Intracranial endoscopy

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The authors' intention is to reduce the invasiveness of intracranial procedures while avoiding traumatization of brain tissue, to decrease the risk of neurological and mental deficits. Intracranial endoscopy is a minimally invasive technique that provides rapid access to the target via small burr holes without the need for brain retraction. Craniotomy as well as microsurgical brain splitting and dissection can often be avoided. Furthermore, because obstructed cerebrospinal fluid pathways can be physiologically restored, the need for shunt placement is eliminated. The ventricular system and subarachnoid spaces provide ideal conditions for the use of an endoscope. Therefore, a variety of disorders, such as hydrocephalus, small intraventricular lesions, and arachnoid and parenchymal cysts can be effectively treated using endoscopic techniques. With the aid of special instruments, laser fibers, and bipolar diathermy, even highly vascularized lesions such as cavernomas may be treated. Moreover, during standard microsurgical procedures, the endoscopic view may provide valuable additional information ("looking around a corner") about the individual anatomy that is not visible with the microscope. In transsphenoidal pituitary surgery, transseptal dissection can be avoided if an endonasal approach is taken. In the depth of the intrasellar space, the extent of tumor removal can be more accurately controlled, especially in larger tumors with para- and suprasellar growth.

The combined use of endoscopes and computerized neuronavigation systems increases the accuracy of the approach and provides real-time control of the endoscope tip position and approach trajectory. In the future, the indications for neuroendoscopy will certainly expand with improved technical equipment.

Key Words * neuroendoscopy * neuronavigation * aqueductoplasty * third ventriculostomy * arachnoid cyst * hydrocephalus * intraventricular tumor * pituitary surgery

Although the first intracranial endoscopic procedures were performed at the beginning of this century,[21,22,29,90] endoscopic techniques have never achieved widespread popularity among neurosurgeons. The main reasons were poor miniaturization of endoscopes, insufficient instruments, poor illumination, and attendant problems with hemostasis and infections. However, because of the ongoing refinement of endoscopes and instruments, as well as development of bright cold light sources and mini video cameras, endoscopes have been increasingly used in brain surgery since the late 1980s.[116] The use of neuroendoscopy in combination with frame-based or, recently, frameless stereotaxy (computer neuronavigation) increases the safety and precision of the endoscopic approach. Nevertheless,
neuroendoscopy is still in its infancy. In this paper, we will continue the discussion of neuroendoscopy's indications as well as its advantages and disadvantages; the debate is ongoing as new endoscopes and instruments are presented with increasing frequency.

DESCRIPTION OF EQUIPMENT

For intracranial neuroendoscopy, a sophisticated and complex neuroendoscopic system that includes various rigid, semiflexible, and flexible scopes, and bright cold light sources is needed, as well as a high-resolution video camera system, effective instruments, and irrigation devices. Combination with a guiding system is helpful, and sometimes even mandatory. We use the universal Gaab neuroendoscopic system developed by the senior author.[35]

The endoscopes are introduced via an operating sheath (6.5-mm Gaab I; 4.0-mm Gaab II miniature system) that is initially inserted with the aid of a trocar, which permits the intraoperative exchange of different scopes without reinserting scopes through brain tissue, thus eliminating unnecessary injury to the surrounding healthy brain. Rigid rod-lens scopes (Karl Storz GmbH and Co., Tuttlingen, Germany) are preferable because of their superb optical quality and wide-angle view, as well as ease of guidance and orientation. These endoscopes provide an excellent overview of the intraventricular anatomy. Although minor hemorrhages may blur the view, the surgeon will remain oriented, which is extremely difficult with the poor optics of a fiberscope. Rigid scopes with four different angles of view are available (0, 30, 70, and 120°). The 0° and 30° scopes are used for inspection and manipulation; the 70° and 120° scopes are used for inspection only ("looking around a corner"). Because the operating endoscope (wide-angle straight-forward scope with angled eyepiece) has no separate working channel, it allows the whole inner diameter (about 6 mm) of the endoscopic sheath to be used, which permits effective tissue removal and implant insertion of devices such as stents. The miniature endoscope (3.2-mm outer diameter) has been developed for use in pediatric patients. This semirigid minifiber endoscope (10,000 fibers/mm²) incorporates an instrument channel as well as two separate channels for irrigation in- and outflow. When manipulations "around a corner" are to be performed, steerable fiberscopes containing an instrument channel of 1.2 mm (outer diameter 2.5 mm and 3.5 mm) are used. However, for most endoscopic procedures we prefer the rigid rod-lens scopes because of their superior optical properties.

Various mechanical instruments of different sizes are available, such as scissors, biopsy and grasping forceps, hooks, and puncture needles. Both the operating endoscope and the miniature scope allow manipulations to be performed with rigid instruments in a straight line, which provides a good tactile feedback from the tissue and makes easy guidance of the tools possible. Bipolar as well as monopolar diathermy probes and a laser guide are used for hemostasis and dissection. We prefer a 1.064-µm Nd:YAG laser. Balloon catheters are used to enlarge ventriculostomies or other fenestrations.

For irrigation, we use the Malis irrigator for which the flow is easily controlled using a foot switch. Lactated Ringer's solution at 36 to 37°C is preferable to saline, because postoperative increases in body temperature, often observed after abundant irrigation with saline, are rarely encountered. It is very important to make sure that the outflow channel is open to prevent dangerous increases in intracranial pressure (ICP).

Xenon light sources provide the best illumination, because the color temperature of xenon light resembles that of sunlight (6000 K). The light is transmitted via fiberglass or fluid cables from the light fountain to the endoscope.
Digital 1- or 3-chip mini video cameras are attached to the endoscope via a sterile optical bridge. Because the camera and bridge are draped with a sterile covering, the sterile intraoperative exchange of endoscopes is allowed using the same camera without sterilizing the sensitive electronics. High-resolution video monitor screens display the endoscopic picture. Each endoscopic procedure is taped with a S-VHS recorder. Analog video recordings can be processed using a digital processing unit (Digivideo, Karl Storz GmbH and Co.) to enhance contrast as required. Finally, the documentation equipment includes a video printer and digital still recorder. For some endoscopic procedures, the simultaneous use of two endoscopes is beneficial. The images from both scopes can be displayed on one video monitor with the aid of a digital picture-in-picture device (Twinvideo, Karl Storz GmbH and Co.) In this way, the surgeon obtains information provided by both scopes while looking at only one screen.

GENERAL OPERATIVE TECHNIQUE

After induction of general anesthesia, the patient is typically placed in the supine position with the slightly anteflexed head placed in a horseshoe-shaped headrest or pin fixation. If computerized neuronavigation is used, the dynamic reference frame is mounted on the Mayfield clamp and the camera bar adjusted. After image registration, the operating field is prepared and draped. Antibiotics are not routinely used.

The optimum position of the entry point is commonly determined by evaluating preoperative computerized tomography (CT) scans or magnetic resonance (MR) images.[36] However, if the ventricles are small or the target is located in the posterior part of the third ventricle, it is very helpful to use a guiding system to find the ideal access route, thus avoiding infliction of unnecessary brain trauma. When treating some cystic lesions, such as parenchymal cysts or loculated hydrocephalus, it is mandatory to use navigational guidance because there are often no anatomical landmarks, and one can easily get lost in the cavity. Frame-based stereotaxy,[4,32,44,96-99,143] ultrasound-guided stereotaxy,[9] and recently, frameless computer-based stereotaxy[28,81,82] have been used in combination with neuroendoscopy to increase the accuracy of the approach. In cooperation with Carl Zeiss and Karl Storz GmbH & Co., we have developed a universal guiding system for endoscopic purposes.[119] With the aid of an infrared-based computerized navigation system, the Surgical Tool Navigator, the endoscopic sheath can be inserted precisely into the ventricles even if they are very narrow. This technique also allows accurate planning of the approach before starting with surgery (for example, the straight approach through the foramen of Monro to the aqueduct without injuring the fornix). Frameless neuronavigation enables free-hand movement of the endoscope with real-time control of the endoscope tip position and of the approach trajectory. The accuracy is between 2 mm and 3 mm, which has proved to be sufficient for endoscopic purposes. After reaching the target area with navigational guidance, minor position corrections can be made under direct endoscopic view.

In general, the entry point is located contralateral to the dominant hemisphere. However, if the ventricular system is asymmetrical, the approach should be performed via the larger foramen of Monro. After a 3-cm straight scalp incision, a 10-mm burr hole is made. Once the dura has been opened, the operating sheath with trocar is inserted free hand or under navigational guidance into the lateral ventricle and fixed with two Leyla retractor arms. The trocar is then replaced by the rigid diagnostic scope. After identification of the main landmarks--choroid plexus, fornix, and veins--the target area is approached. Care must be taken to avoid damaging the fornix and subependymal veins while introducing the sheath into the foramen of Monro. After completion of the procedure, the diagnostic scope is used to inspect the
target area to ensure that there is no active bleeding. Then the operating sheath and the endoscope are simultaneously withdrawn to visualize any bleeding in the cortical puncture channel. We pack the burr hole with a gelatine sponge and tightly suture the galea to prevent subgaleal cerebrospinal fluid (CSF) accumulation and fistula formation. The skin is closed using running atraumatic suture.

INDICATIONS FOR NEUROENDOSCOPY

A prerequisite for safe endoscopic procedures is clear visualization of the anatomy. Preformed cavities filled with crystal-clear CSF, such as the ventricular system, subarachnoid space, and some cystic lesions, provide optimum conditions for the application of endoscopes. Therefore, hydrocephalus, intraventricular lesions, and space-occupying arachnoid or parenchymal cysts are ideal indications for the use of an endoscopic approach. Due to the further improvement of endoscopic hemostasis (that is, the development of bipolar coagulation probes and suitable laser devices), even highly vascularized tumors can be resected. Furthermore, neuroendoscopes can also be used together with the operating microscope to obtain more detailed information for the dissection.

Management of Hydrocephalus

Hydrocephalus represents the classic indication for a neuroendoscopic approach. As early as 1910, Lespinasse performed fulguration of the choroid plexus in two infants.[22] In 1923, Mixter[90] performed the first endoscopic third ventriculostomy. Currently, hydrocephalus remains the most frequent intracranial disease treated endoscopically.

Endoscopic third ventriculostomy has become a well-established procedure for the treatment of noncommunicating hydrocephalus (Fig. 1).[62-64,71,129] In our experience, third ventriculostomy has been successful in controlling obstructive hydrocephalus caused by tumors, aqueductal stenoses, hemorrhages, and infarctions. Although the procedure is commonly considered to be safe and straightforward, severe and, rarely, fatal complications may occur.[48,87,123] The correct placement of the fenestration in the floor of the third ventricle is of utmost importance to avoid vascular and neural damage. The perforation of the floor should be made halfway between the infundibular recess and mammillary bodies in the midline, just behind the dorsum sellae. In this way, hypothalamic injury, oculomotor palsy, and vascular injury are unlikely to occur. Careful inspection of a CT scan or sagittal MR image to assess the individual relation of the basilar artery and the floor of the third ventricle is advisable.
Different techniques have been recommended for performing third ventriculostomy, including blunt perforation with a leukotome[45,67] or the scope itself,[64,129,132] inflation of balloon catheter,[94] coagulation with monopolar diathermy,[71,109] and laser fiber.[131] We prefer the blunt perforation, originally proposed by Frerebeau, et al.,[33] in which a No. 3 French Fogarty catheter or closed biopsy forceps is used along with subsequent enlargement of the opening by inflating the balloon of the catheter. Sometimes the floor is very tough and its blunt perforation causes considerable tension to the floor and adjacent hypothalamus. Furthermore, there is a risk that the catheter may slip away and perforate the floor too far laterally or posteriorly, which increases the risk of vascular or nerve complications. In these cases, we use a bipolar diathermy rod to achieve the initial perforation, which is then enlarged by inflating the balloon of the Fogarty catheter.
A successful third ventriculostomy does not necessarily reduce the ventricles to normal size. Often the ventricles remain dilated, in spite of complete clinical recovery.[75,129] In two large series in which endoscopy was performed in over 100 patients, the success rate was reported to be between 70% and 81% in patients older than 2 years of age and between 45% and 50% in the patients under the age of 2 years.[61,129] However, with proper patient selection, the success rate may be increased.[67] Unfortunately, to date there is no reliable test available to predict the success of the procedure. Therefore, we use endoscopic techniques first to avoid placing a shunt (indication "ex juvantibus").

Even in long-term shunt-dependent patients in whom shunts have malfunctioned, third ventriculostomy may be effective and should be attempted.[65,140] If the endoscopic attempt fails, a shunt may be reinserted with clear indication.

Endoscopic techniques are also useful in the accurate placement of ventricular catheters or in shunt revision procedures.[74,133,141] Under direct view, the catheter is placed in the ideal position away from the choroid plexus to decrease the risk of shunt obstruction. During a shunt revision procedure, the retained ventricular catheter can be freed from surrounding choroid attachments or scarring by using bipolar diathermy or laser devices. Another valuable indication for an endoscopic approach is loculated hydrocephalus.[77] Intraventricular septations are widely fenestrated and embedded ventricular catheters removed. After converting the multiloculated compartment into a single loculation, shunt systems can be simplified, which results in a lower complication and shunt-revision rate.

With aqueductal stenosis, endoscopic aqueductoplasty offers an alternative treatment option to third ventriculostomy. Initially, the aqueduct is inspected using the aid of rigid rod-lens scopes and steerable fiberscopes. If the aqueduct is occluded by a thin membrane, this membrane is simply perforated. In short stenoses, the aqueduct is restored by gently inflating the balloon of a Fogarty catheter. A stent may be inserted into the aqueduct to prevent later occlusion by scarring. Reopening of the aqueduct in long stenoses carries a high risk of midbrain injury with neurological sequelae, such as dysconjugate eye movement, Parinaud's syndrome, oculomotor palsy, or trochlear palsy. In these cases, it is safer to perform a third ventriculostomy. Another potential use of aqueductoplasty and aqueductal stent placement is in patients with trapped fourth ventricle.[130] Endoscopic aqueductoplasty in which stents are not placed seems to be effective in short stenoses. However, longer follow-up periods are necessary to evaluate the long-term aqueductal patency after aqueductoplasty.

Endoscopic choroid plexus coagulation has been sporadically recommended for the treatment of communicating hydrocephalus.[105,114,115] However, what explains the high failure rate is the fact that there is a considerable amount of extrachoroidal ventricular fluid formation.[88,89] Recently choroid plexus coagulation has been proposed for use in selected milder forms of communicating hydrocephalus.[104] Nevertheless, the efficacy of this procedure and clear indication criteria remain to be determined.

Ensuring the independence of the shunt should be the primary aim in the management of obstructive hydrocephalus. Moreover, even after long-term shunt dependence, endoscopic internal shunting should be considered to eliminate the need for a shunt. If the endoscopic attempt fails, a shunt can be inserted in a subsequent procedure.

**Intraventricular Tumors**

Small, poorly vascularized tumors of the lateral or third ventricle that cause enlargement of the ventricles
by occluding CSF pathways are ideal indications for an endoscopic approach. The ventricular dilation provides sufficient space for maneuvering the endoscope and manipulating the instruments. However, intraventricular lesions are also accurately approached via small ventricles by using computerized neuronavigation.

A major limiting factor in endoscopic tumor resections is the tumor size. Most neuroendoscopes currently available have a working channel of 2.4 mm at best. It is clear that the use of the devices to remove even small tumors is a time-consuming procedure. The benefits of the minimally invasive technique--less brain retraction and small burr-hole approach--are then outweighed by the duration of the operation. Therefore, our operating endoscope has no separate working channel. The whole inner diameter (> 6 mm) of the operative sheath through which the endoscope is introduced is available for the removal of large tumor pieces. The size limitation of a tumor to obtain effective endoscopic removal is difficult to determine. If the tumor is too large, however, endoscopic piecemeal resection may become time consuming and ineffective. Therefore, a solid tumor should not exceed 2 cm in diameter. In addition, the consistency and vasculature of the tumor must be considered. Resection of a soft tumor is easier and faster than the removal of a firm lesion. If the tumor is cystic or contains major cystic parts, even larger lesions can be resected endoscopically (Fig. 2). Highly vascularized lesions such as cavernomas and hemangiomas can also be safely removed with the aid of a Nd:YAG laser and bipolar diathermy. In the case of larger tumors (with accompanying hydrocephalus) not amenable to endoscopic resection, a third ventriculostomy or aqueductal stent placement to restore CSF flow is indicated. If the tumor occupies the entire third ventricle and risks obstructing the foramen of Monro and aqueduct, the stent should be inserted through the entire third ventricle and aqueduct connecting lateral, third, and fourth ventricles. Unilateral occlusion of the foramen of Monro may be treated by septostomy of the septum pellucidum. Sometimes both stent placement and septostomy are necessary to restore CSF flow. A biopsy sample can be obtained of any tumor visible at the ventricular surface.
Fig. 2. Imaging studies demonstrating craniopharyngioma. A-D: Intraoperative neuroendoscopic views; E and F: computerized tomography scans. A: Photograph demonstrating foramen of Monro with fornix (F), choroid plexus (C), thalamostriate vein (TV), and tumor (T) within the third ventricle. B: Photograph depicting the capsule resection by using forceps. C: Photograph showing the outflow of greenish content after opening. D: Photograph showing the stent placed in aqueduct. E: Axial scan revealing a hypodense cystic tumor within the third ventricle and accompanying hydrocephalus. F: Postoperative axial scan demonstrating the complete evacuation of the tumor, aqueductal stent in place, and resolution of hydrocephalus.

Although stereotactic biopsy sampling is the classic option to clarify the tissue diagnosis of lesions in various locations, "blind" stereotactic puncture of tumors in the vicinity of the foramen of Monro has the potential danger of injuring the fornix and causing the ependymal veins to hemorrhage.[76] Stereotactic biopsy sampling of pineal lesions risks damaging the great vein and the internal veins. Endoscopic biopsy sampling offers distinct advantages when compared with pure stereotactic MR- or CT-guided biopsy sampling. The lesions can be visualized. The individual anatomy including the capsule's vasculature is inspected and vessels at risk can be cauterized. Anatomical changes in coordinates, such as after cyst aspiration, can be recognized, and much more tissue can be obtained under direct view. Bleeding can be avoided or detected early, and hemostasis is achieved under visual control. Especially for lesions located in the pineal region, we consider the endoscopic approach to be superior to
stereotactic biopsy sampling. Despite recent reports on large series of stereotactically obtained biopsy samples of pineal lesions,[70,108] in which this technique was described as safe and reliable, we are concerned about the "blind" sampling of tissue in this area. We prefer neuroendoscopic exploration and obtaining a biopsy sample under direct visualization.[40] By using the same approach, accompanying CSF pathway obstruction can easily be relieved by placing a stent in the aqueduct or by performing a third ventriculostomy. Thus, endoscopy offers histological verification and permanent reconstitution of blocked CSF pathways. After obtaining an accurate histological diagnosis, the decision is made for subsequent microsurgical intervention, radiotherapy, chemotherapy, and/or radiosurgery.

After the scope has been guided to the tumor, the surgeon inspects the tumor to become familiar with the relationship to the surrounding structures. Before tumor dissection, capsule vessels are cauterized with the aid of a bipolar diathermy probe or an Nd:YAG laser in noncontact mode. Tissue specimens are then obtained for histological examination. Depending on the tumor size, removal usually starts with intracapsular debulking or dissection in the plane between tumor and normal brain tissue. During this dissection, feeding arteries must be identified early and coagulated before bleeding obscures the clear view. Use of the Nd:YAG laser has proven suitable for the removal of well-vascularized tumors.[121] A chisel laser fiber is initially used in noncontact mode for vessel coagulation and tumor shrinking. Tumor dissection is then accomplished with the same or a conical fiber in contact mode for cutting. The laser-assisted resection requires vigorous irrigation to avoid thermal damage to the adjacent brain tissue.[42]

Because each endoscopic tumor resection is accompanied by some bleeding, all procedures are performed under continuous irrigation with Ringer's solution at 36°C to maintain a clear view.[37] The irrigation is controlled with a Malis irrigator. To focus the irrigation on the hemorrhage source, a separate irrigation tube is precisely placed. For forced rinsing, a 20-ml syringe is used manually. The hemostasis of small hemorrhages represents no problem, because these usually cease spontaneously after a few minutes of irrigation. In rare cases, irrigation periods of more than 10 minutes become necessary to stop a larger venous bleeding and to make visibility clear again. To prevent a dangerous increase in ICP, care must be taken to maintain a sufficient outflow of irrigation fluid. Larger vessels at risk of being torn during tumor resection should be cauterized using the bipolar diathermy probe. In well-vascularized tumors, the CSF can be aspirated and the procedure performed in a dry field. With this "dry-field" technique, bleeding vessels are more easily identified and hemostasis is quickly achieved, because bloody CSF no longer obscures vision.

The preliminary results of endoscopically managed intraventricular tumors are promising.[38] Therefore, endoscopic techniques should be considered for the treatment of selected intraventricular lesions. However, all preparations should be made for immediate microsurgical intervention should complications arise or the endoscopic procedure be deemed ineffective.

Colloid Cysts

Transcallosal-transventricular,[2,55] transcortical-transventricular,[2,79,86,92] transcallosal-interfornicial,[5] transcortical-transventricular stereotactic approaches,[1,13] and stereotactic aspiration[12,27,47,68] have been recommended for the treatment of colloid cysts. Shunting should not be considered as a treatment option because of its attendant high rate of complications.[17] In microsurgical procedures the complete removal of the cyst is the rule.[30] However, potential risks are well known. Complications associated with the transcallosal approach include venous infarction,
thrombosis of the sagittal sinus, disconnection syndromes, fornicial injury, and infarcts to the thalamus and basal ganglia.[80] The transcortical approach has been reported to be associated with a higher rate of seizures.[79,86] Because of its simplicity and low risk, CT-guided stereotactic aspiration of colloid cysts has been advocated.[12,27] However, in hyperdense cysts, in which solid content is indicated, stereotactic aspiration has often failed.[68] An endoscopic or microsurgical procedure then is necessary.[69] In addition, performing "blind" stereotactic aspiration carries the risk of injuring the fornix and causing bleeding from ependymal veins.[76] Most importantly, a high recurrence rate (up to 80%) following aspiration of colloid cysts has been reported after long-term follow-up study.[85] Failure of the procedure has been detected within the first 2 months and after more than 8 years. Some patients became comatose due to tentorial herniation. These findings underline the fact that simple aspiration is not sufficient. The key seems to be achieving a wide opening of the cyst and complete or near-complete resection of the capsule. Because sudden death caused by colloid cysts has been reported,[1,110,113] even asymptomatic cysts with signs of CSF pathway obstruction should be treated surgically.

In our experience, any cyst contains at least partially solid components. Hence, simple stereotactically guided aspiration will not result in complete evacuation of the cyst. However, by using the endoscopic technique a total evacuation and at least near-total resection of the membrane can be achieved. Postoperative external ventricular drainage is not necessary. The aim of surgery in treating colloid cysts is restoration of the foramina of Monro, resolution of hydrocephalus, and prevention of recurrent blockade of the foramina. This can be achieved by using microsurgical and endoscopic techniques. Although currently, low morbidity and mortality rates following microsurgical removal of colloid cysts have been achieved by experienced surgeons, the endoscopic minimally invasive burr-hole approach is less traumatic to the brain and is equally as effective. Recently, Mathiesen, et al.[84] have reported a series in which the microsurgical removal of 24 colloid cysts (22 transcallosal and two transcortical) was performed by experienced neurosurgeons. Nevertheless, transient memory deficit caused by fornicial traction was noted in 26%. Two colloid cysts that were surgically treated by less experienced surgeons even resulted in death or permanent memory loss. The authors stressed that piecemeal removal, as we performed in our endoscopic technique, rather than in toto removal is the key to avoid fornicial injury and consequent memory impairment.

Colloid cysts are the intraventricular lesions most often treated endoscopically.[14,19,20,24,26,76,106,143] The endoscopic approach combines the minimal invasiveness of stereotactic aspiration with the effectiveness of microsurgery. By using an endoscope, CSF pathways that are still obstructed after cyst removal can be restored, which is not possible when using simple stereotactic techniques.[134] Therefore we consider the endoscopic removal of colloid cysts the therapy of choice.[117] However, the question remains whether small remnants of the membrane, which may be left in place, cause cyst recurrence. Only long-term evaluations can answer this question.

Arachnoid Cysts

The CSF-like content of congenital arachnoid cysts provides excellent conditions for the application of an endoscope. Arachnoid cysts are predominantly located in the sylvian fissure.[18,51,139] However, cysts in any other location, such as the anterior[7] and posterior cranial fossa,[31,58,78] quadrigeminal cistern,[49,100,127] interhemispheric fissure,[51] suprasellar region,[56,103] or intraventricular space,[72,83,138] are suitable for an endoscopic approach.

Many operative procedures have been recommended for the treatment of arachnoid cysts, including
microsurgical cyst excision[25,72,93,112] or fenestration,[7,58] stereotactic aspiration,[57,101] cyst fenestration with arachnoidplasty,[125] cystocisternostomies,[11] ventriculocystostomies,[103,107] cystosubdural shunting,[136] cystoperitoneal shunting,[6,18,51] and endoscopic fenestration.[16,23,120] However, the best treatment option remains to be determined. Major complications associated with microsurgical cyst fenestration/resection and shunting procedures reported in the literature include meningitis, hemiparesis, oculomotor palsy, subdural hematomas, new grand mal seizures, and even death following the former[3,18,78,137] and shunt malfunction and infection following the latter.[3,6,51,73] Shunt placement is obviously safer, but it is associated with a higher incidence of additional surgical procedures and the disadvantage of life-long shunt dependence.[73,93] By using endoscopic techniques, the complications associated with microsurgery are rare, and similar or even better results are achieved.

Surgical intervention is indicated in symptomatic space-occupying arachnoid cysts (Fig. 3). If MR imaging demonstrates no mass effect, or the relation of symptoms and arachnoid cyst is debatable, the ICP should be monitored for increased ICP and/or pathological pressure waves. The surgical indication for asymptomatic arachnoid cysts is controversial.[6] In spite of the high vulnerability of arachnoid cysts in patients who have sustained minor head trauma, we consider surgery for asymptomatic arachnoid cysts in adults to be unjustified. In contrast, surgery should be performed in children who harbor asymptomatic cysts that exert a mass effect,[6,95] although spontaneous regression of arachnoid cysts has been sporadically reported.[135] Because cyst expansion may jeopardize normal development and function of the adjacent brain in children, this potentially harmful effect outweighs the risk of the operative procedure.[18,51]

Fig. 3. Axial CT scans revealing a space-occupying arachnoid cyst in the sylvian fissure (left) and, 6 months after cystocisternostomy, a decrease in cyst size as well as resolution of midline shift and ventricular compression (right).

The entry point is selected according to the best trajectory determined from assessing MR imaging or with the aid of a computerized neuronavigation system that is especially helpful in cystic cavities lacking well-known landmarks and when small hemorrhages obscure a clear view. It is of the utmost importance to cauterize the fragile arachnoidal blood vessels in the entry zone of the operating sheath to avoid
bleeding after movements of the endoscope. Outflow of CSF should be minimized to prevent collapse of
the cyst and accumulation of CSF between the outer cyst membrane and the dura mater, which may
result in subdural hematoma.[3] Additionally, care should be taken not to detach the outer cyst
membrane from the dura mater when inserting the operating sheath, which would also result in cyst
collapse. Depending on cyst location, cystocisternostomies, ventriculocystostomies, and
ventriculocystocisternostomies are performed. Each operation is performed under continuous irrigation
with Ringer's solution at 36°C. If significant bleeding occurs and even under intensive irrigation clear
visibility cannot be maintained, the endoscopic procedure must be abandoned, and the operation must be
continued microsurgically. Before removing the scope, the cyst is vigorously irrigated to remove any
clots that may promote arachnoid fibrosis and closure of the fenestration.

In suprasellar arachnoid cysts, a slit valvelike structure formed by arachnoid membranes around the
basilar and vertebral arteries has been observed endoscopically.[16,111,118] The valves open and close
synchronously with arterial pulsations. These cysts are obviously filled by CSF pulsations of vascular
origin, which pump the CSF into the cyst. Due to the one-way configuration of the valve, the CSF cannot
escape from the cyst. Interestingly, in none of the arachnoid cysts in other locations have we found a
valvelike structure.

Neuroendoscopy is a safe and effective treatment option for arachnoid cysts and should be seriously
considered as the initial therapy. Should the endoscopic procedure fail, microsurgical fenestration or
shunting can be subsequently performed without causing additional risk to the patient. By performing
neuroendoscopy, the surgical trauma can be reduced to a minimum and craniotomies as well as shunt
dependence can be avoided.

**Pituitary Surgery**

The microsurgical transseptal transsphenoidal approach to pituitary tumors has been established as the
standard technique for decades.[50] Guiot, et al.,[46] were the first to use an endoscope in
transsphenoidal pituitary surgery. Endoscopes were mainly used as an adjunct to the operating
microscope in the transseptal approach.[41,124,142] However, transseptal dissection is not without
reported potential complications such as breathing problems, septum perforations and deviations, and
numbness of the maxillary dentation after sublabial incision. Inspired by the endoscopic sinus surgery
performed by otolaryngologists, an endoscopic endonasal approach to the pituitary gland has been
developed.[52,59,60,126] To obtain sufficient working space for endoscope and instruments within one
nostril, it is necessary to outfracture or resect the middle turbinate and displace the nasal septum. With an
endoscopic sheath-aided access under the control of combined neuronavigation and lateral fluoroscopy,
which we are currently developing, this can be avoided.[39] Various endoscopes and instruments are
introduced via the sheath into the operating field without damaging the nasal mucosa. However, one
disadvantage is the restricted ability to maneuver the instruments, a problem that will be overcome with
the development of specially designed instruments.

The endonasal endoscopic approach to pituitary or clival lesions offers simple and rapid access to the
target, reduces the postoperative discomfort of the patients, and shortens the hospital stay. Nasal packing
is not required, or, if it is, only for a short time. Endoscopes provide an excellent panoramic view in the
depth of the sphenoid sinus and sella. The ability to inspect supra- and parasellar tumor extensions, not
visible when using the operating microscope, increases the completeness of tumor removal.

**Endoscope-Assisted Microsurgery**
Another field of application for neuroendoscopes in neurosurgery is endoscope-assisted microsurgery—i.e., the supplementary use of endoscopes during microsurgical procedures.[34,43,102] This technique is very useful for inspecting areas not visible in the field of the microscope (that is, "looking around a corner"). In vestibular schwannoma surgery, the endoscope is used to confirm completeness of tumor removal in the internal auditory canal.[128] However, endoscopes cannot only be used for visualization but also for microsurgical dissection. The surgeon can manipulate microsurgical instruments under endoscopic control by looking at the monitor screen. This is especially advantageous in surgery for deeply located lesions in which visualization obtained through the microscope is hindered by structures in front of the lesion. The lack of stereoscopic vision can be compensated for by a surgeon with some experience in this technique. Retraction of brain tissue can be significantly reduced. Finally, the optical quality in the depth of the brain is far superior compared with that obtained through a microscope. Another valuable indication for endoscope-assisted microsurgery is in aneurysm surgery. Aneurysms can be inspected before clip placement to identify the neck and adjacent vessels. Furthermore, the placement of the clip can easily be controlled without manipulating the aneurysm. In this way, incidental occlusion of vessels or incomplete clipping of the aneurysm can be avoided.

### Other Indications

Endoscopes have been used for the treatment of intracerebral and epidural, as well as acute and chronic subdural hematomas.[8,10,54,66] Although most chronic subdural hematomas respond to simple burr-hole evacuation and temporary drainage, this treatment may fail in loculated hematomas. A valuable treatment option in these cases is the use of endoscopic membrane fenestration to create a single loculation that can be drained successfully. However, this procedure should be reserved for patients with hematomas in whom simple burr-hole drainage was insufficient. In our opinion, endoscopic evacuation of epidural hematomas via burr holes is rarely justified in cases of small hemorrhages when patients are in good clinical condition. In most cases, especially with patients in a critical state, an immediate craniotomy and decompressive procedure are required, which should not be delayed by using time-consuming endoscopic techniques. Furthermore, hemostasis of sometimes profuse arterial bleeding is more effectively achieved using bipolar forceps. Finally, circular tacking of the dura up to the edge of the craniotomy is essential to prevent reaccumulation of the hematoma. In treating intracerebral hematomas, we found endoscopic evacuation not to be superior to standard microsurgical removal. The microsurgical procedure was more effective, quick, and the visualization was better with the microscope. Endoscopically, we perform clot removals and third ventriculostomies to restore obstructed CSF pathways in patients with intraventricular hemorrhages that cause hydrocephalus.

Stereotactic-endoscopic evacuation of brain abscesses has been reported.[53] The extent of abscess aspiration can be controlled under direct vision. However, the results seem to be the same when compared with standard stereotactic puncture and drainage.

Another indication for an endoscopic approach is intraparenchymal cysts, which may occur in various locations of the brain.[15,122] Fenestration of the cyst wall that creates a communication with the ventricles or subarachnoid space is the procedure of choice.

Endoscopic techniques can be considered for the removal of intraventricular cysticercosis cysts.[91] Because sudden cyst migration is well known, immediate preoperative MR imaging should be performed.
Sources of Equipment

The Gaab neuroendoscope system is manufactured by Karl Storz GmbH & Co., and by Codman and Shurtleff, Inc. (Randolph, MA). Both the Nd:YAG laser and the Surgical Tool Navigator were obtained from Carl Zeiss (Oberkochen, Germany). Codman and Shurtleff, Inc. produces the Malis irrigator.

CONCLUSIONS

The introduction of the operating microscope in the 1960s permitted atraumatic microsurgical dissection in the depth of the brain via small craniotomies. With the use of neuroendoscopic techniques, surgical invasiveness can be further reduced and identical or even better results can be achieved. Craniotomies and shunt placement can often be avoided. However, neuroendoscopy is still in its infancy. Like microsurgery, it has a steep learning curve. With proper patient selection and improvement of the technical equipment, the results will certainly improve. However, neuroendoscopy is not a technique per se. It is one of the tools of the neurosurgeon, such as stereotaxy, the operating microscope, or neuronavigation, available to perform a sophisticated surgery and should be utilized together with other techniques as necessary. There is no doubt that with further development of specially designed neuroendoscopes and instruments, as well as the increasing skill of the surgeons, endoscopic techniques will be used more commonly and the indications will expand.

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