Endoscopic cerebral aqueductoplasty: a trans–fourth ventricle approach

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Object. Advances in endoscopic technology have afforded the neurosurgeon new avenues in the treatment of hydrocephalus, rendering many patients independent of shunts, thus averting shunt complications and failure. Cerebral aqueductoplasty has gained popularity as an effective treatment for membranous and short-segment stenoses of the sylvian aqueduct. Traditionally, this procedure has been performed via a coronal approach, passing through the lateral ventricle, foramen of Monro, and third ventricle into the aqueduct. The authors report on the success of a novel technique for this operation, in which they use a suboccipital foramen magnum trans–fourth ventricle approach.

Methods. A retrospective chart review was performed to document the success of cerebral aqueductoplasty procedures via the foramen magnum trans–fourth ventricle approach in patients who had membranous or short-segment stenosis of the cerebral aqueduct. Nine patients underwent 11 cerebral aqueductoplasty procedures. At a mean of 21 months of postoperative follow up, all patients demonstrated resolution of their preoperative symptoms. The only surgical complication was transient vertical diplopia or upgaze weakness in two patients. There was no permanent morbidity. Recurrent aqueductal stenosis developed in one patient twice, requiring the placement of an aqueductal stent via the same approach.

Conclusions. The authors state that in their experience, performing cerebral aqueductoplasty via the foramen magnum trans–fourth ventricle approach is both effective and safe. They advocate the use of this technique, if performed by an experienced neuroendoscopist, for select cases involving membranous or short-segment stenosis of the cerebral aqueduct, a trapped fourth ventricle, or aqueductal stent placement.

KEY WORDS • aqueductal stenosis • hydrocephalus • trapped fourth ventricle • endoscopy • pediatric neurosurgery
Patient Selection

Inclusion criteria included symptomatic patients with ventriculomegaly and either membranous or short-segment stenosis of the cerebral aqueduct, as previously proposed by Schroeder and Gaab. The criteria were met by nine patients (six males and three females) who underwent 11 cerebral aqueductoplasty procedures in which the foramen magnum trans–fourth ventricle approach was used. At the time of surgery, patient ages ranged from 15 months to 70 years (mean age 23 years).

Surgical Technique

After induction of general endotracheal anesthesia, the patient is positioned prone with the head flexed in Mayfield head clamps or on a horseshoe (cerebellar) frame. The patients placed in horseshoe frames were younger than 15 months of age and, consequently, would not tolerate skull clamps. In those cases, we secured the head firmly with surgical adhesive tape to minimize the possibility of movement. The importance of firm, movement-free fixation in all age groups is crucial. Preoperatively, the MR image is reviewed carefully to identify the amount of neck flexion needed to align the cerebral aqueduct and foramen magnum. The midpoint of the skin incision is chosen as the site at which the aqueduct–foramen magnum line projects on the skin. After the patient is prepared and draped, a 2- to 4-cm incision is made, depending on the size of the patient. The dissection is taken down through the avascular midline between the neck muscles to identify the foramen magnum. A 5-mm opening in the dura mater between the suboccipital bone and C-1 is made, allowing the introduction of a glass-rod endoscope under direct vision to minimize the risk of injury to the brainstem, vascular structures, or cerebellar tonsils. The endoscope is advanced in between the cerebellar tonsils into the fourth ventricle, and the cerebral aqueduct is immediately visualized (Fig. 1). If there is difficulty viewing the aqueduct, a Kerrison rongeur is used to remove a small amount of bone from the suboccipital bone. This step allows the endoscope to follow a trajectory between the cerebellar tonsils, thus permitting significant flexibility in the working angle. Various techniques are used to open the aqueduct, depending on the reason for the obstruction and the particular anatomical characteristics, and include the following: 1) using irrigation gently to open the membranes within the aqueduct; 2) using the blunt tip of the endoscope gently to dilate a small aqueduct; and 3) using microscissors carefully to cut tough tethering tissue at the entrance to the aqueduct. In one patient who required three surgical interventions because of repeated occlusion of the cerebral aqueduct, an aqueductal stent was placed using endoscopic forceps at the time of the third intervention. Once the opening is completed, the endoscope is removed. The dura is reapproximated with one 4-0 suture. The wound is then closed in layers.

Results

Case-Specific Data

A tabular summation of the case histories for the nine patients who underwent foramen magnum trans–fourth ven-
within the membrane (Fig. 2). A pinhole opening was identified in the inflammatory membrane that occluded the inferior aspect of the aqueduct. A relatively thick duct, with dilated third and lateral ventricles and a small ventricle cerebral aqueductoplasty was included in Table 1. What follows is a detailed description of three cases, which illustrate our experience with this procedure.

**Case 1.** This man initially presented at the age of 46 years with imbalance, occasional urinary incontinence, daily fecal incontinence, and progressive cognitive slowness. His medical history was significant for an episode of the Asian flu during childhood, accompanied by high fever and seizures. Results of imaging studies at the time of presentation demonstrated an adhesion in the inferior aspect of the aqueduct, with dilated third and lateral ventricles and a small fourth ventricle. We proceeded with a foramen magnum trans–fourth ventricle aqueductoplasty. A relatively thick inflammatory membrane was found to obscure the inferior aspect of the aqueduct. A pinhole opening was identified within the membrane (Fig. 2 left). The membrane was bluntly dissected away, leaving the aqueduct patent (Fig. 2 center and right). The patient’s symptoms began to improve immediately after the operation, and at his 8-week follow-up appointment, he reported complete resolution of symptoms. At the 7-month follow-up examination, he demonstrated a mild vertical diplopia on extreme lateral gaze. The patient continues to report infrequent paroxysmal visual symptoms. At the 7-month follow-up, he reported complete resolution of symptoms. The fourth ventricle had dilated again, necessitating a repeat foramen magnum trans–fourth ventricle endoscopic aqueductoplasty for treatment of her trapped fourth ventricle. The aqueduct was occluded by significant adhesions, which were obliterated it altogether. They were lysed and the aqueduct gently dilated. There was no surgical complication, and in the 3-week follow-up she had complete resolution of symptoms.

**Case 2.** This boy presented at 5 years of age. Notable in his history was premature birth, intraventricular hemorrhage, and hydrocephalus that had been treated by shunt insertion. He had undergone frequent shunt revisions, receiving an additional fourth ventricular shunt later in life. Because of the frequent revisions, he was referred to our institution with a 1-month history of increasing lethargy, HA, & fatigue. Initially, he underwent placement of a right coronal Rickham reservoir, which was eventually replaced by a left occipital VP shunt. The patient was transferred to our institution and had a history of multiple shunt revisions and a cranial expansion for slit ventricle syndrome. She presented with a 3-day history of vomiting and irritability, with no sign of viral illness. A computerized tomography scan revealed ventriculomegaly and a trapped fourth ventricle. She underwent VP shunt revision the following day. Within 6 months of the shunt revision, it became evident that the fourth ventricle remained dilated, despite resolution of the lateral ventriculomegaly. Because of persistent headaches, irritability, ataxia, and esotropia, she underwent a foramen magnum trans–fourth ventricle aqueductoplasty for treatment of her trapped fourth ventricle. The aqueduct was occluded by significant adhesions, which were obliterated it altogether. They were lysed and the aqueduct gently dilated. There was no surgical complication, and at the 3-week follow-up she had complete resolution of symptoms.

**Case 3.** This girl initially presented at 11 months of age. She was born 29 weeks prematurely and had suffered a Grade III intraventricular hemorrhage in the perinatal period. Initially, she underwent placement of a right coronal Rickham reservoir, which was eventually replaced by a left occipital VP shunt. The patient was transferred to our institution and had a history of multiple shunt revisions and a cranial expansion for slit ventricle syndrome. She presented with a 3-day history of vomiting and irritability, with no sign of viral illness. A computerized tomography scan revealed ventriculomegaly and a trapped fourth ventricle. She underwent VP shunt revision the following day. Within 6 months of the shunt revision, it became evident that the fourth ventricle remained dilated, despite resolution of the lateral ventriculomegaly. Because of persistent headaches, irritability, ataxia, and esotropia, she underwent a foramen magnum trans–fourth ventricle aqueductoplasty for treatment of her trapped fourth ventricle. The aqueduct was occluded by significant adhesions, which were obliterated it altogether. They were lysed and the aqueduct gently dilated. There was no surgical complication, and at the 3-week follow-up she had complete resolution of symptoms. Within 6 months, the patient returned to the clinic with recurrent headaches, ataxia, irritability, and worsening esotropia. The fourth ventricle had dilated again, necessitating a repeated foramen magnum trans–fourth ventricle endoscopic aqueductoplasty. It was obvious that the aqueduct had collapsed again because of the adhesions, causing obstruction of flow. There was no surgical complication, and a follow-up examination 4 weeks later revealed complete resolution of symptoms.

**Case 4.** This girl initially presented at 1 year of age. She was born 34 weeks prematurely and had suffered a Grade III intraventricular hemorrhage in the perinatal period. Initially, she underwent placement of a right coronal Rickham reservoir, which was eventually replaced by a left occipital VP shunt. The patient was transferred to our institution and had a history of multiple shunt revisions and a cranial expansion for slit ventricle syndrome. She presented with a 3-day history of vomiting and irritability, with no sign of viral illness. A computerized tomography scan revealed ventriculomegaly and a trapped fourth ventricle. She underwent VP shunt revision the following day. Within 6 months of the shunt revision, it became evident that the fourth ventricle remained dilated, despite resolution of the lateral ventriculomegaly. Because of persistent headaches, irritability, ataxia, and esotropia, she underwent a foramen magnum trans–fourth ventricle aqueductoplasty for treatment of her trapped fourth ventricle. The aqueduct was occluded by significant adhesions, which were obliterated it altogether. They were lysed and the aqueduct gently dilated. There was no surgical complication, and at the 3-week follow-up she had complete resolution of symptoms. Within 6 months, the patient returned to the clinic with recurrent headaches, ataxia, irritability, and worsening esotropia. The fourth ventricle had dilated again, necessitating a repeated foramen magnum trans–fourth ventricle endoscopic aqueductoplasty. It was obvious that the aqueduct had collapsed again because of the adhesions, causing obstruction of flow. There was no surgical complication, and a follow-up examination 4 weeks later revealed complete resolution of symptoms.

**Case 5.** This girl initially presented at 1 year of age. She was born 34 weeks prematurely and had suffered a Grade III intraventricular hemorrhage in the perinatal period. Initially, she underwent placement of a right coronal Rickham reservoir, which was eventually replaced by a left occipital VP shunt. The patient was transferred to our institution and had a history of multiple shunt revisions and a cranial expansion for slit ventricle syndrome. She presented with a 3-day history of vomiting and irritability, with no sign of viral illness. A computerized tomography scan revealed ventriculomegaly and a trapped fourth ventricle. She underwent VP shunt revision the following day. Within 6 months of the shunt revision, it became evident that the fourth ventricle remained dilated, despite resolution of the lateral ventriculomegaly. Because of persistent headaches, irritability, ataxia, and esotropia, she underwent a foramen magnum trans–fourth ventricle aqueductoplasty for treatment of her trapped fourth ventricle. The aqueduct was occluded by significant adhesions, which were obliterated it altogether. They were lysed and the aqueduct gently dilated. There was no surgical complication, and at the 3-week follow-up she had complete resolution of symptoms. Within 6 months, the patient returned to the clinic with recurrent headaches, ataxia, irritability, and worsening esotropia. The fourth ventricle had dilated again, necessitating a repeated foramen magnum trans–fourth ventricle endoscopic aqueductoplasty. It was obvious that the aqueduct had collapsed again because of the adhesions, causing obstruction of flow. There was no surgical complication, and a follow-up examination 4 weeks later revealed complete resolution of symptoms.
Endoscopic cerebral aqueductoplasty

FIG. 2. Case 1. Left: Intraoperative endoscopic image of the stenotic cerebral aqueduct. Note the pinhole opening at the inferior aspect of the aqueduct. Center: Intraoperative endoscopic image of the cerebral aqueduct after fenestration of an inflammatory membrane. Right: Intraoperative endoscopic image of the roof of the third ventricle as seen from the aqueduct. Note the thalamic adhesion, fornices, internal cerebral veins, foramina of Monro, and choroid plexus.

scopnic placement of a modified T-piece lumbar catheter through the aqueduct. There was no surgical complication. The girl had complete resolution of her symptoms on postoperative follow up. Except for an occasional lateral shunt revision, the patient continued to do well at 22 months postoperatively.

Postoperative Outcomes

All patients experienced resolution of their preoperative symptoms, as detailed in Table 1. The 2-year-old child (Case 5) who required three surgical interventions had resolution of symptoms after each procedure. She remains asymptomatic and has a smaller fourth ventricle since the aqueductal stent was placed. Transient vertical gaze paresis developed in two patients postoperatively. In Case 1 the diplopia improved gradually over a period of 11 months, after which it resolved; in Case 6, the mild upgaze weakness resolved after 2 weeks. There was no hemorrhage, infection, CSF leak, or permanent neurological deficit postoperatively.

Discussion

Nine patients presented to our institution with obstructive hydrocephalus caused by membranous or short-segment stenosis of the cerebral aqueduct. The cause of stenosis was most commonly infectious (Case 4), congenital (Case 8), hemorrhagic (Cases 3, 5, and 6), or neoplastic (Cases 7 and 9) in origin. Although this study represents only a small cohort of patients with aqueductal stenosis, we posit that infection, hemorrhage, and tumors are the three most common causes of aqueductal stenosis that are amenable to suboccipital trans–fourth ventricle cerebral aqueductoplasty.

Cerebral Aqueductoplasty Compared With Third Ventriculostomy

Although third ventriculostomy has long been reported as a successful treatment for obstructive hydrocephalus caused by aqueductal stenosis, its complications are equally well documented. They include but are not limited to injury to the BA, infliction of hypothalamic damage during perforation of the third ventricular floor, and formation of arachnoidal adhesions in the interpeduncular and preopticine cisterns.4,5,9,14,19 In specific cases of obstructive hydrocephalus caused by membranous or short-segment stenosis of the aqueduct, cerebral aqueductoplasty is a viable alternative to third ventriculostomy and offers the following advantages:16,19 1) It restores the physiological pathway of CSF flow. 2) There is no risk of blind injury to the BA. (Although the endoscope is introduced near the posterior inferior cerebellar arteries, these are well visualized during the aqueductoplasty approach.) 3) Hypothalamic damage is not possible. 4) No cortical injury is caused by the approach. 5) Third ventriculostomy is unlikely to help patients with a trapped fourth ventricle. In such cases, an aqueductoplasty, a posterior fossa exploration, or a fourth ventricular shunt would be needed.23

Cerebral Aqueductoplasty

The success of cerebral aqueductoplasty is being reported with increasing frequency.16,17,19 Radiographic data have confirmed its efficacy by demonstrating, through cine MR imaging, that patients undergoing aqueductal restoration have CSF flow rates equivalent to those in controls.20 We have found the procedure to be a successful treatment option for membranous or short-segment stenosis of the aqueduct or a trapped fourth ventricle and have used this approach for the placement of aqueductal stents.

Traditional Approach Compared With Foramen Magnum Trans–Fourth Ventricle Approach

The traditional approach to cerebral aqueductoplasty, whereby intracranial entry is made anterior to the coronal suture, has proven successful. It does, however, present the following disadvantages: 1) To reach the lateral ventricle, the endoscope must first traverse brain tissue; this is not the case with the fourth ventricular approach. 2) The ease of descent into the aqueduct depends on the degree of ventricular dilatation. In patients who present with the slit ventricle syndrome, access to the aqueduct via a traditional approach may be exceedingly difficult; in the fourth ventricular approach, the size of the ventricle is minimally relevant to the ability of the surgeon to perform the procedure. 3) The trajectory of the typical transfrontal aqueductoplasty procedure is circuitous, often requiring the use of a flexible endoscope. Conversely, with appropriate head positioning, the trajectory of the fourth ventricular approach is straight. 4) This circuitous approach to the transfrontal aqueductoplasty has caused complications, as outlined by Schroeder and Gaab.20 These complexities have included the occurrence of epidural hematoma, aqueductal roof injury, and fornix con-
tusion. Although problems with the fourth ventricular procedure will undoubtedly arise as more cases are performed, such injury to the important third ventricular structures would not be expected. Because the fourth ventricular trajectory is straight, the potential for injury to the fourth ventricular floor is minimized. In addition, because entry to the aqueduct is also straight (in direct extension of the trajectory used to enter the fourth ventricle), the risk of permanent injury to the collicular plate is minimized. In our patient population, two individuals experienced transient vertical gaze paresis, and there was no permanent complication at a mean of 17 months of follow up. 5) In cases of a trapped fourth ventricle, in which adhesions exist both within the aqueduct and at the foramen of Magendie, approaching both stenotic regions from a transfrontal trajectory is complicated. Using a suboccipital approach in this setting proves comparatively advantageous.

Conclusions
Cerebral aqueductoplasty is an effective and successful treatment for membranous and short-segment stenosis of the sylvian aqueduct. It has traditionally been performed using a transfrontal approach through the lateral and third ventricles. Such a procedure, however, is complicated by requisite navigation through brain tissue, risk of fornicinal contusion, and reliance on substantial ventricular dilation for surgical access. We have successfully performed cerebral aqueductoplasty by using a novel technique whereby access to the cerebral aqueduct is gained via a foramen magnum trans–fourth ventricle approach. Indeed, the approach presents intrinsic risk to specific surrounding midbrain and posterior fossa structures, and thus we advise that this procedure be performed only by an experienced neuroendoscopist. Metliculous dissection and vigilant surgical technique remain critical aspects of successful endoscopy.

References