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Neuro-oncologic applications of endoscopy

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No other subspecialty of neurosurgery exemplifies the advantages of endoscopy more than neuro-oncology. From a pure technical standpoint, visualization is the *sine qua non* of surgery. If a surgeon cannot see what he is doing, he is ineffective and dangerous. Cranial neurosurgery in particular is a constant struggle against poor visualization. In an attempt to minimize operative trauma, the surgeon aims to limit the size of the exposure and to avoid vigorous brain retraction. Meanwhile, the tumor/brain interface is often hard to distinguish, and the tumor often insinuates itself behind or between structures that cannot be sacrificed. Critical structures, such as cranial nerves, vessels, and eloquent brain tissue, may prohibit direct visual access to some parts of the tumor. At the same time, in the case of the more benign tumors that occur in the cranial cavity, total excision is vital to the patient's survival [1,2]. Complete removal of an acoustic neuroma is nearly tantamount to cure. Other extra-axial tumors, such as craniopharyngiomas and meningiomas, also must be removed as completely as possible to reduce the incidence of tumor recurrence. Because low-grade gliomas respond poorly to radiotherapy and chemotherapy, prognosis is directly related to the degree of tumor resection. Ependymomas are also historically insensitive to adjuvant therapies, and total macroscopic removal is paramount [3]. Any tool that improves visualization, thereby offering patients a better surgical outcome, should be embraced by the neuro-oncologic surgeon.

The endoscope is such a tool. It enhances the surgeon's view by increasing illumination and magnification [4,5]. It allows the surgeon to view tumor remnants, such as those hidden behind the tentorial edge, a cranial nerve, or eloquent brain tissue. Once the tumor is removed, the surgeon can use the endoscope to assess the degree of resection. Often, the same surgery can be performed through a smaller craniotomy by using the endoscope, in keeping with the concept of minimally invasive yet maximally effective surgery [6]. Adjunctive procedures, such as third ventriculostomy and septostomy, can be performed through the same access to manage related problems, such as secondary hydrocephalus. Endoscopic tumor removal or cerebrospinal fluid (CSF) diversion may allow patients to avoid shunt placement. Finally, the endoscope is an excellent teaching tool. The anatomic definition and unique angles of view available to the endoscope help residents with their understanding of operations and help to illuminate anatomicopathologic concepts underlying neuro-oncologic surgery.

Applications

Applications for the endoscope are limited only by one's imagination. Initially used for intraventricular surgery alone, the endoscope has also become an invaluable tool in the surgical management of extra-axial pathologic processes. It is being increasingly applied as an adjunct to the removal of masses in the subarachnoid space. Within the ventricle, the endoscope is a versatile tool for diagnosing and treating tumors and associated problems of CSF circulation.

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We discuss the neuro-oncologic applications of endoscopy under the following headings:

1. Ventriculoscopy
2. Management of secondary hydrocephalus
3. Endoscopic tumor biopsy
4. Endoscopic intraventricular tumor resection
5. Endoscope-assisted microsurgery

Ventriculoscopy

The prognosis of some primary intracranial tumors is dependent on the presence or absence of ependymal spread of tumor. Patients with primitive neuroectodermal tumors, for example, fall into the high-risk group rather than the low-risk group if there is evidence of spinal or ventricular ependymal tumor involvement. Although MRI is reliable in the detection of ependymal tumor spread in most cases, some patients may have ependymal spread without radiologic evidence [7]. Ventriculoscopy can be more sensitive than MRI with little added morbidity. Through a frontal or parietal burr hole, one can access the lateral ventricle, examine the surface, document any findings with color photography, and even biopsy suspicious areas. This can be performed with a 10-minute general anesthetic, which is substantially less time than is needed for an MRI examination. Furthermore, if present, definitive treatment of CSF obstruction can be achieved by either third ventriculostomy or tumor resection at the same sitting.

Fig. 1 shows endoscopic pictures of the lateral ventricle of a patient with a pineal primitive neuroectodermal tumor who had no imaging evidence of ependymal tumor involvement. The patient had an endoscopic third ventriculostomy (ETV) and, thereafter, chemotherapy. The response to chemotherapy was well documented by ventriculoscopy, thereby allowing the patient to be a candidate for high-dose chemotherapy and autologous bone marrow transplantation.

Management of secondary hydrocephalus

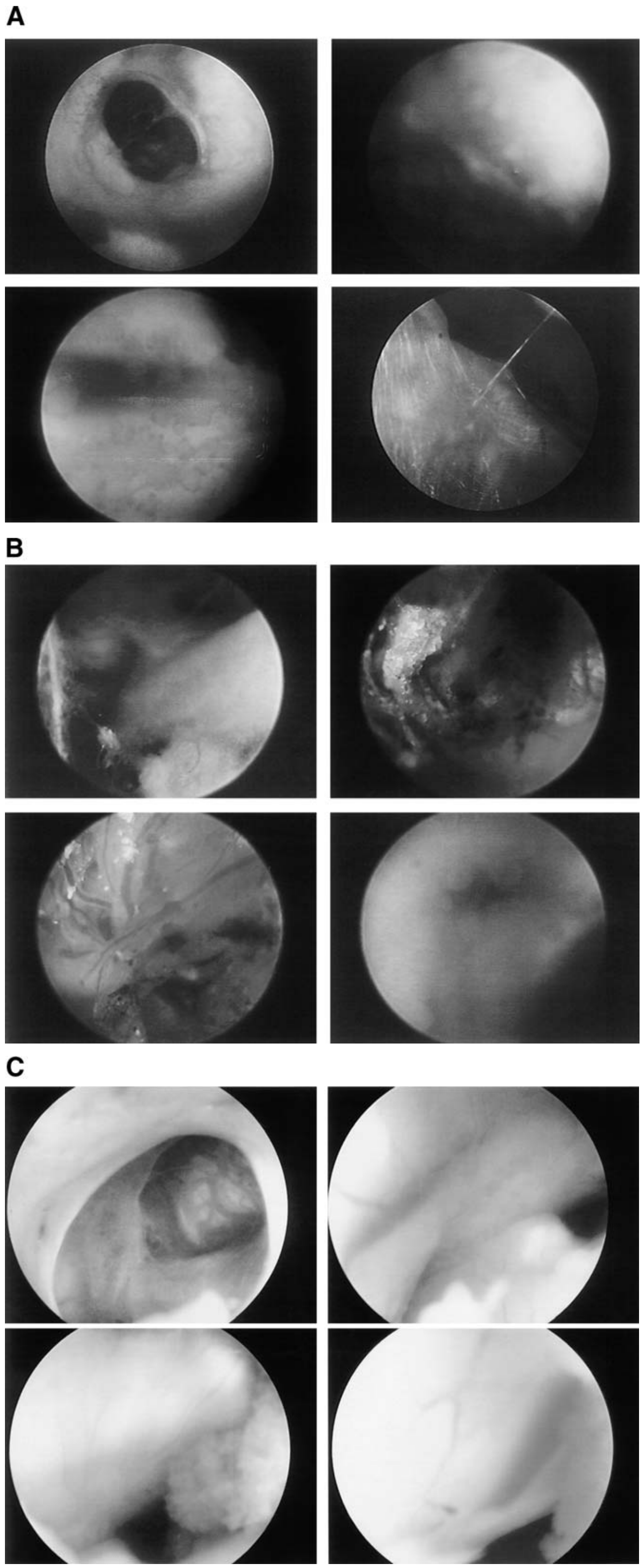
The management of secondary hydrocephalus is a controversial area of pediatric neuro-oncology. There are several different treatment paradigms. A popular option would be to place a temporary external CSF drain as a primary procedure, remove the obstruction, and then, as a secondary procedure, shunt those patients who continue to require CSF drainage. Another option is to insert a permanent shunt as a primary procedure before tumor resection. A third option would be to perform an ETV either primarily or secondarily. The arguments in favor of the early management of the hydrocephalus are as follows:

1. There are some circumstances in which the surgeon cannot definitively treat the primary cause of obstruction, and CSF diversion is the only option. These patients may present with symptoms of raised intracranial pressure and impending brain herniation.
2. The surgeon may need more time for preoperative assessment (eg, the patient with a bleeding diathesis, the patient who needs staging of his or her tumor).
3. The primary CSF diversionary procedure may be definitive. An example of this is the patient with a tectal glioma, in whom symptoms are usually secondary to hydrocephalus and not the primary tumor.
4. On rare occasions, MRI reveals pathology previously "hidden" by the hydrocephalus (Fig. 2). The patient in Fig. 2 presented with severe intracranial hypertension and was thought to have hydrocephalus from aqueductal stenosis. After ETV, it became clear that the obstruction was secondary to a pineal region tumor.
5. Some surgeons believe that operative conditions for the definitive surgery are better after prior drainage of CSF.

The arguments against initial treatment of the hydrocephalus are as follows:

1. Many patients do not have a permanent CSF flow problem; therefore, some shunts are placed unnecessarily. Of course, this is not a concern when temporary CSF diversion is undertaken using external ventricular drainage.
2. If the obstruction is caused by a posterior fossa tumor, there is potential for upward

Fig. 1. (*A*) The ependyma is frosted with plaque-like tumor that was not seen on MRI. (*B*) After conventional chemotherapy, the clinical response is documented ventriculoscopically. (*C*) After high-dose chemotherapy and autologous bone marrow transplantation, the ependymal surface is clear of visible tumor.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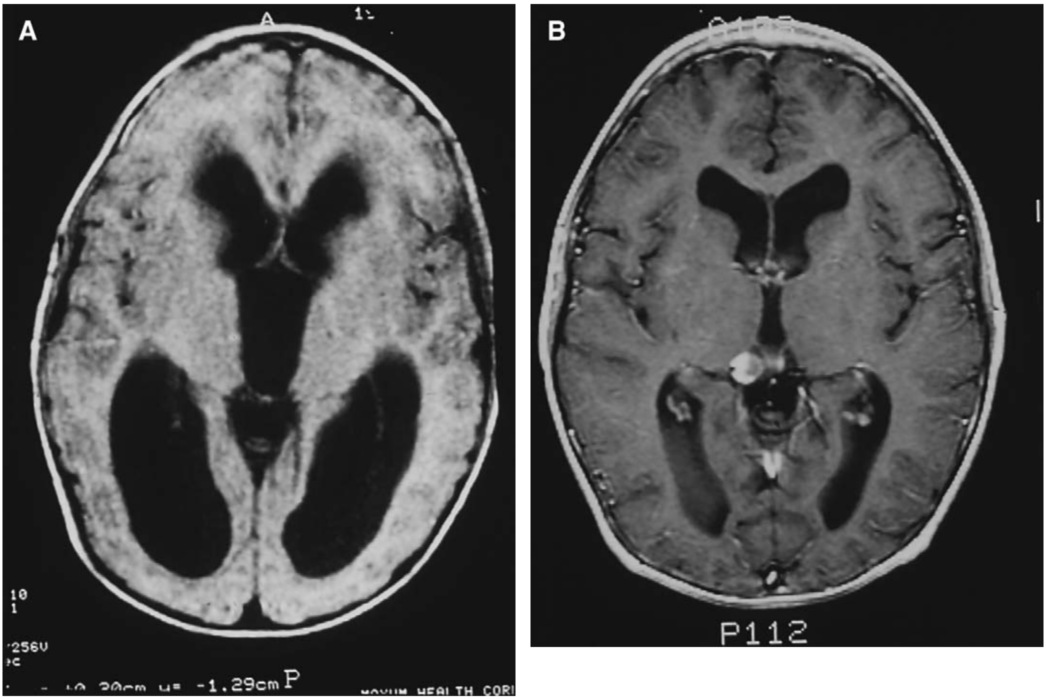

Fig. 2. (*A*) The patient is an 11-year-old boy with profound hydrocephalus of unclear etiology. (*B*) After an endoscopic third ventriculostomy and resolution of the hydrocephalus, an occult pineal region tumor is now apparent.

herniation with decompression of the supratentorial CSF spaces.

3. There is a risk of infection with external drainage.
4. There is a risk of spreading tumor cells to the peritoneum with extracranial CSF diversion.

ETV is a reasonable option if the surgeon decides to treat the secondary hydrocephalus before definitive treatment of the primary tumor. This operation can be done through a standard frontal burr hole similar to that which would be made for insertion of an external ventricular drain (Fig. 3). Similarly, CSF samples can be taken at the time of surgery, and one may also explore the third ventricle, taking biopsies if necessary. There is no risk of ongoing infection as can be seen with external drainage; no risk of seeding as has been documented with ventriculoperitoneal shunting; and no risk of upward herniation, which can potentially happen with any extracranial diversionary procedure. Finally, ETV may be the definitive treatment if the obstruction is caused by a tumor that does not require removal, such as a tectal plate tumor.

Endoscopic septum pellucidotomy may also be the definitive treatment for some types of hydrocephalus. Fig. 4 shows the MRI scan of an elderly lady who presented with headaches and disorientation. She was found to have a cystic tumor of the third ventricle causing obstruction of only one of the lateral ventricles. The provisional diagnosis was a craniopharyngioma, and she underwent endoscopic cyst fenestration and drainage, followed by septum pellucidotomy. The postoperative scans showed complete resolution of the unilateral hydrocephalus and shrinkage of the cystic component of the biopsy-proven craniopharyngioma.

Technical notes

The technique of ETV is described in elsewhere in this issue. There are a few precautions when performing ETV for hydrocephalus secondary to a tumor. First, the anatomy may be altered. A tumor like a pontine glioma may distort the floor of the third ventricle and displace the basilar artery forward so that the safe zone to penetrate the floor is a submillimetric area just

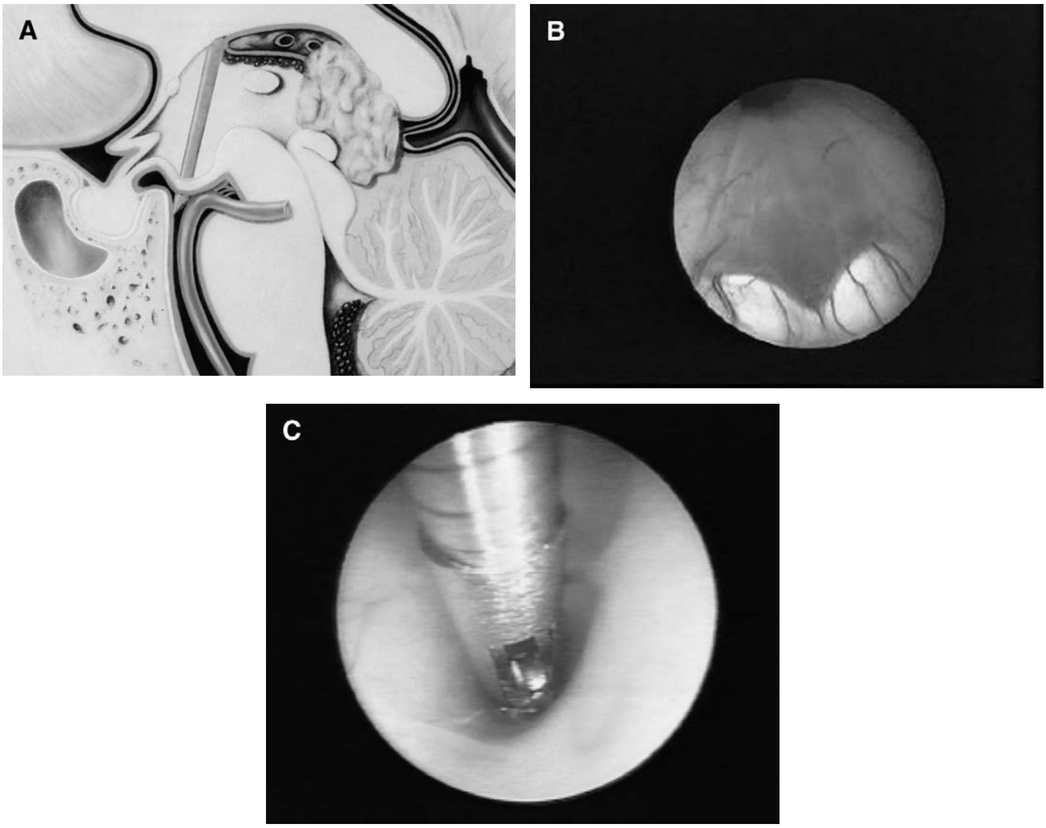

Fig 3. (*A*) The endoscopic third ventriculostomy is performed in the third ventricular floor just behind the mamillary bodies. The close relation to the basilar apex is illustrated. (*B*) In chronic hydrocephalus, the third ventricular floor is thin and visualization of the mamillary bodies is easy. (*C*) In acute hydrocephalus, it may not be possible to see the usual landmarks. The floor is thicker, and a sharp technique may be necessary. In this instance, more experience is required to identify the proper location for the ventriculostomy safely.

behind the dorsum sella and just in front of the basilar bifurcation. Using a blunt technique to create the stoma would be prudent in such a case. Second, hydrocephalus resulting from tumor obstruction may be relatively acute in onset. When this is the case, the floor of the third ventricle is often opaque and nonattenuated. This makes penetration more difficult and invariably requires a sharper technique without visualization of the underlying neurovascular structures. This ‘‘blind’’ fenestration through a thick floor can be hazardous and should not be undertaken by the novice endoscopist. Third, ETV combined with biopsy of posterior third ventricular tumors cannot be done through the standard ETV burr hole. The ideal trajectory for the anterior third ventricular floor is just anterior to the coronal suture, whereas that for the posterior third ventricle is just posterior to the hairline or 8 cm behind the nasion and 3 cm from the midline. The foramen of Monro is sometimes expanded enough to allow access to both parts of the third ventricle through a single burr hole placed between the coronal suture and the hairline. This may be assessed before surgery by close inspection of the MRI.

A comment should be made about the use of flexible fiberscopes. It is true that with a rigid endoscope, it is difficult to perform an ETV and biopsy of a posterior third ventricular tumor through the same burr hole. Nonetheless, we believe that a rigid endoscope is preferable to using a flexible scope insofar as it can be impossible to be sure where the back of the flexible endoscope is. The risk of complications in most hands is consequently higher with flexible endoscopes. It is our personal practice not to use flexible endoscopes in the head.

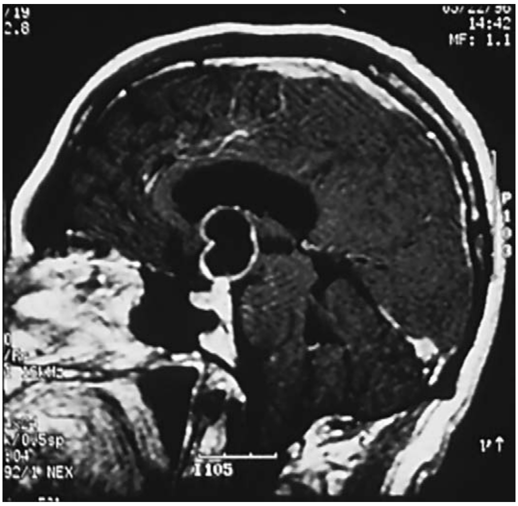

Fig. 4. Cystic craniopharyngioma in an elderly woman who presented with high intracranial pressure. The cyst was fenestrated endoscopically, and a septum pellucidotomy was performed. The patient's symptoms resolved, and she did not require shunting.

Fig. 5. Biopsy of a tumor in the posterior wall of the third ventricle with grasping forceps. Bleeding after such a biopsy can usually be managed with irrigation alone.

Endoscopic tumor biopsy

There are no studies showing that endoscopic tumor biopsy is any better than stereotactic needle biopsy. Anecdotally, however, there seem to be definite advantages to this technique. Endoscopic biopsy should be considered when the tumor is either within the ventricle or at least presenting to the ventricular surface. The advantages are as follows:

1. Direct visualization of the tumor allows more accurate and safer sampling. A region for biopsy can be chosen under endoscopic vision, and vessels can be avoided.
2. The specimen obtained is larger and not subjected to as much mechanical artifact. It does not need to be sucked up a needle or manipulated.
3. Any resultant bleeding can be stopped by either coagulation or packing under direct visualization.
4. If the tumor is relatively avascular, it may be removed totally by endoscopic techniques.
5. Other procedures can be performed at the same operation (eg, ETV, septum pellucidotomy).

Examples of tumors that are typically approachable endoscopically are colloid cysts, subependymal giant cell astrocytomas, other low- (including tectal gliomas) and high-grade gliomas [Fig. 5], central neurocytomas, subependymomas, and choroid plexus tumors and cysts [8]. Most of these tumors are relatively avascular, and hemorrhage is rarely a problem. The burr hole is made so that the scope enters the ventricle as far from the tumor as possible and so that the scope is directly viewing the tumor rather than peering from around a corner. The distal approach allows the surgeon to orient himself by identifying normal anatomic structures before encountering the abnormal anatomy. Because most of the distal part of the scope is within the ventricle, it also allows the surgeon to move the scope in multiple directions more freely without damaging the surrounding normal brain. Starting from farther away means that only relatively small excursions are necessary within the normal brain to visualize the entire target. Many surgeons are hesitant to employ endoscopy for tumors because of the fear of bleeding. Almost all bleeding can be controlled with irrigation alone until the bleeding stops. If bipolar and monopolar instruments are available, they can be used, but they are often ineffective. Patience and copious irrigation are the keys.

For tumors that are primarily intra-axial, there are few advantages of endoscopic biopsy over standard stereotactic techniques. Some extra-axial tumors that require biopsy, such as those that might be seen around the circle of Willis and suprasellar region, are well suited to this technique, however. For these tumors, stereotactic techniques are too dangerous and standard open craniotomy is extremely invasive. Endoscopic biopsy allows a minimally invasive approach with excellent visualization and safety. The opening is made through a supraorbital brow incision and a small frontal craniotomy. The suprasellar region is then approached using standard microsurgical technique, and the scope is introduced when the cisterns have been opened. Biopsies should be taken with straight or angled cup forceps passed along the scope and not down a working channel. The instruments should always be passed ahead of the endoscope so that their progress can be observed. Blind passage of the instruments into the endoscope's field of view risks damaging structures located behind the tip.

Endoscopic intraventricular tumor resection

Not all intraventricular tumors should be approached endoscopically. The ideal tumor for endoscopic consideration has the following characteristics:

1. Moderate to low vascularity
2. Soft consistency
3. Less than 2 cm in diameter [9]
4. Associated secondary hydrocephalus
5. Histologically low grade
6. Situated in the lateral ventricle

Clearly, from this list of desirable features, almost all patients with colloid cysts are appropriate candidates for this technique. The results with these tumors are often excellent, and in at least one study, endoscopic resection was clearly superior to microsurgery (Figs. 6 and 7) [10]. Other tumors that are well suited to total endoscopic removal are subependymal giant cell astrocytomas around the frontal horn of the lateral ventricle, other low-grade gliomas that are exophytic into the ventricles, central neurocytoma, small choroid plexus tumors, and the purely intraventricular craniopharyngioma.

There are few articles in the neurosurgical literature on the application of endoscopy for the removal of intraventricular tumors. Most of the experience with endoscopic tumor resection has specifically addressed the removal of colloid cysts [10–12]. Whichever technique is used, patient

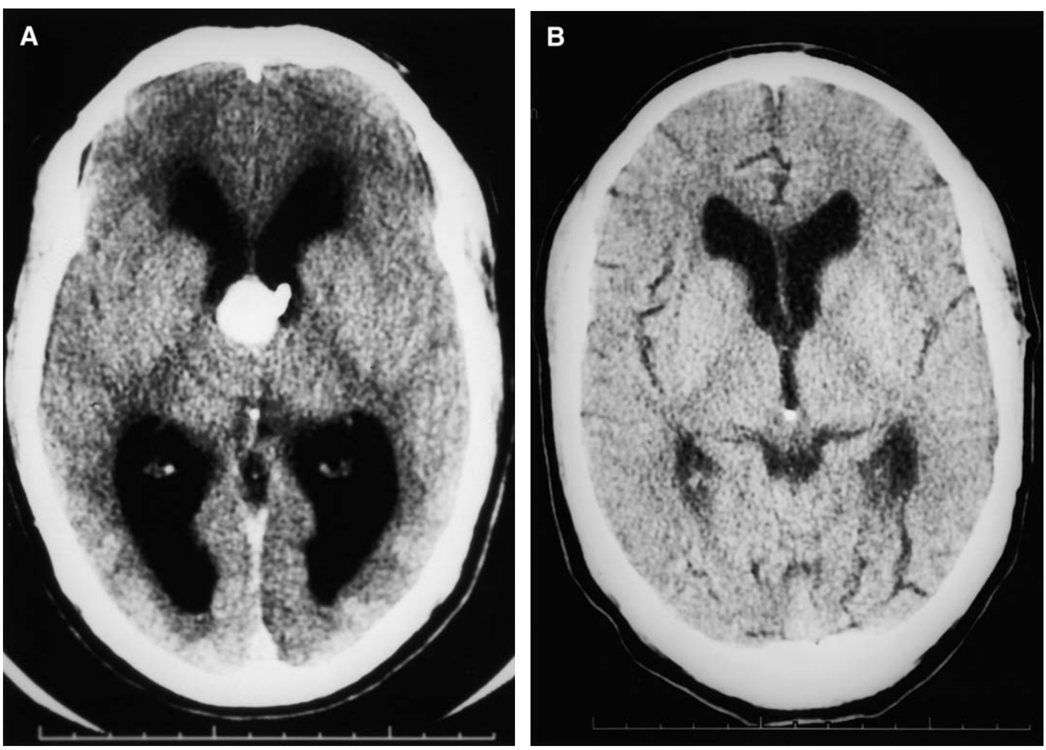

Fig. 6. Pre-endoscopic (*A*) and postendoscopic (*B*) removal of a colloid cyst. Note resolution of the hydrocephalus and preservation of the normal anatomy.

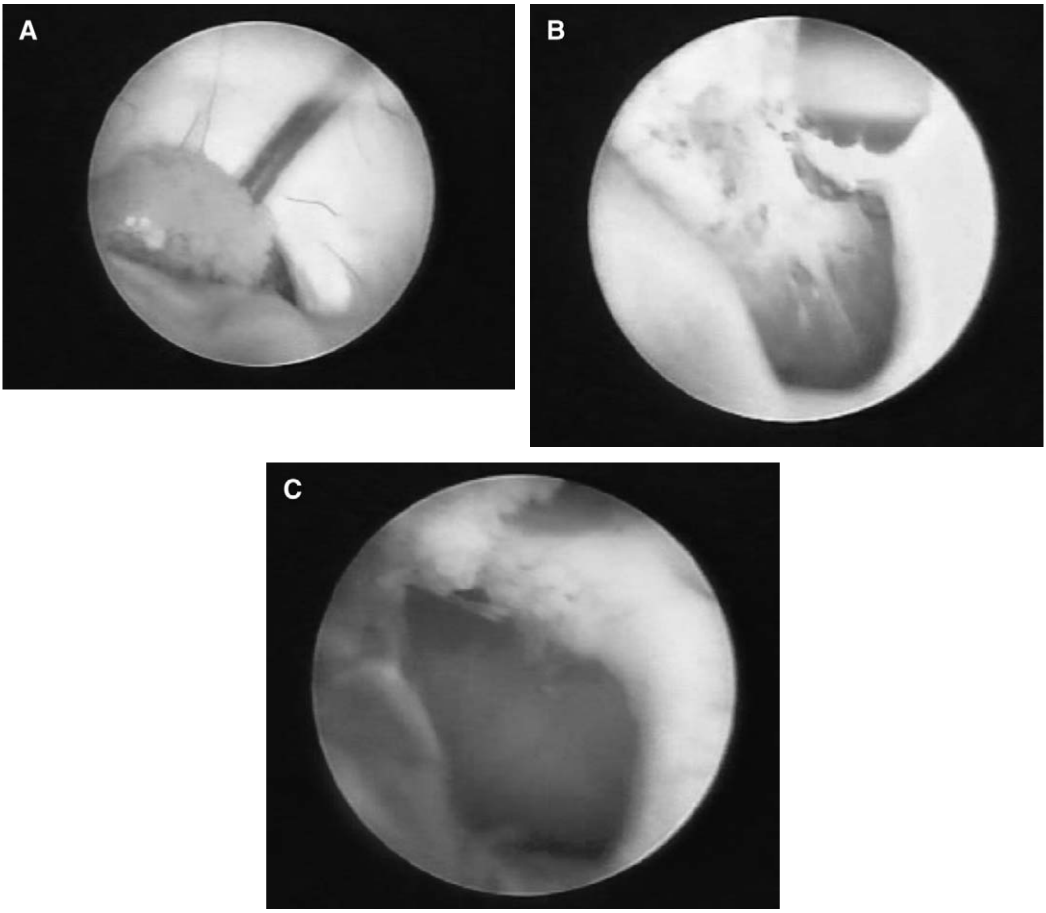

Fig. 7. (*A*) Initially narrow view of the foramen of Monro. The choroid plexus is to the left of the image, with the septal vein located superiorly. (*B*) The choroid plexus is coagulated with monopolar cautery. The cyst is now clearly visible as a gray structure through the foramen. (*C*) View of the foramen of Monro after removal of the colloid cyst. The fornix is seen to the right of the image, the septal vein superiorly, the thalamostriate vein to the lower left, and the choroid plexus to the upper left.

selection is controversial. For tumors in the vicinity of the foramen of Monro, the presence of hydrocephalus is an absolute indication for some form of surgical intervention. Headache in the absence of hydrocephalus can be a sign of intermittent obstruction of the foramen of Monro or some other part of the ventricular system, and patients should be informed of the possibility of insidious onset of hydrocephalus and sudden death. Another indication for surgery would be radiologic progression either in size or enhancing characteristics. This is particularly true for giant cell subependymal astrocytomas that are located in the frontal horn of the lateral ventricle. Whatever tumor is approached, some basic principles apply. An approach trajectory that avoids eloquent structures but allows a good view of the tumor is essential. Most intraventricular tumors are dealt with in the same fashion. Once good visualization is achieved, the outside of the tumor is coagulated with either monopolar electrocautery or a laser. Copious irrigation is used to clear blood and debris and to prevent too much heat from building up inside the ventricle. If there is a cyst, it is opened and drained. The contents are removed via suction or piecemeal. The remaining wall is coagulated and removed piecemeal. Hemostasis is obtained with copious irrigation. The scope is withdrawn while inspecting the tract for intraparenchymal bleeding. A small wick of Gelfoam is placed in the cortical opening to prevent CSF leakage from the ventricle.

Endoscopic colloid cyst removal

The colloid cyst is the prototypical intraventricular tumor; as such, we discuss its removal in some detail. The colloid cyst represents the ideal intraventricular tumor that can be completely resected via the endoscopic approach. The goals of surgery are to extirpate totally the cyst wall, to avoid spillage of the cyst contents, to minimize trauma to the adjacent structures (ie, fornices, walls of the third ventricle), to spare venous structures, and to minimize cortical damage along the approach route. The first two goals are more difficult with the endoscope than with open surgery, whereas the last three are actually easier to achieve. The lower morbidity and shorter operating time form the rationale for the endoscopic approach. In practice, complete cyst drainage and removal can be better accomplished endoscopically than microsurgically once the skill is mastered. The choice of endoscopy as the treatment modality should depend on (1) proper patient selection, (2) adequacy of the equipment, and (3) adequacy of the surgeon's experience and preparation.

Patient selection

Almost all patients with colloid cysts are good candidates for the endoscopic approach. We encourage endoscopic removal as the preferred first procedure, with the option of craniotomy if endoscopy is unsuccessful. In fact, a wide range of management strategies and therapeutic options are available to treat patients with colloid cysts. These include observation, shunting of the lateral ventricles, stereotactic aspiration, open transcortical or transcallosal resection, and endoscopic removal. For a patient who presents nonemergently, such as with an incidentally discovered colloid cyst, it is important to discuss all options. Nonetheless, given the risk of acute CSF obstruction, herniation, and death associated with these masses, we recommend definitive treatment by the least morbid route, which is via the endoscope.

The main technical factor that affects colloid cyst removal is the density of the cyst contents. This can best be estimated using noncontrast CT. Hypodense or isodense contents are usually fairly liquid and can be removed through the small apertures of the endoscope without difficulty [13]. A small suction catheter attached to a 10- or 20-mL syringe may help in this regard. Hyperdense cysts may have more tenacious contents, which can prove more difficult to remove with the endoscope. Cup forceps may need to be used to remove the contents of these denser cysts piecemeal. On MRI, high signal on T1-weighted imaging correlates with higher cholesterol content [14], thicker consistency, and more difficult removal.

Technique

The patient is positioned straight supine with the head up 45°. A single burr hole is placed on the nondominant side 8 cm behind the nasion and approximately 7 cm lateral to the midline. This is farther lateral than previously published by the senior author (C.T.), a modification that has allowed better removal of the component of the cyst in the roof of the third ventricle. A strip shave is made for the incision, which is 4 cm long and coronally oriented over the site of the burr hole. Preparations should be made to preserve the option of converting to an open craniotomy, with a craniotomy tray and microscope available. If the ventricles are small, frameless stereotactic guidance is used to guide the placement of the endoscope sheath and trocar. Otherwise, freehand cannulation of the ventricle with a ventricular needle precedes placement of the sheath.

A 2- to 5-mm 30° rigid endoscope with at least one working channel is placed down into the ventricle. The boundaries of the foramen of Monro are appreciated: the fornix above and anteriorly, the choroid plexus and the septal and thalamostriate veins exiting posteroinferiorly, and the anterior nucleus of the thalamus located below. The foramen of Monro is normally 0.3 to 0.8 mm in diameter. In the presence of a colloid cyst, it is variably expanded. The cyst is attached to the roof of the anterior third ventricle, and its anterolateral surface usually bulges into or through the visible part of the foramen. Every effort is made to preserve all normal structures in removing a colloid cyst. Generally, this can be accomplished; however, three structures may be sacrificed, if necessary, to provide widened access to the tumor, in descending order of preference: choroid plexus, the thalamostriate vein, and the ipsilateral fornix. The first structure is sacrificed with impunity, but sacrifice of the latter two should only be considered if all other options have been exhausted. If choroid plexus obstructs the view of the cyst, it can be coagulated with a monopolar probe and dissected free from the foramen without difficulty. No morbidity attends this maneuver. The thalamostriate vein may be large and present an obstacle. Every effort should be made to preserve the vein. Past authors have warned of potentially devastating consequences from sacrificing a thalamostriate vein, but this has not been borne out in subsequent reports by other authors or in our own experience. The primary reason not to sacrifice the vein is that it is far more difficult to do this safely using the endoscope than microsurgically. The bleeding from the vein can be daunting. Fortunately, sacrifice of the vein rarely becomes necessary. Last, although it is not preferable, a thinned-out ipsilateral fornix may need to be sacrificed to provide adequate access to a large colloid cyst. Permanent short-term memory loss is sometimes a consequence of this maneuver. Other structures that may be pitfalls in this case are the thalamus, the internal capsule, and the head of the caudate, all of which must not be harmed. The internal capsule runs in the groove between these other two structures; damage to this structure during endoscopic procedures has resulted in contralateral hemiparesis.

Once exposed, the surface of the cyst is gently devascularized with electrocautery. Although a laser may also be used for this role, the results are not superior to monopolar electrocautery despite the greater expense and complexity. The wall of the cyst is then pierced with the monopolar probe, and the contents are removed piecemeal or with suction attached to a hand syringe once inside the cyst. After it is emptied, the cyst wall is coagulated and removed piecemeal. Care is taken not to provide excessive traction on the roof of the third ventricle, because severe bleeding from the internal cerebral veins can result. Other authors have written that a small amount of the cyst wall may have to be left on the third ventricle roof and the columns of the fornix, but this has at times been associated with recurrence. In the senior author's personal series, complete removal was possible in 24 of 26 cases; the remaining two patients underwent transcortical removal of the residual. From the anterolateral approach described here, the 30° endoscope affords a view of the roof of the third ventricle that can help to confirm complete removal of the cyst wall.

It has not been necessary to place drains at the time of surgery or to maintain them after surgery. Most authors with experience in this area have used drains in their early cases and, over time, moved away from using them. A drain may be considered in a patient in whom the risk of sudden decompensation because of postoperative hydrocephalus is believed to be high. Ultimately, it is up to the surgeon to make an individual assessment on a case-by-case basis. In the senior author's personal series, no patient has required placement of a permanent ventricular shunt.

Variations in technique

Endoscopic removal of colloid cysts using a flexible fiberscope has been described. Although this approach is possible, it offers no advantage over rigid endoscopy, has a substantially higher learning curve, requires more coordination with an assistant, and is associated with greater risk. This approach is absolutely contraindicated for any surgeon not already familiar with the fiberscope.

The technique described previously is a one-portal technique. We have found this approach adequate in most cases. From the anterolateral approach, both fornices and the roof of the third ventricle can be seen from one side. A two-portal ipsilateral technique has been described by Jimenez [15], but we have not found this to add much to the procedure and believe that the addition of more portals goes against the goals of a minimally invasive approach.

Complication avoidance

Copious irrigation is important throughout the procedure to maintain good visualization and dissipate heat generated by the electrocautery. We use 20-mL syringes to provide pulsed hand-injected irrigation. This allows good feedback as to how much pressure is being generated as well as rapid adjustment of irrigation depending on local conditions. This method does necessitate frequent changing of syringes throughout the case. It is important that a good path for egress of CSF be maintained so that fluid does not build up under pressure during the procedure. Herniation has been described as a result of induced hydrocephalus in this setting. A tube attached to the outlet port, which can be raised or lowered, permits the "pop-off" pressure to be varied, allowing the amount of ventricular dilatation to be controlled. Lactated Ringer's solution is used as the irrigation solution. It is slightly hypo-osmolar (276 mOsm) but is physiologically more like CSF than normal saline. Some authors have described postoperative confusion for 24 to 48 hours after procedures in which normal saline (308 mOsm) is used as the irrigant. There is no widely commercially available CSF substitute at present.

Bleeding from the colloid cyst or choroid plexus should be addressed with monopolar coagulation. All other bleeding should be addressed with irrigation. Almost all bleeding stops with irrigation alone if the irrigation is continued long enough; this may mean continuous irrigation for as long as 20 minutes. The value of copious irrigation cannot be overemphasized. With patience, almost any degree of bleeding can controlled in this manner. If this is not adequate, in some cases, bleeding vessels may have to be sacrificed with the use of electrocautery. In cases of generalized ooze, a balloon may be inflated gently in the foramen of Monro or the endoscope itself may be used to provide focal compression. Other techniques for controlling difficult bleeding include irrigation with cool saline (which causes vasoconstriction), draining the CSF to perform "dry field" coagulation, and raising the height of the drain until the intracranial pressure exceeds venous pressure. If nothing stops the bleeding, the procedure may be need to be converted to an open craniotomy. In our experience, this last step has never actually been necessary.

Conclusions

The endoscopic removal of colloid cysts is one of the most satisfying of neuroendoscopic procedures. Once some experience is gained, the technique is faster and less morbid than the open approach. Skills obtained working on these tumors provide the foundation for the techniques that allow the removal of other intraventricular tumors.

The principles discussed here can be applied to any mass that meets the indications for endoscopic removal. The following points reiterate the techniques applicable to the removal of intraventricular tumors in general:

1. Have the correct instrumentation available. Essential tools are a pair of grabbing forceps and scissors, a good assistant or a scope-holding device so you can work with two hands, a coagulation device (either monopolar or bipolar), a means of irrigating, and straight and 30° angled scopes.
2. Make the ventricular entry as far away from the tumor as possible. The further the tip of the scope is from the burr hole, the smaller is the angle required to displace the end of the scope a given distance. This allows the surgeon to angle the rigid scope in different directions without causing as much brain injury as would otherwise occur. It also gives the surgeon a chance to view the tumor from a distance, an important point when there is excessive bleeding. A good amount of ventricle between the entry point and the tumor means the scope can be pulled back from the bleeding site without exiting the ventricle.
3. Maintain the ventricular volume to ensure a workable operative field. This is achieved with continuous irrigation. Of course, it is imperative to make sure there is an unimpeded egress of fluid so as to prevent iatrogenic intracranial hypertension. A channel on the endoscope leading to an open port, serving as a pop-off valve, may be useful in this regard.
4. Manage hemorrhage with the following techniques: copious irrigation usually clears the operative field of blood and allow the surgeon to continue without using the other techniques. It is important to keep the temperature of the fluid close to body temperature and the composition as close to CSF as possible. Lactated Ringer's solution is preferred because it is the closest to isotonic of the relatively available fluids. Irrigation settles almost all bleeding eventually, although it may take upward of 20 minutes of continuous lavage in some cases. Using the scope or an instrument to tamponade the bleeder can be effective, especially when combined with head-up elevation and irrigation. The next technique is to attempt direct coagulation with either a bipolar or monopolar instrument. This technique can be quite a challenge given the obscuration of the field with blood, the mobile vessels, the presence of adjacent vital structures, and the difficulty of finding the exact bleeding point with a single instrument. Finally, if all these techniques fail, the ventricle can be drained of CSF. This allows more effective bipolar and monopolar coagulation without clouding of the operative field. The obvious downside is the collapse of the ventricular walls, resulting in constriction of the operative field. This can be partially offset by injecting air into the ventricle, which keeps the walls apart if there is a good seal around the working channels and around the brain/scope interface.
5. Finally, it is imperative to keep in mind the patient's best interests. Large and vascular intraventricular tumors are difficult to remove by pure endoscopic techniques. The

operation can become long and tedious with more blood loss and risk to surrounding eloquent brain tissue than a routine microsurgical approach. Do not hesitate to abandon the endoscope if you feel more confident using a more familiar technique. Always remember the dictum: minimally invasive and maximally effective.

Endoscope-assisted microsurgery

Endoscope-assisted microsurgery is the area of neuroendoscopy that has received the least attention by neurosurgeons but whose potential value to the neuro-oncologic surgeon is the greatest. Microsurgery itself evolved to maximize visualization and minimize retraction; endoscopy allows the neurosurgeon to move another step further toward achieving these goals. With endoscopy, previously inaccessible or poorly accessible tumors located in the skull base, within narrow cavities, deep to key vascular or neural structures, or around corners in the intracranial space can be clearly visualized; once visualized, they can be resected. The introduction of the endoscope has the potential to revolutionize the approach to certain tumor types by allowing safe radical removal. These techniques are particularly applicable to a wide range of troublesome tumors, including but not limited to sellar tumors, including pituitary tumors, craniopharyngioma, and Rathke's cleft cysts; clival chordomas; pineal lesions, intraparenchymal tumors near the brain stem or cranial base; acoustic neuromas; and anteriorly or centrally located posterior fossa tumors [16,17]. At the point at which dissection must halt because of the failure of the microscope to provide an adequate view, the endoscope should be brought into play.

A summary of the advantages of the endoscope as an adjunct to microsurgery includes the following:

1. Better definition of the normal and pathologic anatomy. The endoscope can be used to clarify the anatomy before and during tumor removal. Key neural or vascular structures can be identified and thereby spared. This may be particularly important when working around or within the brain stem, between small perforating vessels, or between the cranial nerves.
2. Identification of portions of the tumor located behind or adherent to vital structures. Some portions of tumor that are apparently invasive into the brain have brain/tumor interfaces that can be identified when visualized at more direct angles than is possible with the operating microscope alone.
3. Minimization of retraction. The authors seldom employ any fixed retractors even in the approach to extremely deep lesions. The endoscope allows narrow corridors to be used, reducing the need to displace sensitive structures.
4. Assessing adequacy of tumor removal. At the conclusion of the procedure, endoscopic inspection allows a more accurate estimation of the completeness of resection or, if complete resection cannot be achieved, documentation of where and how much residual tumor remains.
5. As a teaching tool. The endoscope offers a superior and often novel view of the anatomy, which can be beneficial to residents' understanding of the surgical approach. Furthermore, the operating surgeon and the student share the same view, which is not generally true even with an operating microscope.

The benefit contributed by adding endoscopy to a traditional craniotomy cannot be overemphasized. Tumors frequently extend at acute angles to the cranial base or to the cortical surfaces along which the traditional surgical approach is made (Fig. 8). Although these avenues are inaccessible to the microscope, which requires a direct line of sight, they are ideal for endoscopy. The degree of retraction required can frequently be lessened substantially. Traditionally, all microsurgical approaches can be conceptualized as forming the shape of a cone, with the base on the surface of the head and the working space at the apex. With the use of angled endoscopes, this limitation can be overcome. At the tip of the cone of visualization and illumination available to the microscope, 360° of additional view can be obtained. When working around the brain stem and cranial nerves, the corridor available to the microscope is often narrow, because extensive retraction is frequently not an option. The endoscope allows the surgeon to obtain the maximal access possible via the spaces naturally present in the extra-axial compartment.

The endoscope has allowed a conceptual change in the approach to low-grade or "benign" tumors. A specific example of this point may be

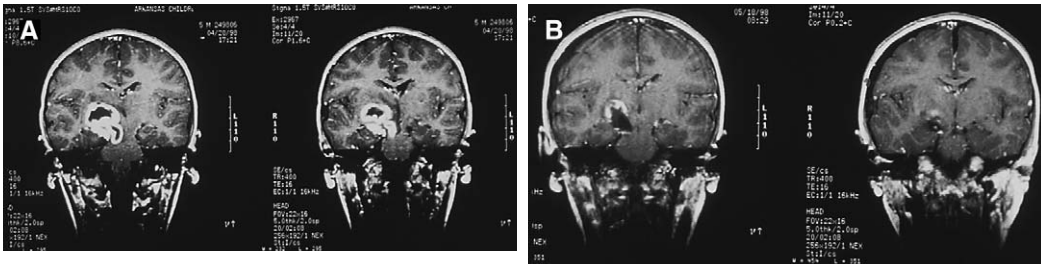

Fig. 8. Preoperative (*A*) and postoperative (*B*) views of a tumor approached using a purely microsurgical approach. Note the location of residual tumor. This residuum would still be accessible with the endoscope.

illustrated by the case of craniopharyngioma: failure to achieve a complete resection ultimately proves disastrous for the patient. In the past, some surgeons have discouraged radical debulking of the hypothalamic portion of these tumors because of the unacceptable side effects attended by damage to this vital structure. In fact, poor visualization is what limits adequate and safe removal of tumor. With the endoscope, the occult parts of the tumor can be removed under vision, making this part of the tumor as accessible as the directly visualized portion (Fig. 9). Angled instruments allow access to the endoscopically visualized parts of the tumor. Because the prognosis for a number of tumors is a function of the adequacy of tumor removal, the use of the endoscope in this fashion to obtain the best removal possible and to document that removal is highly recommended. Using this rationale, the authors encourage an aggressive approach to the management of low-grade tumors, such as pilocytic astrocytomas, pleomorphic xanthoastrocytomas, and dysembryoplastic neuroepithelial tumors, as well as so-called ‘‘benign tumors,’’ such as craniopharyngiomas and meningiomas.

Thus far, there are no studies documenting the superiority of the endoscopic approach to tumor removal. Some reports have begun to document its use in transsphenoidal surgery; surgeons familiar with the improved view offered in this venue can easily imagine the same benefits applied within the rest of the cranial cavity.

The endoscope is a powerful ally, but as is the case with all tools, the surgeon should become fully familiar with it before using it with patients. Practice is required to develop the visuomotor skills necessary to guide the tip in and out of narrow spaces safely, to watch the video image while still respecting superficial structures along the shaft, and to work with other instruments while maintaining good visualization with the endoscope. Familiarization with the endoscopic perspective and a review of the pertinent microsurgical anatomy are essential before using the endoscope on patients. Used properly, it is an invaluable adjunct to traditional microsurgery.

Technical notes

1. Guide the endoscope in and out of the field under direct vision. The most dangerous aspect of using the endoscope is the risk of impacting structures while introducing the endoscope. It is important to guide the endoscope by viewing it along the length of its barrel rather than by watching the image on the screen. After placing the endoscope into the working area, it is essential to continue to mind the shaft: if the scope is not fixed, small barely noticed movements at the tip can be the result of larger excursions at the back of the scope, which potentially can have disastrous consequences. An experienced assistant or a microscope with a head-up endoscope display can help in this regard.
2. Use a fixed endoscope holder so that once the endoscope is in place, the surgeon can work with both hands. This allows the surgeon to use more complex instruments and also prevents the endoscope from drifting against vital structures located superficially along the operative corridor.

Summary

Neuro-oncology, in all its aspects, provides an ideal venue for the application of endoscopy. The main obstacle to its use has been neurosurgeons’ lack of familiarity with the techniques

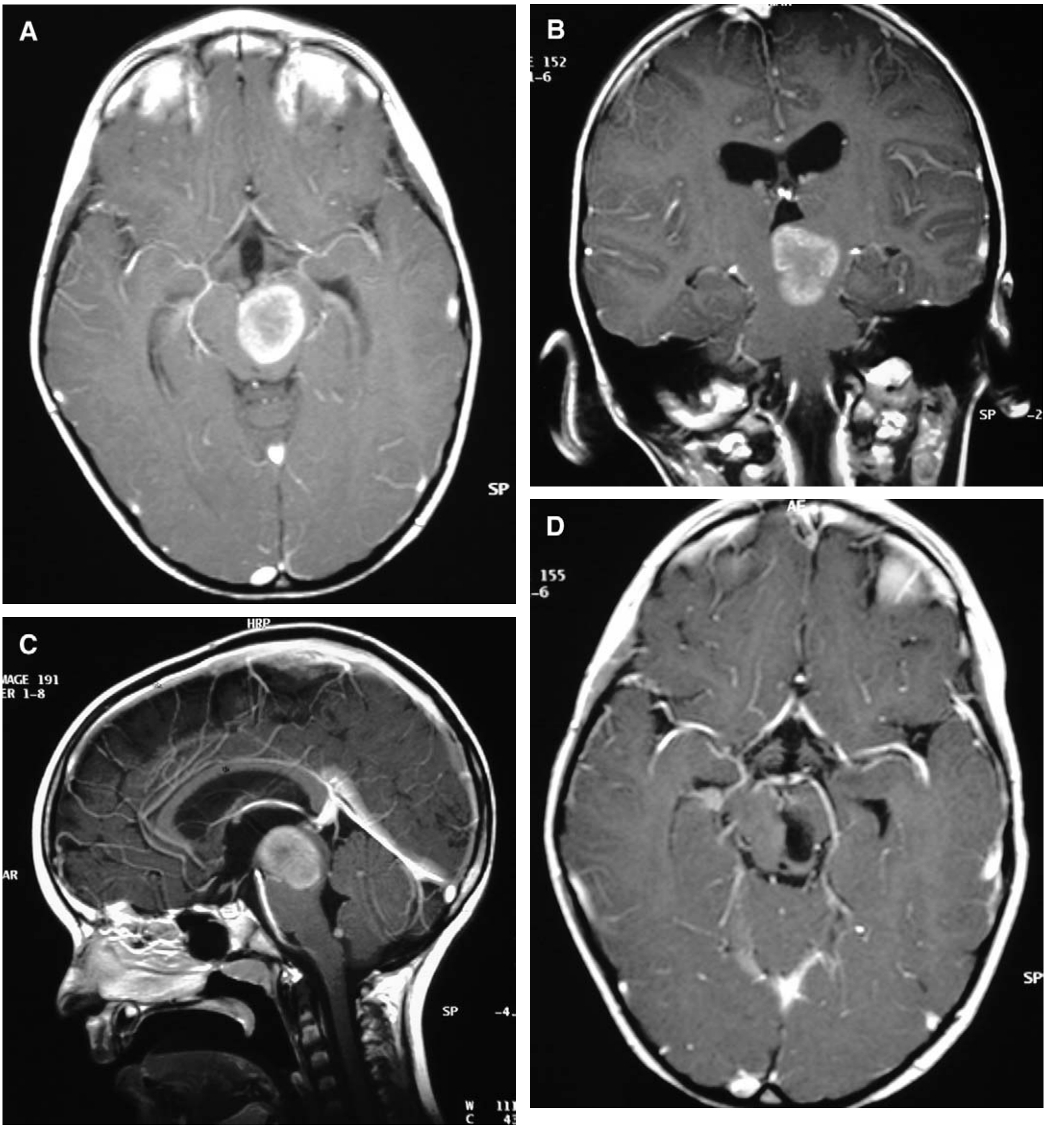

Fig. 9. (*A–C*) These MRI scans show a midbrain tumor in a 5-year-old girl. The tumor was removed through a small keyhole craniotomy and a transcallosal subchoroidal approach to the third ventricle. Once the microscope demonstrated what appeared to be complete removal, the endoscope was passed into the tumor cavity and more tumor was removed. (*D–F*) These MRI scans show complete tumor removal. The pathologic finding was a benign xanthoma. There has been no recurrence after 4 years of follow-up.

and their advantages. As the neuro-oncologic surgeon uses the endoscope more, endoscopy will take its rightful place in the surgeon's armamentarium. The advantages of improved visualization of intraventricular pathology, better management of tumor-related hydrocephalus, less morbid biopsies, and minimally invasive removal of intraventricular tumors are invaluable adjuncts to traditional tumor management. Furthermore, endoscopy is the logical next step for surpassing the limitations of traditional microsurgery. Endoscopy is still in its infancy. Rigorous application of the technology is increasingly allowing us to provide our patients the most maximally effective and minimally invasive surgery possible.

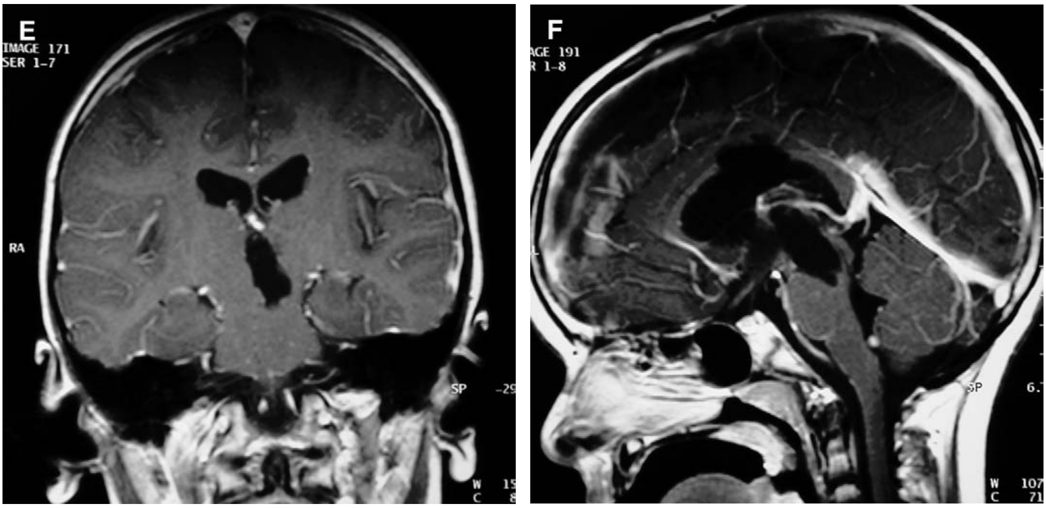

Fig. 9 (*continued*)

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