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Review Article

# 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*


**Aneela Darbar, Fatima Mustansir, Ummey Hani, Mir Ibrahim Sajid**

*Department of Neurosurgery, The Aga Khan University, Karachi, Pakistan*


## 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


***Address for correspondence:***
*Dr. Fatima Mustansir,*
*17/1, Main Khayaban-e-Seher,*
*Phase 6, DHA, Karachi*
*75500, Pakistan.*
*E-mail: fatimamustansir5@gmail.com*



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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 Liliequist 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 meningomyelocele, 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 meningomyelocele. 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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### Conflicts of interest

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## References

1. Abd-El-Barr MM, Cohen AR. The origin and evolution of neuroendoscopy. Childs Nerv Syst 2013;29:727-37.
2. Esposito F, Cappabianca P. Neuroendoscopy: General aspects and principles. World Neurosurg 2013;79 2 Suppl:S14.e17-9.
3. Hsu W, Li KW, Bookland M, Jallo GI. Keyhole to the brain: Walter Dandy and neuroendoscopy. J Neurosurg Pediatr 2009;3:439-42.
4. Beems T, Grotenhuis JA. Long-term complications and definition of failure of neuroendoscopic procedures. Childs Nerv Syst 2004;20:868-77.
5. Demerdash A, Rocque BG, Johnston J, Rozzelle CJ, Yalcin B, Oskouian R, *et al*. Endoscopic third ventriculostomy: A historical review. Br J Neurosurg 2017;31:28-32.
6. Oertel J, Vulcu S, Eickele L, Wagner W, Cinalli G, Rediker J. Long-term follow-up of repeat endoscopic third ventriculostomy in obstructive hydrocephalus. World Neurosurg 2017;99:556-65.
7. Yadav YR, Parihar V, Pande S, Namdev H, Agarwal M. Endoscopic third ventriculostomy. J Neurosci Rural Pract 2012;3:163-73.
8. Shim KW, Park EK, Kim DS, Choi JU. Neuroendoscopy: Current and future perspectives. J Korean Neurosurg Soc 2017;60:322-6.
9. Morgenstern PF, Osbun N, Schwartz TH, Greenfield JP, Tsiouris AJ, Souweidane MM. Pineal region tumors: An optimal approach for simultaneous endoscopic third ventriculostomy and biopsy. Neurosurg Focus 2011;30:E3.
10. Kobayashi N, Ogiwara H. Endoscopic third ventriculostomy for hydrocephalus in brainstem glioma: A case series. Childs Nerv Syst 2016;32:1251-5.
11. Fallah A, Wang AC, Weil AG, Ibrahim GM, Mansouri A, Bhatia S. Predictors of outcome following cerebral aqueductoplasty: An individual participant data meta-analysis. Neurosurgery 2015;78:285-96.
12. Madsen PJ, Mallela AN, Hudgins ED, Storm PB, Heuer GG, Stein SC. The effect and evolution of patient selection on outcomes in endoscopic third ventriculostomy for hydrocephalus: A large-scale review of the literature. J Neurol Sci 2018;385:185-91.
13. Greenfield JP, Hoffman C, Kuo E, Christos PJ, Souweidane MM. Intraoperative assessment of endoscopic third ventriculostomy success. J Neurosurg Pediatr 2008;2:298-303.
14. Isaacs AM, Bezchlibnyk YB, Yong H, Koshy D, Urbaneja G, Hader WJ, *et al*. Endoscopic third ventriculostomy for treatment of adult hydrocephalus: Long-term follow-up of 163 patients. Neurosurg Focus 2016;41:E3.
15. Foroughi M, Wong A, Steinbok P, Singhal A, Sargent MA, Cochrane DD. Third ventricular shape: A predictor of endoscopic third ventriculostomy success in pediatric patients. J Neurosurg Pediatr 2011;7:389-96.
16. Borcek AO, Ucar M, Karaaslan B. Simplest radiological measurement related to clinical success in endoscopic third ventriculostomy. Clin Neurol Neurosurg 2017;152:16-22.
17. Azab WA, Mijalcic RM, Abdelnabi EA, Khan TA, Mohammad MH, Shaat MS. Infundibular recess angle reduction after endoscopic third ventriculostomy: Does it reflect clinical success? World Neurosurg 2015;84:549-54.
18. Kulkarni AV, Riva-Cambrin J, Browd SR. Use of the ETV Success Score to explain the variation in reported endoscopic third ventriculostomy success rates among published case series of childhood hydrocephalus. J Neurosurg Pediatr 2011;7:143-6.
19. Kulkarni AV, Drake JM, Mallucci CL, Sgouros S, Roth J, Constantini S; Canadian Pediatric Neurosurgery Study G. Endoscopic third ventriculostomy in the treatment of childhood hydrocephalus. J Pediatr 2009;155:254-9.e251.
20. Warf BC. Hydrocephalus in Uganda: The predominance of infectious origin and primary management with endoscopic third ventriculostomy. J Neurosurg 2005;102 1 Suppl:1-15.
21. Warf BC. Comparison of endoscopic third ventriculostomy alone and combined with choroid plexus cauterization in infants younger than 1 year of age: A prospective study in 550 African children. J Neurosurg 2005;103 6 Suppl:475-81.
22. Kulkarni AV, Riva-Cambrin J, Browd SR, Drake JM, Holubkov R, Kestle JR, *et al*. Endoscopic third ventriculostomy and choroid plexus cauterization in infants with hydrocephalus: A retrospective Hydrocephalus Clinical Research Network study. J Neurosurg Pediatr 2014;14:224-9.
23. Wang S, Stone S, Weil AG, Fallah A, Warf BC, Ragheb J, *et al*. Comparative effectiveness of flexible versus rigid neuroendoscopy for endoscopic third ventriculostomy and choroid plexus cauterization: A propensity score-matched cohort and survival analysis. J Neurosurg Pediatr 2017;19:585-91.
24. Fallah A, Weil AG, Juraschka K, Ibrahim GM, Wang AC, Crevier L, *et al*. The importance of extent of choroid plexus cauterization in addition to endoscopic third ventriculostomy for infantile hydrocephalus: A retrospective North American

observational study using propensity score-adjusted analysis. J Neurosurg Pediatr 2017;20:503-10.

25. Riva-Cambrin J, Kestle JR, Rozzelle CJ, Naftel RP, Alvey JS, Reeder RW, *et al*. Predictors of success for combined endoscopic third ventriculostomy and choroid plexus cauterization in a North American setting: A Hydrocephalus Clinical Research Network study. J Neurosurg Pediatr 2019;24:1-11.
26. Dewan MC, Lim J, Morgan CD, Gannon SR, Shannon CN, Wellons JC 3rd, *et al*. Endoscopic third ventriculostomy with choroid plexus cauterization outcome: Distinguishing success from failure. J Neurosurg Pediatr 2016;25:655-62.
27. Liu JK, Das K, Weiss MH, Laws ER Jr., Couldwell WT. The history and evolution of transsphenoidal surgery. J Neurosurg 2001;95:1083-96.
28. Yang I, Wang MB, Bergsneider M. Making the transition from microsurgery to endoscopic trans-sphenoidal pituitary neurosurgery. Neurosurg Clin N Am 2010;21:643-51, vi.
29. Solari D, Villa A, De Angelis M, Esposito F, Cavallo LM, Cappabianca P. Anatomy and surgery of the endoscopic endonasal approach to the skull base. Transl Med UniSa 2012;2:36-46.
30. Gaillard S. The transition from microscopic to endoscopic transsphenoidal surgery in high-caseload neurosurgical centers: The experience of Foch Hospital. World Neurosurg 2014;82 6 Suppl:S116-20.
31. Juraschka K, Khan OH, Godoy BL, Monsalves E, Kilian A, Krischek B, *et al*. Endoscopic endonasal transsphenoidal approach to large and giant pituitary adenomas: Institutional experience and predictors of extent of resection. J Neurosurg 2014;121:75-83.
32. Kassam A, Snyderman CH, Mintz A, Gardner P, Carrau RL. Expanded endonasal approach: The rostrocaudal axis. Part I. Crista galli to the sella turcica. Neurosurg Focus 2005;19:E3.
33. Prosser J, Vender J, Alleyne C, Solares C. Expanded Endoscopic endonasal approaches to skull base meningiomas. J Neurol Surg Part B Skull Base 2012;73:147-56.
34. de Lara D, Ditzel Filho LF, Prevedello DM, Carrau RL, Kasemsiri P, Otto BA, *et al*. Endonasal endoscopic approaches to the paramedian skull base. World Neurosurg 2014;82 6 Suppl:S121-9.
35. Jho HD, Ha HG. Endoscopic endonasal skull base surgery: Part 1--The midline anterior fossa skull base. Minim Invasive Neurosurg 2004;47:1-8.
36. Oyama K, Tahara S, Hirohata T, Ishii Y, Prevedello DM, Carrau RL, *et al*. Surgical anatomy for the endoscopic endonasal approach to the ventrolateral skull base. Neurol Med Chir (Tokyo) 2017;57:534-41.
37. Kassam A, Snyderman CH, Mintz A, Gardner P, Carrau RL. Expanded endonasal approach: The rostrocaudal axis. Part II. Posterior clinoids to the foramen magnum. Neurosurg Focus 2005;19:E4.
38. Fomichev D, Kalinin P, Kutin M, Sharipov O. Extended transsphenoidal endoscopic endonasal surgery of suprasellar craniopharyngiomas. World Neurosurg 2016;94:181-7.
39. Mascarenhas L, Moshel YA, Bayad F, Szentirmai O, Salek AA, Leng LZ, *et al*. The transplanum transtuberculum approaches for suprasellar and sellar-suprasellar lesions: Avoidance of cerebrospinal fluid leak and lessons learned. World Neurosurg 2014;82:186-95.
40. Abbassy M, Woodard TD, Sindwani R, Recinos PF. An overview of anterior skull base meningiomas and the endoscopic endonasal approach. Otolaryngol Clin North Am 2016;49:141-52.
41. Wardas P, Tymowski M, Piotrowska-Seweryn A, Markowski J, Ładziński P. Hadad-Bassagasteguy flap in skull base reconstruction – Current reconstructive techniques and evaluation of criteria used for qualification for harvesting the flap. Wideochir Inne Tech Maloinwazyjne 2019;14:340-7.
42. Amin BK, Daniel MP, Ricardo LC, Carl HS, Ajith T, Paul G, *et al*. Endoscopic endonasal skull base surgery: Analysis of complications in the authors' initial 800 patients. J Neurosurg 2011;114:1544-68.
43. Wang WH, Hung YC, Hsu SP, Lin CF, Chen HH, Shih YH, *et al*. Endoscopic hematoma evacuation in patients with spontaneous supratentorial intracerebral hemorrhage. J Chin Med Assoc 2015;78:101-7.
44. Li Y, Yang R, Li Z, Yang Y, Tian B, Zhang X, *et al*. Surgical evacuation of spontaneous supratentorial lobar intracerebral hemorrhage: Comparison of safety and efficacy of stereotactic aspiration, endoscopic surgery, and craniotomy. World Neurosurg 2017;105:332-40.
45. Ye Z, Ai X, Hu X, Fang F, You C. Comparison of neuroendoscopic surgery and craniotomy for supratentorial hypertensive intracerebral hemorrhage: A meta-analysis. Medicine 2017;96:e7876.
46. Yao Z, Hu X, You C, He M. Effect and feasibility of endoscopic surgery in spontaneous intracerebral hemorrhage: A systematic review and meta-analysis. World Neurosurg 2018;113:348-56.e342.
47. Wang C, Liu C, Xiong Y, Han G, Yang H, Yin H, *et al*. Surgical treatment of intracranial arachnoid cyst in adult patients. Neurol India 2013;61:60-4.
48. Hayes MJ, TerMaath SC, Crook TR, Killeffer JA. A review on the effectiveness of surgical intervention for symptomatic intracranial arachnoid cysts in adults. World Neurosurg 2019;123:e259-72.
49. Galassi E, Tognetti F, Gaist G, Fagioli L, Frank F, Frank G. CT scan and metrizamide CT cisternography in arachnoid cysts of the middle cranial fossa: Classification and pathophysiological aspects. Surg Neurol 1982;17:363-9.
50. Azab WA, Almanabri M, Yosef W. Endoscopic treatment of middle fossa arachnoid cysts. Acta Neurochirurgica 2017;159:2313-7.
51. Elhammady MS, Bhatia S, Ragheb J. Endoscopic Fenestration of middle fossa arachnoid cysts: A technical description and case series. Pediatr Neurosurg 2007;43:209-15.
52. Kirollos RW, Javadpour M, May P, Mallucci C. Endoscopic treatment of suprasellar and third ventricle-related arachnoid cysts. Childs Nerv Syst 2001;17:713-8.
53. Gui SB, Wang XS, Zong XY, Zhang YZ, Li CZ. Suprasellar cysts: Clinical presentation, surgical indications, and optimal surgical treatment. BMC Neurol 2011;11:52.
54. Gangemi M, Colella G, Magro F, Maiuri F. Suprasellar arachnoid cysts: Endoscopy versus microsurgical cyst excision and shunting. Br J Neurosurg 2007;21:276-80.
55. Crimmins DW, Pierre-Kahn A, Sainte-Rose C, Zerah M. Treatment of suprasellar cysts and patient outcome. J Neurosurg 2006;105 2 Suppl:107-14.
56. Gangemi M, Seneca V, Colella G, Cioffi V, Imperato A, Maiuri F. Endoscopy versus microsurgical cyst excision and shunting for treating intracranial arachnoid cysts. J Neurosurg Pediatr 2011;8:158-64.
57. Sengul G, Tuzun Y, Cakir M, Duman S, Colak A, Kadioglu HH, *et al*. Neuroendoscopic approach to quadrigeminal cistern arachnoid cysts. Eurasian J Med 2012;44:18-21.
58. Cinalli G, Spennato P, Columbano L, Ruggiero C, Aliberti F, Trischitta V, *et al*. Neuroendoscopic treatment of arachnoid cysts

of the quadrigeminal cistern: A series of 14 cases. J Neurosurg Pediatr 2010;6:489-97.

59. El-Ghandour NM. Endoscopic treatment of quadrigeminal arachnoid cysts in children. J Neurosurg Pediatr 2013;12:521-8.
60. Choi JU, Kim DS, Huh R. Endoscopic approach to arachnoid cyst. Childs Nerv Syst 1999;15:285-91.
61. van Beijnum J, Hanlo PW, Fischer K, Majidpour MM, Kortekaas MF, Verdaasdonk RM, *et al.* Laser-assisted endoscopic third ventriculostomy: Long-term results in a series of 202 patients. Neurosurgery 2008;62:437-44.
62. Kunwar S. Endoscopic adjuncts to intraventricular surgery. Neurosurg Clin N Am 2003;14:547-57.
63. Lee MH, Kim HR, Seol HJ, Shin HJ. Neuroendoscopic biopsy of pediatric brain tumors with small ventricle. Childs Nerv Syst 2014;30:1055-60.
64. Giannetti AV, Alvarenga AY, de Lima TO, Pedrosa HA, Souweidane MM. Neuroendoscopic biopsy of brain lesions: Accuracy and complications. J Neurosurg 2015;122:34-9.
65. Depreitere B, Dasi N, Rutka J, Dirks P, Drake J. Endoscopic biopsy for intraventricular tumors in children. J Neurosurg 2007;106 5 Suppl:340-6.
66. Samadian M, Maloumeh EN, Shiravand S, Ebrahimzadeh K, Sharifi G, Mousavinejad A, *et al*. Pineal region tumors: Long-term results of endoscopic third ventriculostomy and concurrent tumor biopsy with a single entry approach in a series of 64 cases. Clin Neurol Neurosurg 2019;184:105418.
67. Knaus H, Matthias S, Koch A, Thomale UW. Single burr hole endoscopic biopsy with third ventriculostomy–measurements and computer-assisted planning. Childs Nerv Syst 2011;27:1233-41.
68. Veto F, Horváth Z, Dóczi T. Biportal endoscopic management of third ventricle tumors in patients with occlusive hydrocephalus: Technical note. Neurosurgery 1997;40:871-7.
69. Oppido PA, Fiorindi A, Benvenuti L, Cattani F, Cipri S, Gangemi M, *et al*. Neuroendoscopic biopsy of ventricular tumors: A multicentric experience. Neurosurg Focus 2011;30:E2.
70. Roth J, Constantini S. Combined rigid and flexible endoscopy for tumors in the posterior third ventricle. J Neurosurg 2015;122:1341-6.
71. Stachura K, Grzywna E. Neuronavigation-guided endoscopy for intraventricular tumors in adult patients without hydrocephalus. Wideochir Inne Tech Maloinwazyjne 2016;11:200-7.
72. Schroeder HW, Wagner W, Tschiltschke W, Gaab MR. Frameless neuronavigation in intracranial endoscopic neurosurgery. J Neurosurg 2001;94:72-9.
73. Decq P, Le Guerinel C, Brugieres P, Djindjian M, Silva D, Keravel Y, *et al*. Endoscopic management of colloid cysts. Neurosurgery 1998;42:1288-94.
74. Ibáñez-Botella G, Segura M, De Miguel L, Ros B, Arráez MÁ. Purely neuroendoscopic resection of intraventricular tumors with an endoscopic ultrasonic aspirator. Neurosurg Rev 2019;42:973-82.
75. Boogaarts HD, Decq P, Grotenhuis JA, Le Guerinel C, Nseir R, Jarraya B, *et al*. Long-term results of the neuroendoscopic management of colloid cysts of the third ventricle: A series of 90 cases. Neurosurgery 2011;68:179-87.
76. Selvanathan SK, Kumar R, Goodden J, Tyagi A, Chumas P. Evolving instrumentation for endoscopic tumour removal of CNS tumours. Acta Neurochirurgica 2013;155:135-8.
77. Cinalli G, Imperato A, Mirone G, Di Martino G, Nicosia G, Ruggiero C, *et al*. Initial experience with endoscopic ultrasonic aspirator in purely neuroendoscopic removal of intraventricular tumors. J Neurosurg Pediatr 2017;19:325-32.
78. Baldo S, Magrini S, Tacconi L. Purely endoscopic resection of cavernoma of the septum pellucidum. Surg J (New York, NY) 2019;5:e42-5.
79. Oertel JM, Schroeder HW, Gaab MR. Endoscopic stomy of the septum pellucidum: Indications, technique, and results. Neurosurgery 2009;64:482-91.
80. Aldana PR, Kestle JR, Brockmeyer DL, Walker ML. Results of endoscopic septal fenestration in the treatment of isolated ventricular hydrocephalus. Pediatr Neurosurg 2003;38:286-94.
81. Gangemi M, Maiuri F, Cappabianca P, Alafaci C, de Divitiis O, Tomasello F, *et al*. Endoscopic fenestration of symptomatic septum pellucidum cysts: Three case reports with discussion on the approaches and technique. Minim Invasive Neurosurg 2002;45:105-8.
82. Harter DH, Omeis I, Forman S, Braun A. Endoscopic resection of an intraventricular dysembryoplastic neuroepithelial tumor of the septum pellucidum. Pediatr Neurosurg 2006;42:105-7.
83. Udayakumaran S, Onyia CU, Cherkil S. An analysis of outcome of endoscopic fenestration of cavum septum pellucidum cyst – More grey than black and white? Pediatr Neurosurg 2017;52:225-33.
84. Hamada H, Hayashi N, Kurimoto M, Umemura K, Hirashima Y, Endo S. Neuroendoscopic septostomy for isolated lateral ventricle. Neurol Med Chir (Tokyo) 2003;43:582-7.
85. Roth J, Olasunkanmi A, Rubinson K, Wisoff J. Septal vein symmetry: Implications for endoscopic septum pellucidotomy. Neurosurgery 2010;67:395-401.