

A Review of Common Endoscopic Intracranial Approaches

Abstract

With the evolution of surgical techniques, endoscopy has emerged as a suitable alternative to many instances of more invasive methods. In this review article, we aim to discuss the endoscopic advancements, procedural details, indications, and outcomes of the most commonly practiced neuroendoscopic procedures. We have also summarized the uses, techniques, and challenges of neuroendoscopy in select neurosurgical pathologies.

Keywords: Endoscopic third ventriculostomy, endoscopy, neuroendoscopy, skull base

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Introduction

Since the 20th century, endoscopes have been an indispensable tool in the neurosurgical arsenal, allowing unprecedented access to deep structures within both the cranial and spinal compartments without major tissue invasion.^[1] Our current understanding of neurological anatomy and physiology, combined with advancements in the quality and resolution of endoscopes, has enabled neuroendoscopy to treat more neurosurgical conditions than before and perform procedures such as endoscopic third ventriculostomy (ETV), endoscopic skull base tumor resection, removal of intracranial cysts, intraventricular tumor biopsy and resection, and septum pellucidotomy.^[2,3]

Endoscopic Third Ventriculostomy

ETV is the most frequently performed neuroendoscopic procedure in recent times.^[4] The procedure requires making of an opening in the floor of the third ventricle using an endoscope to permit cerebrospinal fluid (CSF) drainage into the basal cisterns.^[5] This section discusses the indications for ETV, surgical techniques and determinants of ETV outcomes, the ETV success score (ETVSS), and postprocedure complications.

In 2017, Oertel *et al.* reported obstructive hydrocephalus to be the causative pathology of all 126 ETVs performed within a 6-year period at their institute.^[6] Primitively,

ETV was used to treat hydrocephalus caused only by aqueductal stenosis (AS), both congenital and acquired. However, it is currently indicated in hydrocephalus caused by congenital conditions such as Dandy–Walker malformation, syringomyelia, meningomyelocele, and craniosynostosis, as well as secondary to shunt malfunction, cerebellar infarcts, slit ventricle syndrome, posterior fossa lesions,^[7,8] pineal lesions,^[9] and brainstem lesions^[10] causing obstructive hydrocephalus.

The current preferred methods of treating congenital AS are ETV and CSF shunting. Another procedure, endoscopic cerebral aqueductoplasty (CA), has also been used for treating AS in the past but has been largely replaced by newer techniques such as ETV. Fallah *et al.* conducted a meta-analysis of cohort studies of patients undergoing CA for AS. They found that 75% of patients did not require a second CSF diversion procedure and the morbidity rate (mostly ophthalmoparesis and hemorrhage) was 22%. While the authors found CA to be effective in patients with a congenital etiology, those who were older, and those who had concurrent stenting with CA, they still recommended strongly considering ETV when it is not contraindicated, due to its lower morbidity rate.^[11]

Preoperative patient selection is one of the greatest predictors of postoperative

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outcomes for patients undergoing ETV. In 2018, Madsen *et al.* correlated ETV failure with decreasing patient age, presence of a high-risk pathology for hydrocephalus, and inexperience of the surgeon.^[12] The former two factors were included in Greenfield's 5-point grading scale to assess preoperative risk factors and intraoperative evaluation as predictors of ETV outcomes. The remaining three components of the scale included intraoperative findings of abnormal third ventricular anatomy, scarred or thickened Lilliequist membranes in the subarachnoid space, and absence of CSF pulsations in the third ventricle at the completion of the procedure.^[13] In a retrospective study, Isaacs *et al.* demonstrated a 22% relative risk of ETV failure in patients in whom VP shunt surgery failed before an ETV, along with an almost eightfold complication rate.^[14]

Surgical techniques leading to the most favorable patient outcomes consist of making the burr hole at the highest possible site, placed at or just anterior to the coronal suture and about 2.5 cm to 3 cm lateral from the midline. This is made possible by positioning the patient supine and with their head flexed, ensuring optimal trajectory into the third ventricle and avoiding over drainage of CSF. Other interventions required blunt fenestrations to be made at the most transparent site between the mammillary body and the infundibular recess and anterior to the artery complex to avoid injury to the basilar artery.^[7]

Pre- and postoperative imaging has also been implicated in the success of ETVs. Yadav *et al.* suggested that ETVs were safer in patients displaying a generous prepontine subarachnoid space, also known as the prepontine interval, on radiology.^[7] In their retrospective analyses of patients undergoing ETV, Foroughi *et al.*^[15] and Borcek *et al.*^[16] described third ventricular bowing as a strong preoperative radiological predictor of ETV success. Borcek *et al.* also reported a reduction in third ventricle floor depression, lamina terminalis bowing, anterior commissure-tuber cinereum distance, mammillary body-lamina terminalis distance, and third ventricular width on magnetic resonance imaging (MRI) as postoperative radiological indicators of ETV success.^[16] In another cohort, Azab *et al.* suggested that a reduction in the infundibular recess angle led to better clinical outcomes of ETV during the early postoperative period.^[17] Functional patency of the stoma on a postoperative cine phase-contrast MRI also indicated a successful outcome.^[7]

A means to determine ETV success was the development of ETVSS, calculated as age score, added to the etiology and previous shunt scores. These ranged from 0 (meaning virtually no chance of ETV success) to 90 (meaning a roughly 90% chance of ETV success).^[18]

The overall rate of temporary complications has been reported to be between 2% and 5%, occurring within 4 weeks of surgery. These include central nervous system

infections, fever, stoma block, CSF leak, and postoperative intracranial hematomas. Such complications can be avoided by ensuring proper patient selection, utilizing appropriate surgical technique, and providing good postoperative care.^[7]

Endoscopic Third Ventriculostomy with Choroid Plexus Cauterization

Although ETV is a successful alternative to CSF shunting, its efficacy can be suboptimal in certain cases, such as in children <12 months old, those with a history of CSF diversion, postinfectious or posthemorrhagic etiologies, or hydrocephalus associated with meningocele, and those with age being the greatest predictor of success.^[19] Warf observed a similar trend in the early 2000s, where children <12 months old (except for those with postinfectious etiologies) had ETV success rates of 50% or less.^[20] He proposed combining ETV with choroid plexus cauterization (CPC) (also earlier referred to as choroid plexectomy and choroid plexus [CP] coagulation) to treat this subset of patients. He was the first to report a study comparing the efficacy of ETV alone and ETV combined with bilateral CPC (ETV-CPC) in Africa. He found that ETV-CPC was superior to ETV alone in children <12 months old and with hydrocephalus associated with non-post-infectious etiologies and meningocele. After performing an ETV, Warf described using a flexible endoscope and a Bugbee wire to cauterize the CP of the lateral ventricle, starting from the Foramen of Monro (FM) and moving posteriorly till the tip of the temporal horn. Next, he performed a septostomy to gain access to the contralateral lateral ventricle to perform the same procedure contralaterally. The bilateral CPC added 15–30 min to the ETV procedure.^[21]

Following Warf's efforts in Africa, Kulkarni *et al.* reported one of the earliest series of 36 patients who underwent ETV-CPC in North America.^[22] Their 12-month success rate was 52% compared to Warf's 66%. Kulkarni *et al.* found that failure (defined as recurrence of symptomatic hydrocephalus, loculated compartments requiring repeat CSF diversion surgery, and death) rates were higher in cases where <90% of the CP was cauterized. However, in their series, Kulkarni *et al.* used rigid endoscopes in the majority of cases, as opposed to a flexible endoscope, as recommended by Warf. In doing so, they found that cauterization of >90% of the CP was achieved with flexible endoscopes in 88% of cases compared to only 14% of cases when rigid endoscopes were used.^[22] The choice between using rigid and flexible endoscopes is usually dependent on surgeon familiarity with the equipment.^[22,23] Although more surgeons prefer to use rigid endoscopes because they are better acquainted with them, flexible endoscopes do allow more extensive CP cautery, especially in the anterior temporal horns of the lateral ventricles. Wang *et al.* carried out a comparative analysis of flexible versus rigid endoscopes for ETV-CPC to shed more light on this issue.

Although they found worse outcomes for ETV-CPC done with rigid endoscopes in unadjusted analyses, the analyses, once adjusted for confounders, showed a nonsignificant result. Therefore, more research has to be done to analyze the effectiveness of flexible endoscopes.^[23]

Fallah *et al.* did not find a difference in the need for a second CSF diversion procedure following either subtotal CPC (CPC from the FM to the posterior temporal horn bilaterally) or partial CPC (unilateral or bilateral CPC that only extended from the FM to the atrium on one side), showing that the extent of CPC does not determine failure rates.^[24] Further studies have shown young age (0.8–1 month) to be an important predictor of ETV-CPC failure when compared to older patients.^[25,26]

Skull Base Approach

The surgical approach to skull base lesions has changed dramatically since the early 1900s when transnasal approaches to the sella turcica started being attempted as a substitute for traditional transcranial approaches that carried a significant degree of morbidity and mortality. These newer approaches mitigated the amount of retraction and manipulation of brain tissue and critical neurovascular structures. The transnasal approach to sellar lesions was propelled into the mainstream first with advances in operative microscopes and now with neuroendoscopes.^[27,28]

The main principle behind the transnasal approach is to use the nose to access natural orifices and corridors, such as the sphenoid sinus, to gain access to the skull base. The prototypical transnasal surgery is the transsphenoidal approach to the sella for pituitary tumors.^[29] Endoscopic approaches for pituitary tumors and skull base lesions have phased out microscopic approaches because they lead to decreased nasal morbidity, allow better views of the intrasellar and suprasellar areas, give the same endocrinologic results as the microscopic approach, and provide better control of the cavernous sinus.^[30] In 2014, Juraschka *et al.* retrospectively analyzed 73 patients having undergone endoscopic transsphenoidal resection of pituitary adenomas, reporting an average resection rate of 82.9%, and vast improvement in visual fields and acuity postoperatively.^[31] Statistically significant predictors of extent of resection with the endoscopic endonasal approach include a high Knosp grade (extent of invasion of the cavernous sinus by a pituitary macroadenoma), preoperative tumor volume and diameter, hemorrhagic component, posterior extension of the tumor, and sphenoid sinus invasion.^[31]

Advances in endoscopes and our understanding of anatomy have taken the transsphenoidal approach as a foundation and extended it to areas beyond the sella, allowing access to the entire ventral skull base from the crista galli up to and through the odontoid. These are called the extended or expanded endonasal approaches (EEAs)^[32] and consist

of transcribriform, transplanum/transtuberculum, and transsphenoidal and transclival approaches.^[33] EEAs can be classified into two planes according to the orientation of the surgical field: sagittal and coronal. The sagittal plane allows access to the median skull base, whereas the coronal plane allows access to the paramedian skull base and lateral structures.^[34] EEAs in the midline skull base allow access to access the anterior middle fossa through the cribriform plate,^[32,35] the suprasellar cistern through the planum sphenoidale and tuberculum sellae, and the prepontine and premedullary cisterns through the clivus. They may also be used for lesions of the paramedian skull base, depending on the surgeon's expertise,^[29,36] and allow access to the ventral cervicomedullary junction, Meckel's cave, the middle cranial fossa, the petrous apex, the jugular foramen, and the pterygopalatine and infratemporal fossae.

Kassam *et al.* have used EEAs to manage a variety of skull base conditions. The most common nonneoplastic pathology was a CSF leak. The most common benign neoplasms were pituitary adenomas, meningiomas, and craniopharyngiomas. Malignant lesions included esthesioneuroblastomas, sinonasal cancers, chordomas, and chondrosarcomas.^[37] In 2016, Fomichev *et al.* conducted a retrospective analysis of patients who underwent bilateral endoscopic transsphenoidal surgery for supradiaphragmatic tumors that were primarily craniopharyngiomas. Gross-total resection was achieved in 72% of cases and vision improved in 89% of patients, showing EEA to be more effective and less traumatic, with relatively rare postoperative mortality.^[38] The transplanum/transtuberculum approach to the anterior skull base suprasellar cistern is the second most commonly performed of the extended endonasal approaches, indicated in suprasellar prechiasmatic preinfundibular lesions, and very large pituitary macroadenomas extending beyond the planum, craniopharyngiomas, Rathke cleft cysts, and anterior skull base lesions.^[8,39] Abbassy *et al.* highlighted the relative advantages of EEAs toward resecting anterior skull base meningiomas: less retraction of brain tissue, early medial decompression of the optic nerves, visualization of the optic perforators supplying the optic chiasm, and removal of the tumor in the medial orbital canal in case of tuberculum sellae meningiomas.^[40]

The most common complication associated with endoscopic endonasal skull base surgeries is a postoperative CSF leak, which can be managed with a lumbar drain and/or an additional endoscopic approach. The rates of postoperative CSF leaks have declined with the use of vascularized tissue for reconstruction of the skull base, such as the Hadad-Bassagasteguy flap.^[41] Other less frequent complications are transient and permanent neurologic deficits and intracranial infections. On the whole, endoscopic endonasal skull base surgery provides a viable access point to a variety of skull base lesions, and the safety profile will continue to improve with acquisition of surgical skills and experience.^[42]

Intracranial Hemorrhage

Spontaneous intracranial hemorrhage (ICH) secondary to hypertensive disease accounts for significant morbidity and mortality and poses a significant threat of permanent disability if not urgently managed. Early surgery to alleviate mechanical compression of normal brain tissue and toxic effects of the hematoma may limit injury to the brain.^[43]

While craniotomy was used as an appropriate treatment for ICH, its benefits were marginal at best.^[44] Neuroendoscopy has been applied as an alternative treatment option for ICH in recent times, but its application remains controversial.^[45] According to a meta-analysis by Yao *et al.* in 2018, endoscopic intervention for hematomas significantly reduced rates of mortality and poor outcomes and led to decreased risks of rebleeding and pneumonia postoperatively. Significantly better results in neuroendoscopy were reported with late surgery (>48 h) than with early surgery (>24 h).^[46] In 2017, Ye *et al.* conducted a meta-analysis to compare the efficacy of craniotomy with neuroendoscopy in evacuation of the hematoma. They concluded neuroendoscopic surgery significantly improved clinical outcomes compared to craniotomy, reducing the total risk of mortality and other complications, increasing hematoma evacuation rates, and decreasing operation time.^[45] In 2015, Wang *et al.* described the steps to neuroendoscopic evacuation of ICH, which involved making a cortical incision, dilating the channel, and introducing the transparent sheath that led to gushing out of the hematoma under high intracranial pressure. This was followed by changing the angle of the transparent sheath, endoscope, and suction tip to remove the residual hematoma and paving with a hemostatic agent before closure. They reported a significant decrease in the median operative time and blood loss, as well as decreased intensive care unit stay from 11 to 6 days, hence reducing hospital costs.^[43] While Li *et al.* report more effective hematoma clearance and better functional outcomes in the craniotomy group,^[44] the literature has not reported any additional complications with neuroendoscopic treatment of ICH.

Intracranial Cysts

Current management options for large, symptomatic arachnoid cysts broadly consist of microsurgical fenestration through craniotomy, neuroendoscopic fenestration, and cystoperitoneal shunting.^[47,48] In their meta-analytic review of surgical treatment options for arachnoid cysts, Hayes *et al.* found craniotomy and endoscopy to have similar efficacy in studies that looked at both pediatric and adult populations, while endoscopy was superior to craniotomy and shunting in adult-only studies.^[48]

The location of the cyst is an important factor in deciding the best surgical approach and determining outcomes. Middle cranial fossa cysts are classified into Types

I, II, and III based on the Galassi classification.^[49] In their review of operative techniques for middle cranial fossa cysts, Azab *et al.* concluded symptomatic Type II and III Galassi cysts to be suitable indications for endoscopic treatment.^[50] Elhammady *et al.* reported successful outcomes in endoscopic treatment of all six middle cranial fossa cysts included in their study, adding that the endoscopic transcortical approach showed promise in minimizing postoperative extra-axial fluid collections.^[51] Suprasellar cysts can also be adequately treated with endoscopy to relieve shunt dependency.^[52] Two endoscopic techniques, ventriculocystostomy (VC) and ventriculocystocisternostomy (VCC), can be used for suprasellar cysts. Several studies have found VCC to be superior to VC alone.^[53-55] For intrahemispheric cysts and cysts of the brain convexity, Gangemi *et al.* state that they are best treated with craniotomy with direct fenestration or shunting because of near obliteration of adjacent subarachnoid spaces.^[56] Due to their close proximity to the pineal quadrigeminal neurovascular structures, quadrigeminal cysts should undergo minimally invasive treatment.^[57] Endoscopic treatment of quadrigeminal cysts has yielded good results, with shunt independency rates ranging from 78% to 92.9%.^[58,59] In addition, Cinalli *et al.* found that VC combined with ETV for quadrigeminal cysts leads to better outcomes than VC alone.^[58]

While the use of lasers in endoscopic neurosurgery is not very widespread, one potential avenue for their use is in the fenestration of arachnoid cysts. Choi *et al.* reported a series of 36 patients with arachnoid cysts who were treated endoscopically with an Nd-YAG laser system. The laser was used to incise the cyst wall or shrink the cyst to a smaller size, allowing the cyst wall to be removed or a connection between the cyst and normal CSF pathways to be made. They reported that 78% of the arachnoid cysts were obliterated, without any significant mortality or morbidity.^[60] van Beijnum *et al.* have described the use of Nd-YAG and diode lasers in a large cohort of patients treated with laser-assisted ETV. They reported technically successful procedures in 196 of 202 patients (97%), with an overall success rate of 68% on a 2-year follow-up.^[61] While there are other reports of pathologies treated with laser-assisted neuroendoscopy, more research has to be done to assess the success and safety of lasers in neuroendoscopy, especially compared to more established techniques.

Intraventricular Tumor Biopsy and Resection

In addition to allowing access to ventricles to treat hydrocephalus, endoscopy has gained favor in the biopsy and resection of intraventricular tumors.^[62] Endoscopic intraventricular biopsies have proven to be efficacious and relatively free of complications over the years.^[63-65] Such approaches can be combined with ETVs, offering an option to concurrently treat obstructive hydrocephalus occurring

due to the tumor being biopsied.^[65] In a recent series of 64 patients who underwent ETV and concurrent biopsy of pineal region tumors, Samadian *et al.* achieved an initial positive diagnosis in 97% of patients, with transient deficits such as intraventricular hemorrhage, seizure, diabetes insipidus, and meningitis that were successfully managed and only one instance of a permanent memory deficit.^[66]

ETV and posterior third ventricular tumor biopsies can be performed together using one of the techniques outlined ahead. When planning the operation, the surgeon must be able to reach the anterior part of the third ventricle for the ETV and the posterior part for the tumor biopsy; this requires two separate trajectories and entry points through the FM. One approach involves making a compromised burr hole, midway between the two entry points, and uses a rigid endoscope.^[67] Alternatively, two separate burr holes can be made for each entry point, again using a rigid endoscope.^[68] The third option is to make a single burr hole but uses a flexible endoscope to reach both the anterior and posterior portions of the third ventricle.^[69] A fourth technique, which is less frequently reported and used, involves the use of combined rigid and flexible endoscopy through one burr hole.^[69] Roth and Constantini recommend using this technique, which may be superior to only using one type of endoscope in terms of ease of procedure and patient safety.^[70]

Conversely, pure endoscopic resection of intraventricular tumors is a much more challenging task, especially in the cases of solid tumors and tumors without hydrocephalus. Neuroendoscopes should be used cautiously for complete resection, due to problems in spatial orientation while introducing the endoscope, limited field of view, and loss of visibility in the setting of moderate to severe bleeding. For these reasons, endoscopic interventions in patients with enlarged ventricles allow better access to the ventricles and guarantee more safety when maneuvering within the ventricles.^[71]

In a series of 11 patients with intraventricular tumors without hydrocephalus, Stachura and Grzywna performed endoscopic intraventricular tumor resection in 8 of them.^[71] They did not run into any major perioperative complications and found no difference in results compared to tumors with associated hydrocephalus. Along with other surgeons, they recommend using neuronavigation to overcome the limitations of neuroendoscopy in tumor resection.^[71-73] Tumors located in the lateral ventricles and anterior portion of the third ventricle are the ideal target for endoscopic resection. On the other hand, tumors in the posterior part of the third ventricle should be cautiously approached because of the potential for injury to adjacent structures.^[71]

Similarly, solid tumors are harder to remove because of the inadequacy of instruments that can fragment these tumors and visibility issues due to bleeding. While microsurgical resection remains the procedure of choice to resect solid

tumors,^[74] endoscopic tumor resection is being used more frequently due to technological advances in instruments such as ultrasonic aspirators. While endoscopes were mainly used to resect small and cystic tumors such as colloid cysts,^[73,75] these ultrasonic devices have expanded our ability to resect many other solid tumors. The first resection of a solid intraventricular tumor using an endoscopic ultrasonic aspirator was reported by Selvanathan *et al.* in 2013.^[76] In a subsequent series of 12 pediatric patients who underwent resection of intraventricular tumors using only an endoscope and ultrasonic aspirator, 7 patients achieved near-total resection and 5 patients achieved partial resection. The tumors ranged from medulloblastomas, atypical teratoid rhabdoid tumors, subependymal giant cell astrocytomas, craniopharyngiomas, optic pathway gliomas, and pineal tumors.^[77] Ibáñez-Botella *et al.* received similar results in their series of nine patients who had lesions such as SEGAs, colloid cysts, pilocytic astrocytoma, epidermoid tumor, and central neurocytoma.^[74] The results of these reports have shown endoscopic resection with ultrasonic aspirators to be a feasible alternative to the traditional microsurgical transcallosal and transfrontal approaches. Endoscopic approaches lead to less blood loss, shorter operating times, and faster recovery than open approaches. Reservations about endoscopy arise in the case of large and highly vascular lesions, such as cavernomas. However, Baldo *et al.* recently reported successful removal of a cavernoma of the septum pellucidum through a purely endoscopic transventricular approach.^[78]

In summary, adequate preoperative patient selection according to certain favorable tumor characteristics discussed above, surgical expertise, and use of additional tools such as ultrasonic aspirators and neuronavigation can make endoscopic intraventricular tumor biopsy and resection a feasible alternative to traditional microsurgical approaches.

Septum Pellucidotomy

Endoscopic septum pellucidotomy (ESP) is a well-established procedure; however, it is not as frequently performed as the other endoscopic procedures discussed in this review. ESP is used in the treatment of unilateral hydrocephalus. It may also allow surgeons to create a communicating pathway between the lateral ventricles in the presence of a lesion at the FM or third ventricle, thereby facilitating drainage of both ventricles through one shunt. In one of the largest series of ESPs, Oertel *et al.* found tumor-related obstruction of the FM to be the most common indication for ESP, followed by multicystic hydrocephalus, septum pellucidum cysts, membranous or inflammatory isolated lateral ventricle, and giant aneurysms.^[79] This is in accordance with other reports in the literature.^[78,80-84]

ESP involves performing an endoscopic septostomy from one side of the septum in an avascular area. Variations in ESP technique exist among different surgeons; Aldana

et al. performed ESPs 1 cm superior and 2 cm anterior to the anterosuperior border of the FM,^[80] Oertel *et al.* perforated the septum 5–10 mm posterior to the FM, midway between the corpus callosum (CC) and the fornix,^[79] and Hamada *et al.* created openings between the anterior and posterior septal veins.^[84] After studying septal vein symmetry in cadavers, Roth *et al.* describe ESPs done at the anterior area of the middle septal region, at the level of the FM, mid-height between the CC and fornix, as the ideal approach.^[85]

Oertel *et al.* conducted successful ESPs in 31 of 32 cases and achieved an improvement in CSF circulation in 87% of patients. Moreover, they only performed two revisions for closure, due to insufficient septostomy and reclosure due to infection, and did not report any permanent complications. On the basis of these findings, they concluded the technique to be safe and successful.^[79]

Conclusion

The applications of endoscopes in neurosurgery are innumerable. While endoscopic approaches have been firmly established in the treatment of hydrocephalus and skull base lesions, there is more work to be done in the fields of arachnoid cysts, intraventricular tumors, and intracranial hemorrhage. Continuing advancements in surgical skill, technology, and anatomical knowledge will allow neuroendoscopy to treat an even wider range of neurosurgical pathologies.

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