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Neuroendoscopy: past, present, and future

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Neuroendoscopy began with a desire to visualize the ventricles and deeper structures of the brain. Unfortunately, the technology available to early neuroendoscopists was not sufficient in most cases for these purposes. The unique perspective that neuroendoscopy offered was not fully realized until key technological advances made reliable and accurate visualization of the brain and ventricles possible. After this technology was incorporated into the device, neuroendoscopic procedures were rediscovered by neurosurgeons. Endoscopic third ventriculostomy and other related procedures are now commonly used to treat a wide array of neurosurgically managed conditions. A seemingly limitless number of neurosurgical applications await the endoscope. In the future, endoscopy is expected to become routine in modern neurosurgical practice and training.

KEY WORDS • neuroendoscopy • third ventriculostomy • history of neurosurgery • endoscope

EARLY HISTORY

The field of neuroendoscopy began with great promise; this new modality held the potential to allow neurosurgeons to visualize anatomical structures never before studied in live patients. The perspective would be unique, a magnified view of the ventricular system viewed from within its walls. In reality, however, the technology available to the pioneers of neuroendoscopy was far too primitive for these purposes.[1,54] Illumination was a major problem, and magnification was another. Although there were early reports of successful visualization of intracranial anatomy and even treatment of pathological entities within the ventricles, most attempts at early neuroendoscopic procedures were met with frustration because of the technical limitations imposed by the instruments available at the time.

Max Nitze is credited with designing the first modern endoscope in 1879. According to Schultheiss, et al.,[47] this was a crude device composed of a series of lenses with an illumination source at the tip. The first neurosurgical endoscopic procedure was performed by L'Espinasse. In 1910, he reported the use of a cystoscope to perform fulguration of the choroid plexus in two infants with hydrocephalus.[54] One patient died postoperatively, but the other was successfully treated. Twelve years later, in 1922, Walter Dandy described the use of an endoscope to perform choroid plexectomy.[8] This followed his descriptions several years earlier of open choroid plexectomy for the treatment of hydrocephalus.[9] This latest attempt to perform the procedure endoscopically, however, was ultimately unsuccessful. That same year, Dandy reported the first ventriculostomy for the treatment of hydrocephalus: fenestration of the lamina terminalis via a craniotomy and a transfrontal approach.

In 1923, Fay and Grant[12] were able to visualize and photograph successfully the interior of the ventricles of a child with hydrocephalus by using a cystoscope. The exposure times, however, ranged from 30 to 90 seconds, which demonstrates the poor illumination available to them with their cystoscope. That same year, Mixter performed the first successful ETV by using a urethroscope in a 9-month-old girl with obstructive hydrocephalus. Mixter's report, which is detailed in Abbott[1] and Walker,[54] went largely unnoticed, however, possibly because of the cumbersome size of his instruments and the poor illumination that they offered.

In 1932, Dandy again reported use of an endoscope for choroid plexectomy. This time the procedure was successful, but he found the results to be only comparable to those of open choroid plexectomy.[1] In 1934, Putnam[41] described cauterization of the choroid plexus with an endoscopic device. The procedure was performed 12 times in seven patients, was successful in at least three cases, and resulted in two deaths. As related in Abbott, 9 years later Putnam reported his series of endoscopic choroid plexectomy in 42 patients. There were 10 perioperative deaths (25%) and 15 patients failed to respond, although 17 had successful relief of increased intracranial pressure.

After Mixter's paper from 12 years earlier, there were no reports of ETV until 1935, when Scarff[45] described his initial results after using a novel endoscope equipped with a mobile cauterizing electrode, an irrigation system that prevented collapse of the ventricles, and a movable operating tip that could be used to perforate the floor of the third ventricle. He punctured the floor of the third ventricle in one patient and achieved dramatic results: a 3-cm decrease in head circumference 6 weeks postoperatively. The ventricu-

Abbreviations used in this paper: CCD = charge-coupled device; CSF = cerebrospinal fluid; ETV = endoscopic third ventriculostomy.

lostomy eventually failed, however, and the patient died. A healed scar over the ventriculostomy site was found at autopsy. Scarff noted, "This case demonstrates clearly the feasibility of the procedure but points out also the necessity of enlarging the opening beyond a mere puncture wound."

In 1947, McNickle[38] described a percutaneous method of performing third ventriculostomy in patients with both obstructive and communicating hydrocephalus. Initially he used a 19-gauge needle and an endoscope for visualization. Later, he abandoned the endoscope, using only x-ray films and feel for localization. McKnickle reported few complications, and despite the inclusion of patients with nonobstructive hydrocephalus, he recounted success rates that were superior to Dandy's open approach.

Despite the numerous reports that demonstrated the potential utility of neuroendoscopy, the field never gained favor in general neurosurgical practice. The fact was that poor magnification and illumination made neuroendoscopy difficult and unreliable. Even in the hands of a skilled surgeon such as Dandy, endoscopic procedures were met mostly with frustration.

DECLINE OF NEUROENDOSCOPY

Although Fay, Grant, Putnam, Scarff, and others continued to perform neuroendoscopic procedures during the subsequent decades, these procedures were never attempted by most neurosurgeons because of the technical difficulties and high death rates.

Advent of Ventricular Shunts

The report by Nulsen and Spitz[39] in 1952 detailing the treatment of hydrocephalus by using ventricular shunt placement marked the beginning of the era of ventricular CSF shunting and the end of the initial era of neuroendoscopy. The development of ventricular CSF shunting was a landmark for the treatment of hydrocephalus. In the years to come, others would confirm that these procedures could be performed simply and with low mortality rates. In addition, initial success rates were promising and superior to those of other available treatments.[54] During this era there was no perceived need to pursue new endoscopic methods for treatment of hydrocephalus. As CSF ventricular shunts became more commonplace in the treatment of hydrocephalus, the need for intraventricular endoscopy and ETV lessened even more.

Development of Microneurosurgery

The birth of microneurosurgery in the 1960s[25,57] pushed endoscopy further into the background. The microscope addressed all of the deficiencies of the neuroendoscope, allowing neurosurgeons to perform operations deep within the brain and at the base of the skull with both adequate illumination and magnification. In addition, the microscope was facile enough to delineate different trajectories and new surgical approaches. As microneurosurgery gained popularity, the use of endoscopy waned further.

During the 1960s, reports of neuroendoscopic procedures in the literature became sparse. Nevertheless, it was during this period that scientists made a number of key technological advances that would pave the way for modern neuroendoscopy.

Technological Advances

New Lens Type. In 1966, Hopkins and Storz developed a rigid endoscope that used a new type of lens, the SELFOC lens. Conventional lenses have a uniform refractive index, whereas the SELFOC lens used gradient index glass that had a refractive index that varied with the radial dimension of the lens.[34] At the time, conventional endoscopes required the careful placement of a series of relay and field lenses to construct an appropriate image. This new technology essentially obviated the need for the relay lenses while preserving light transmission.[4] These lenses also created a wider effective field of vision.

Invention of CCDs. The advent of CCDs marked another technological breakthrough. In 1969, George Smith and Willard Boyle invented the first CCDs at Bell Laboratories.[6] The CCDs are solid-state devices, usually a silicon chip, which are capable of converting optical data into electrical current. "Charge-coupling" refers to the manner in which the electronic charges are stored and transmitted. The CCDs are ideal for use in low-light environments and were readily incorporated into the system's apparatus, resulting in both improved quality of the transmitted images and decreased size of the endoscopic systems.

Fiberoptics. Another important technological breakthrough was the development of fiberoptics. Fiberoptic cables were first used in the 1950s and 1960s, and refined further in the 1970s. Fiberoptics allowed the light source to be separated from the rest of the endoscope.[49] Light could also be emitted from the tip of the endoscope without significant heating through one set of cables, while specialized, coherently arranged cables could be constructed to conduct images without a loss of luminescence. As discussed in Abbott,[1] in 1963 Scarff described the first use of a "fiber lighting" system with an external light source for ventriculoscopy.

These advances, which brought together brighter light sources and cameras with improved resolution, the two key components of any endoscope, were an important part of the rediscovery of neuroendoscopy. As these new technologies were incorporated into the modern endoscope, neurosurgeons began to reconsider the field of neuroendoscopy.

Rediscovery of Neuroendoscopy

Although CSF shunting procedures had revolutionized the treatment of hydrocephalus, ventricular shunting brought with it the frustration associated with this procedure's complications. Shunt malfunction, infection, migration, overdrainage, and other complications were encountered frequently.[54] Even in modern series, the frequency of shunt malfunction and the long-term morbidity associated with it remain high.[30] The search for a better solution to the problem of hydrocephalus led neurosurgeons to investigate new treatments and to revisit old ones that existed before ventricular shunts began to be used.

With the improved imaging capability of endoscopes, interest in ETV for the treatment of obstructive hydrocephalus was renewed. The ETV procedure (Fig. 1) offers a more physiological solution to the problem of hydrocephalus than ventricular shunts by allowing the egress of ventricular CSF directly into the subarachnoid space. It also allows patients with hydrocephalus an opportunity for a

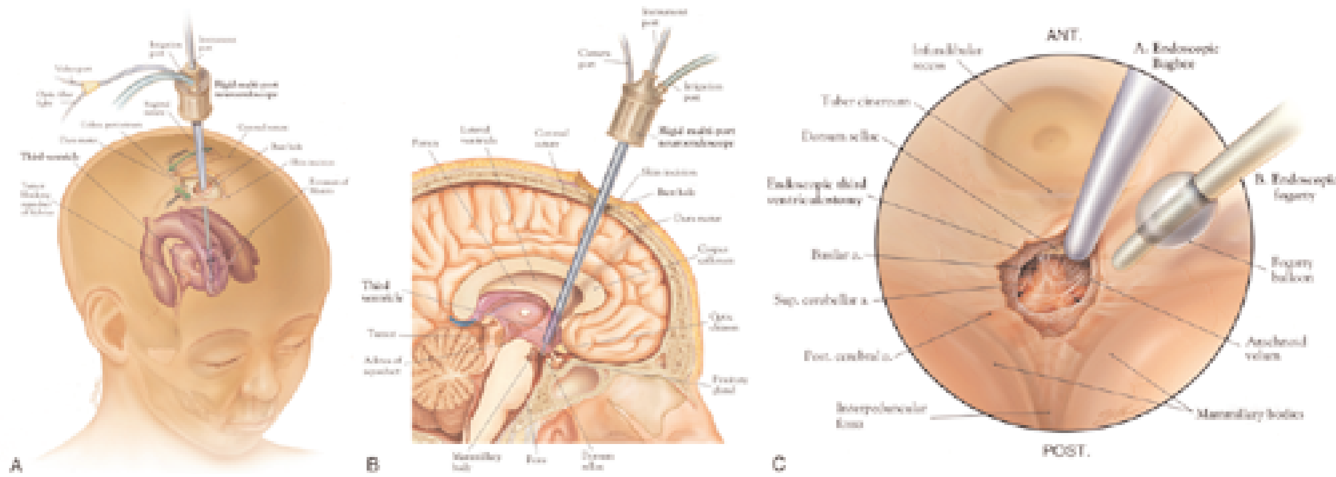

Fig. 1. Artist's illustrations demonstrating ETV. Oblique view (A) demonstrating typical location of the bur hole and trajectory; midsagittal view (B) demonstrating location of ventriculostomy; and magnified endoscopic view (C) of the floor of the third ventricle and site of ventriculostomy. a. = artery; ant. = anterior; post. = posterior; sup. = superior.

"shunt-free" existence without the complications associated with ventricular shunts.

In 1978, Vries[53] described his experience treating five patients with hydrocephalus, in whom he performed ETVs by using a fiberoptic endoscope. He was able to show that the procedure was technically feasible with the then-current technology. Nevertheless, all of his patients required ventricular CSF shunting. It was not until 1990 that Jones and colleagues[29] described a 50% shunt-free success rate for ETV in 24 patients with various forms of hydrocephalus. Four years later, Jones and coworkers[28] had improved their success rate to 61% in a series of 103 patients.

Currently ETV is primarily used to treat obstructive hydrocephalus caused by benign aqueductal stenosis or compressive periaqueductal mass lesions. In this population of patients, shunt-free success rates currently approach 80 to 95%.[5,13,18,22,33,44,48] The ETV procedure has recently been reported to be superior to ventricular shunt placement for hydrocephalus caused by pineal region tumors[56] and tectal gliomas.[33,55] This procedure was subsequently proposed as the primary surgical approach for treatment of hydrocephalus in these cases.[33,41,55,56]

FUTURE OF NEUROENDOSCOPY

The success of neuroendoscopy in recent years has relied heavily on the success of ETV for the treatment of obstructive hydrocephalus. Now, however, the field of neuroendoscopy is prepared to extend itself beyond just ventriculostomy procedures. The endoscope is currently being used for all types of neurosurgically treatable disorders: intraventricular tumors, skull base tumors, craniosynostosis, degenerative spine disease, intracranial cysts, and rare subtypes of hydrocephalus. The diversity of these disorders demonstrates the vast potential of the endoscope in neurosurgery. In the future, one can expect routine use of the endoscope for management of a multitude of neurosurgically treatable pathological conditions, either as the primary surgical approach or as an adjunct.

Complicated Hydrocephalus

As ETV has gained popularity for the treatment of obstructive hydrocephalus, use of the endoscope has been explored for treatment of other complicated forms of hydrocephalus. Septum pellucidotomy or septostomy can be performed endoscopically to treat isolated lateral ventricles.[20] Fenestration of loculated ventricles can also be performed,[20,40] along with marsupialization and fenestration of intracranial cysts.[11] Aqueductoplasty has recently been explored for treatment of the trapped fourth ventricle syndrome and aqueductal stenosis.[15,46]

Uses in Neurooncology

Fukushima and colleagues[16,17] were the first to report use of the neuroendoscope for biopsy procedures in intraventricular tumors. In addition to tumor biopsy sampling, the endoscope has been used for resection of colloid cysts and other intraventricular lesions.[2,32,43,50,51] Luther, et al.,[35] recently reported a low rate (3.5%) of hemorrhagic sequelae from neuroendoscopic procedures for intraventricular tumors. The use of the neuroendoscope provides the unique ability to perform tumor resection, tumor biopsy sampling, relief of hydrocephalus by ETV, and CSF sampling in a single procedure.[14,36,50] Planning of the surgical approach for these procedures can even be facilitated with frameless stereotactic guidance.[51]

Neuroendoscopy for skull base tumors began with Carrau, et al.,[7] and their original reports of endonasal transsphenoidal hypophysectomy at the University of Pittsburgh. De Divitiis, et al.,[10] have expanded the scope of this approach to include other lesions of the sellar and parasellar region. The bilateral endonasal endoscopic approach now allows for visualization of tumors at the anterior skull base up to the crista galli and down to the level of C-2.[38]

There has been recent interest in the use of the neuroendoscope to assist with "traditional" skull base microsurgery. The endoscope has already been reported to be a useful adjunct to the microscope in posterior fossa approaches[19] and aneurysm surgery.[31] The future of neuroendoscopy in skull base surgery will involve its use both as the primary surgical approach and as an adjunct to the microscope. New combined endoscopic and microscopic surgical approaches will play an important role in the future of skull base surgery.

Spine Surgery

The neuroendoscope has been an important part of the minimally invasive spine surgery movement. Endoscopic approaches include thoracoscopic sympathectomy,[21] discectomies,[3,21] lumbar laminotomies,[23] anterior approaches for spinal reconstruction,[52] and resection of tumors and cysts.[21,24]

Craniosynostosis Technique

Jimenez and Barone and their colleagues[26,27] have pioneered the minimally invasive surgical treatment of craniosynostosis. Their technique involves the creation of strip craniectomies through the endoscope, followed by application of a molding helmet to recontour the cranium. Using a strictly endoscopic approach, they have reported a low rate of complications and good success rates. Furthermore, the rate of blood transfusion in their most recent report was only 9% in 139 patients.[27]

CONCLUSIONS

Neuroendoscopy has a rich history that dates back to the early decades of the twentieth century. The continued evolution of this modality will rely on new technological advances, improved understanding of endoscopically demonstrated neurosurgical anatomy, discovery of novel applications, and the training of neurosurgeons in neuroendoscopic procedures.

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