syndrome (retinal hemorrhages), 1 subacute subdural hematoma (surgical), and 1 acute subdural hematoma (non-surgical). Other complications included 2 local wounds and 2 CSF leaks (the wound was oversewn). There were 2 surgical interventions for complications: 1 craniotomy for the subdural hematoma and 1 for the subcortical brain abscess.

There were 6 deaths in our series that occurred within 30 days postprocedure. Three of the deaths involved critically ill NICU patients in whom the EVD was removed because the ICP decreased after ETV. The other 3 deaths were from myocardial infarction, generalized sepsis in a patient with trisomy 21, and a giant posterior fossa aneurysm.

Eighty-five of the patients who underwent initially successful ETV procedures had 5 years or more of follow-up (Figure 3). Among these patients, there were 3 delayed failures (3/85, 3.5%) at 9, 18, and 36 months, respectively, after the ETV procedure. An attempt at reopening the stoma in the cases of delayed failure was unsuccessful.

DISCUSSION

Key Results and Interpretation

Overall Success

The overall success rate of 72.8% in adults in this large series is comparable to rates of 72%22 and 77%23 reported by others. Multiple outcome parameters to define ETV success have been proposed, including the measurement of ventricle size. However, successful ETV is not always well correlated with ventricle size.17 Success of ETV has also been defined as an outcome dependent on the absence of a further CSF diversion procedure, which in our study would include replacement of or inability to remove an EVD.20,24,31 However, in our series, we chose to further limit the definition of success by counting as ETV failures 30 patients who did not improve clinically after ETV and did not undergo further CSF diversion procedures, including VPS insertion, because of family refusal, patient refusal, and/or comorbidities. In adults in whom comorbidities and age are factors affecting the outcome of the ETV procedure, the definition of success should not be applied solely on the basis of no further CSF diversion procedure. In the current series of ETVs, with the exception of the 3 late failures, all failures were evident within the first 6 to 8 weeks after ETV. Our success and complications in ETV were not affected by the limited use of navigation systems.32

ETV and VPS Revision

Our patients with a previous VPS and known obstructive hydrocephalus (aqueduct stenosis or tumor) were optimal candidates for ETV for VPS malfunction, even if the VPS was performed many years before (Table 2). Headache alone in an ambulatory patient with a VPS was not the sole indication for ETV. VPS obstruction or malfunction in the current series included those with an isotope shunt study showing abnormal or no flow of CSF, enlarging ventricles from baseline, change in mental status, somnolence, acute incapacitating headache, emergency ventriculostomy or shunt tap to reverse neurological deterioration, and infection. If the VPS patient was critically dependent on the shunt preoperatively, a temporary EVD was placed for removal after a successful clamp test in the NICU, because the success of the ETV was not assured. Unless infected, residual VPS hardware was not removed routinely at the time of ETV.

There were 23 patients with VPS malfunction with an “unknown” cause of hydrocephalus of whom 15 became shunt-free after ETV (Tables 1 and 2). The 23 patients were included in the classification of “unknown” because: (1) there was no report or record of why the VPS was inserted; (2) MR imaging did not show aqueduct stenosis or brainstem deformity; there was no mass or cyst causing obstruction; and no mass in the cisterns; and/or (3) symptomatic obstruction of the VPS was documented. It is still possible that some patients had aqueduct stenosis, but this could not be clearly documented by us or the neuroradiologist (according to a written report). In addition, there were 3 patients who had remote complete resection of a posterior fossa tumor followed by VPS placement and presented decades later with symptomatic VPS malfunction. All 3 patients had successful ETVs, rather than VPS revision. In such cases, the hydrocephalus is presumed to be related to posterior fossa adhesions in the cisterns and/or fourth ventricle outflow obstruction.33 Buxton et al34 reported treatment of a mixed group of pediatric and adult patients in whom ETVs were performed for obstructed VPS with a success rate of 73% in the noncommunicating hydrocephalus group and an overall success rate of 52%. However, serious

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FIGURE 3. Kaplan-Meier graph showing the probability of successful treatment over time in 243 endoscopic third ventriculostomy (ETV) procedures completed between 2000 and 2014. Success was defined as no further cerebrospinal fluid diversion procedure performed in addition to clinical improvement. Flattening of the curve reflects few failures with time beyond 49 months.
complications occurred in 5.6%. O’Brien et al. reported an overall 70% success rate in ETV for obstructed VPS in a pediatric patient group. Hader et al. reported a high incidence of complications with ETV in patients with VPS malfunction. Woodworth et al. reported 71% immediate success with ETV for obstructive hydrocephalus in patients with VPS obstruction, but only 25% remained recurrence-free after 2 years. Baldauf et al. reported a 60% success rate with ETV in obstructed VPS in a mixed pediatric and adult population, but advised against ETV if no obstruction was identified on MR imaging. In our series, we did not have late failures in the 35 of 46 (76%) successful ETVs for shunt malfunction. In addition, we did not experience an increased rate of complications with ETV in previously shunted adult patients. All 11 (of 46) patients in whom ETV for shunt malfunction failed underwent uneventful subsequent VPS revision. One reason not to remove the VPS in noninfected cases is that the preexisting hardware is available for revision of the shunt should the ETV fail.

With increasing numbers of the pediatric VPS population transitioning into the adult group and an overall shunt failure rate over 20 years reported as high as 81% in this group, ETV may play an important role in increasing the number of shunt-free individuals. Neither technological advances in shunt systems nor the experience of large series has led to a reduction in VPS malfunction rates over the years.

ETV in Patients With Extended EVD
Since 2000, we have used ETV increasingly in patients in the NICU and, in particular, to avoid extended implantation of an EVD (Table 3). In the hemorrhagic group of EVD to ETV (n = 30, Table 3), there were 6 SAHs and 3 ETVs that were successful, all in cases of basilar hemorrhage. In the rest of the hemorrhagic patients (n = 24), CSF flow was obstructed by blood in the ventricle or thalamic hemorrhage. In 4 of these patients, the ETV failed. Patients who are in an intensive care unit or critical-care setting with EVD-dependent hydrocephalus, irrespective of cause, are at particular risk for infection. There is an increasing risk of infection at 5 days after EVD placement that escalates at 9 to 10 days. The overall infection rate in EVD-dependent patients can range from 9% to 31%. Before the year 2000, patients on our neurosurgical service with extended EVD and failure of clamping at 10 days or more had permanent CSF diversion with a VPS.

With respect to patients with IVH who are dependent on EVDs, previous reports of ETV are mixed among pediatric and adult groups, and ETV success rates range from 50% to 100%. The severity of hemorrhage has not been found to be a significant factor in determining the success of the ETV, and the hydrocephalus is presumed to be caused by obstruction of the CSF circulation or at the aqueduct. Oertel et al. reported 19 patients with IVH and extended EVD placement at a mean interval of 8 days before ETV. Fifty percent of patients improved postoperatively, and patients were subjected to endoscopic intraventricular clot removal during the procedure. Among the EVD-dependent patients in our series, there were 8 cases of IVH and 3 of thalamic hemorrhage with 1 post-ETV failure. No intraventricular clot was removed during ETV performance or EVD placement. In addition, we used ETV successfully for EVD dependence in 4 patients with nonaneurysmal SAH with large preopticine clots. The 3 failures in the hemorrhage group were in cases of aneurysmal SAH (2 anterior communicating artery aneurysms, 1 giant posterior fossa aneurysm).

In no case of IVH or SAH was visualization of the third ventricle floor hindered at the time of ETV. At times, the endoscope was used to push formed clot aside to pass into the third ventricle and also on occasion to push formed clot downward in the prepontine cistern to make a “pocket” for drainage through the ETV stoma. The 1 complication of ETV in the EVD-dependent group was a case of SAH from an anterior communicating artery aneurysm postclipping in which extended EVD placement was required after failed ETV. A subcortical abscess developed before VPS insertion. In the EVD-dependent group subjected to ETV, no recurrent or intraoperative hemorrhages occurred in any of the patients with SAH, IVH, or thalamic hemorrhage. In the SAH group, ETV was only performed in coiled or surgically clipped aneurysmal SAH or in angiographically negative nonaneurysmal SAH.

Communicating Hydrocephalus and Aqueduct Stenosis
We preferred to use the broad classification of communicating hydrocephalus to include the NPH cases as well. In the adult, distinguishing features between aqueduct stenosis and communicating hydrocephalus (including NPH) may not be apparent. In particular, the triad of gait, incontinence, and dementia can be seen in adults with aqueduct stenosis. Some of the controversy depends on how one defines aqueduct stenosis and how critically one looks at the details of the brain MR imaging in an adult presenting with ostensibly communicating hydrocephalus and presumably with NPH, as well. Triventricular dilatation alone was not used as the sole criteria for the diagnosis of aqueduct stenosis. Headache is a significant concern in aqueduct stenosis, but in our series, ETV afforded relief of headache in some patients with communicating hydrocephalus.

Our patients were classified into the aqueduct stenosis category when there was a recognizable nonmass constriction in the aqueduct (or membrane), a proximal “trumpet” deformity of the aqueduct, and triventricular dilatation with a normal fourth ventricle. Relying solely on triventricular dilatation for the diagnosis of aqueduct stenosis may lead to attributing aqueduct stenosis to many patients with communicating hydrocephalus (including NPH). Our method of classifying aqueduct stenosis in the selection of patients for ETV yielded a 91% (51/56) success rate and, in general, is consistent with other reports.

In the process of reviewing the medical records and imaging reports of the 243 ETV procedures, 6 cases were moved to other
classifications. Three of the 6 were moved to the aqueduct stenosis category from the communicating hydrocephalus group. The other 3 were moved from the NPH to the non-NPH communicating group. Pinto et al\textsuperscript{26} reported significant previous events and previous medical problems in more than 50% of patients initially classified as having NPH and reclassified them into other non-NPH groups. In our series, 18 of the communicating group of 57 patients (Table 1) were classified as straightforward NPH patients (average age 76 years, range 68-87 years) with an ETV success rate of 33%. The NPH subgroup excluded all patients with head trauma, previous VPS placement, headache, or any central nervous system event in the past. Two NPH patients had only gait disturbance and both had successful ETVs. There have been previous reports of success rates (neurological improvement) after ETV for idiopathic NPH in the 72% range, more frequently in patients with predominant gait disturbance than in those with predominant dementia.\textsuperscript{52}

The application of ETV to communicating hydrocephalus seems counterintuitive at first glance. However, the complexity of CSF dynamics beyond simple models of CSF production and absorption has been recently appreciated.\textsuperscript{53} The translocation of bulk CSF flow,\textsuperscript{53} ventricular wall compliance,\textsuperscript{54} vascular pulse pressure dynamics,\textsuperscript{55,56} and venous sinus obstruction\textsuperscript{57} are factors that can be affected by an ETV in cases of communicating hydrocephalus.

There was a separate group of 14 patients with communicating hydrocephalus postcraniotomy for posterior fossa tumor (Table 1) who developed symptomatic hydrocephalus either years or months after total resection. In each case, there was no obvious persistent obstruction or recurrent tumor. Five of the 14 patients already had a VPS and presented with shunt malfunction. Four of these 5 underwent successful ETV. ETV was successful in 12 of 14 patients (85.7%) in this group overall. Our experience with successful ETVs in the postoperative posterior fossa group is similar to that reported by others.\textsuperscript{29,30}

Complications

There were 2 patients early in our series with delayed arousal from general anesthesia. Each patient initially showed alarming signs of fixed dilated pupils, generalized muscular rigidity, and dysconjugate gaze on early arousal from anesthesia. Neither patient awoke with residual deficit. Both cases predated careful attention to irrigation volume and ensuring that the normal saline used for irrigation was maintained at 90°F. Both patients had ETVs before the routine introduction of ICP monitoring at our center. Schroeder et al\textsuperscript{21} reported 3 patients with confusion and decreased levels of consciousness after ETV. Attention to the volume of irrigation and its temperature as well as ICP changes during ETV and other intraventricular endoscopic procedures has been emphasized by others.\textsuperscript{58-63}

The patient who experienced status epilepticus, which occurred 1 day after ETV, sustained permanent cognitive loss and had the most serious complication in our series. The Terson syndrome developed in a 34-year-old man with a posterior third ventricle mass who had an ETV as an initial procedure but awoke with blurred vision, acuity with correction of 20/100 bilaterally, and bilateral retinal hemorrhages. His vision fully recovered in 1 year to 20/20 OD and 20/30 OS with normal fields. The 1 case of a subacute subdural hematoma occurred in a 28-year-old man with aqueduct stenosis who returned 1 month after ETV with recurrent headaches. A CT scan of the head revealed a large subacute subdural hematoma over the right convexity on the side of the ETV entry point. He required a craniotomy and recovered uneventfully. There was 1 case of acute subdural hematoma on the side of the ETV that resolved uneventfully, without surgical intervention and with no permanent deficit.

In our series of ETVs, there were no instances of vascular injury to the basilar complex as reported by others.\textsuperscript{20,64-68} In adults, tortuosity and herniation of the basilar complex against the floor of the third ventricle can put the P1 segment of the posterior cerebral artery particularly in the path of the penetration of the floor of the third ventricle during ETV.\textsuperscript{69} With an opaque neural floor, this creates even more uncertainty of the position of the major branches of the basilar complex under the floor of the third ventricle.\textsuperscript{22,24} With our technique, coring (“cookie cut”) of the neural floor (tuber cinereum) exposes the thin membrane of the floor, allowing one to see the silhouette of the basilar complex.\textsuperscript{24} Others have used low-energy infrared lasers\textsuperscript{70} or water-jet dissection\textsuperscript{71} to remove the neural opaque floor. There were no cases of postoperative hypothalamic storm, hyperthermia, or diabetes insipidus in our series, although these complications have been reported by others.\textsuperscript{64-66,72}

In the current 250 intended procedures for ETV, there were no cases of postoperative parenchymal or intraventricular hematomas related to the ETV. All 250 patients had postoperative CT scans of the head within 24 hours. With our current technique, a ventricular catheter is in place and the endoscope follows the identical path into the lateral ventricle with each pass.\textsuperscript{25} Navigation was used in only 6.4% of the 250 ETV procedures; therefore, its application was not a factor in the low incidence of postoperative hematoma. Grunert et al\textsuperscript{50} reported no correlation between stereotactic guidance in ETV procedures and severe complications. In previously reported non-ETV groups involving simple ventricular puncture for EVD placement, Ko et al\textsuperscript{27} reported a 20.5% rate of hemorrhage on CT scans after EVD placement, but only 1.4% of all cases were symptomatic. In addition, they reported a 43.1% hemorrhage rate on CT scans in patients who underwent the placement of ventricular catheters for VPS, but neurological change in only 2.9%. Kakarla et al\textsuperscript{74} reported a 5% hemorrhagic complication rate associated with bedside EVD placement, with 1.2% of that EVD population symptomatic. Woernle et al\textsuperscript{49} reported an incidence of 3.6% of hemorrhagic complications after EVD with fewer occurrences for the more experienced surgeon. Conversely, in previous ETV series, the incidence of postoperative parenchymal hemorrhage has been in the range of 1% or less.\textsuperscript{21,64-66,76} Thus, it seems that the postoperative ETV rate of intracerebral hemorrhage is less than
that reported for simple ventricular EVD placement, despite the larger diameter of the ETV tract (4-6 mm) compared with a standard ventricular catheter (2.8 mm). Certainly, ETV is not without risk; and in elderly patients as well as in NPH patients, the morbidity can be significant.77

Three successful ETVs are reported in the group of 6 deaths because the patients were in the NICU and the EVDs were removed from those who experienced a decrease in ICP after ETV. The other 3 deaths were included among the failures because the signs and symptoms in those patients did not improve before death from other causes (1 myocardial infarction, 1 generalized sepsis in a patient with trisomy 21, and 1 giant aneurysm).

Limitations

The definition of success after ETV relies, to a great extent, on the narrative of the physician in follow-up examinations and, as previously mentioned, no further CSF diversion procedure. However, our retrospective review of the records did find 30 patients with unsuccessful ETVs who did not undergo further CSF diversion. In the extended EVD group, the sole determination of success was the removal of the EVD after ETV and no further CSF diversion or EVD replacement. The unknown is whether these patients would have required an ETV if the EVD had been left in place for a longer period. The assumption is that the ETV shortened the time in the NICU, reduced the incidence of infection, and saved some patients from the implantation of a VPS.

CONCLUSION

ETV has been a practical alternative to VPS at our institution for the treatment of adult hydrocephalus for the past 14.5 years. Of particular significance has been the application of ETV in cases of VPS malfunction (rather than shunt revision), in some cases of communicating hydrocephalus, and in extended external ventricular drainage in patients in the NICU. ETV in our series has been very effective in all forms of obstructive hydrocephalus. Because of the low success rate of ETV in pure NPH patients, we do not recommend ETV in that group. In our limited experience with communicating hydrocephalus after supratentorial tumor surgery, the application of ETV is questionable. This is in contrast to the high success rate of ETV for communicating hydrocephalus in postoperative posterior fossa tumor patients (even remote). In SAH, ETV should only be considered for angiographically negative nonaneurysmal SAH or in totally protected postoperative cerebral aneurysm patients. The best candidates for ETV in SAH are those patients with predominantly basal SAH or intraventricular third ventricle extension. As a general principle, in adult patients with communicating hydrocephalus, one should be cautious in the assessment for ETV because the success rate is improved by a history of head trauma, younger age group, and any central nervous system event, particularly in the basal cisterns. The broad use of ETV in adult communicating hydrocephalus is still unsettled, and we only recommend ETV in patients with communicating hydrocephalus in the various subgroups outlined in our reported series. The overall success rate of 72.8% and the low complication rate in 243 completed ETVs (250 procedures) performed at our center have made the procedure quite acceptable as an alternative to VPS for properly selected patients. Over the years, our paradigm has shifted to determining first whether a patient is a candidate for ETV and then, if not, defaulting to VPS placement.

Disclosures

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