Extra-axial endoscopic third ventriculostomy: preliminary experience with a technique to circumvent conventional endoscopic third ventriculostomy complications

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OBJECTIVE Endoscopic third ventriculostomy (ETV) is mostly safe but may have serious complications. Most of the complications are inherent to the procedure’s intra-axial nature. This study aimed to explore an alternative route to overcome inherent issues with conventional ETV. The authors performed supraorbital, subfrontal extra-axial ETV (EAETV) via the lamina terminalis.

METHODS This prospective study began in October 2021 and included patients with obstructive triventricular hydrocephalus with a Glasgow Coma Scale score of 8 or more and a minimum follow-up of 3 months. Patients with multiloculated hydrocephalus and those younger than 1 year of age were excluded. The preoperative parameters etiology, symptoms, Evans’ Index, frontal occipital horn ratio (FOHR), and third ventricle index were recorded. The surgical procedure is described. Postoperative evaluation included clinical (modified Rankin Scale [mRS]) and radiological assessment with CT and cine phase-contrast MRI. Preoperative and postoperative parameters were compared statistically.

RESULTS Ten patients were included in this study. Six patients had acute hydrocephalus, and 4 had chronic hydrocephalus. After EAETV, all patients showed clinical improvement. An mRS score of 0 or 1 was achieved in 9 patients, but the mRS score remained at 4 in a patient with tectal tuberculoma. There was a significant reduction in Evans’ Index, FOHR, and third ventricle index after EAETV (p < 0.05). The mean percent reduction in Evans’ Index was 20.80% ± 13.89%, the mean percent reduction in FOHR was 20.79% ± 12.98%, and the mean percent reduction in the third ventricle index was 37.45% ± 14.74%. CSF flow voids were seen in all cases. The results of CSF flow quantification parameters were as follows: mean peak velocity 3.82 ± 0.93 cm/sec, mean average velocity 0.10 ± 0.05 cm/sec, mean average flow rate 46.60 ± 28.58 μL/sec, mean forward volume 39.90 ± 23.29 μL, mean reverse volume 34.10 ± 15.98 μL, mean overall flow amplitude 74.00 ± 27.61 μL, and mean stroke volume 37.00 ± 13.80 μL. One patient developed a minor frontal lobe contusion. The frontal air sinus was breached in 5 patients, but none had CSF rhinorrhea. Transient supraorbital hypesthesia was seen in 3 patients. No patient had electrolyte disturbance or change in thirst or fluid intake habits.

CONCLUSIONS EAETV is a feasible, safe, and effective surgical alternative to conventional ETV.

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KEYWORDS extra-axial endoscopic third ventriculostomy; EAETV; complications of ETV; hydrocephalus; surgical technique

ENDOSCOPIC third ventriculostomy (ETV) is the most common physiological treatment for hydrocephalus. Although safe in expert hands, ETV may have infrequent but dreaded complications. The overall complication rate varies from 2% to 15%.1–4 The lamina terminalis is a semitransparent membrane forming the anterior wall of the third ventricle. A success rate of nearly 70% after transventricular lamina terminalis fenestration using a flexible and rigid endoscope has been reported.5 Many procedural complications of conventional ETV can be avoided by using a subfrontal extra-axial approach for lamina terminalis fenestration. Few surgeons have performed microscopic subfrontal lamina terminalis fenestration with 100% success.6,7
The reported use of the endoscope for subfrontal lamina terminalis fenestration is limited to cadaveric studies only. The procedural safety and clinical efficacy of this procedure remain uncertain in living beings. To our knowledge, the present study is the pilot study describing ETV through the lamina terminalis via an extra-axial supraorbital minicraniotomy for managing hydrocephalus in pulsating brains. We describe the safety, efficacy, and surgical nuances of the extra-axial ETV (EAETV).

**Methods**

This prospective study began in October 2021 after approval by the institution’s scientific and ethical committee. Written consent was obtained from study participants. We included hemodynamically stable patients with obstructive triventricular hydrocephalus with a Glasgow Coma Scale score of 8 or more and a minimum follow-up of 3 months. Patients with multiloculated hydrocephalus and those younger than 1 year of age were excluded. During the study period, a total of 14 patients underwent EAETV; of these patients, 10 completed the 3-month follow-up and were included in this study.

**Preoperative Evaluation**

The etiology of hydrocephalus, symptoms, Evans’ Index (maximum distance between the two frontal horns divided by the maximum biparietal diameter), frontal occipital horn ratio (FOHR) (average of the maximum distance between the two frontal horns plus the maximum distance between the two occipital horns divided by the maximum biparietal diameter), and third ventricle index (maximum width of the third ventricle divided by the maximum biparietal diameter) were recorded. In patients with acute hydrocephalus, preoperative fundus findings were documented. Preoperative fundus findings and visual acuity were recorded in cases of chronic hydrocephalus.

**Surgical Procedure**

The surgical technique was designed by the principal author (S.K.). The surgical technique in a case of acute hydrocephalus is demonstrated in Video 1.

**VIDEO 1.** Surgical steps of the EAETV. © Sanjeev Kumar, published with permission. Click here to view.

The steps of EAETV in a case of chronic hydrocephalus are showcased in Fig. 1.

**Positioning**

Patients were positioned supine under general anesthesia with the head rested above the torso on a horseshoe rest. The head was extended to 10°–20° to facilitate gravity-induced fallback of the frontal lobe (Fig. 1A). Local anesthesia (2% xylocaine with adrenaline) was infiltrated at the right eyebrow.

**Incision and Exposure**

A curved skin incision was made along the eyebrow extending from the supraorbital foramen to the lateral orbital rim up to the level of the lateral canthus. The incision was taken down to the periosteum, and the scalp flap was raised in a subperiosteal fashion. Care was taken to avoid injury to the supraorbital nerve and vessels. A piece of temporalis muscle was dissected off and retracted just enough to place a key burr hole. The dura mater was dissected off the bone, and a minicraniotomy of approximately 3 × 2 cm was made (Fig. 1B and C). Brain decongestants were used judiciously (mannitol 1 g/kg, propofol 50–150 μg/kg/min, and end-tidal CO₂ 30–35 mm Hg). The dura was opened linearly and retracted with sutures.

**Brain Retraction and Endoscope Insertion**

The frontal lobe was dynamically retracted with the suction cannula over cotton patties. This created space for entry of the rigid endoscope (Hopkins II: 4-mm diameter, 18-cm length, 0°, without sheath; Karl Storz) (Fig. 1D). During the initial dynamic retraction, we used a single-handed technique until the release of CSF and brain relaxation. A right-handed surgeon used his left hand for suction and his right hand for the endoscope. We did not use a scope holder for endoscope stabilization. A scope holder can be used depending on the surgeon’s preference.

**Arachnoid Dissection**

As the endoscope traverses the anterior cranial fossa floor, there may be some blood ooze from the dura as the endoscope and the suction tip graze against the dura. These small oozes are self-limiting. After traversing the anterior cranial fossa floor and reaching the planum sphenoidale (Fig. 1E–G), optic nerve and ipsilateral internal carotid artery, enclosed in arachnoid membrane, are identified (Fig. 1H). An arachnoid knife and nerve hook were used for arachnoid dissection. At this stage, the surgeon switched over to bimanual technique, and the assistant surgeon held the endoscope while the operating surgeon used their left hand for suctioning and right hand for dissection. CSF drainage helped to further relax the brain. Further arachnoid dissection exposed the optic nerve. The ipsilateral optic nerve was traced up to the optic chiasm, and the ipsilateral anterior cerebral artery (ACA) was identified. The contralateral optic nerve and ACA were identified with further medial arachnoid dissection. The lamina terminalis was seen as a semitransparent membrane. The bilateral ACA–anterior communicating artery (ACoM) complex was minimally dissected to widen the exposure of the lamina terminalis (Fig. II–L).

**Fenestration**

Once the lamina terminalis was widely visible, it was fenestrated with sharp-tipped equipment (bayonet forceps or endoscissors) (Fig. 1M). No monopolar or bipolar coagulation was required. The stoma was further widened. Because the stoma is near the optic apparatus and hypothalamus, we did not use a Fogarty balloon catheter for stoma widening. The floor of the third ventricle was inspected through the stoma (Fig. 1N–P).

**Closure**

After satisfactory wide fenestration of the lamina terminalis, the dura was closed primarily. The dura was slightly stripped off the anterior cranial fossa floor to aid tensionless watertight closure. The bone flap was replaced and

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fixed. The surgical incision was closed in layers without a drain (Fig. I–T).

**Postoperative Evaluation**

All patients underwent radiological evaluation with noncontrast CT on postoperative day 1 and at discharge. The follow-up clinical and radiological assessments were done at a minimum follow-up period of 3 months. Neurological outcomes were evaluated using the modified Rankin Scale (mRS). Ophthalmological assessment was done with fundus examination, visual acuity, and field charting. The preoperative parameters were compared with postoperative results. In all patients except one with tectal tuberculoma, cine phase-contrast MRI was performed after 3 months to check the stoma's patency and quantification of CSF flow (3T Magnetom and Argus Flow Analysis software, Siemens). A CSF flow study was done before lesion decompression in a patient with tectal tuberculoma. The MRI study protocol was adopted from the existing literature. Three through-plane image sequences (phase image, magnitude image, and rephased image) were used for CSF flow quantification. The region

**FIG. 1.** Case 7. Surgical steps of EAETV in a patient with chronic hydrocephalus. A: Patient positioning. B: Incision and exposure. C: Supraorbital craniotomy (3 × 2 cm, insets). D: The endoscope. E: Retraction of the anterior dural flap. F and G: Subfrontal entry of endoscope and brain retraction. H: Arachnoid membrane enveloping the right optic nerve (white arrow) and the thinned and bulging lamina terminalis (black arrow). I: Opening of the arachnoid with an arachnoid knife. J–L: Arachnoid dissection with nerve hook, olfactory tract (J, white arrow), and A1 segment of the ACA (K, white arrow) are seen. M: The thinned-out lamina terminalis was opened during arachnoid dissection, with a jet of CSF flowing out (white arrow). N: Anterior third ventricle endoscopic view. The left posterior clinoid (black arrow), left oculomotor nerve (white arrow), and left mammillary body are seen. O: The basilar artery (white arrow) and its branches (posterior cerebral artery and superior cerebellar artery) are visible. P: The premammillary membrane (white star) is seen along with both mammillary bodies (black arrows). The white arrow indicates the dilated proximal aqueduct. Q: Wide fenestration of the lamina terminalis. A prefixed chiasm (white arrow) is appreciable. R: Lax brain before wound closure. S: Three-dimensional CT reconstructed image. The bone flap is fixed with titanium miniplates and screws. T: Clinical photograph of the patient with a scar on the right eyebrow. Figure is available in color online only.
of interest was placed at the fenestration site. The quantitative parameters of peak velocity, average velocity, average flow rate, forward volume, reverse volume, overall flow amplitude (OFA; forward + reverse volume), and stroke volume (average of forward and reverse volume) across stoma were recorded. The qualitative (flow voids) results were extracted from in-plane sequences.

Statistical analysis was performed using IBM SPSS (version 23, IBM Corp.). Age, ventricular indices, and CSF quantification parameters are expressed as mean ± SD. The preoperative parameters were compared with postoperative parameters using paired-samples t-test; p < 0.05 was considered significant.

Results

Ten patients were included in this study. The overall mean age was 35.20 ± 20.28 years (range 6–63 years). There were 7 males and 3 females. Six patients had acute-onset hydrocephalus and 4 had chronic hydrocephalus. In patients with acute-onset hydrocephalus, 3 had an intracerebral bleed, 2 had aqueductal stenosis with acute decompression, and 1 had aqueductal stenosis with multiple shunt revisions and malfunctions. Among the 4 patients with chronic hydrocephalus, 3 had aqueductal stenosis and 1 had tectal tuberculoma. The fundus was unremarkable in 2, 7 had papilledema, and 1 had optic atrophy. The pre- and postoperative clinical and radiological characteristics of patients are shown in Table 1.

All patients showed clinical improvement. Nine patients achieved an mRS score of 0 or 1, but the mRS score remained at 4 in a patient with tectal tuberculoma. Papilledema resolved in all 7 patients. Visual acuity remained static in all 4 patients with chronic hydrocephalus. The patients with chronic hydrocephalus had improvements in headache and gait ataxia.

Overall, there was a significant reduction in the Evans’ Index, FOHR, and third ventricle index after EAETV. In all 6 patients with acute hydrocephalus, there was a significant reduction (p < 0.05) and normalization of the Evans’ Index, FOHR, and third ventricle index. In 4 patients with chronic hydrocephalus, the Evans’ Index, FOHR, and third ventricle index were significantly decreased (p < 0.05) but not normalized. Overall, the mean percent reduction in Evans’ Index was 20.80% ± 13.89% (range 10.26%–57.53%), the mean percent reduction in FOHR was 20.79% ± 12.98% (range 7.08%–40.75%), and the mean percent reduction in third ventricle index was 37.45% ± 14.74% (range 11.36%–59.74%). In patients with acute hydrocephalus, the mean percent reduction in Evans’ Index was 25.80% ± 16.35% (range 14.72%–57.53%), the mean percent reduction in FOHR was 27.72% ± 12.44% (range 15.03%–40.75%), and the mean percent reduction in third ventricle index was 46.63% ± 9.11% (range 36.34%–59.74%). In patients with chronic hydrocephalus, the mean percent reduction in Evans’ Index was 13.29% ± 2.86% (range 10.26%–16.71%), the mean percent reduction in FOHR was 10.40% ± 2.63% (range 7.08%–13.39%), and the mean percent reduction in third ventricle index was 23.68% ± 9.63% (range 11.36%–31.95%) (Tables 1 and 2 and Figs. 2–4).

The results of CSF flow quantification parameters were as follows: mean average peak velocity 3.82 ± 0.93 cm/sec, mean average velocity 0.10 ± 0.05 cm/sec, mean average flow rate 46.60 ± 28.58 μL/sec, mean forward volume 39.90 ± 23.29 μL, mean reverse volume 34.10 ± 15.98 μL, mean OFA 74.00 ± 27.61 μL, and mean stroke volume across the stoma 37.00 ± 13.80 μL (Table 3).

Our first patients developed retraction-induced clinically silent frontal lobe contusion. The frontal air sinus was breached in 5 patients, but none had CSF rhinorrhea. Transient supraorbital hypesthesia was seen in 3 patients, who all improved. One patient had a dural tear during craniotomy and developed pseudomeningocele, which subsided at 2 months. No patient had electrolyte disturbance or change in thirst or fluid intake habits. There was no optic nerve injury or visual deterioration in any case.

Discussion

History of Lamina Terminalis Fenestration for Hydrocephalus

The ideology of fenestration of the lamina terminalis for managing hydrocephalus dates to 1922, when Walter Dandy managed 6 patients with unsatisfactory results because of the need to sacrifice one optic nerve. Dandy eventually abandoned the procedure. In 1936, Stookey and Scarff performed lamina terminalis fenestration through a supraorbital approach in 6 patients. In 1963, Scarff presented a literature review of 425 patients with a 70% success rate. In Scarff’s surgical illustrations, the procedure required a bicoronal flap, frontal craniotomy, ventricular tap, and puncture of the lamina terminalis and floor of the third ventricle with the unaided eye. During the same era, the introduction of ETV with decreased complication and increased success rates led to a decline in the interest of lamina terminalis fenestration.

Van Lindert successfully performed a microscopic lamina terminalis fenestration through a supraorbital approach in 2 patients with slit ventricle syndrome. Meybodi and Miri treated 8 patients with hydrocephalus by subfrontal microscopic third ventriculostomy via the lamina terminalis with 100% success. Iacoangeli et al. used a supraorbital craniotomy and microscopic lamina terminalis fenestration for removal of posterior third ventricle tumors. Following microscopic lamina terminalis fenestration, they introduced the endoscope for tumor removal. After tumor removal, in 4 of 7 patients, they performed conventional ETV through prefrontal or prefrontal membrane under neuronavigation as an add-on procedure. Their systemic review of transventricular lamina terminalis fenestration (7 studies, 42 patients), Giussani et al. reported 71.42% success and 21.42% complication rates. In all of these case series, lamina terminalis fenestration was unplanned, done when conventional ETV was difficult due to anatomical constraints, and at times, required a flexible endoscope. With a rigid endoscope, a more posterior en-
### TABLE 1. Clinical characteristics and outcomes of hydrocephalus patients who underwent EAETV

<table>
<thead>
<tr>
<th>Case No.</th>
<th>Age (yrs), Sex</th>
<th>HCP Diagnosis</th>
<th>Clinical Presentation</th>
<th>Radiological Assessment</th>
<th>Neuro Outcome</th>
<th>Neuro Complications</th>
<th>FU (mos)</th>
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</thead>
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<tr>
<td>Acute HCP</td>
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<tr>
<td>1</td>
<td>55, F</td>
<td>Thalamic bleed</td>
<td>E2V2M5, papilledema</td>
<td>Evans' Index, %</td>
<td>mRS 0</td>
<td>Frontal contusion</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>24, F</td>
<td>AS</td>
<td>E2V2M5, papilledema</td>
<td>FOHR, %</td>
<td>mRS 0</td>
<td>None</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>63, F</td>
<td>Vermian bleed</td>
<td>E2V1M5</td>
<td>3rd Ventricle Index, %</td>
<td>mRS 1, mild ataxia</td>
<td>None</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>28, M</td>
<td>Cerebellar hemorrhage</td>
<td>E2V1M5</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>44, M</td>
<td>AS w/ shunt malfunction</td>
<td>E1V2M5, papilledema</td>
<td></td>
<td>mRS 0</td>
<td>None</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>47, M</td>
<td>AS</td>
<td>E3V3M6, headache, papilledema</td>
<td></td>
<td>mRS 0</td>
<td>None</td>
<td></td>
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<tr>
<td>Chronic HCP</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
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</tr>
<tr>
<td>7</td>
<td>14, M</td>
<td>AS</td>
<td>Headache, vomiting, papilledema, VA 6/6</td>
<td></td>
<td>mRS 0, vision static</td>
<td>None</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>15, M</td>
<td>AS</td>
<td>Headache, vomiting, papilledema, VA 6/9</td>
<td></td>
<td>mRS 0, vision static</td>
<td>None</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>56, M</td>
<td>Tectal tuberculoma</td>
<td>No vision, upgaze palsy, optic atrophy, ataxia</td>
<td></td>
<td>mRS 4, no vision, ataxia improved</td>
<td>None</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>6, M</td>
<td>AS</td>
<td>Headache, vomiting, papilledema, VA 6/6</td>
<td></td>
<td>mRS 0, vision static</td>
<td>None</td>
<td></td>
</tr>
</tbody>
</table>

AS = aqueductal stenosis; E, V, M = eye, verbal, motor criteria of the Glasgow Coma Scale; FU = follow-up; HCP = hydrocephalus; neuro = neurological; VA = visual acuity.
try point on the skull is needed, but the posterior margin of the foramen of Monro restricts access.13

Principles of EAETV

Our technique, like conventional ETV, works on the principle of the pressure gradient between intraventricular and subarachnoid CSF.14 The indications are similar to those of conventional ETV. The reduction in ventricular size after conventional ETV occurs earlier for acute hydrocephalus than for chronic hydrocephalus.10,15,16 Surgery aims to optimize intraventricular pressure rather than size.10,17,18 Our findings are in accordance with these observations. All 6 patients with acute hydrocephalus had normalization of ventricular indices and resolution of the symptoms. The 4 patients with chronic hydrocephalus had clinical improvement and showed significant reduction but not normalization of ventricular indices. Follow-up MRI in these patients showed other evidence of a reduction in intracranial pressure in the form of visualization of subarachnoid spaces (Fig. 4). Additionally, EAETV immediately opens the intracranial perioptic CSF space, relieving pressure on nerve fibers.

Clinical and Radiological Success of EAETV

ETV success is defined as avoiding a shunt in a patient who would otherwise require one, clinical evidence of normal intracranial pressure, evidence of stable or decreased ventricular size, and in cases of previous shunt treatment, the shunt is either removed or proven to be nonfunctional.19 A failure is considered if the patient shows no change in clinical symptoms or ventricular size or requires a shunt within days or months of the procedure.19 Most neurosurgeons rely on clinical status and imaging correlations.10,16,18 The ventricle’s postoperative size does not always align with clinical outcomes.10,15,16,18,20 Santamarta et al. showed an overall 9% reduction in the mean Evans’ Index and a 25% reduction in the mean third ventricle index in cases of successful ETV.15 In their blinded study, Buxton et al. found the highest positive predictive value for a decrease in third ventricular size after successful ETV.17 Kulkarni et al. found a 16% mean reduction in FOHR in patients after successful ETV.21 Overall, in our series the mean reduction in Evans’ Index was 20.8%, the mean reduction in the third ventricle index was 37.45%, and the mean reduction in FOHR was 20.79%. The success rate of an ETV varies with patient selection.1,4,22,23 The preoperative ETV Success Score (ETVSS) can predict outcome.22 The ETVSS includes age, etiology, and pre-ETV shunt treatment. Younger patients, those with nonaqueductal obstructions, and those with previous shunt treatment have poor success scores.2,10,22,23 The best candidates for conventional ETV are patients with obstructive hydrocephalus.4,14,20,22,24 In this series, all patients had obstructive hydrocephalus with an ETVSS of 80 or more. All were improved clinically and radiologically at 3 months of follow-up, and none required an add-on procedure for hydrocephalus.

### TABLE 2. Radiological outcomes after EAETV

<table>
<thead>
<tr>
<th>Ventricle Index</th>
<th>Overall</th>
<th>mean ± SD (range)</th>
<th>Acute HCP</th>
<th>mean ± SD (range)</th>
<th>Chronic HCP</th>
<th>mean ± SD (range)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Preop</td>
<td>Postop</td>
<td>p Value</td>
<td>Preop</td>
<td>Postop</td>
<td>p Value</td>
</tr>
<tr>
<td>Evans’ Index</td>
<td>41.18 ± 11.49 (31.57–66.67)</td>
<td>32.70 ± 11.59 (18.62–58.75)</td>
<td>0.002</td>
<td>36.03 ± 4.77 (31.57–43.82)</td>
<td>26.12 ± 3.90 (18.62–29.85)</td>
<td>0.027</td>
</tr>
<tr>
<td>FOHR</td>
<td>51.48 ± 7.90 (40.65–65.59)</td>
<td>41.88 ± 9.27 (29.90–56.79)</td>
<td>&lt;0.001</td>
<td>47.34 ± 4.82 (40.65–54.16)</td>
<td>35.44 ± 3.33 (29.90–39.21)</td>
<td>0.006</td>
</tr>
<tr>
<td>3rd ventricle index</td>
<td>12.93 ± 3.47 (8.10–19.31)</td>
<td>8.31 ± 3.68 (4.67–15.31)</td>
<td>&lt;0.001</td>
<td>10.96 ± 1.57 (8.10–12.26)</td>
<td>5.82 ± 1.22 (4.67–7.69)</td>
<td>&lt;0.001</td>
</tr>
</tbody>
</table>

The p values were calculated using the paired-samples t-test. Boldface type indicates statistical significance.

FIG. 2. Preoperative and postoperative axial CT scans obtained in 2 patients with acute hydrocephalus secondary to intracerebral hemorrhage. The EAETV site is demonstrated by white arrows. Case 1. A: This patient had a right thalamic bleed with hydrocephalus. B: Postoperative scan showing resolution of hydrocephalus. The patient developed a minor frontal contusion that resolved by the time of the last follow-up scan. Case 3. C: This patient had a vermian hemorrhage and upstream hydrocephalus. D: Postoperative scan showing resolution of hydrocephalus.
The patency of conventional ETV stoma has been assessed by cine phase-contrast MRI. The qualitative assessment represents flow voids toward the stoma. The quantitative values need interpretation with caution for inconsistencies among studies. As our technique is novel, we evaluated the patency of fenestration of the lamina terminalis in all cases and found bidirectional CSF flow across the stoma, suggesting patency. The anatomical alignment of the foramen of Monro and ventriculostomy site is different in EAETV; therefore, different qualitative (flow voids) and quantitative values are expected from those after conventional ETV. The fluid stream follows the path of least resistance (i.e., stoma) and generates flow voids. The volume of a liquid (CSF) flowing through the stoma depends on the intraventricular and subarachnoid pressure gradient. In a study of 38 patients, Bargalló et al. found that stroke volumes (the average of forward and reverse volumes) were significantly higher in patients with clinical improvement. The OFA is considered a better quantitative parameter than other variables to predict success after conventional ETV. Hassanien et al. classified the stoma’s patency based on OFA into three categories as follows: 1) patent stoma with adequate flow (OFA > 75 μL), 2) patent stoma with low flow (OFA 25–75 μL), and 3) obstructed stoma with impaired flow (OFA < 25 μL). In their study, 50% of patients were classified in the first category, 20% in the second category, and 50% in the third category. In our study, 60% were classified in the first category, 40% in the second category, and none in the third category. In our cases, the mean peak velocity (3.82 ± 0.93 cm/sec) of the CSF and the mean OFA (74.00 ± 27.61 μL) are in accordance with the mean peak velocity (3.14 ± 1.85 cm/sec) and the mean OFA (79.40 ± 74.36 μL) observed by Hassanien et al. after conventional ETV.

The patency of lamina terminalis fenestration after ruptured aneurysm clipping has been questioned. The suggested primary cause of stoma obstruction is attributed to the edematous frontal lobe. The presence of subarachnoid hemorrhage and subsequent arachnoid scarring may contribute to failure in the long term. In the immediate postoperative period, Chohan et al. checked lamina terminalis fenestration patency in patients with an external ventriculostomy drain when intraventricular and subarachnoid pressure gradients were minimal. A recent meta-analysis proved the effectiveness of lamina terminalis fenestration in reducing shunt-dependent hydrocephalus. Our patients differ from the patients in that study, as our patients did not have frontal lobe edema or subarachnoid scarring. The significant reduction in ventricular indices and CSF flow voids toward the stoma after EAETV suggests that even

FIG. 3. Preoperative and postoperative axial CT scans obtained in 2 patients with acute hydrocephalus secondary to aqueductal stenosis. A and B: Case 2. Preoperative (A) and postoperative (B) images obtained in an adult female with acute hydrocephalus. The EAETV site is demonstrated by the white arrow. The hydrocephalus resolved after EAETV. C and D: Case 5. This patient underwent initial ventriculoperitoneal shunt placement 30 years earlier for aqueductal stenosis. Since then, he has undergone three shunt revisions and two external ventricular drain surgeries. Image obtained before EAETV (C). After EAETV, the hydrocephalus resolved (D).

FIG. 4. Preoperative and postoperative axial CT scans obtained in 2 patients with chronic hydrocephalus. A and B: Case 7. Preoperative (A) and postoperative (B) images obtained in a patient with aqueductal stenosis. Postoperatively, there is a reduction in ventricular indices, along with the opening of subarachnoid spaces. The patient’s symptoms resolved. C and D: Case 8. Preoperative (C) and postoperative (D) images obtained in a patient with aqueductal stenosis. The postoperative image shows a reduction in ventricular indices, along with the opening of subarachnoid spaces. The patient’s symptoms resolved.
though the frontal lobe regains its position, CSF continues to egress through the stoma.

Advantages of EAETV

An ETV can fail because of restenosis of the stoma.\textsuperscript{31–33} The lamina terminalis is a stretched-out membrane unlike the redundant pre mammillary membrane. The lamina terminalis stretches between the optic chiasm inferiorly, anterior commissure superiorly, and optic tracts bilaterally. This anatomical feature may reduce the chances of restenosis. EAETV connects the third ventricle, lamina terminalis cistern, and chiasmatic cistern and therefore does not necessitate Liliequist membrane fenestration.\textsuperscript{31,32} If required, opening of other basal cisterns can be done to improve CSF circulation. EAETV can also provide an alternative virgin window for repeat ETV. It avoids the challenges of reopening a stenosed stoma, which poses risks of neurological injuries and subarachnoid scarring in interpeduncular cisterns, thus jeopardizing success.

EAETV can be safely performed in patients with anatomical constraints such as a smaller foramen of Monro, thick or opaque pre mammillary membrane, narrow pre mammillary space, and high-riding basilar artery.\textsuperscript{6,34,35} The lamina terminalis is a thin sheet of gray matter and stretched semitranslucent triangular membrane forming the anterior wall of the third ventricle. Its height from the upper edge of the optic chiasm to the lower edge of the anterior commissure ranges from 7 to 10 mm (average 8.25 mm). Its maximum width between two medial edges of the optic tracts ranges from 8 to 18.5 mm (average 12.8 mm). The average surface area is approximately 52.84 mm\textsuperscript{2}.\textsuperscript{36} Anatomically, the lamina terminalis is the thinnest and widest part of the third ventricle, and only a minimal amount of retraction is required to expose it. In diffuse pontine glioma, limited prepontine space may preclude optimal stoma creation in the pre mammillary membrane.\textsuperscript{37} In the long run, the prepontine space may be further compromised with tumor growth. We believe that EAETV will be safe, effective, and durable in these situations.

Being an extraventricular approach, EAETV avoids the risk of any minor or major intraventricular hemorrhage. In EAETV, the ACA-AComA complex is on the visible side of the lamina terminalis and can be easily dissected and controlled if the need arises. In most cases (95%), the perforator branches of the ACA-AComA complex to the hypothalamus and optic apparatus arise and traverse laterally and do not interfere with central fenestration.\textsuperscript{38} The source of minor bleeding in EAETV is the dura mater, which is self-limiting, and retraction injury to the frontal lobe can occur if the surgeon is not gentle. We did not require any intradural coagulation in either case. Our first patient developed a frontal lobe contusion managed with Surgicel. The extraventricular nature of this procedure provides another advantage of avoiding injury to the substrate of memory (fornix and mammillary bodies), hemiparesis, and gaze palsy.\textsuperscript{1,3,14,38} No irrigation is required in EAETV, thus avoiding irrigation-induced hypothalamic dysfunctions like cardiovascular changes, hyponatremia, diabetes insipidus, and endocrine dysfunctions.\textsuperscript{1,3,2,4,9–43} EAETV is a direct and more anatomical approach to the third ventricle. Being extra-axial, it is expected to be associated with a lower risk of seizures and neurological deficits. There was no new neurological deficit or seizures in any of our patients. We prescribed a 1-week course of a prophylactic anticonvulsant agent in the first patient who developed frontal lobe contusion. Histologically, the inferior portion of the lamina terminalis (site of fenestration) is composed of glial tissue and has a paucity of neurons. The organum vasculosum of the lamina terminalis is mostly rudimentary and resides midway between the anterior commissure and optic chiasm (above the site of fenestration).\textsuperscript{44} For this reason, lamina terminalis fenestration dur-

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### TABLE 3. CSF flow assessment after EAETV

<table>
<thead>
<tr>
<th>Case No.</th>
<th>Peak Velocity (cm/sec)</th>
<th>Average Velocity (cm/sec)</th>
<th>Average Flow Rate (μL/sec)</th>
<th>Forward Vol (μL)</th>
<th>Reverse Vol (μL)</th>
<th>OFA (μL)*</th>
<th>Stroke Vol (μL)†</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>−3.71</td>
<td>0.216</td>
<td>62</td>
<td>72</td>
<td>33</td>
<td>105</td>
<td>52.5</td>
</tr>
<tr>
<td>2</td>
<td>−3.64</td>
<td>0.111</td>
<td>25</td>
<td>69</td>
<td>53</td>
<td>122</td>
<td>61</td>
</tr>
<tr>
<td>3</td>
<td>4.83</td>
<td>−0.137</td>
<td>−91</td>
<td>8</td>
<td>45</td>
<td>53</td>
<td>26.5</td>
</tr>
<tr>
<td>4</td>
<td>−5.06</td>
<td>−0.147</td>
<td>−35</td>
<td>9</td>
<td>38</td>
<td>47</td>
<td>23.5</td>
</tr>
<tr>
<td>5</td>
<td>−3.97</td>
<td>0.098</td>
<td>77</td>
<td>39</td>
<td>9</td>
<td>48</td>
<td>24</td>
</tr>
<tr>
<td>6</td>
<td>2.13</td>
<td>0.059</td>
<td>38</td>
<td>56</td>
<td>22</td>
<td>78</td>
<td>39</td>
</tr>
<tr>
<td>7</td>
<td>4.24</td>
<td>0.084</td>
<td>78</td>
<td>58</td>
<td>27</td>
<td>85</td>
<td>42.5</td>
</tr>
<tr>
<td>8</td>
<td>−2.99</td>
<td>0.095</td>
<td>−37</td>
<td>29</td>
<td>56</td>
<td>85</td>
<td>42.5</td>
</tr>
<tr>
<td>9</td>
<td>−4.70</td>
<td>0.095</td>
<td>13</td>
<td>22</td>
<td>14</td>
<td>36</td>
<td>18</td>
</tr>
<tr>
<td>10</td>
<td>−2.97</td>
<td>−0.016</td>
<td>−10</td>
<td>37</td>
<td>44</td>
<td>81</td>
<td>40.5</td>
</tr>
</tbody>
</table>

Mean ± SD (range) | 3.82 ± 0.93 (2.13–5.06) | 0.10 ± 0.05 (0.016–0.216) | 46.60 ± 28.58 (10–91) | 39.90 ± 23.29 (8–72) | 34.10 ± 15.98 (9–56) | 74.00 ± 27.61 (36–122) | 37.00 ± 13.80 (18–61) |

Positive values represent systolic events and negative values represent diastolic events.

* Forward + reverse volume.
† Average of forward and reverse volume.
ing aneurysm clipping or the corridor for third ventricular tumors has been found to be safe. None of our patients developed an impairment in thirst or blood pressure.

**Limitations of EAETV**

Most of the concerns regarding EAETV are those that are inherent to the supraorbital approach itself, namely, a scar at the eyebrow, transient periorbital swelling, transient supraorbital hypesthesia, and frontal air sinus violation. The skin incision should stay in the eyebrow’s hairline to conceal the scar. The incision should be made down to the pericranium, and the flaps should be raised in a subperietonal fashion. If stretching of supraorbital nerves is evident, the foramen can be deroofed. The scar becomes faint and acceptable in the long term in most patients. In a series of pediatric supraorbital craniotomy, there were excellent cosmetic outcomes without noticeable effects on the orbitozygomatic growth.45

The surgeon may experience difficulty in negotiating the endoscope, especially in the setting of raised intracranial pressure. We essentially seek the help of an anesthesiologist to aid in brain relaxation using mannitol and other decongestants. A gradual fronto lobe retraction creates sufficient space for the endoscope. Some patients may have CSF-filled subarachnoid spaces at the frontal pole, which can be drained to relax the brain. If the surgeon is uncomfortable at any moment while performing EAETV, a microscope may be a helpful adjunct. Access to the lateral ventricle is not possible in EAETV, and choroid plexus cauterization, if intended, cannot be achieved. With a rigid scope, the posterior third ventricle is also difficult to access. There is a possibility that arachnoid dissection may promote scarring and adhesion in the long run. An appreciable CSF flow on MRI at the 3-month follow-up in all patients hints at the patency of fenestration. EAETV has a long learning curve and takes 40–50 minutes of operating time.

EAETV utilizes a mini-supraorbital craniotomy; thus, watertight dural closure is feasible. The dura mater of the anterior cranial fossa can be stripped off to aid in primary closure. If required, dural closure may be reinforced with fibrin glue. A watertight dural closure, plugging the sinus opening with a small piece of temporalis muscle, sealing with bone wax, and exteriorization of the sinus are the keys to managing a breached frontal air sinus. Our study has the limitations of few cases and a relatively short follow-up duration.

We have named our procedure the “extra-axial endoscopic third ventriculostomy” as it provides a clear impression regarding the approach. In the literature, “lamina terminalis fenestration,” “lamina terminalis—endoscopic third ventriculostomy,” and “endoscopic third ventriculostomy–lamina terminalis” have been used to indicate transventricular lamina terminalis fenestration.5

**Conclusions**

The preliminary results after EAETV are encouraging. Its long-term efficacy is yet to be proven with longer follow-up. More endoscopic neurosurgeons should test the interoperator safety, feasibility, and effectiveness of this procedure. EAETV may be used as an alternative technique in cases in which conventional ETV is technically difficult.

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**References**


Disclosures
The authors report no conflict of interest concerning the materials or methods used in this study or the findings specified in this paper.
Author Contributions
Conception and design: Kumar. Acquisition of data: Kumar, Sahana. Analysis and interpretation of data: Kumar, Rathore, Tawari. Drafting the article: Kumar, Sahana, Rathore, Jain, Tawari, Singh. Critically revising the article: Kumar, Sahana, Rathore. Reviewed submitted version of manuscript: Kumar, Sahana, Rathore, Jain, Singh, Sahu, Madhariya. Approved the final version of the manuscript on behalf of all authors: Kumar. Statistical analysis: Kumar. Administrative/technical/material support: Kumar, Tawari, Sahu, Madhariya. Study supervision: Kumar, Sahana, Jain, Singh, Sahu, Madhariya.

Supplemental Information
Videos

Online-Only Content
Supplemental material is available with the online version of the article.

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