Endoscopy and MIS in Neurosurgery

Khandkar Ali Kawsar, Atul H. Goel and Forhad H. Chowdhury

Abstract: The utilization of neuroendoscopes in neurosurgery is a remarkable advancement. It limits neural injury and maximizes the view of operative areas in the brain, spine, and peripheral nerves, which may be remote. The entrance and approaches to ventricles and cisterns have become attractive and easier. Devising optic endoscopic lenses—long and angled instruments—changed endoscopic neurosurgery into a very versatile super-specialty. In this chapter, we will first discuss the history of neuroendoscopy; later, its utility in hydrocephalus, skull base surgery, neuro-oncological surgery, aneurysm surgery, craniosynostosis, and transcranial cystic lesion treatment will be discussed. Some important endoscopic operations will be discussed with relevant anatomical landmarks. In the later part of the chapter, we will address spinal endoscopy and peripheral nerve endoscopy.

Abbreviations

AC	arachnoid cyst	AICA	anterior inferior cerebellar artery
AP	anterior–posterior	CNS	central nervous system
CSF	cerebrospinal fluid	CT	computed tomography
EACS	endoscopy-assisted craniosynostosis surgery	ECTR	endoscopic carpal tunnel release
EEA	endoscopic endonasal approach	EES	endoscopic endonasal surgery
ETV	endoscopic third ventriculostomy	HFS	hemifacial spasm
HH	hypothalamic hamartoma	HPA	hypothalamic–pituitary axis
ICA	internal carotid artery	ICH	intracranial hematoma
ID	internal diameter	MIS	minimally invasive surgery
MRI	magnetic resonance imaging	MVD	microvascular decompression
PECD	percutaneous endoscopic cervical discectomy	PETD	percutaneous endoscopic thoracic discectomy
REZ	root entry zone	SCA	superior cerebellar artery
SIADH	secretion of inappropriate antidiuretic hormone	TELD	transforaminal endoscopic lumbar discectomy
TCL	transverse carpal ligament	TDH	thoracic disc herniation
UN	ulnar nerve	VP	Ventriculoperitoneal

1. Introduction

Using an endoscope, neuroendoscopy treats diseases of the CNS. Two newborns with hydrocephalus underwent the first neurosurgery endoscopic operation with a cystoscope in 1910, and one of them experienced a successful recovery (Li et al. 2005; Sgouros 2013; Walker 2001). In 1922, after more than a decade had passed, Walter Dandy attempted a choroid plexectomy but failed (de Divitiis et al. 2002). Mixter accomplished the first endoscopic third ventriculostomy (ETV) in 1923, on a 9-month-old infant with obstructive hydrocephalus by utilizing a urethroscope (Mixter 1923). After employing a new endoscope with an electrocautery, an irrigation system to preclude ventricular collapse, and a movable operative tip to penetrate the third ventricular floor, Scarff first presented his findings in 1935 (Li et al. 2005; Walker 2001).

Early in the 1970s, developments in optics and electronics led to the creation of high-resolution rigid and flexible endoscopes, which were effectively employed for ventricular surgery. The use of ETV for the management of hydrocephalus with endoscope-assisted, minimally invasive surgical techniques, which started in the 1980s to 1990s and are still used today, has advanced to the current stage of neuroendoscopy (Teo and Mobbs 2004).

Initially, only the ventricles could be used for endoscopic treatments because they are filled with a crystal-clear fluid, the ideal medium. At present, the neuroendoscopic field has expanded beyond ventricular operations and is utilized for all varieties of neurosurgically manageable conditions, including craniosynostosis, rare subtypes of hydrocephalus, intraventricular tumors, intracranial cysts, hypothalamic hamartomas (HH), and skull base tumors (Shim et al. 2017).

Similar to other endoscopic operations, minimum tissue damage, improved visualization, improved cosmetic outcomes, shorter hospital stays, and lower surgical morbidity are the benefits of minimally invasive endoscopic procedures. The utilization of neuroendoscopy approaches may help to reduce this risk. In neurosurgery, the surgeon works to reduce operative trauma by limiting the exposure size and avoiding unintended brain retraction, which can occur via rising local cerebral tissue pressure as well as reduced regional cerebral blood flow and may ultimately affect the neurologic result after micro-neurosurgical operation. The endoscope is a great teaching tool since it improves the surgeon's perspective by enhancing illumination as well as magnification (Perneczky and Fries 1998; Teo 2000). A survey of neurosurgeons comparing the endoscope and the microscope revealed that the endoscope is superior for gazing around corners (30°, 70°, and 110°) and the microscope is preferable only for reduced hand fatigue and 3D vision, advantaged that are now provided by endoscopic holders (Teo and Mobbs 2004).

2. Neuroendoscopic Instruments

Surgeons must own a specific neuroendoscopy kit (Figure 1). The control units of the camera, video camera, light source, monitor, video recorder, and computerized system for storing video clips or single-picture capture should all be included in the endoscopy tower. Endoscope positioning as well as fixation arms that can be secured to the headrest or the operating table assist the surgeon in preventing arm fatigue, which can otherwise impair eye–hand coordination and limit flexibility (Siomin and Constantini 2004).

A pair of scissors and grasping forceps (Figure 2), a coagulation tool (either bipolar or monopolar), a straight scope, an irrigation, and one or more angled telescopes are among the endoscopic tools used by surgeons (Figure 3).

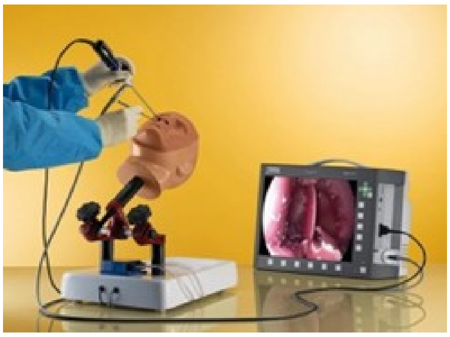

Figure 1. Endoscopic instruments. Source: Figure by authors.

Figure 2. Endoscopic grasping forceps. Source: Figure by authors.

Figure 3. Straight and angled scopes. Source: Figure by authors.

A skilled assistant can show the surgeon the challenging areas and can enable two-handed operation. It is crucial to have recording units that can record images for later analysis in digital or video format (Alberti et al. 2001). Thanks to flexible neuroendoscopes, the range of neuroendoscopy has expanded (Figure 4).

In order to boost the accuracy of the endoscopic approach, frameless computerized navigation is being employed more and more in cranial endoscopic procedures. It was tested to be accurate, dependable, and beneficial in several intracranial neuroendoscopic procedures. Excellent red distinction and remarkable color depth are provided by modern three-chip technology. Even with quick camera movements, the most recent full HD technology produces images without latency. The goals and requirements for endoscopic interventions will evolve as we learn more about various CNS disorders. Future indications for minimally invasive or even ultra-microsurgical access will require the use of supervisory-controlled robotic systems, telemanipulated neurosurgery, shared control systems, or perhaps totally robotic telesurgery (Grotenhuis 2014).

Figure 4. Flexible endoscope. Source: Figure by authors.

3. Endoscopic Third Ventriculostomy (ETV)

3.1. History and Background

The history of ventricular cerebrospinal fluid (CSF) diverting began in 1951 (Nulsen and Spitz 1951). With the enhanced neuroimaging capabilities of endoscopes, intrigue in ETV for the management of obstructive hydrocephalus was revived in the 1970s, after a brief hiatus in the use of this operation. Vries wrote about his experiences treating five hydrocephalus patients in 1978, where he used a fiberoptic endoscope to show that ETVs were theoretically possible (Vries 1978). Jones and colleagues first reported a 50% shunt-free chance of success for ETV in 24 cases with different types of hydrocephalus in 1990 (Jones et al. 1990). In a set of 103 patients, the same researchers reported an elevated rate of success of 61% four years later (Jones et al. 1994). ETV is now utilized to treat obstructive hydrocephalus brought on by compressive periaqueductal tumor lesions or benign aqueductal stenosis. Shunt-free success rates in the modern era range from 80% to 95% (Sgouros 2013).

As knowledge in this area increases, the indications for ETV are being extended to include cases with meningomyelocele, Chiari malformation, hydrocephalus associated with Dandy–Walker syndrome, and even noncommunicating kinds of hydrocephalus. Due to avoiding shunt reliance and associated difficulties, ETV is increasingly preferred to ventriculoperitoneal (VP) shunt implantation in some circumstances (Sufianov et al. 2008).

3.2. Important Operative Landmarks

It is crucial to recognize significant ventricular features and structures for good ETV. Here, we go through a few significant features that surgeons should be familiar with in order to complete the process properly. Figure 5 depicts the equipment needed for ETV as well as an endoscopic view with some significant landmarks.

The choroid plexus is a significant anatomical landmark because it persists at the choroidal fissure despite severe abnormalities in the ventricular architecture, providing the surgeon with an essential navigational tool. The third ventricle is reached after the foramen of Monro by the anterior section of the choroid plexus.

The fornix, which makes up the upper and anterior edge of the Monro's foramen, is another significant anatomical feature. When the endoscope is passed from the lateral to the third ventricle, the fornix is vulnerable to harm because of its placement; the chance of injury and subsequent memory loss increases with more passages. When detected, the thalamostriate vein, which dives into the foramen of Monro along with the choroid plexus, provides another significant landmark. The third ventricle's lateral walls are created by the hypothalamus. The structures most vulnerable to damage during an ETV are the supraoptic and paraventricular arcuate nuclei because of their location in the lateral wall and closeness to the trajectory, which may result in endocrinologic disruption (Unal and Aydoseli 2018).

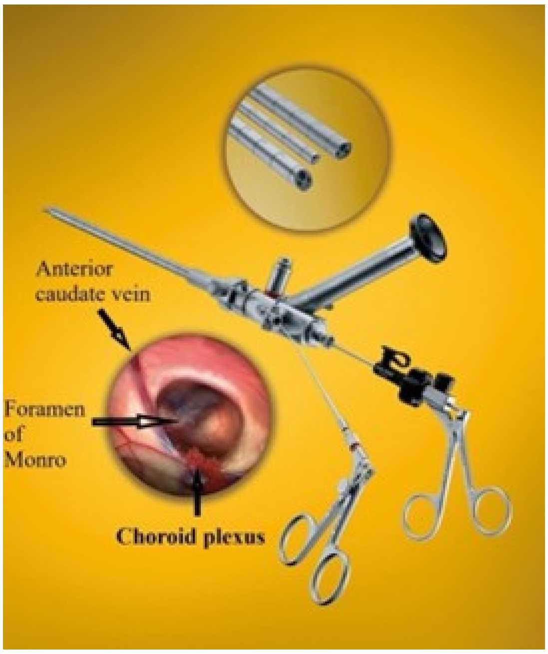

Figure 5. ETV instrument with a working channel and view of the foramen. Source: Figure by authors.

In front of the coupled mamillary bodies, the third ventricle's floor must be carefully fenestrated (Figure 6). The Liliequist membrane needs to be fenestrated and the ETV endoscope has to be advanced in order to boost rates of success. This stage will reveal the basilar artery.

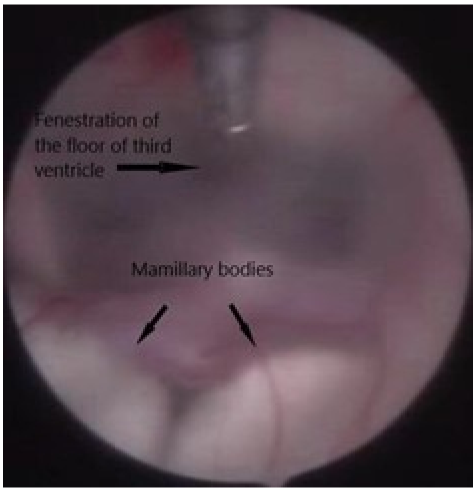

Figure 6. Fenestration of the floor of the ventricle. Source: Figure by authors.

3.3. Precautions

When there is a history of prior tumors, shunt surgery, or a thicker third ventricle floor, there are a number of precautions to be taken when performing an ETV. Tumors, like a brainstem glioma, can change the anatomy. The third ventricle's floor may become distorted as a result, and the basilar artery may move forward, reducing the safe area for floor penetration. When a tumor blocks the third ventricle, hydrocephalus may develop rather quickly, with the third ventricle's floor appearing opaque and unattenuated. Without being able to see the underlying neurovascular systems, perforation will be challenging and inevitably demand sharper technique, increasing the danger.

3.4. Success Rate of ETV

Since they have less pronounced ventricular enlargement, a thicker third ventricle floor, and a frequently aberrant architecture, cases who have previously been shunted are technically more challenging. If the third ventricle's floor is excessively thick, blood obscures the endoscopic vision, or if the basilar artery is situated beneath or dangerously near to the desired point of fenestration, ETV treatment may need to be abandoned in some individuals. Nevertheless, after three years, ETV has an average success rate of about 75%, although this varies depending on the case, including the surgeon's skill. Particularly in individuals with posterior fossa neoplasms, the outcomes of ETV are favorably comparable to those achieved after shunting (Sainte-Rose et al. 2001). Additionally, ETV seems to have a financial benefit over shunting (Barlow and Ching 1997).

ETV failure might happen early or late. Bleeding at the fenestration zone, undiscovered extra arachnoid membranes obstructing the CSF flow, an insufficient fenestration size, and other variables can all lead to early failure. Later sealing of the opening by gliotic tissue or an arachnoid layer causes late failure. This issue may be quite significant. There are now a number of accounts in the literature about deaths that followed late failure of ETV (Hader et al. 2002), and this continues to be a management challenge since this failure can happen suddenly and may be unforeseen. Early or delayed failure may be caused by tumor development and insufficient CSF absorption at the site of the arachnoid villi. Why a patient population with open fenestrations shows deterioration after several months of good health is unknown (Tisell et al. 2000). The literature lists hypothalamic dysfunction, bradycardia, and bleeding from injury to ependymal veins, arteries, or the choroid plexus as procedure-related problems. Short-term problems, which are mostly peroperative and technique-related, and long-term problems, which happen at a significantly lower rate, are the two main categories of complications (Brockmeyer et al. 1998).

4. Complex Hydrocephalus Simplifications and Intracranial Cysts

4.1. Multiloculated Hydrocephalus

Even when a patient has a working VP shunt, multiloculated hydrocephalus is characterized by discrete CSF compartments that tend to expand inside the ventricular system. Meningitis, post-shunt infection, intraventricular hemorrhage, head trauma, ependymal injury during shunt placement, and other inflammatory processes frequently result in multiloculation (Andresen and Juhler 2012). More than 30% of newborns who survive a neonatal meningitis attack will eventually develop hydrocephalus; the majority of these neonates run the risk of having multiloculated hydrocephalus (Reinprecht et al. 2001). The ventricular catheter or typical locations of CSF absorption cannot absorb accumulated CSF because the compartments are divided by septa (Spennato et al. 2004). Several shunts are not recommended since they have a high failure rate and can lead to infections.

By fenestrating the membrane, endoscopy provides a straightforward method of navigating separated CSF compartments and ventricles. Carefully studying the preoperative MRI is essential for effective surgical planning. Entry locations are chosen so that the fewest possible burr holes can be used to fenestrate the greatest number of cysts (El-Tantawy 2018). The burr hole used to insert a ventricular catheter can also be used for this. In most patients with loculated ventricles, septum pellucidum fenestration to join the two lateral ventricles will prevent the need for two shunts (Unal and Aydoseli 2018).

Chronic ependymal inflammation and the emergence of new septa, according to Spennato et al., are explanations for the increased prevalence of shunt blockage in multiloculation. Multiloculated hydrocephalus was viewed as a progressive illness (Spennato et al. 2007). After initial surgery, 38.5% of people with multiloculated hydrocephalus needed extra neuroendoscopic fenestrations, according to Akbari et al., while 33% of patients, according to El-Ghandour, required repeat endoscopic fenestration during the follow-up period (El-Ghandour 2008; Akbari et al. 2015).

It was recently discovered that aqueductoplasty could be used to treat trapped fourth ventricle conditions. Techniques of applied neuroendoscopy have been expanded to include endoscopic fourth ventriculostomy as well as Monro and Magendie foraminoplasty (Li et al. 2005; Oi and Abbott 2004; Sgouros 2013).

4.2. Intracranial Cysts

The ventricular system is capable of harboring a wide variety of cysts. Arachnoid cysts, which are often extra-axial; choroid plexus cysts; neoplastic cysts; and parasitic cysts (e.g., cysticercotic and hydatid cysts) can appear within the ventricles. Arachnoid cysts can often be successfully removed endoscopically or via fenestration in patients.

Approximately 1% of all cerebral mass lesions are intracranial arachnoid cysts (ACs) (Robinson 1971). Due to the improved accessibility of CT and MRI, its incidence appears to have grown recently (Hanieh et al. 1988; Fernández Molina 2013). Different surgical procedures are advised. Pure endoscopic AC fenestration has grown in popularity and is actually favored by many neurosurgeons as a result of the advancement of neuroendoscopy, particularly in situations with suprasellar or quadrigeminal cistern cysts and cysts in the posterior fossa (Oertel et al. 2020; Gangemi et al. 2011; Karabagli and Etus 2012; Wang et al. 2013).

Nine out of fourteen children (64%) with arachnoid cysts in an initial series were managed successfully via neuroendoscopic fenestration through a burr hole, obviating the need for craniotomy (Guiot 1973). Endoscopic transsphenoidal surgery is especially suited for cysts that are restricted to the pituitary fossa. Without the use of shunting, ventriculo-cysto-cisternostomy allows for long-term decompression of suprasellar arachnoid cysts. The majority of patients who have intraventricular cysts or tumors also have hydrocephalus. Given that CSF diversion and tumor therapy may be performed simultaneously, this renders endoscopic surgery especially useful (Di Rocco et al. 2005; Fukushima et al. 1973). Arachnoid cysts, cavum velum interpositum cysts, ventricular neuroepithelial cysts, colloid cysts, and large pineal cysts were all successfully fenestrated by Teo et al. Frameless stereotactic assistance has been helpful in directing the burr hole toward these cysts in circumstances where the ventricles are very small. Arachnoid cyst surgery aims to alleviate symptoms. This is especially important for endoscopic fenestration since, despite significant clinical improvement, the cyst's appearance may only minimally shrink on postoperative imaging (Teo and Mobbs 2004).

5. Endoscopic Applications in Neuro-Oncology

The field of neuro-oncology offers the best setting for endoscopic use. Traditional tumor care can benefit greatly from the advantages of enhanced intraventricular pathology visibility, improved hydrocephalus management of tumors, safer biopsies, and minimally invasive excision of intraventricular tumors (Teo and Mobbs 2004).

A surgeon might utilize an endoscope to gauge the extent of resection after removing a tumor. With an endoscope, the very same neurosurgery can frequently be performed using a smaller craniotomy, according to the idea of minimally invasive but highly successful surgery (Perneczky et al. 1999). Endoscopy may increase the survival chances for people with benign tumors by enabling a more thorough excision (Wallner et al. 1988; Garcia and Fulling 1985). Third ventriculostomy and septostomy are examples of adjunctive treatments that can be carried out via the same access to treat related issues like secondary hydrocephalus without the need for shunt insertion (Teo and Mobbs 2004).

The first description of endoscopic stereotactic imaging and excision of intra-axial brain tumors was published in 1980 (Jacques et al. 1980; Shelden et al. 1980). The excision of tumors using stereotactic endoscopy through a conduit made of a dilator in the shape of a bullet was also reported in 1990 (Otsuki et al. 1990). Through the use of a dilatable conduit, Kassam et al. documented the creation of an entirely endoscopic method for intra-axial tumor removal. In an effort to provide a parafascicular route to the tumor, a channel is constructed through the dilated white matter. The endoscope works parallel to the conduit (port), which generates an air medium that enables bimanual dissection. The procedure carefully abides by established microsurgical principles (Kassam et al. 2009).

For the microscopic removal of deep cerebral tumors, Dr. Kelly invented a stereotactic tubular retraction device with a 20 mm diameter. His work served as the foundation for the initial development of endoscopic resection (Kelly et al. 1986, 1988; Russell and Kelly 2002). Because a cone of light is delivered by a microscope, which tapers from the light source until it lands on the target, the conduit needs to offer microscopic visualization that is greater than an endoscopic conduit. The endoscope, in comparison, uses an inverted light cone to produce illumination and magnification. In order to deliver the endoscope millimeters away from the destination, a considerably smaller port or conduit (11.5 mm) can be employed, producing a "flashlight" effect that illuminates the tumor. Utilizing this benefit of the neuroendoscope, intra-axial tumor resections can be carried out (Kassam et al. 2009).

Despite the endoscope's lack of binocular vision, this was not a serious drawback. Proprioceptive input made possible by bimanual dissection makes up for lost binocular vision with ease. This is comparable to an observer's perspective being used when performing microscopic neurosurgery. After gaining sufficient expertise, a surgeon acquires 3D perception based on movement and touch (tactile feedback). According to Kassam et al., endoscopic visualization for subcortical tumors may be more effective than microscopic visualization as the endoscope enables close-up vision of the pathology to be treated and unfettered "flashlight" lighting in deep areas (Kassam et al. 2009). The benefit of using a microscope is evident and makes it preferable for cortical lesions as well as dissections, but this straight endoscopic view also offers important advantages for deep-seated brain tumors. In fact, once the microscope has been removed from the region, endoscopic vision has been utilized to certify adequate excision for intraparenchymal neoplasms (Teo and Nakaji 2005).

With this method, selected primary and secondary brain neoplasms may be safely excised. Tumors far larger than the tube itself can be efficiently eliminated via dynamic port retraction and piecemeal extirpation. The long-term outcome will ultimately depend on the biology of the neoplasm. The port, however, may present a viable option (in carefully chosen patients) to achieve the objectives of surgery, namely, cytoreduction or total tumor excision with a manageable degree of morbidity, reducing both the volume of the corticectomy and the amount of white-matter dissection necessary for the excision of the neoplasm (Kassam et al. 2009).

The burr hole is positioned to allow the scope to enter the ventricle as far away from the lesion as feasible and to allow the scope to observe the tumor directly, rather than peeping around a corner. Before coming across the problematic anatomy, the surgeon might situate themself by recognizing normal anatomical structures when using the distal technique. The surgeon can move the scope more freely and without risking harm to the surrounding healthy brain because the majority of the remote part of the scope is inside the ventricle (Teo and Mobbs 2004).

Not all intraventricular tumors require endoscopic treatment. The ideal tumor should be histologically low-grade, with accompanying secondary hydrocephalus, moderate to low vascularity, and soft consistency (Teo and Mobbs 2004). It might never be feasible to confirm these characteristics before surgery.

A few rules should be followed when dealing with intraventricular tumors. The surgeon must select a trajectory that avoids ornate structures while providing a clear view of the tumor. To make the tumor removal process easier, the exterior of the lesion is coagulated using either unipolar cautery or a laser. In order to remove blood and debris and to stop the ventricle from becoming too hot, there is extensive irrigation. Cysts must be opened, drained, and their contents extracted piecemeal or by suction, including piecemeal coagulation and removal of the remaining wall. After the procedure is finished, the scope is removed as the tract is checked for intraparenchymal hemorrhage (Teo and Mobbs 2004). Irrigation is used extensively to achieve hemostasis. During intraventricular hemostasis, a cut-end Foley catheter can be utilized to remove blood clots (Kawsar et al. 2015).

A tried-and-true treatment option for intraventricular brain tumors is endoscopic tumor biopsy. Both the diagnostic yield and risk are high (>90% and 3.5%). Endoscopic biopsy can treat Langerhans cell histiocytosis, infiltrative optic/hypothalamic pathway glioma, and germ cell tumors (Sgouros 2013). Tumors or colloid cysts that are pedunculated at the ependymal wall can be removed endoscopically. Except for when the cyst is exceptionally large, which raises the danger of venous damage at the Monro's foramen, endoscopic removal of a colloid cyst is technically feasible through the lateral ventricle in the majority of cases (Sgouros 2013; Yamini et al. 2004). Obstructive hydrocephalus or vision loss may be temporarily or permanently relieved by transventricular endoscopic neoplasm cyst decompression (Shim et al. 2017).

Rare congenital anomalies known as hypothalamic hamartomas that arise from the inferior hypothalamus are linked to epileptic fits, early puberty, and cognitive issues. All patients, with the exception of those who have premature puberty, need surgery. The HH type (as determined by Delalande and Fohlen (2003) or Choi et al. (2004)) should determine whether a single treatment or combination of treatments is utilized. Small HHs have been attempted to be surgically removed using endoscopic excision assisted by stereotactic guidance, although some of the tumors persisted. Surgery for the excision of HHs is frequently carried out in stages. However, according to recent research, endoscopic disconnection of HHs appears to be both safer and more efficient than other methods (Choi et al. 2004; Rekate et al. 2006). Most of the time, navigation assistance is advised due to the clear need for precision in lateral and third ventricles of a normal size (Shim et al. 2017).

6. Endoscope-Assisted Microsurgery

The next step after standard microsurgery is endoscopy, which enables the neurosurgeon to see tumor remains, including those concealed under a cranial nerve, eloquent cerebral tissue, or the tentorial margin.

The field of endoscopic neurosurgery that is expanding the fastest is this one. The goal of microsurgery has been to reduce retraction and increase visibility. Endoscopy enables the neurosurgeon to take these objectives one step closer. In order to remove tumors and clip aneurysms, surgeons often need to view "around corners", which is made possible by acutely angled, rigid, and flexible scopes. The extra-axial components of the skull base can be approached in a number of ways to enhance visibility without risking conventional microsurgical methods. The endoscope is placed down the same surgical field, which is the approach that is most frequently used. While this does not add to the morbidity, it tends to clog the already small operative field. The scope can be placed through a contralateral burr hole to avoid cramming more devices down a small craniotomy. A very small supraorbital incision can be utilized to gain entry to the subarachnoid area, and routine microsurgical dissection is then carried out to determine the lesion. When the pathology is visible, the scope is locked in position and the ipsilateral side is the object of attention. For instance, this method provides superb imaging of the aneurysm clip points or the oblique extent of a neoplasm. Endoscopy is being utilized more frequently to examine aneurysms, tumor resection beds, and other pathologies. The benefits of endoscopy for these uses have been explored by a number of authors (Brockmeyer et al. 1998; Lewis et al. 1994; Gamea et al. 1994).

The endoscope provides an improved and frequently innovative perspective of the anatomy, which can help residents comprehend a surgical strategy. Additionally, the student and the operating surgeon have the same perspective, which is not always the case with an operating microscope. The possibility of striking structures while inserting the endoscope is the most hazardous part of utilizing the endoscope. Instead of focusing on the image on the screen, it is important to direct the endoscope by looking down the length of its barrel. It is crucial to keep an eye on the shaft after inserting the endoscope into the working zone because, if it is not fixed, slight, hardly perceptible movements at the tip may lead to a big excursion at the backside of the scope, that could have devastating results. The surgeon may be able to work with both hands if they are using a fixed endoscope holder. By doing so, the surgeon will be able to employ more sophisticated tools and avoid having the endoscope brush up against important structures in the operational corridor (Teo and Mobbs 2004).

7. Endoscopy for Base of the Skull Lesions

Carrau and colleagues (Carrau et al. 1996), who described their initial experience with endonasal transsphenoidal hypophysectomy at the University of Pittsburgh, are credited with pioneering the use of neuroendoscopy to treat skull base tumors. Other pathologies of the sellar and parasellar areas were included in the scope of this method by de Divitiis and colleagues (de Divitiis et al. 2002). The anterior skull base tumors can now be seen up to the crista galli as well as down to the level of the axis using the bilateral endonasal endoscopic technique. The lesions in (a) the crista galli to tuberculum sellae, (b) the sellae and suprasellar area, (c) the upper clival zone, and (d) the lower clival zone up to the level of the axis are shown in Figure 7.

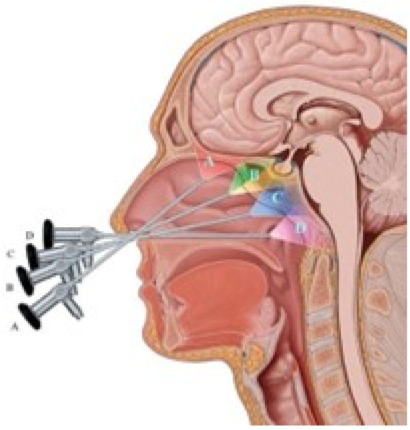

Figure 7. Angulation of endoscope and access to the broad area of the skull base. Source: Figure by author.

With positive outcomes and minimal morbidity, the endoscopic endonasal approach was used for the surgical excision of pituitary tumors and craniopharyngioma (Shim et al. 2017). Based on the size of the mass, the endoscopic approach for sellar and suprasellar neoplasms should be chosen. Endoscopic removal of supradiaphragmatic lesions and transtuberculum–transplanum sphenoidale removal of suprasellar prechiasmatic preinfundibular lesions are both options (Sgouros 2013).

Endoscopic endonasal surgery is particularly challenging when dealing with tumors in the tuberculum sellae region. It is a small anatomical area with delicate but significant microvasculature and probable circle of Willis involvement. The most popular vascularized flap to be used to treat high-flow leaks is the nasal septal flap (Hadad et al. 2006; El-Sayed et al. 2008). Excision of the planum and cribriform anteriorly along the base of the skull is a logical extension of the endoscopic endonasal approach (Roxbury et al. 2016).

The pathologies of the petroclival region, clivus, and intradural posterior fossa (immediately next to the clivus), can now be effectively treated by endoscopic endonasal surgery (EES). The clival and paraclival areas have historically been challenging to access, particularly pathologies that have considerable bilateral extension or significant sagittal plain extension. The typical split of the clivus into thirds, each requiring a different method, shows that for such tumors a mix of open procedures is frequently necessary (Sekhar et al. 1993).

The anterior surgical corridor offers access to pathologies that reach right and left across the midline, whereas EEAs are particularly adaptable to the sagittal plain. This means that a single endonasal conduit can be used to access even larger neoplasms that cover the total clival region. Midline access to the interpeduncular fossa, basilar top, mammillary bodies, and third ventricle floor is made possible using an endoscopic superior transclival approach. The dorsum sellae and the posterior clinoid processes, which must be accessible and excised during this approach, make up the upper clivus, also called the "sellar clivus". The basilar artery, anterior inferior cerebellar artery, ventral pons, prepontine cistern, and cisternal section of the abducens nerve are all accessible via a middle transclival approach. The paraclival ICAs as well as the petroclival fissure obstruct the sphenoidal clivus laterally. The interdural portion of cranial nerve VI restricts the middle transclival exposure laterally (Zwagerman et al. 2016).

A number of experts have written papers on methods for treating Meckel's cave lesions that expand inferiorly as well as laterally to the cavernous sinus (Wang et al. 2016; Raza et al. 2014; Jouanneau et al. 2014). The vertebro-basilar junction, vertebral arteries, posterior inferior cerebellar arteries, IX–XII cranial nerves, premedullary cistern, and ventral medullary surface are all exposed during the lower transclival approach through the lower clival segment, which is located beneath the roof of the choana (Zwagerman et al. 2016). An endoscopic image of the cerebellopontine angle is depicted in Figures 8 and 9 (Chowdhury et al. 2012).

CSF rhinorrhea, which frequently results from trauma and iatrogenic deformation of the base of the skull and is secondary to neoplastic inflammatory and pseudotumor syndromes, has been treated using endoscopic procedures. Endoscopic restructuring of tissue planes and total disconnection of the cranial space from sinonasal cavities can be used to correct faults in the skull base and accomplish a multi-layered reconstruction. A single layer of fascia or fat, followed by tissue glue, can be used to heal small bone defects. Multi-layered closure is necessary for larger skull base lesions with significant intraoperative CSF leakage. A homologous fat graft in the bone deficiency, followed by the fascia lata, an osseous buttress, and tissue glue, can be used to achieve this. A gasket seal repair can be added to these larger skull base abnormalities (Sgouros 2013; Hadad et al. 2006). Kawsar et al. reported positive results in their series, and Fortes et al. demonstrated endoscopic correction of CSF leakage via transpterygoid transposition of a temporoparietal fascia flap (Fortes et al. 2007). Figure 10 illustrates the flap's course through the endoscopic method (Kawsar et al. 2020).

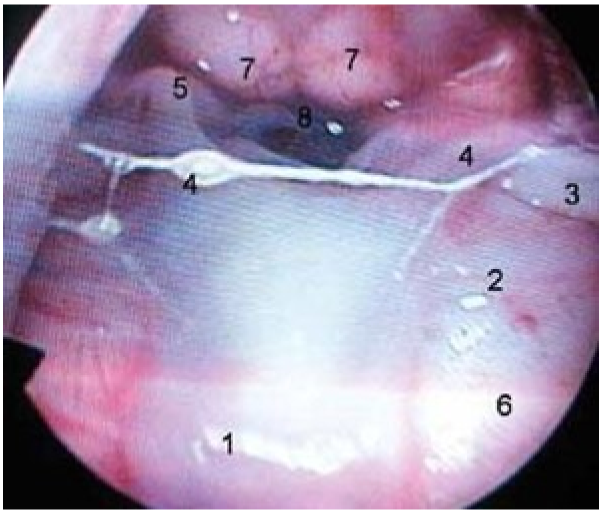

Figure 8. Endoscopic view of the interpeduncular fossa. 1—basilar artery, 2—superior cerebellar artery, 3—3rd nerve, 4—posterior cerebellar artery, 5—posterior communicating artery, 6—basilar pons, 7—mamillary body, and 8—thalamoperforator. Source: Figure by authors.

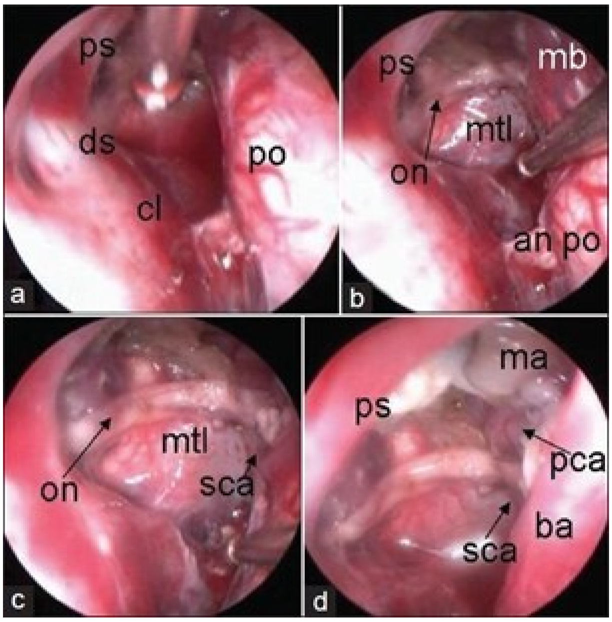

Figure 9. (**a**–**d**) Intraoperative sequential endoscopic exploration of CP angle. ps—pituitary stalk, ds—dorsum sellae, cl—clivus, po—pons, on—oculomotor nerve, mb—midbrain, mtl—medial temporal lobe, an—abducent nerve, sca—superior cerebellar artery, pca—posterior cerebral artery, ba—basilar artery, and ma—mamillary body. Source: Figure by authors.

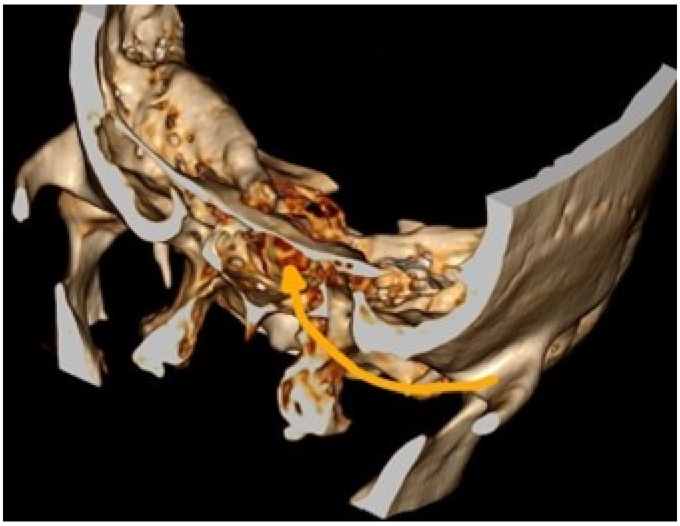

Figure 10. Route of endoscopic transposition of vascularized transpterygoid temporal muscle flap (TPTMF flap). Source: Figure by authors.

8. Endoscopic Transsphenoidal Surgery

8.1. Introduction

Although Gerard Guiot is credited with being the first neurosurgeon to employ the endoscope in the transsphenoidal procedure, he eventually gave up due to poor visibility (Guiot et al. 1963; Liu et al. 2001). Many surgeons (Apuzzo et al. (1977) along with Bushe and Halves (1978); Halves and Bushe (1979)) did not record the utilization of the endoscope as a technical accessory in the microscopic excision of extrasellar pituitary pathologies until the late 1970s. In the beginning, endoscopy was used to supplement microsurgery so that other surgeons could observe things that were out of their line of sight using tilted mirrors (Liu et al. 2001; Hardy 1967). Axel Perneczky, who pioneered the use of the endoscope in cerebral neurosurgery, stressed the importance of an endoscopic understanding of micro-anatomy, which may not be fully understood with a microscope, and developed the idea of minimally invasive neurosurgery (Fries and Perneczky 1998; Perneczky and Fries 1998).

As a consequence of the collaboration between neurosurgical and ENT surgeons, the pure endoscopic transsphenoidal procedure (i.e., utilization of the neuroendoscope as the only viewing instrument) was established in the early 1990s. At the Central Hospital of the University of Nancy, Jankowski and colleagues published their experiences of three instances in which they applied a solely endoscopic transsphenoidal procedure to the sellae turcica in 1992 (Jankowski et al. 1992).

More recently, the idea of extending techniques to the base of the skull has been introduced. Other technical accessories like microvascular Doppler, neuronavigation, and endoscopic endonasal transsphenoidal surgery have been used to treat lesions outside the sellae turcica (Kaptain et al. 2001; Locatelli et al. 2000).

8.2. Operative Procedural Techniques

Under general anesthesia, the patient is in supine position with the trunk raised 10° and the head turned 10° in the direction of the surgeon. The patient's head is fixed with three pins or tape in a horseshoe headrest, but not rigidly. The nasal cavities are crammed with pledgets drenched in dilute adrenaline just before the endoscope is inserted. The following three phases can be used to divide the operation.

8.2.1. Nasal Phase

The major anatomical landmarks, like the nasal septum medially and inferior turbinate laterally, can be recognized after entry with the endoscope. The choana can be seen by moving in that direction and following the inferior turbinate's tail. Medially, the vomer (a midline pointer) and, superiorly, the sphenoid sinus floor limit the choana (Figure 11).

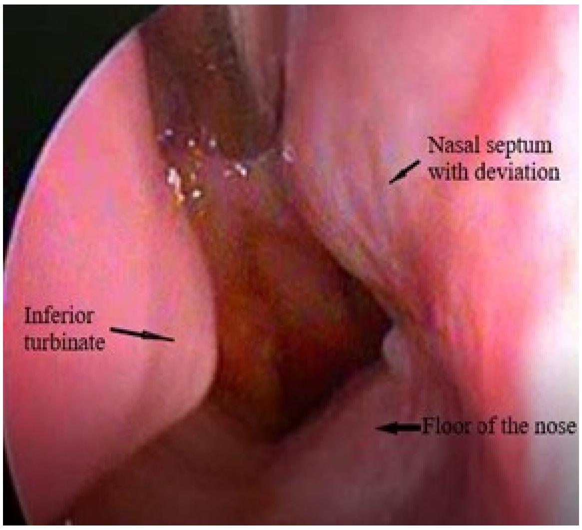

Figure 11. Nasal stage of endoscopic pituitary. Source: Figure by authors.

To increase the surgical passage between the nasal septum and the middle turbinate, the middle turbinate is softly moved laterally. The sphenoid ostium can be seen while looking up with an endoscope; it is typically 1.5 cm superior of the choana's roof. The superior or supreme turbinate, if they cover the sphenoid ostium, can be gently lateralized or eliminated while still preserving the cribriform plate's lateral lamella.

To avoid damaging the ethmoidal plate and causing a CSF leak, great care should be taken when removing or laterally luxating these turbinates.

8.2.2. Sphenoid Phase

In order to prevent arterial hemorrhage from the septal arterial branches of the sphenopalatine artery, this step of the treatment begins with the cauterization of the spheno-ethmoid recess as well as the region surrounding the sphenoid ostium. The septum of the nose is separated from the sphenoid rostrum using a microdrill. With care taken not to over extend the incision in the inferolateral side, at which the sphenopalatine artery and its major branches lie, the ventral wall of the sphenoidal sinus is then extensively opened with a microdrill and rongeur, working circumferentially.

To achieve the correct working direction for the complete instrument when within the sphenoid, with its distal end in the sellae, it is essential to extensively expose and uncover the anterior wall of the sphenoid. The sellar floor, spheno-ethmoid planum, tuberculum sellae, and clival indentation of the sphenoid sinus are all evident after the excision of all sphenoid septa, as well as its posterior and lateral walls. The bony protuberances of the intracavernous internal carotid artery, the second cranial nerve, and the opto-carotid recess can be seen laterally to the sellar floor (Figure 12). The intracavernous carotid artery's bony protuberances should be identified to mark the sellar floor limits, even though it may not always be possible to identify each anatomical feature.

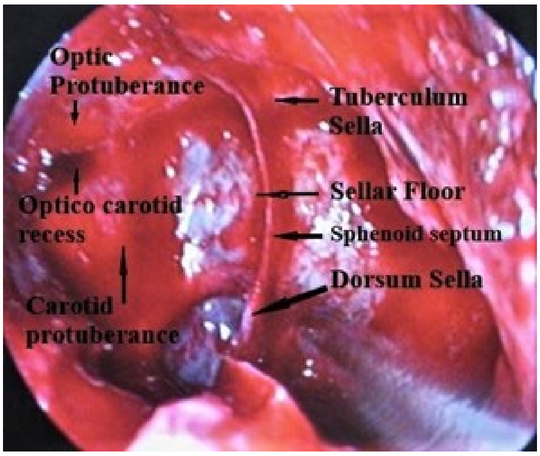

Figure 12. End of the sphenoidal phase with exposure of the sellar floor. Source: Figure by authors.

Hammer and Radberg's initial classification of the sphenoid sinuses into conchal, presellar, and sellar types is still extensively used today (Hammer and Radberg 1962), because it accurately predicts the surgical route utilized in transsphenoidal procedures. Depending on the extension of the pneumatization, Guldner et al. classified the sellar type into incomplete and complete types (Güldner et al. 2012; Hiremath et al. 2018). The modifications and the conventional system concentrate on the posterior limit of pneumatization as well as the ease of accessibility of the sellar floor during transsphenoidal endoscopic surgeries.

8.2.3. Sellar Phase

The endoscope can be fastened to the holder from this point on in the process, freeing both hands of the surgeon. In reality, it is standard procedure for the surgeon to keep using the endoscope while the two instruments are being dynamically moved via one or both nostrils by an aid.

The procedure's sellar phase (Figure 13) adheres to the same guidelines as the microscopic transsphenoidal technique. The sellar floor is opened utilizing a high-speed drill and a Kerrison rongeur, often extending the bone drilling from the tuberculum to the floor of the sellae as well as from one side of the cavernous sinus to the contralateral side. However, its size and shape could be customized depending on the need for lesion removal. The carotid arteries may be more easily identified during such procedures with the aid of an ultrasound Doppler probe, allowing for a safer opening of the dura and subsequent linear, rectangular, or cruciate incisions. The inferior and lateral parts of the lesion are resected before the superior part in cases of macroadenoma. In fact, removing the upper portion first will cause the redundant diaphragm and suprasellar cistern to enter the operating field too early, decreasing the chance to expose and excise the lateral parts of the lesion. The Valsalva maneuver, which causes the suprasellar cistern to protrude into the sellar cavity, can be helpful if the collapse of the suprasellar component of the lesion is not seen.

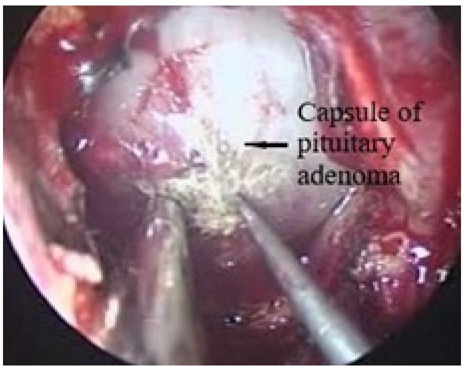

Figure 13. Sellar stage of pituitary. Source: Figure by authors.

Additionally, while performing interior debulking on a microadenoma, it is preferred to detach the tumor pseudocapsule from the pituitary gland to obtain an "enbloc" excision (Oldfield and Vortmeyer 2006).

After the lesion has been removed, an endoscopic examination of the tumor cavity using a 0° and/or an angled telescope is next carried out to see whether any tumor remnants remain.

8.2.4. Sellar Reconstruction

Sellar repair is necessary at the conclusion of the procedure, typically when a peroperative CSF leakage has occurred. Based on the extent of the osteo-dural deficiency and the amount of "dead space" within the sellae, different procedures (intradural and/or extradural repair of the sellae, as well as packing of the sellar tumor cavity with or without packing of the sphenoidal sinus) are used (Cappabianca et al. 2002).

The purpose of this type of repair is to ensure a watertight seal, eliminate dead space, and stop the chiasm from descending into the sellar cavity. To keep the optic system from being compressed, overpacking must be avoided. Except in the event of a small, unanticipated, postoperative CSF leakage, lumbar drainage is no longer used. The middle turbinate is softly repositioned in a medial direction once the endoscope has been gradually removed. There is no use of nasal cavity packing.

8.3. Advantages of Endoscopic Transsphenoidal Surgery

Transsphenoidal endoscopy has a number of benefits for patients (such as less nasal injury, no nasal packing, less perioperative pain, and (typically) rapid recovery) as well as for surgeons (e.g., a wider and closer vision of the surgical area; increased scientific activity, as evidenced by the peer-reviewed literature on the subject in the last ten years; smoother interdisciplinary co-operation, etc.) (Spencer et al. 1999; Snyderman et al. 2007; Cappabianca et al. 2008).

8.4. Complications of Endoscopic Transsphenoidal Surgery

Major morbidity was reported in 1% to 2% of case scenarios and postoperative CSF fistulas in 3.9% of patients in the Ciric et al. study (Ciric et al. 1997), which is taken as the gold standard for transsphenoidal surgery complication questionnaires pertaining to perioperative complications, with further reduced rates among more experienced surgeons (Barker et al. 2003).

The postoperative occurrence of CSF leaks was reported to range from 1.4 to 16.9% by Lobatto et al. in a systematic study (Lobatto et al. 2018). The published frequency of DI varies from 0.3% to 45% and is different, in part, due to inconsistent definitions (Abhinav et al. 2020). Two skilled pituitary groups who utilized accepted definitions for DI or whose surgical experience primarily targeted endoscopic excision of pituitary tumors recently published their postoperative DI frequency with reasonably comparable outcomes (Ajlan et al. 2018; Nayak et al. 2018).

Both investigations indicated a DI occurrence of 26% and 16.6% in 178 and 271 patients, respectively, with only 10% and 4% developing persistent DI (Ajlan et al. 2018; Nayak et al. 2018).

While late hyponatremia is the most frequent reason for unplanned re-hospitalization after pituitary tumor surgery, hypernatremia can also cause substantial morbidity during the perioperative period (Bohl et al. 2016). The majority of delayed hyponatremia (SIADH) cases, which often develop between postoperative days 4 and 7, are a secondary effect of incorrect antidiuretic hormone release. It has a documented incidence of 3.6% to 19.8% (Barber et al. 2014; Hussain et al. 2013; Jahangiri et al. 2014).

Hypothalamic–pituitary axis (HPA) dysfunction is still regarded as a clinical issue. Adrenal insufficiency is the condition that poses the greatest risk to life, with current case studies indicating rates ranging from 3 to 21% (Little et al. 2019).

Nasal structural support can be lost as a result of excessive nasal septum removal, which can lead to external nasal malformation. Extended approaches requiring nasal septal flap repair may increase this risk (Rowan et al. 2016, 2020). When substantial posterior superior segments of the nasal septum and its mucosa as well as the nearby superior and middle turbinate mucosa are removed (structures that form the olfactory cleft), hyposmia or more serious anosmia may result. As a result, while a sufficient surgical corridor is made towards the sellae and a nasoseptal flap is procured, special attention is typically given to maintain these structures (Harvey et al. 2015a, 2015b).

With a reported incidence between 0.2 and 0.4%, injury of the ICA during sellar drilling and exposure or excision of the tumor is uncommon but is linked with considerable morbidity (Perry et al. 2019). Iatrogenic injuries can cause serious stroke, permanent disability, or even death (Chin et al. 2016). Three percent of cases may involve significant epistaxis that requires further treatment (De Los Reyes et al. 2015; Alzhrani et al. 2018).

The self-reported questionnaire study provided by Ciric et al. showed that the mean surgical mortality for each of the three groups was 0.9% (Ciric et al. 1997). Only one (1/1153) perioperative fatality was reported by Agam et al., representing 0.1% of their series (Agam et al. 2019).

Cases with visual impairments and tumors that had invaded any nearby structures were at a higher danger of complication, possibly reflecting a more serious underlying disease, according to a new paper by Agam et al. (2019). Because of scarring and adhesions that make the operative environment more difficult, revision operations for previous transsphenoidal surgery, craniotomies, and radiosurgery were also more likely to result in problems (Esquenazi et al. 2017).

9. Endoscopy in Intracranial Aneurysm Surgery

9.1. General Roles of Endoscope

The utilization of the endoscope in and around aneurysms is made simpler and safer by the benefits of greater illumination; good, close-up views of local anatomic features; and extended visual angles. The endoscope also makes it easier to determine the best clip locations (Yoshioka and Kinouchi 2015).

Endonasal extended transsphenoidal total exposure of the circle of Willis within the brain in situ was shown by Chowdhury et al. to be the best method for observing the circle for variations, including asymmetry in the cadaveric investigation (Figures 14 and 15) (Chowdhury et al. 2012). Taniguchi et al. published that, in their series of fifty-four case scenarios, the endoscope made clear the intricate additional local anatomy in nine cases (16.7%); in five cases (9.3%), the neurosurgeons repositioned the clip based on endoscopic data collected after the initial clip application (Taniguchi et al. 1999).

In a series of research by Kalavakonda et al. (2002), a neuroendoscope was utilized to inspect the applied clip in 75 of 79 cases (95%) and anatomical features in 26 cases (33%). Important details including the perforators, parent artery, their branches, the aneurysm's neck and back wall, the extent of the clipping of the neck, and the incorporation of the parent artery in the clip could all be seen using the endoscope in 15 (19%) aneurysms. In six instances, the clip was moved due to a residual neck or the incorporation of the parent artery, and in one instance, the clip location was altered due to compression of the second nerve (Kalavakonda et al. 2002). In 150 of 180 cases in a recent publication by Fischer et al., a neuroendoscope was utilized to obtain extra topographic data prior to clipping (83%) (Fischer et al. 2012). In four cases, clipping under endoscopic vision was successful. In 130 of the 180 surgeries, endoscopic examination was performed after clipping (Yoshioka and Kinouchi 2015).

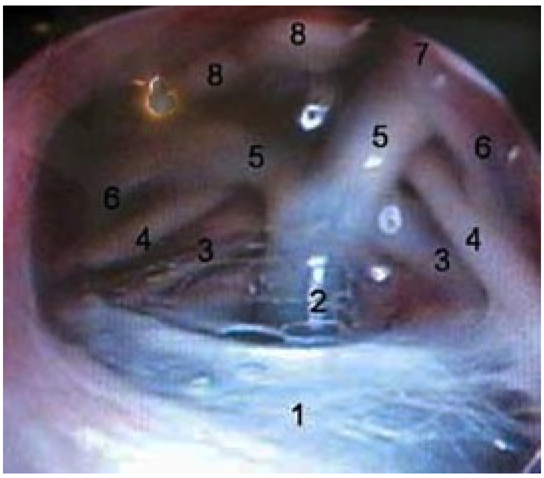

Figure 14. Endoscopic exposure of circle of Willis. 1—Liliequist membrane, 2—basilar artery, 3—superior cerebellar artery, 4—3rd nerve, 5—posterior cerebral artery, 6—posterior communicating artery, 7—P2 segment of posterior communicating artery, and 8—mamillary body. Source: Figure by authors.

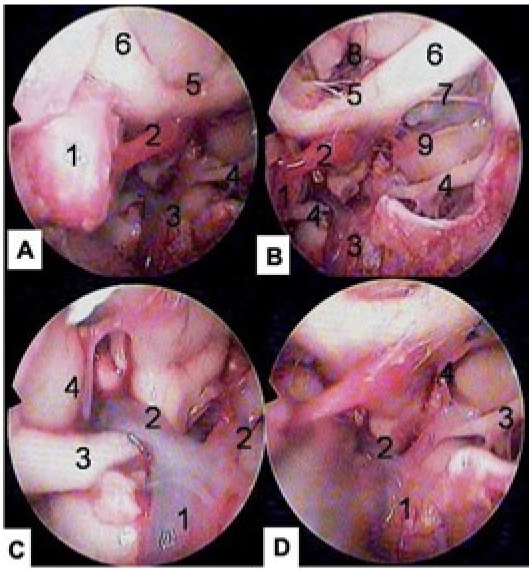

Figure 15. Endoscopic exploration of circle of Willis with pituitary gland mobilization. (**A**,**B**) 1—pituitary gland, 2—pituitary stalk, 3—basilar artery, 4—3rd nerve, 5—optic chiasm, 6—optic nerve, 7—anterior cerebral artery, 8—anterior communicating artery, and 9—medial temporal lobe. (**C**,**D**) 1—basilar artery, 2—posterior cerebral artery, 3—3rd nerve, and 4—medial temporal lobe. Source: Figure by authors.

The mass of the lesion makes it more difficult to insert and fix the endoscope in the operational region, so very large aneurysms typically benefit less from the endoscope than smaller ones in the same place (Galzio et al. 2013). The treatment of brain aneurysms with deep locations particularly benefits from the endoscope. Consequently, the area is another crucial consideration. The usefulness of the endoscope for such aneurysms is restricted when they are superficially placed, such as middle cerebral artery aneurysms, and for distant aneurysms, like pericallosal aneurysms (Yoshioka and Kinouchi 2015). This chapter does not cover the detailed approach to aneurysms.

Additionally, some endoscopic drawbacks have been reported (de Divitiis et al. 2002). During initial examination, the aneurysm may burst due to the endoscope. The endoscope may become worthless if there is blood in the surgical area, so the clot must be cleared before continuing. Instrumentation made especially for endoscopic surgery is still lacking (Kalavakonda et al. 2002). Prior to the development of more recent 3D endoscopes, three dimensional images were not possible.

10. Microvascular Decompression

In general, offending vessels cause hemifacial spasms (HFSs), primary trigeminal neuralgia (TN), and glossopharyngeal neuralgia, which frequently compress the pertinent nerve at the root entry or exit zone (REZ). Microvascular decompression (MVD) is a well-researched and successful treatment (Haines et al. 1980; Antonini et al. 2014; Campos-Benitez and Kaufmann 2008; Pollock and Schoeberl 2010; Apra et al. 2017).

MVD procedures have been performed using endoscopic techniques like endoscopic or endoscope-assisted MVD (E-MVD). Some drawbacks of microscopic MVD (M-MVD) can be addressed in the meantime, as the technique develops and neurosurgeons gain experience in endoscopic surgery. When compared to microscopy, several publications claimed that endoscopy is more effective at locating the zone of neurovascular conflict (Duntze et al. 2011; Chen et al. 2008; Burchiel et al. 1988).

TN is characterized by rostromedial compression of the trigeminal nerve by the lateral pontomesencephalic section of the SCA, which typically runs medial to the trigeminal nerve (Hitotsumatsu et al. 2003; Martin et al. 1980). By using an endoscopic method, the lateral pontomesencephalic section of the SCA can be transferred rostromedially and then anchored at the cerebellar tentorium. While not requiring brain retraction or petrosal vein ligation, a 30° endoscopic vision through the lateral tentorial surface of the cerebellum allows good exposure of the trigeminal nerve from the REZ to the Meckel cave and also reveals the path of the lateral pontomesencephalic portion of the SCA as the culprit artery along the midbrain . The SCA lateral pontomesencephalic segment's perforators can also be seen with a clean endoscopic view. The SCA lateral pontomesencephalic segment's perforators are quite lengthy and do not obstruct transposition to tentorial fixation.

For hemifacial spasm, the flocculus emerges just lateral to the eighth cranial nerve, and the REZ of the facial nerve is placed immediately medial to the eighth cranial nerve in the supraolivary fossette. The root output zone of the seventh nerve is frequently compressed from a caudal direction by the lateral pontomedullary portion of the AICA (Hitotsumatsu et al. 2003; Martin et al. 1980). By using an endoscopic technique, the AICA should be anchored at the petrosal dura and transferred caudally.

The neurovascular structures and relationships surrounding the supraolivary fossette behind the flocculus are clearly visible in a 30° endoscopic view through the petrosal surface of the cerebellum through a retrosigmoid keyhole. After the AICA has been mobilized, the problematic artery can easily be identified as the facial nerve root exit zone. Small perforators may be seen clearly by the endoscope even when they are hidden by obstructions (Ishikawa et al. 2015), and secure identification of perforators helps prevent harm during decompression treatments, particularly for the transposition technique.

It is demonstrated in the meta-analysis by Li et al. (Li et al. 2019) that E-MVD is better when perioperative safety is taken into account, as there are less perioperative problems. Postoperative efficacy, as indicated by the recent cure rate, long-term cure rate, and offending vessel identification rate, was also better with E-MVD. Facial paralysis was much lower in E-MVD, but CSF leakage and dysaudia also exhibited a similar tendency to the prior discussions (Kabil et al. 2005; Badr-El-Dine et al. 2002). The results suggest that EMVD is the best surgical technique for MVD to treat facial spasms and trigeminal or glossopharyngeal neuralgia.

11. Surgery for Craniosynostosis

Craniosynostosis' minimally invasive surgical cure was invented by Jimenez and colleagues (Jimenez and Barone 1998; Jimenez et al. 2004). Before the age of six months, endoscopy-assisted craniosynostosis surgery (EACS) can be used to treat this issue, along with postoperative helmet shaping therapy. Three months old is the ideal age for EACS. With a conventional arsenal and a 0-degree endoscope with a working shaft utilized for endoscopic face lift surgery sans irrigation, the procedure—basically a strip craniectomy—can be carried out. The authors presented a low risk of complications as well as a high percentage of success.

A craniectomy in scaphocephaly is carried out from the anterior to the posterior fontanelle. With powerful scissors, the bone is sliced. The removed strip needs to be 11 cm long and 4–5 cm wide. Wedge-shaped osteotomies or lateral barrel stave osteotomies can be introduced in front of the lambdoid sutures and behind the coronal suture. This endoscopic method has a strong success rate and fewer complications. Furthermore, in their most recent publication, only 9% of the 139 patients needed blood transfusions. Within three weeks following surgery, the children donned a helmet for ten months. Skin problems were infrequent, although probable pressure sores or eczema were given special attention (Jimenez et al. 2004; Sgouros 2013; Shim et al. 2017).

12. Endoscopic and Endoscope-Assisted ICH Evacuation

Endoscope-Assisted Evacuation: It is the term used to describe the formation of a minor craniotomy or craniectomy followed by evacuation using an endoscope and a sucker or combination device beside each other in the lumen of the sheath. In prospective research conducted in 2009 by Kim and Kim, patients with minor ICH (30 cm^3) restricted to the basal ganglia and thalamus were divided into two groups: those who had stereotactically guided active removal (n = 204) and those who underwent conservative care (n = 103); the 1st group had better outcoome (Kim and Kim 2009). At 180 days following initial presentation, patients who received endoscope-assisted evacuation had reduced mean mRS scores (1.2 vs. 3.0 for those who were medically treated) (Hersh et al. 2018).

Endoscopic Evacuation: Pure endoscopic evacuation was employed in one of the early investigations to investigate active MIS ICH evacuation. In this single-center study, accomplished by Auer et al. and published in 1989, the investigators randomly assigned 100 cases (within 48 h of onset) who had supratentorial ICH of more than 10 cm^3 as well as an altered degree of awareness (Auer et al. 1989). When comparing to the medically managed sample, most cases had a 50–70% reduction in hematoma volume following endoscope-assisted surgery and saw considerably lower death and morbidity rates (30 and 60% versus 70 and 75%). The surgery was most beneficial for patients with hemorrhages ≤ 50 cm^3 and who were younger than 60 (Hersh et al. 2018).

13. Spinal Endoscopy

13.1. Introduction

Endoscopic spine surgery is one type of minimally invasive surgery that has evolved from conventional open spine surgery in degenerative disc disease. With the development of and advancements in optics, high-resolution video cameras, endoscopic light sources, high-speed burrs, irrigation pumps, etc., minimally invasive spine procedures are now possible for all sections of the spine using a variety of endoscopic approaches. Less tissue and muscle dissection; less trauma; less blood loss; less disruption of the epidural vascular supply, which prevents epidural fibrosis and scarring; shorter hospital stays; quicker functional recovery; better quality of life; better cosmetic results; and simpler access for recurrent cases are all benefits of endoscopic spine surgery (Choi et al. 2017).

Initially only utilized for lumbar, cervical, and thoracic disc herniations, endoscopic spine surgery is now also employed for spinal canal stenosis, including endoscopic-aided fusion surgeries. In the management of teenage disc herniations, spinal endoscopy can be quite helpful, especially for athletes and those who participate in competitive sports, where minimal tissue stress, cosmetic improvement, and rapid functional recovery are all highly desired outcomes (Choi et al. 2017).

13.2. History of Endoscopic Spine Surgery

Lymen Smith introduced real minimally invasive spine surgery by injecting chymopapain intradiscally, or chemonucleolysis, in 1963 (Hoogland 2003). In order to test the viability of mechanical nuclear debulking, Kambin inserted a Craig cannula using a posterolateral route in 1970. The success rate of the mechanical nucleotomy performed in 1975 (Hijikata et al. 1975) via a posterolateral approach to the disc's nucleus was 64%. Then, using a posterolateral approach, Schreiber and Suezawa created a succession of cannulas, which telescoped one over another, and inserted them into the intervertebral disc's center. Larger forceps could be inserted and nuclear tissue could be evacuated more quickly due to the larger cannulas with an internal diameter (ID) of 7 to 8 mm. For the first time, Friedman and Jacobson used a far lateral procedure for lumbar intervertebral disc herniation, inserting a 40-gauge French thoracostomy tube through an incision above the iliac crest and guiding it to the disc after manually removing disc pieces with forceps (Choi et al. 2017; Friedman 1983). Onik et al. (1985) performed a central nucleotomy in 1985 using a nucleotome, a technology that gained popularity due to its low cost and ease of use. Kambin started using a laser to vaporize disc fragments in 1990, but the laser's large arc of deflection and damage to the neural structure prevented sufficient decompression. The parameters of the safe working area for the posterolateral approach between departing and crossing nerve roots were described by Kambin after an extensive cadaver study. He talked about Kambin's triangle (Figure 16). Adipose tissue and a very small superficial vein loosely surround the triangle (Kambin 1991, 1992; Kambin and Gellman 1983). All prior trials on minimally invasive disc access were blind. Kambin and Sampson published a purely endoscopic visualization method for a non-sequestrated intervertebral disc herniation as an extraforaminal approach; however, this technique eventually developed into a translaminar approach for discectomy (Kambin and Sampson 1986). In 1996, Sofamor Danek began a transforaminal endoscopic discectomy through a foramen (Mathews 1996). Choi et al. made a significant contribution to the reconfiguration of the endoscopic approach by entry to the far lateral intervertebral disc herniation (Choi et al. 2006; Kim et al. 2011).

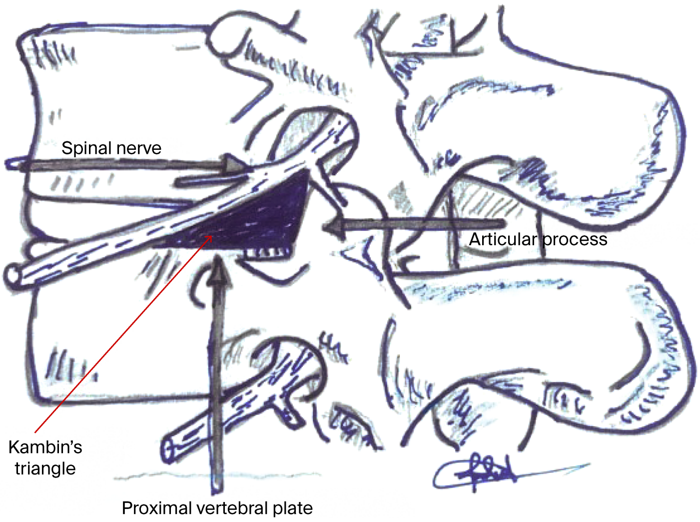

Figure 16. Illustration showing Kambin's triangle. Source: Figure by authors.

13.3. Endoscopic Lumbar Spinal Surgery

13.3.1. Transforaminal Endoscopic Lumbar Discectomy (TELD)

In the TELD, discectomy and decompression are carried out through the foramen between the exiting and traversing roots of the vertebrae. The crucial TELD procedure involves precisely inserting the needle into the disc through the Kambin's safe triangle, which is located between the outgoing and traversing roots. The superior endplate of the inferior vertebra serves as the Kambin's triangle's inferior boundary, while the thecal sac and the crossing nerve root, which is constrained by the facet, serve as its anterior boundary (Figure 16) (Choi et al. 2017).

During percutaneous procedures, the pedicle and associated disc space are utilized as radiographic landmarks. The position of needle insertion in the X-ray view is separated into horizontal lines parallel to the endplates in the anteroposterior view and a posterior vertebral line in the lateral view. For the majority of transforaminal surgeries, the posterior vertebral line and the medial pedicular line are typically used as reference points. To determine the largest and safest working cannula to enter the foramen, the working zone's dimensions are also crucial. Cannulas of 6.5 mm are safer when inserted at the medial pedicular line in the anteroposterior X-ray view, while 7.5 mm cannulas are safer when put at the midpedicular line, according to (Mirkovic et al. 1995) cadaveric study. The majority of functioning cannulas on the market have a diameter of about 7.5 mm.

Standard indications to keep in mind for discectomy.

Contraindications are (Choi et al. 2017):

- Severe disc migration and extensive disc calcification;
- L5-S1 level (special in males; cases with long iliac wings);
- More than single level (relative contraindication);
- Foraminal and spinal canal stenosis (relative contraindication);
- Spondylolisthesis;
- Recurrent intervertebral disc herniation (reoperation);
- Anomalies of the nerve root, like-conjugate root;
- Cauda equine syndrome.

Surgical Approach of TELD

TELD is accomplished in the lateral or prone position while the patient is under local anesthesia (1% lidocaine) as well as sedation with midazolam (0.05 mg/kg, 30 min prior to surgery) and fentanyl (0.8 g/kg, 10 min prior to surgery). Due to superior anatomical alignment, most surgeons choose the prone position. The distance from the midline and the needle trajectory used to target the ruptured fragment, sans entering the peritoneal sac and only grazing the facet, are estimated to determine the skin entry location for the needle depending on preoperative CT scan and MRI. In the C-arm anteroposterior (AP) view, the needle is pointed 10° downwards to form a 10° angle with the upper and lower endplates, sequentially, and advanced further until the first bony hindrance of the facet is felt. A limited adjustment of the trajectory can be made by beveling the needle; doing so allows for more superficial advancement and vice versa, with the needle slightly withdrawn, elevated, and inserted into the foramen while the C-arm is in the side view. The most crucial aspect is a precise and secure entry into the lower third of Kambin's triangle (Figure 16). The lower lumbar spine posterior vertebral line and medial pedicular line are the sites of annular puncture because the lamina is wider and less likely to puncture the dura. Next, puncture the annulus. Conduct a discography by injecting a mixture of 2 to 3 mL radiopaque dye and normal saline mixed in 2:1:2 ratios once the needle has reached the disc's center in AP view. During surgery, dye makes it easier to identify nuclear fragments. Change the needle for a guide wire, and then slide the obturator over the guide wire until it pierces the annulus. With the use of a mallet and tapper, withdraw the guide wire, and then thread the working cannula over the obturator. Insert the endoscope through the working cannula after removing the obturator. When performing a procedure, keep an eye out for any excessive discomfort radiating to the leg that could be caused by compression over the departing root (the traveling root is shielded by a facet), and adjust the needle trajectory as necessary. After the endoscope has been inserted, try to identify the structures, remove the fragment with various forceps, and, if necessary, repair the annular tear using bipolar cold cauterization and a Ho-YAG laser. Thecal sac and transverse root mobility without restriction, recent epidural hemorrhage, and pain relief are indications of sufficient decompression.

Extraforaminal disc herniation, high-grade above or below migrating disc herniations, and a high iliac crest for the L5-S1 level require special modification of the conventional procedure.

For extraforaminal intervertebral disc herniation:

(1) The needle direction needs to be steeper;
(2) The angle of needle insertion should be between 10 and 50%, depending on preoperative images;
(3) The distance from the midline needs to be between 5 and 8 cm;
(4) The midpedicular line should be used in the AP view and the posterior vertebral line should be used in the lateral C-arm view;
(5) The superior endplate of the caudal vertebra should be in the direction of the needle.

For migrated disc herniation:

(1) The entry point of the needle ought to be lower than the disc space, and vice versa for down-migrated disc herniations;
(2) Foraminoplasty (undercutting the non-articular section of the upper facet) or oblique pediculotomy (cutting of medial and upper wall of the lower pedicle) may be necessary for high-grade, down-migrating disc herniation (Choi et al. 2017).

Interlaminar Approach

Due to anatomical restrictions such a high iliac crest or up-migrated intervertebral disc herniation, where the trajectory is not on the plane of herniation, the transforaminal approach can occasionally be challenging at the L5-S1 level. The interlaminar approach can be helpful in certain circumstances. The interlaminar approach is feasible for L5-S1-level intervertebral disc herniation because the interlaminar window is greatest (31 mm) and there is little upper laminar overhang. The use of endoscopic surgery to treat spinal canal stenosis has grown recently (Choi et al. 2017).

13.3.2. Complications

Immediate Complications

- Neural and vascular structure injury;
- Peritoneal sac perforation, including abdominal contents;
- Missed or left fragments;
- Wrong spinal level or side exploration;
- Breakage of instrument.

Early Postoperative Complications

- Psoas muscle hematoma;
- Postoperative development of hematoma;
- CSF cyst formation;
- Infection.

Delayed Complications

- Recurrent intervertebral disc herniation;
- Possible spinal instability (Choi et al. 2017).

13.4. Endoscopic Cervical Spine Surgery

13.4.1. Percutaneous Endoscopic Cervical Discectomy (PECD)

The benefit of performing anterior PECD is that it can be conducted as a day-case procedure under local anesthesia, avoiding the need to fuse that segment and the difficulties associated with it. Additionally, because the patient is awake and conscious, there is ongoing feedback from them throughout the process, making it safer.

Indications: Annular rupture with concordant pain on provocative discography, whether contained or not, and paracentral or central intervertebral disc herniation that does not improve with conservative management for an acceptable period of time with correlating MRI and CT scans.

Contraindications:

- Migrated intervertebral disc herniation;
- Collapse disc space < 5 mm;
- Calcified disc;
- Instability;
- Infection;
- Previous history of anterior cervical spinal surgery (Choi et al. 2017).

13.4.2. Percutaneous Endoscopic Posterior Cervical Foraminotomy

Another endoscopic procedure, posterior cervical foraminotomy, can be used to treat foraminal intervertebral disc herniation, which can sometimes be challenging to treat with PECD. It has the advantages of not damaging the anterior normal disc, allowing for the removal of the herniated foraminal fragment, and avoiding anterior cervical discectomy plus fusion. It is also known as "key hole foraminotomy". It might be used for osteophytic foraminal stenosis.

Indications:

- Foraminal intervertebral disc herniations (mainly one-sided arm pain);
- Single/multilevel foraminal stenosis (one-sided arm pain);
- Persistent symptoms in spite of past anterior cervical discectomy and fusion.

Contraindications:

- Axial neck ache;
- Existence of cervical kyphosis;
- Instability (Choi et al. 2017).

13.5. Thoracic Spinal Endoscopy

13.5.1. Percutaneous Endoscopic Thoracic Discectomy (PETD)

Thoracic disc herniations (TDHs), which make up 0.25 to 0.75% of all disc herniations, are less common than lumbar or cervical disc prolapses. Thus, TDH surgery is extremely uncommon, accounting for approximately 0.15–1.8% of all medically corrected disc herniations. The frequency of TDH is rising today along with the usage of CT scans and MRI. With a posterior or posterolateral approach, PETD has evolved to lessen trauma and improve the postoperative course of TDHs. Jho described the posterolateral procedure for percutaneous endoscopic transpedicular thoracic discectomy in 1997 (Jho 1999). This prevented the need for additional skin cuts in the chest wall, as was necessary with thoracoscopic techniques, for postoperative chest drainage. Later, in 2010, Choi et al. (2010) utilized a 4 mm 0° endoscope and a low-energy, non-ablative laser to demonstrate the safety and effectiveness of PETD from a posterolateral perspective. The current standard of care for thoracic disc herniations has been compared to PETD, which has been described as a safer surgery with superior results.

The indications are the same for conventional thoracic discectomy. The disc has to be soft.

Contraindications:

- Calcified or hard disc;
- Ossified posterior longitudinal ligament;
- Proof of progressive or acute degenerative spinal cord disease;

- Severe disc narrowing;
- Severe spinal cord compression.

Complications:

- Damage to the spinal cord as well as its nerve roots;
- Vascular injury, such as injury to the thoracic aorta or inferior vena cava, can be life threatening;
- Visceral injury to the mediastinal viscera or lung (Choi et al. 2010, 2017; Jho 1999).

14. Endoscopy in Peripheral Nerve Surgery

Since the late 1980s, endoscopic carpal tunnel release (ECTR) procedures have been carried out. Shorter recovery times, reduced postoperative pain, lower postoperative wound sensitivity, and less scarring are benefits of ECTR. Flat learning curves for surgeons; reduced vision, which could lead to incomplete transverse carpal ligament (TCL) sectioning and a higher risk of neurovascular damage; and higher costs are drawbacks. This method produced outstanding outcomes in several published investigations. Using Brown's biportal endoscopic approach, Hankins et al. demonstrated an 82.6% total recovery, while Chen et al. demonstrated a 91% full recovery utilizing Menon's uniportal endoscopic technique (Hankins et al. 2007; Chen et al. 2011). Endoscopy was also used in attempts to cure cubital tunnel syndrome. Among 85 cubital tube releases, Tsai et al. observed a 64% success rate (Tsai et al. 1999). Ahčan and Zorman demonstrated even better outcomes; in their series, 91% of patients experienced a good or outstanding outcome (Ahčan and Zorman 2007). Decompression was accompanied by subcutaneous transposition in the research by Krishnan et al. of eleven treated patients, with outstanding results in 63.7%, good in 27.3%, and satisfactory in 9.1% of cases. While solely "in situ" decompression was conducted in these series (Krishnan et al. 2006).

There have reportedly been endeavors in endoscopic cubital tunnel release. Zlowodzki reported four randomized controlled studies. These investigations utilized the subcutaneous method in two studies and submuscular transposition in the other two. The studies covered 261 patients in all, with a follow-up period of, on average, 21 months. The "in situ" decompression patient group's complication rate was 9%, but the anterior subcutaneous transposition patient group's complication rate was 30% (Mullick and Dellon 2008). Tsai et al. published 85 endoscopic cubital tunnel releases using a 2–3 cm incision along the ulnar nerve (UN) path at the elbow. The authors decompressed the area up to 10 cm proximal as well as 10 cm distal to the medial epicondyle. A total of 64% of the patients in this series demonstrated improvement following surgery, although two of them later underwent transposition surgeries due to reoccurring problems (Tsai et al. 1999). Ahčan and Zorman described endoscopic release of a 20 cm length of UN through a 3.5 cm incision above the cubital tunnel, with good and excellent outcomes obtained in 91% of cases (Ahčan and Zorman 2007).

Brachial plexus endoscopic surgery is still in the research and development phase. Even though technology has advanced greatly over the past few years, there are still situations when the precise location and nature of a lesion cannot be determined, necessitating open surgical examination. In an effort to discover a minimally invasive method for exploring the brachial plexus that would also enable surgical repair of the severed nerve, a few cadaveric studies utilizing surgical robotic systems have been carried out (Mantovani et al. 2011).

Sural nerve harvesting is an intriguing use of endoscopes in peripheral nerve surgery. As is well known, the sural nerve is most likely the most popular donor for nerve transplantation. The typical open method for harvesting sural nerves involves making a succession of very small incisions along this nerve's course. Endoscopic sural nerve harvesting is a new method that has been devised in recent years. The surgery takes about 25 min to complete and only one 12 mm long skin incision is needed, as opposed to three in the traditional open technique (Park et al. 2006).

15. Future Directions

Neuroendoscopic surgery is expected to have a promising future. The sector will gain from additional advancements in camera and optical downsizing, surgical instrument design developments, the development of novel navigation or robotics systems, multiport endoscopy, and improved endoscope-assisted microsurgery using bimanual microdissection techniques. Endoscopic neurosurgery will be extended beyond intraventricular or skull base pathologies to intraparenchymal cranial lesions due to the continued development of endoscopic tools and cutting-edge surgical procedures, such as multiport approaches. These developments are crucial for the development of endoscope-assisted microsurgery in the future.

Other objectives include fully robotic telesurgery, shared control systems, or even remotely operated robotic neurosurgery. To meet future indications for minimally invasive or even ultra-micro-access neurosurgery, nanotechnology breakthroughs are required.

Neuroendoscopy is anticipated to become commonplace in contemporary neurosurgery practices in the future. For aspiring neurosurgeons, institutions should offer training programs (Shim et al. 2017).

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